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ECOLOGY, ECONOMY AND ETHICS: HOW TO CREATE HARMONY BETWEEN FISHERS AND COMMON BOTTLENOSE DOLPHIN (*TURSIOPS TRUNCATUS*, MONTAGU 1821) IN THE NORTHERN TYRRHENIAN SEA

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A Maria Vittoria,

che studiare e sapere ti diano sempre libertà di agire!

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ABSTRACT

This PhD project, conducted from 2021 to 2023, was co-financed by the University of Siena and the Life DELFI project "Dolphin Experience Lowering Fishing Interaction" (LIFE 18 NAT/IT/000942). Its primary objective was to reduce negative interactions between small-scale artisanal fisheries and the common bottlenose dolphin (*Tursiops truncatus*), a coastal species classified as "Least Concern" by the IUCN and listed in Article 4 of Directive 2009/147/EC and in Annex II of Directive 92/43/EEC with its Natura 2000 code 1349.

The PhD thesis contributed to this goal by using interactive acoustic deterrent devices as a potential solution. Worldwide these deterrents are proved beneficial by keeping dolphins away from fishing nets, reducing the risk of entanglement and by catch, while also minimizing damages to fishing gear and catch representing an economic issue for artisanal fishers. This objective was mainly achieved through the use of a new generation of interactive acoustic deterrent device, the DiD01, known also as pingers, developed by STM S.r.l. of Verona (Italy), with the following technical features: frequency 5-500 kHz at 168 dB 1 µPa at 1 m. The PhD project's study area focused on the southern part of Tuscany, in the Northern Tyrrhenian Sea. The selection of the study area for the thesis was carried out through an initial bottom-up analysis, which helped identify artisanal fishers most affected by these issues, using an *ex ante* questionnaire. Of the 35 questionnaires distributed in Tuscany, only 18 were considered for the analysis, as they concerned fishers using fixed gillnets (trammel - GTR, gillnet - GNS, or combined – GTN). A total of 83.33% of fishers reported having interactions with dolphins during fishing activities, with an estimated economic damage of around €4,800.00 ± €3,392.80 per year. The 77.78% of the fishers expressed interest in resolving the harmful dolphin-fishery interactions by testing proposed within Life DELFI project. After the *ex ante* monitoring, the most collaborative fishers were selected to carry out the pinger trials, reaching at the end of the three years a total of 25 fishers working on 20 different vessels. The area of interest during the first year (2021) were four (Porto Santo Stefano, Talamone, Marina di Grosseto, and Piombino), whose study's results were reported in Ceciarini et al., (2023). In the following two years (2022 and 2023), Porto Ercole was also added, expanding the study to five areas.

To evaluate efficiency of pingers to keep common bottlenose dolphin away from fishing nets, net with (TEST) and nets without (CTRL) the device were deployed with the aim to: **i**) assess the differences in species richness and abundance between nets with and without pinger, **ii**) evaluate the differences between CTRL and TEST nets for "Catch Per Unit Effort" by weight ($CPUE_W$); **iii**) evaluate how $CPUE_W$ could be influenced from several factors such

as season, depth, latitude, or dolphin interactions; **iv**) evaluate the effectiveness and efficiency of the DiD01 in reducing harmful interactions, such as damage to the catch or the nets. From March 2021 to November 2023, a total of 868 fishing trials were conducted using nets with and without pingers (n=573 and n=295, respectively).

The total number of species captured was 83 (5 molluscs, 7 crustaceans, 6 cartilaginous fishes, and 65 bony fishes). The most frequently caught species in the CTRL nets were cuttlefish and gilthead seabream, while in the TEST nets, were cuttlefish, gilthead seabream, and octopus. Considering all five areas, the species most caught both in terms of weight and number of individuals were: cuttlefish, red mullet, caramote prawn, and spottail mantis shrimp. However, data might vary from area to area, with some species being more caught (in terms of kg or *n*) in certain locations than in others. The 41.67% of the 83 species captured corresponded to those included in the common bottlenose dolphin's diet. Moreover, species richness was higher in the test nets, suggesting that the absence of dolphins in the vicinity of the fishing areas, due to the use of pingers, increases the diversity of target species. Through binomial statistical analysis, comparing $CPUE_W$ between CTRL and TEST nets over the three years, results revealed that it was significantly different only for 2023. Afterwards, linear regression model showed that $CPUE_W$ was significantly higher in 2022 and 2023 ($p<0.05$), it was significantly lower in winter than autumn, in the north respect of the south part and in deeper than in shallower waters ($p<0.05$). However, $CPUE_W$ was not significant depending on presence or absence of dolphin interactions ($p>0.05$). Dolphin-related catch damages were greater in nets without compared to those with pingers. The use of this acoustic deterrent device reduced the number of hauls with catch damage by 25.73%, while net damage (holes) decreased by 29.52%. Harmful dolphin interactions dropped by 28.00% with pinger use, all these providing economic benefits to fishers, resulting in total savings of average €1,924.33 ± €679.07 annually. Nevertheless, estimating the potential economic losses requires further in-depth investigation. In 24 trials, dolphin sightings were evenly distributed between control and test nets, with a total of 109 individuals observed. No dolphin bycatch occurred during the fishing operations, but during the PhD project period, two stranded common bottlenose dolphin specimens were recovered along Tuscan coast and reported high evidence of fishery interactions with sings of fishing gears around their bodies. According to an *ex post* questionnaire administered to 18 fishers, 83.31% were satisfied with the use of pingers, though 50% suggested improvements in the technical aspects of the device. Additionally, 66.67% of the fishers expressed interest in pursuing alternative economic activities, such as fishing with tourists on board known as "pescatursimo".

STRUCTURE OF THE THESIS

The first chapter is an introduction divided into three subsections: the first focuses on the relationship between **humans and the sea** over the years, with an emphasis on the state of Mediterranean fisheries and a particular focus on Small-Scale Fisheries in the Mediterranean Sea. The second subsection addresses the relationship between **humans and cetaceans** over time, with a focus on the common bottlenose dolphin, discussing its biological and ecological aspects, especially its communication system and conservation status, along with related anthropogenic threats. The third subsection explores **dolphin–fishery interactions** and how to reduce this harmful relation, discussing all possible solutions and mitigation methods applied to date.

The second chapter describes the study area, and the methods used within the PhD project, including *ex ante* and *ex post* monitoring, investigations with Acoustic Deterrent Devices, statistical analyses, and data modelling. It also focuses on the elaboration of cetacean stranding data.

The third chapter presents the results obtained during the investigations: ex-ante and ex-post monitoring of dolphin-fishery interactions, the effectiveness of Acoustic Deterrent Devices, species composition and captures, and fishing effort in CTRL and TEST nets. It also includes the occurrence of catch and net damage caused by common bottlenose dolphins or other species, with a statistical validation of pinger efficiency through linear regression models. Additionally, cetacean strandings were discussed, with a particular focus on common bottlenose dolphin strandings in Tuscany.

The fourth chapter compares the obtained results with relevant literature, including papers, articles, abstracts, and all bibliographic sources used to contextualize and interpret the findings.

The fifth chapter draws conclusions from the discussions, aiming to provide a practical and pragmatic response to the research questions raised during the study planning.

LIST OF ABBREVIATIONS

A.C. = After Christ
ACCOBAMS = Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea, and Contiguous Atlantic Area
ADD = Acoustic Deterrent Device
AHD = Acoustic Harassment Device
AMD = Acoustic Mitigation Device
B.C. = Before Christ
BRDs = Bycatch Reduction Devices
ca = "circa" a Latin word which means around or approximately
CPC = Contracting Parties and Cooperating State
CFP = Common Fishery Policy
CPUE = Catch Per Unit Effort
$CPUE_N$ = Catch Per Unit Effort Number of individuals
$CPUE_W$ = Catch Per Unit Effort Weight of haul
DDD = Dolphin Deterrent Devices
e.g. = exempla gratia
EMFAF = European Maritime, Fisheries, and Aquaculture Fund
FADs = Floating Aggregating Devices
FAO = Food and Agriculture Organization of the United Nations
FEK = Fisher's Ecological Knowledge
GFCM = General Fisheries Commission for the Mediterranean
GHGs = Greenhouse's gas
GNS = Gillnets
GT= Gross Tonnages
GTN = Combined nets
GTR = Trammel nets
i.e. = id est
IUU = Illegal/Unreported/Unregulated fishing
LME = Large Marine Ecosystem
LOA = Length Overall
MMEDs = Marine Mammal Exclusion Devices
MSY = Maximum Sustainable Yield
SDGs = Sustainable Development Goals
PPUE = Profit Per Unit of Effort
TFEU = Treaty of Functioning of the European Union
TEDs = Turtle Excluder Devices
USD = United States Dollars
VDDs = Visual Deterrent Devices

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Figure 48 – Treemap of species caught in AREA 1 using CTRL nets, represented by the number of individuals captured. Each rectangle represented a different species, with the size proportional to the number of individuals caught (n=6,112). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: SLM (n=17), CBM (n=14), and RPG, POP, MZZ, YRS, CTB SMD, BON, SHR, BSS, HKE, SBS, WEG, MAC, MON, SLO, SQC (n=≤13).

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PREFACE

Leonardo Di Caprio, in an interview about his documentary "Before the Flood" (2016), said:

> *"If you do not believe in climate change, you do not believe in facts, or in science, or in empirical truths, and therefore in my humble opinion should not be allowed to hold public office."*

The American actor made these observations in an effort to fight climate change and raise awareness people about the environmental issues we have been facing during the last century. Despite the exploitation of fossil fuels is not the only and the greatest concern associated with climate change, fossil fuels remain the primary topic of the majority of environmentalist debates. Just consider the current environmental movement's "*Just Stop Oil*" campaign that was launched in the United Kingdom in March 2022 and has as its central keystone that fossil fuels are the primary cause of climate change. Demanding an immediate halt to new investments in fossil fuels, climate activists stage protests in front of petrol stations, fuel depots, and refineries.

However, do we have enough evidence to say that the myth of a long-lasting pre-industrial idyll between humans and their natural ecosystems has been destroyed merely by an unsustainable development model based on the exploitation of fossil fuels or more generally by the Modern Age? No, we do not. This idea is still well rooted among the general public and, also, it is the *leitmotiv* of some forms of radical environmentalism. Is it true that it all began so recently and unexpectedly? No, it is not.

If we compress the geologic timescale of the 4.6 billion years of Earth's history into 24 hours, starting with the planet's birth at midnight and ending with the current midnight, the human ancestors walked the planet only at 23:58:59, less than 2 minutes to now. Unfortunately, in the last two minutes (corresponding to 200,000 years ago), among the Primates' Order, the first Hominids have evolved into the First Modern Man, who has changed the nature of the Earth's planet irrevocably: *Homo sapiens*.

In fact, the bulky presence of man and his activities have also led some academics to assign, albeit unofficially, the characteristics of an entire geological era precisely to human beings, calling it *Anthropocene* (*Anthropo-* from ἄνθρωπος (anthropos) meaning "human" and *-cene* from καινός (kainos) meaning "new" or "recent"). This word was created and made popular by the biologist Eugen Stormer and the chemist Paul Crutzen in 2000, introducing the Anthropocene as a marked epoch in which humans invariably altered Earth's bio- and geosphere (Crutzen 2002; Steffen et al., 2007). Nevertheless, even today, there is much debate over the exact beginning of this era: some think that it began around 12,000 – 15,000

years ago with the agricultural revolution and the rise of sedentary human societies, while others and the creators themselves, who are most supported, advocate the starting period was even closer to the Industrial Revolution time, nominally beginning in 1784 with the development of the Watt steam engine. Whenever this era has begun, inevitably ecosystems have shifted from *nature controlled* to *human dominated.*

Professor Guido Chelazzi, also supported by William F. Ruddiman and other scientists, in his book "L'impronta originale" ("The Original Imprint"; 2013), tells us that a great deal of evidence from human palaeontology, prehistoric archaeology, palaeobotany, and paleoclimatology is used today to shift the date of origin of the man hegemonic role in the functionality of natural ecosystems to at least 8,000 years ago, coinciding with that great cultural transactional, demographic, and socioeconomic revolution known as the Neolithic Revolution. This point of view emphasizes the thesis that human existence should not be considered a separate thing in itself, but rather it is an integral part of a complex ecosystem. So, while humans have the honour of being a part of ecosystems appreciating and exploiting their places, resources, energies, and their beauty, they also have the burden of conducting a functional, responsible, and ethical lifestyle that is focused on preserving the ecosystem itself.

In other words, they must lead a *sustainable* way of life to the well-being of the ecosystem to which humans belong.

Nowadays, it is very challenging to make a single reference to the topic of sustainability because the phrase "*sustainable development*" has undergone so many interpretations over the years and can now be used in so many different contexts. The first year we talked about "*sustainable development*" was in 1972, when, even if it was not used explicitly, the Rome Club's marked the publication of "Limits of Growth" Report. The unsustainable nature of a development model that treats the land as an endless supply of resources, always available for us, was strongly denounced in this Report. The Brundtland Report (*Our Common Future*), published in 1987, is the first document to expressly define the phrase *sustainable development* as development that may satisfy present generation demands without endangering those of future generations (Keeble, 1988). The concept of *development* that wants to be truly *sustainable* cannot be limited to environmental aspects alone but must provide the indissoluble interweaving between these and the issues of economic justice and social equity: true sustainability must be both environmental and economic as well as social. This idea did not emerge until the 1992 Rio de Janeiro UN Conference on Environment and Development, also known as the Earth Summit. The slogan "*Think globally, act locally*"

captures another important message of Rio: the close relationship between global and local issues well described in the Chapter 28, Section III of Agenda 21:

> *"28.1. […] Because so many of the problems and solutions being addressed by Agenda 21 have their roots in local activities, the participation and cooperation of local authorities will be a determining factor in fulfilling its objectives. Local authorities construct, operate and maintain economic, social and environmental infrastructure, oversee planning processes, establish local environmental policies and regulations, and assist in implementing national and subnational environmental policies. As the level of governance closest to the people, they play a vital role in educating, mobilizing and responding to the public to promote sustainable development. […]"*

The approach that simultaneously considers Ecology, Economy and Ethics (meant as social) is a *win-win* approach that goes beyond the biases inspired by depoliticising and intergovernmental consensus building remit, and so, effectively neutralises much radical political critique. Ecology, Economics, and Ethics have been coexisting since the first human civilization and they are inextricably linked and related. Indeed, only a balanced relationship between these three entities may result in the sustainable growth, or better development, of a single family, of a society, an ecosystem, a biome up to the entire biosphere. Ignoring this fundamental relationship is the cause of many of the most serious global environmental issues we are currently facing. In particular, the environmental problems characterising the Anthropocene era such as climate change, biodiversity loss (both terrestrial and marine), disruption of the nitrogen and phosphorus cycles, stratospheric ozone depletion, ocean acidification, global freshwater consumption, land use changes, chemical pollution, and atmospheric aerosol loading particularly affected the lifestyle of many people, touching many of their hearts, enough to work to re-establish, or establish for the first time, harmony between human being and the Environment. In December 2006, The Guardian published an article "Earthshakers: the top 100 green campaigners of all time", showing a list of the scientists, naturalists, activists, journalists, writers, economists, and religious who, in their views, have done the most to save the planet. Some are very similar in terms of extraction and social position, while others are very different – just think that in this list there are Rachel Carson, St. Francis of Assisi, Siddhartha Gautama Buddha, Al Gore, Arnold Schwarzenegger, Charles Windsor (at that time Prince of Wales, at the present moment King Charles III), Mahatma Gandhi, Charles Darwin, etc. At the same time, if The Guardian wanted to publish the list today as The Earthshakers 2.0, it could add names like: Greta Thunberg, Pope Francis, Leonardo Di Caprio, Barack Obama, Ursula Gertrud von der Leyen, and so on. Without a doubt, a *fil rouge* that ties these *eco-heroes* is to observe the role of man on this Planet as an integrated part of it where everything is extremely connected

as it is written in the encyclical letter "Laudato Sì'" of the Pope Francis "On care for our common home":

> *"138. […] It cannot be emphasized enough how everything is interconnected. Time and space are not independent of one another, and not even atoms or subatomic particles can be considered in isolation. Just as the different aspects of the planet – physical, chemical, and biological – are interrelated, so too living species are part of a network which we will never fully explore and understand. […]"*

And finally, this path reached its peak in September 2015 when the ONU General Assembly created the 2030 Agenda, which reaffirms and consolidates the principles of *sustainable development* that view the environmental, economic, and social spheres as interconnected:

> *"[…] The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries - developed and developing - in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests. […]"*

Moving on, a fundamental reorganization of today's society is implied by this new notion of *sustainable development* as a holistic vision, which calls for significant reforms in all spheres of social, economic, political, and cultural systems.

Building on the previous points, the three E's of sustainable development - environment, economy, and ethics - are often seen as the key to addressing the pressing environmental, economic, and ethical challenges facing the world today.

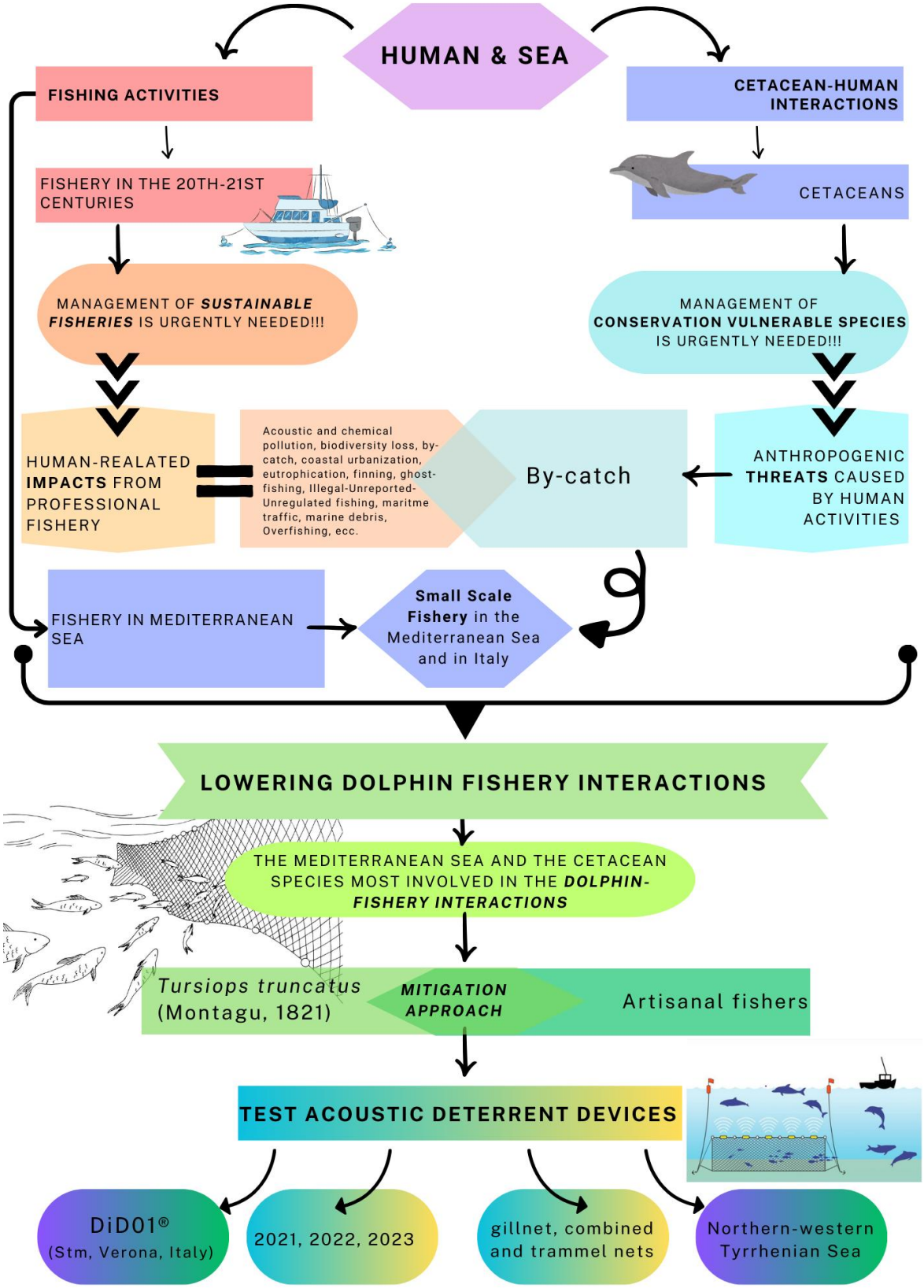
In light of this, when did humans realize the importance of accomplish and overcoming this big issue? Harvard University psychologist Steven Pinker argues humans are now living – throughout most of the world (except those parts where conflicts and wars are still ongoing) – in the most long peaceful era in the history of our species. This state of well-being, or apparent well-being, which distinguishes the Western world in particular, enables us to think about other aspects of life as well as survival in the strict sense, as opposed to what occurs in the world's poorest and most overexploited regions, which instead accuse our world of causing the world's major environmental crisis.

Sir Robert Baden-Powell, the founder of the Boy Scouts, inspired by a quote of Ralph Waldo Emerson, an American 19th century poet, in his last message told scouts to "*try to leave this world a little better than you found it*". This hope serves as a rallying cry, motivating individuals like politicians and scientists to take concrete steps toward achieving sustainable development. Mother Teresa of Calcutta said that "*what we are doing is nothing more than*

a drop in the ocean. But if the drop were not there, the ocean would be missing something" inviting, so, people to do something, that although small is useful.

This PhD thesis aligned closely with this concept as it delved into a specific and well-defined research area at the intersection of environmental sustainability, marine ecology, and fisheries biology. Conducted within the framework of the European Life project, Life DELFI (*Dolphin Experience Lowering Fishing Interactions*, LIFE 18 NAT/IT/000942), at the University of Siena—one of the project's partners—the thesis aimed to develop solutions that integrate ecological, economic, and social dimensions.

From an ecological standpoint, the research focused on safeguarding and protecting a species under threat, emphasizing the conservation of marine life, particularly cetaceans such as dolphins (i.e., *Tursiops truncatus*). Economically, the thesis sought to identify strategies that enable fishers to sustain their livelihoods while minimizing negative interactions with dolphins, thus allowing them to continue relying on the sea as their primary source of income. Socially, the project involved extensive outreach, education, and awareness activities aimed at stakeholders and the general public. These efforts highlighted the importance of marine conservation and encouraged public participation through citizen science initiatives. By engaging the community in small, meaningful actions, the thesis contributed to the broader research goals, fostering a collective responsibility toward the protection of marine environments.


HUMAN & SEA
FISHING ACTIVITIES
CETACEAN-HUMAN INTERACTIONS
FISHERY IN THE 20TH-21ST CENTURIES
CETACEANS
MANAGEMENT OF SUSTAINABLE FISHERIES IS URGENTLY NEEDED!!!
MANAGEMENT OF CONSERVATION VULNERABLE SPECIES IS URGENTLY NEEDED!!!
HUMAN-REALATED IMPACTS FROM PROFESSIONAL FISHERY
Acoustic and chemical pollution, biodiversity loss, by-catch, coastal urbanization, eutrophication, finning, ghost-fishing, Illegal-Unreported-Unregulated fishing, maritme traffic, marine debris, Overfishing, ecc.
By-catch
ANTHROPOGENIC THREATS CAUSED BY HUMAN ACTIVITIES
FISHERY IN MEDITERRANEAN SEA
Small Scale Fishery in the Mediterranean Sea and in Italy
LOWERING DOLPHIN FISHERY INTERACTIONS
THE MEDITERRANEAN SEA AND THE CETACEAN SPECIES MOST INVOLVED IN THE DOLPHIN-FISHERY INTERACTIONS
Tursiops truncatus (Montagu, 1821)
MITIGATION APPROACH
Artisanal fishers
TEST ACOUSTIC DETERRENT DEVICES
DiD01® (Stm, Verona, Italy)
2021, 2022, 2023
gillnet, combined and trammel nets
Northern-western Tyrrhenian Sea

1.1. HUMAN & SEA: relation over the years

The sea has long been a symbol of dreams and epic stories, playing a crucial role in human history beyond space and time. Coastal civilizations have depended on the sea for trade, communication, and, most importantly, as a primary food source through fishing, a practice dating back to the Palaeolithic era (40,000–35,000 years ago) (Casi, 2010). Over time, the sea has gained cultural significance, inspiring artistic expressions such as mosaics, murals, vases, coins, and personal decorations. These artworks highlight the deep and enduring connection between humans and the sea, particularly in the context of fishing (Figure 1).

Figure 1 – **A**. Egyptian wall murals of Menna and family fishing in the marshes (c. 1400 – 1352 B.C.) located at the Metropolitan Museum of Art (New York). **B**. Detail of a late Archaic κύλιξ ("kylix", drinking cup) of a boy fishing with a pole and lifting out a crab while an octopus is hiding from him (c. 400 – 500 B.C.), located in the Museum of Fine Arts (Boston). **C**. Roman mosaic of a young man and an old man, sitting in the boat while fishing (c. 300 A.C.) located at Room 5 "Sala dell' Ermafrodito" of Galleria Borghese (Rome) **D**. A Pompeian mosaic of several species of fish that were the basis for preparing the popular garum (a fermented sauce made with small fish like sardines and mackerel, along with brine and plenty of time, ca. 100 B.C., located at the National Archaeological Museum of Naples.

Along with the figurative arts, bibliographical literature by Greek and Latin authors attested to how essential and strongly rooted the practice of fishing was within their society. First the Greek author Esopo (620 – 564 B.C.) in his fable entitled "Οἱ Ἁλιεῖς", i.e, "*The fishermen*":

> *"Some fishermen were out trawling their nets. Perceiving them to be very heavy, they danced about for joy and supposed that they had taken a large catch. When they had dragged the nets to the shore, they found but few fish: the nets were full of sand and stones, and the men were beyond measure cast down so much at the disappointment which had befallen them, but because they had formed such very different expectations. One of their companies, an old man, said: "Let us cease lamenting, my mates, for, as it seems to me, sorrow is always the twin sister of joy; and it was only to be looked for that we, who just now were over-rejoiced, should next have something to make us sad." Knowing that life is unpredictable, we do not always exalt ourselves for the same circumstances. After all, it is certain that a storm will also come after a prolonged calm."*

Roman authors like Plinius Il Vecchio in the "*Naturalis Historia*" and Marcus Terentius Varrone in "*De Re Rustica*" documented early aquaculture, describing freshwater ponds for food and profit and saltwater ponds for aristocratic entertainment. Fishing in the Mediterranean has played a vital role in human history, with ancient civilizations such as the Phoenicians, Egyptians, Greeks, and Romans developing various fishing techniques and preservation methods like salting, drying, and smoking (Sahrhage and Lundbeck, 2012). The earliest fishing communities appeared in Crete around 8,000 years ago. With the rise of Christianity, fishing and fishermen took on symbolic significance, emphasized in religious texts and iconography (Casi, 2010) as we read in The Bible Gospel of Metthew:

> *"*4:19 *[...] Come after me, and I will make you fishers for men. [...]"*

During the Middle Ages, Mediterranean commercial fishing transitioned from small-scale to commercial enterprises, aided by advancements in boat design, fishing gear, and preservation techniques, including canning (Lackey, 2005). The Renaissance and European colonialism introduced new fishing methods like purse seining and drift netting, while whaling expanded globally (Aguilar, 1986; Dolin, 2008; Lackey, 2005). By the late 1800s, steam-powered ships, mechanized fishing, and refrigeration enabled the rise of large-scale industrial fisheries, shaping modern fishing practices (Lackey, 2005).

1.1.1. State of Mediterranean Sea fisheries

Fishing expanded rapidly in the 20th century, peaking in the 1990s before stabilizing or declining due to overfishing. Global catches now range between 80–90 million tons annually. Meanwhile, aquaculture has grown exponentially, rising from a marginal sector in the 1980s to producing 50% of global fish supply, reaching 82 million tons in 2023. Aquaculture has become crucial for balancing the stabilization of wild catches and meeting the growing demand for fish. In fact, per capita fish consumption has increased from about 9 kg in the 1960s to over 20 kg in 2023, reflecting the rise in global population, economic growth, and greater availability of fish due to aquaculture (FAO, 2023).

In 2021, the fisheries and aquaculture sector in the Mediterranean and Black Sea produced nearly 2 million tonnes, generating $20.5 billion and supporting over 700,000 jobs. While capture fisheries have declined since the 1980s, aquaculture has nearly doubled in the past decade. Türkiye led in both sectors, with Italy and Tunisia prominent in capture fisheries, and Egypt and Greece in aquaculture. European anchovy and sardine dominated catches, though some species declined, while shrimp, cuttlefish, and mullets increased. Small-scale vessels, comprising 82% of the fleet, provided 61% of jobs and 30% of revenue despite only

15% of catches. The overexploitation rate in the Mediterranean and Black Sea dropped from 73% in 2020 to 58% in 2021, the lowest in a decade, alongside a 31% reduction in fishing pressure since 2012 (FAO, 2023).

The overfishing problem today can be traced back to the 1800s when naturalist Thomas Henry Huxley proposed the flawed "principle of inexhaustibility" (Huxley, 1883), which claimed seafood resources were limitless. This theory, widely accepted by many, led to unsustainable fishing practices, increased demand for fish, and the rise of intensive industrial fishing. These factors have contributed to the global overfishing crisis, threatening the survival and stability of fish stocks. *Overfishing* – stock abundance fished to below the level that can produce maximum sustainable yield (MSY) – not only causes negative impacts on biodiversity and ecosystem functioning, but also reduces fisheries captures, which subsequently leads to negative social and economic consequences (FAO, 2022). The United Nations Sustainable Development Goals (SDGs) set a clear target on fisheries (SDG Target 14.4): to end overfishing by 2020, but global fisheries are moving further from this goal, with regional variations in progress. In the Mediterranean and Black Sea, the percentage of overexploited stocks has continued to decrease, reaching 58% in 2021, a 15% drop since 2014. Despite this, more than half of assessed stocks are still fished unsustainably, and fishing pressure remains double the sustainable level. However, there has been a 31% reduction in this ratio since 2012, representing the lowest level in the series.

Nevertheless, some of the human pressures at sea strongly combine each other most of all in the effects that they generate, as it is shown in the alluvial plot below (Figure 2). Indeed, the overfishing is not the only anthropogenic threat affecting marine ecosystems nowadays, but rather several kinds of human-related activities that are carried out along coastal ecosystems, near-shore or off-shore areas, have generated so many potential risks that some have strongly related each other and some other are directly or indirectly connected by cause-effect relationship. Certainly, the presence of man in the sea is evident worldwide in his many activities and from several point of views beginning from the improper management of fishing activity (He and Silliman, 2019), urbanization and coastal overbuilding (Cantasano et al., 2023; Smiraglia et al., 2023, Zhang and Xing, 2023), maritime traffic and shipping (Pirotta et al., 2019), military activities (Parson et al., 2000; Dolman et al., 2009), drilling and mining (Albedawi, 2023; Guo et al., 2023; Messora, 2023), intensive coastal industrial activities (Giannakidou et al., 2020), chemical spills (Beyer et al., 2016; Lovindeer et al., 2023), marine and coastal tourism (Schuhbauer et al., 2023), gathering of materials for human consumption (Murillas-Maza et al., 2011), and source of blue energy (Bari, 2017;

Machado and de Andrés, 2023). Each of these anthropogenic pressures is still threatening nowadays both the environment and humans, posing a real risk to the stability and health of the marine ecosystems. Undoubtedly, every action has one or more negative effects that occasionally have a direct cause-and-effect relationship, but other times they take the form of a secondary effect (Gissi et al., 2021) (Figure 2).

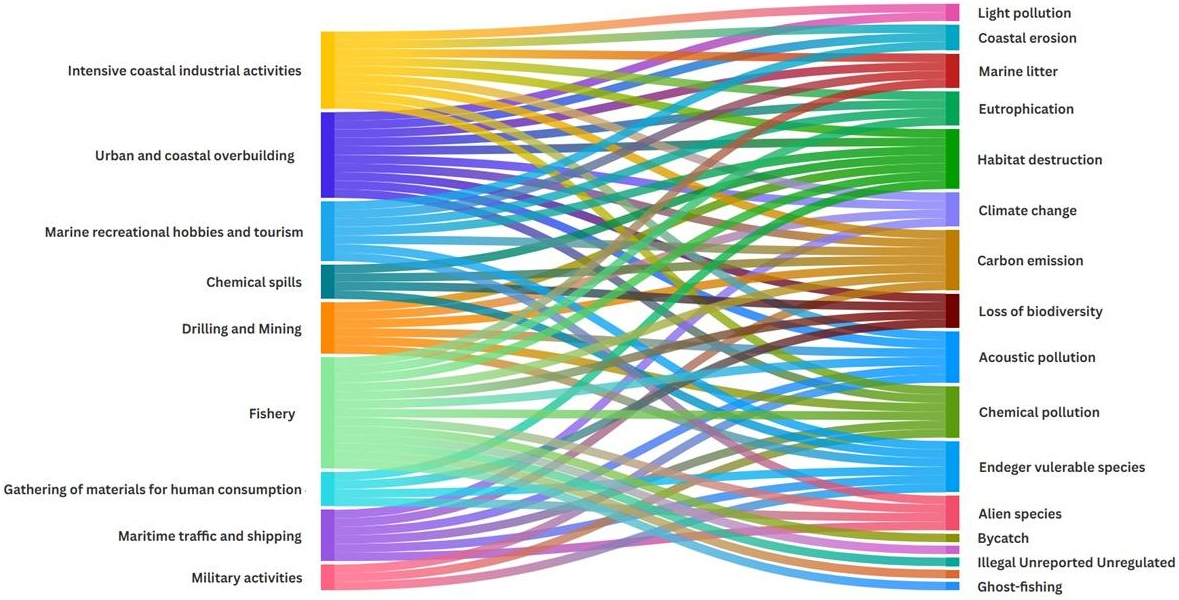


Figure 2 – The alluvial plot delineates several key factors such as the main human-related activities contributing to harmful effects and threats in the marine environment. Each of these factors is represented as a distinct flow within the plot, highlighting their interconnectedness and cumulative effects on coastal and marine environments. On the left side of the plot hum-related activities are shown and on the right side of the plot their relative effects and impacts.

The principal negative effects are: habitat destruction (Lotze et al., 2006; Gilman et al., 2023), the presence of marine litter (Galgani et al., 2015; Cesarano et al., 2023; Madricardo et al., 2020), loss of biodiversity (Coll et al., 2010), acoustic, chemical, and light pollution (Alava et al., 2017; Gaston et al., 2023; Mortimer and Batley, 2023; Picciulin et al., 2023; Weilgart, 2023), coastal erosion (Roebeling et al., 2018), ocean acidification by carbon dioxide emission (Mitchell et al., 2023; Servili et al., 2023), presence of alien species (Bax et al., 2003; Mghili et al., 2023; Rounsevell et al., 2018), climate change (Alava et al., 2017; Cabral et al., 2019), endanger vulnerable species (Carrillo and Ritter, 2010; Pirotta et al., 2019), and eutrophication (Ngatia et al., 2019; Polimene et al., 2023).

Focusing on possible effect on fisheries, it is possible to identify some of these major problematic effects eutrophication (Erkisson, 2011), habitat destruction (Turner et al., 2009), loss of biodiversity (Turner et al., 2009), acoustic and chemical pollution (Amron et al., 2021; Daly and White, 2021), presence of alien species (Sicuro et al., 2016; Báez et al., 2023; Marchessaux et al., 2023), in addition to some specific of this important human activity such as: bycatch (Lucas and Berggren, 2023; Moore et al., 2023), finning (Booth

and Gupta, 2023), illegal/unreported/unregulated fishing known also with the acronymous IUU (Boubekri et al., 2021; Jaleel and Smith, 2023), overfishing (FAO, 2022; Teh et al., 2023) and ghost-fishing (Gilman et al., 2023).

Even though each of these anthropogenic threats is present everywhere, they are not all equally allocated or have the same impact. Contrarily, each threat has a more or less predominate impact depending on the part of the world it is taken into analysis. Focusing on Mediterranean Sea, it is well known that the main threats to the marine environment are habitat loss and degradation, compounded by exploitation, pollution, climate change, eutrophication, and invasion by alien species, maritime traffic, aquaculture and others. All these pose the biggest threats to life in the Mediterranean, with a detailed scale of priority – unfortunately dating back to research carried out a few years ago (Coll et al., 2010).

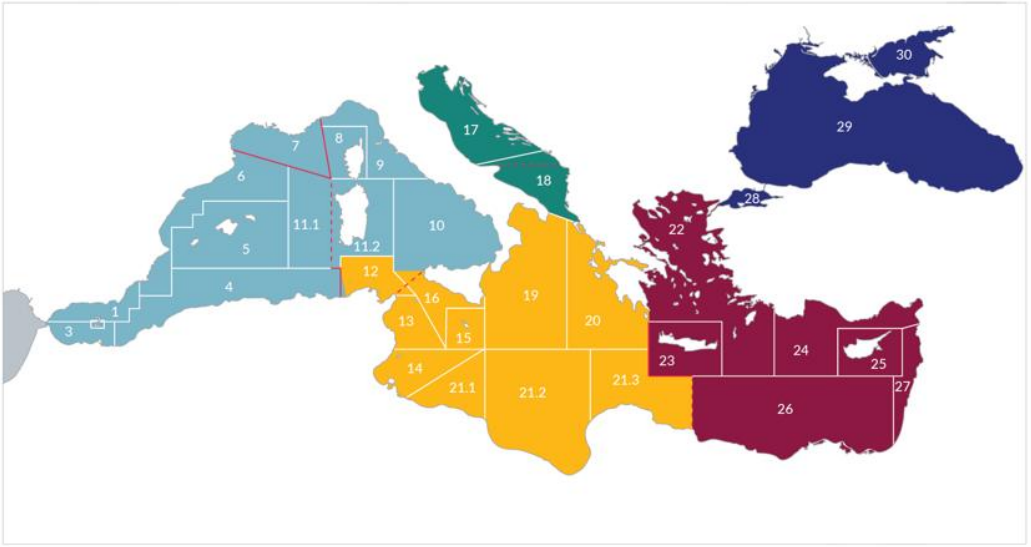
And this Mediterranean critical overview was also pointed out from Nasser Kamel who is the Secretary General of the Union for the Mediterranean, in November 2022:

> *"[...] The climate emergency is global, demanding the attention of everyone. But its impacts and severity are not felt the same everywhere. The Mediterranean region is also more exposed, both for climatic and socio-economic reasons, and if we don't act now, we face dire predictions, including the collapse of entire ecosystems, cities and social structures as we know them. Just this summer, a lethal heatwave wrought havoc with droughts and wildfires across the region and caused huge damage to marine ecosystems. Tens of thousands of people were forced to flee their homes and scores of people have died – in northern Algeria, at least 40 people lost their lives in the August fires. Meanwhile, in south-western France, over 36,700 people were evacuated. Spain and Portugal are facing their driest conditions in more than 1,000 years. An impoverished, destabilised Mediterranean has consequences far beyond regional concerns – it's a global threat as the place where three continents converge. [...]"*

In light of this, within the framework of the present PhD project, it became crucial to focus on sustainable fishing practices. This is due to the fact that exploitation is the second major threat to the Mediterranean Sea, alongside other pre-existing threats and the harmful consequences they impose on the marine environment if not properly managed.

So, it is imperative that fisheries management be given top attention at all governmental and intergovernmental levels, not only from the global level, where FAO policies are concerned, but also from national, and regional management. First of all, in regards of the Mediterranean Sea, under the provisions of Article XIV of the Constitution of the Food and Agriculture Organization of the United Nations (FAO), in 1949 was established the General Fisheries Commission for the Mediterranean (GFCM) which is a regional fisheries management organization at European level, come in force since 1952. The GFCM oversees a subregional approach to fisheries management through its technical units in the GFCM subregions (Figure 3) which are the GSA (Geographical Sub-Areas) defined by FAO within the fishing areas of the Mediterranean and Black Sea. These areas are used to monitor and manage marine resources, allowing for more precise and sustainable fisheries management. GSAs

help coordinate research, conservation, and regulation activities of fishery resources in specific regions. The GFCM continues to protect sensitive species through fisheries restricted areas and a growing database, while regional efforts to reduce bycatch are expanding. Moreover, at European level, fisheries are also governed by a common policy (Common Fishery Policy - CFP), that was first formulated in the Treaty of Rome with its completion in 1983, the policy framework's reforms through decennial reviews in 1993, 2003, and 2014. The CFP, established on legal basis Articles 38-43 of Treaty of Functioning of the European Union, governed with common rules adopted at EU level and applied in all Member States. The original objectives of the CFP were to preserve fish stocks, protect the marine environment, ensure the economic viability of EU fleets and provide consumers with quality food.



01. Northern Alboran Sea	07. Gulf of Lion	13. Gulf of Hammamet	19. Western Ionian Sea	25. Cyprus
02. Alboran Island	08. Corsica	14. Gulf of Gabès	20. Eastern Ionian Sea	26. Southern Levant Sea
03. Southern Alboran Sea	09. Ligurian Sea and northern Tyrrhenian Sea	15. Malta	21.1. Southwestern Ionian Sea 21.2. South-central Ionian Sea 21.3. Southeastern Ionian Sea	27. Eastern Levant Sea
04. Algeria	10. Southern and central Tyrrhenian Sea	16. Southern Sicily	22. Aegean Sea	28. Marmara Sea
05. Balearic Islands	11.1. Western Sardinia 11.2. Eastern Sardinia	17. Northern Adriatic Sea	23. Crete	29. Black Sea
06. Northern Spain	12. Northern Tunisia	18. Southern Adriatic Sea	24. Northern Levant Sea	30. Azov Sea

Note: At its forty-fifth session in November 2022, the GFCM agreed to divide GSA 21 (Southern Ionian Sea) into three marine subareas. The subdivision of GSA 21 into GSAs 21.1, 21.2 and 21.3 will be applied in 2023.

Figure 3 – Map illustrating GFCM GSAs subareas and subregions. The path to the map created by FAO: https://www.fao.org/home/en/ > Data & Info > Maps > GSAs.

The FAO recently released the 2023 report on the state of Mediterranean and Black Sea fisheries, based on input from over 500 scientists and experts. From one hand, FAO reveals a 15% decline in fisheries production since 2020, partly due to the impacts of the COVID-19 pandemic which affected industry revenues and employment in the fisheries sector (FAO, 2023). From the other hand, among the multiple issues the GFCM is facing with, FAO highlights how bycatch is a matter of concern, considered one of the most challenging and hard to resolve. Bycatch, which includes discards and the incidental catch of vulnerable species, is a complex concept with significant implications for the sector, including from economic, regulatory and public points of view. It can affect the survival of commercial and non-commercial resources (i.e., discards) and can threaten vulnerable species (i.e., incidental catch) such as elasmobranchs, sea turtles, marine mammals, and seabirds. On this purpose, the GFCM highlighted the importance of obtaining better information and technical advice on the status of vulnerable species and the need to implement activities for the mitigation of impacts on specific vulnerable groups, as required by the recently adopted GFCM recommendations on the mitigation of fisheries impacts for the conservation of vulnerable species in the Mediterranean (FAO, 2023). The GFCM emphasized the importance of setting clear objectives to reduce interactions between vulnerable species and fishing activities and called for coordinated actions to achieve these goals. It supported the development of a regional action plan on vulnerable species and encouraged CPCs to implement pilot projects based on 2021 recommendations. The Commission also acknowledged ACCOBAMS' efforts to address the incidental catch of cetaceans by illegal driftnets in the Mediterranean and urged the Scientific Advisory Committee to continue its work on reducing incidental catch of vulnerable species across all types of fishing gear. In particular, among the types of fishing gears is considered the number of bycatches changed so far. As it is shown in Figure 4 what it comes out mostly is the 98% of incidental catches of cetaceans occurred by the SSF.

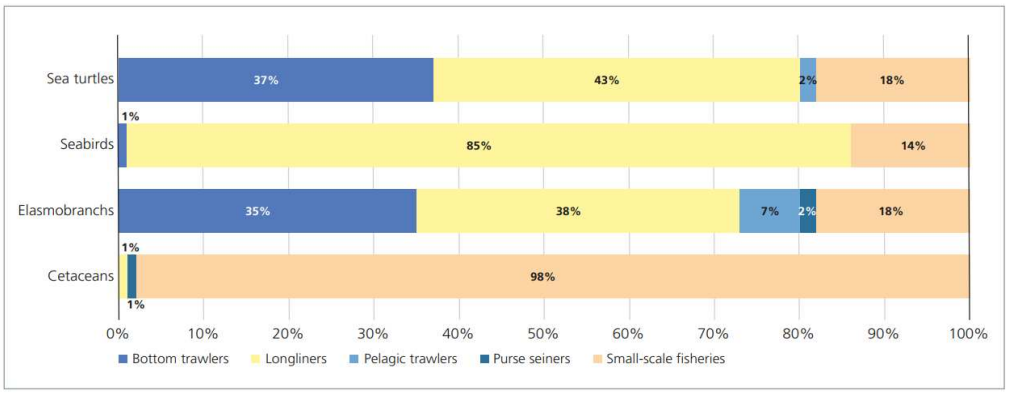


Figure 4 – Relative contributions of main vessel groups to the total incidental catch of vulnerable species groups in the GFCM area of application, 2000-2022.

1.1.1.1. Small-Scale Fishery in Mediterranean Sea

In the Mediterranean Sea, the Small-Scale Fishery (SSF) fleets are typically made up of a sizable number of boats that are based in a variety of harbours and safe docks, the majority of which have an overall length (LOA) of under 12 meters and a small tonnage (1-2 GT) (Lleonart and Maynou, 2003). The small size of the vessel allows it to be operational with low investment and operating costs. Two major characteristics that define SSFs are mixed species catches as well as the variety and seasonality of the gears employed to target them.

Throughout the year, fishing is done in areas that are close to the coast (within 12 nautical miles) and that can be accessed quickly, however it is practiced less frequently in the winter. This means that there are not many hours spent at sea. Moreover, the small size of the vessels means that the fishing, processing, storage, and stowage capacities of the product are not even remotely comparable to those of other type of fishery and/or vessels. The catch is typically sold to customers either at restaurants or immediately at the dock (Raicevich et al., 2020). In addition, in a recent study the SSF was found to be a human marine activity with lower greenhouse gases (GHGs) emissions than others (e.g., carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)), suggesting that it is a good example of less unsustainable use of marine renewable resources, minimizing environmental degradation while maximizing economic and social advantages (Cavraro et al., 2023). SSF plays a major socioeconomic role in the Mediterranean fishing sector, accounting for 82% of the total fishing fleet and for nearly 59% of the workforce on board fishing vessels besides providing a large fraction of total landings, and raise 27% total revenue (FAO, 2023). In SSF, in Mediterranean Sea passive nets or set nets are the most common fishing gears employed, and they play a crucial role because they allow for the catch of a wide variety of demersal, benthic, and pelagic species (Lucchetti et al., 2020). These nets create vertical netting walls that are stabilized in the water column by floats on the upper line (headrope or floatline) and sinkers or weights on the ground-line (footrope or leadline). Their primary function is to intercept swimming fish, crustaceans, and cephalopods (Hameed and Boopendranath, 2000). In Figure 5 are reported the types of the three fundamental fish capture methods utilized by set-nets (Bombace and Lucchetti, 2011): (a) *gilling*, where fish are held by the mesh sliding behind their opercula, (b) *enmeshment*, where fish are held within the mesh around their bodies, and (c) *entanglement*, where fish are held by various protrusions without necessarily entering the net. Fishers modify these nets to enhance one of these mechanisms depending on the desired catch and fishing area. For instance, increasing the net panel's slackness promotes entanglement. Slackness is regulated by vertical tension and hanging ratio – the

ratio between rope length and stretched netting length. Typically, an entangling gillnet has a small hanging ratio and low vertical tension.

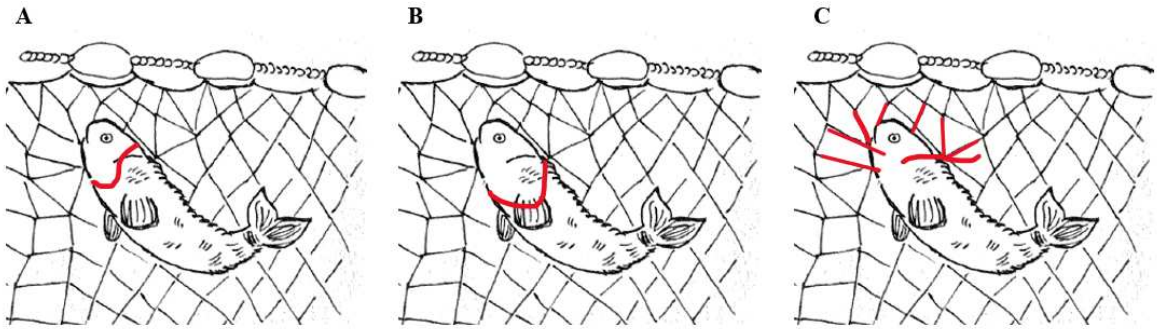


Figure 5 – Basic mechanisms of fish capture in set-nets. **A.** *gilling* **B.** *enmeshment* **C.** *entanglement*. Credits: Calderini G.

According to the net characteristics and design, it is possible to define three main types of fixed net: gillnet, trammel net, and combined net (Figure 6).

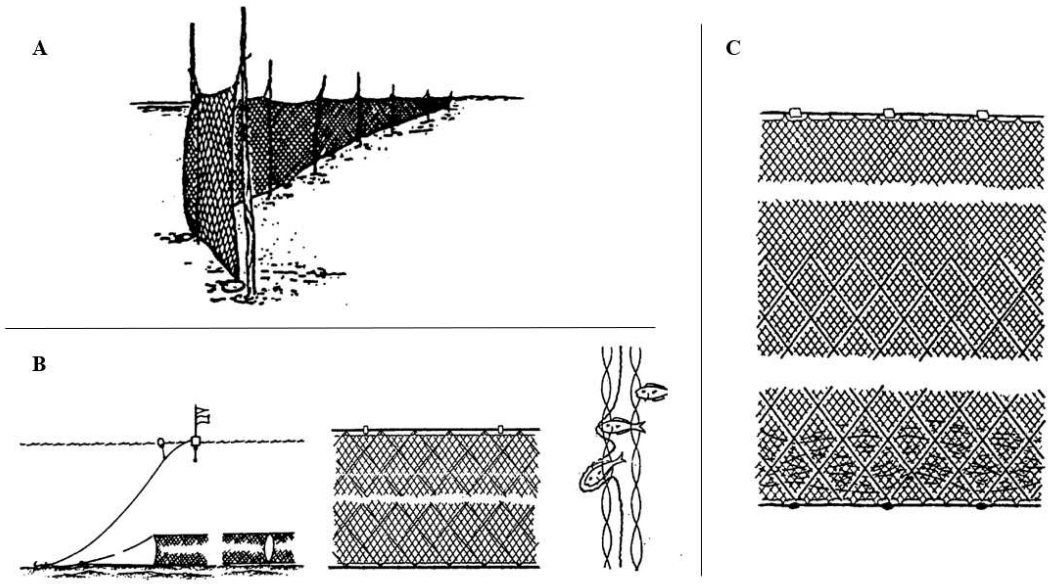


Figure 6 – The three types of gillnets designed by FAO report in the 1990. **A.** the gillnet **B.** the combined net **C.** the trammel net.

- **Gillnets** (FAO Code: GNS) are set nets primarily utilized in coastal waters. These nets gather fish during low tide. As the tide recedes, these nets eventually grant unhindered passage beneath their lower line to fish that are not tangled or caught in the gills. Various factors affect gillnet performance, including mesh size, netting material (usually nylon monofilament), and thread diameter. Mesh size dictates the captured fish's species and size, while the filament's material and thread diameter significantly impact net visibility to both intended and unintended species. These factors also determine net resistance, and the effort needed for caught fish to break free from the net (He, 2006; Lucchetti et al., 2020).
- **Trammel nets** (FAO Code: GTR) are set nets designed with two outer walls featuring larger openings compared to the inner netting panel, which is hung more loosely. The maximum

length is fixed at 6000m as expected by the EU 1241/2019. Fish become captured in the smaller, tightly meshed inner wall after traversing through the outer wall. Only the trammel net adds a further capture mechanism (i.e., *bagging*; exclusive of this net typology (Figure 7).

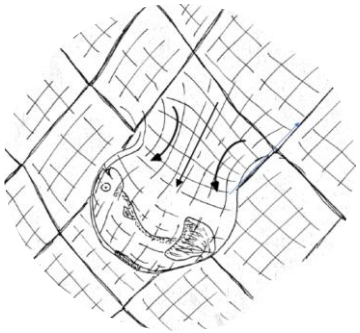


Figure 7 – Illustration of a typical trammel net *bagging* process. Credits: Calderini G.

- **Combined nets** (FAO code: GTN) represent a type of bottom-set that incorporates both gillnets and trammel nets. In this setup, the lower section of the gillnet is substituted with a trammel net. This arrangement enables the capture of bottom-dwelling fish in the lower trammel net section and semi-demersal or pelagic fish in the upper gillnet section. Such gear is less common on Mediterranean scale than GNS and GTR and its use strongly depends on local traditions.

Focusing on Italian legislation, in addition to the ministerial laws and the rules imposed by the Common Fisheries Policy, with the reform of Title V of the Italian Constitution, the terms "agriculture", "fishing" and "hunting" disappear from the text of the art. 117: they do not appear in the lists of State powers, either exclusively or concurrently. The most logical conclusion that the doctrine immediately reached was that these matters belonged to the "residual regional jurisdiction", as the Constitutional Court soon confirmed on the occasion of several rulings (Art. 117 tit. V Italian Constitution).

In Italy, the Small-Scale Fisheries is regulated by Ministerial Decree No. 151 of 30th June, 2017, and it is characterized by: "Small-Scale Artisanal Fisheries" and "Small-Scale Fisheries" (Art.1) with the following definition:

> *"*1.1. *«**piccola pesca artigianale**»* - La pesca praticata da unità di lunghezza fuori tutto inferiore ai 12 metri, abilitante all'esercizio delle pesca costiera locale entro le 12 miglia dalla costa con uno o più sistemi e/o attrezzi da pesca di seguito indicati*: (i) Rete da posta calate (ancorate) GNS (ii) Rete da posta circuitanti GNC (iii) Reti a tremaglio GTR (iv) Incastellate – Combinate GTN (v) Nasse e Cestelli FPO (vi) Cogolli e Bertovelli FYK (vii) Lenze a mano e a canna (manovrate a mano) LHP (ix) Lenze a mano e a canna (meccanizzate) LHM (x) Lenze trainate LTL (xi) Arpione HAR.*
> 1.2. *«**piccola pesca**»* – (a) *piccola pesca artigianale* (b) la pesca praticata da unità di lunghezza fuori tutto inferiore ai 12 metri, abilitate all'esercizio della pesca costiera locale (entro le 12 miglia dalla costa) con uno o più dei sistemi e/o attrezzi da pesca di seguito indicati: *i) Piccola Rete derivante GND ii) Palangaro fisso LLS."*
>
> *"*1.1. *«**Small-Scale artisanal fishery**»* - Fishing conducted by vessels with an overall length of less than 12 meters, authorized for local coastal fishing within 12 nautical miles from the shore, using one or more

of the following fishing systems and/or gear: *(i) Anchored gillnets (GNS) (ii) Drift gillnets (GNC) (iii) Trammel nets (GTR) (iv) Setnets – Combined nets (GTN) (v) Pots and baskets (FPO) (vi) Traps (FYK) (vii) Handlines and rods (operated by hand) (LHP) (ix) Handlines and rods (mechanized) (LHM) (x) Trawling lines (LTL) (xi) Harpoons (HAR).*
1.2. *«**Small-Scale fishery**» - (a) small artisanal fishing (b)* fishing conducted by vessels with an overall length of less than 12 meters, authorized for local coastal fishing (within 12 nautical miles from the shore) using one or more of the following fishing systems and/or gear: *i) Small driftnets (GND) ii) Fixed longlines (LLS).”*

The Italian fishing fleet registered in the Fishing Licenses Archive as of December 31st, 2023, amounts to 11,685 units. The total tonnage was 141,359.34 GT (average 12.10 GT), while the engine power was 915,911.58 kW (average 78.38 kW) with a mean of LOA 9.93 m. With 8,130 vessels, the Small-Scale Fishery represented the most significant segment in numerical terms, accounting for 69.58% of the total fleet on its own. However, its significance reduced considerably in terms of size, amounting to 12.73% of the total tonnage (17,988.34 GT) and 27.23% of the engine power (249,420.15 kW) with a mean of LOA 7.21 m (downloaded data from Fleet Register, December 31st, 2023).

Moreover, in Italy, the SSF sector holds a significant position within the fishing industry, landing nearly 23,000 tons of catch (18% of the national total), with a value of 166.20 million euros (26% of the national total) (Raicevich et al., 2020). In the coming years, with the implementation of the European Maritime, Fisheries, and Aquaculture Fund (EMFAF), further downsizing of fishing capacity was expected. The Annual Report on Italy’s efforts in 2019 to achieve a sustainable balance between fishing capacity and possibilities (Article 22 of Regulation (EC) No. 1380/2013) proposes an action plan to significantly reduce fishing mortality, including through the reduction of fleet capacity. The extent of this reduction will be determined based on the economic resources allocated by the Operational Program of EMFAF 2021/2027.

Focusing on Tuscany, which is the Italian region of interest in this PhD project, firstly its coastline is extended for about 400 km, from Marina di Carrara (MC) to Fosso del Chiarone (GR), and for over 600 km if the islands of the Archipelago are counted. Morphologically, the coast is differentiated into three fundamental types: coastlines characterized by low sandy shores, with gently sloping seabeds and shallow depths even at a considerable distance from the coast; high coastlines with closely spaced bathymetric features and significant depths near the shore; coastlines with high rocky shores of high energy (Archipelago coasts, approximately 1,200 km^2).

The Tuscan fishing fleet has a widely dispersed territorial distribution across a complex of ports and landing sites, diverse in structure and size and this fragmentation can be linked to the predominantly coastal nature of fishing activities in Tuscany and the presence of numerous small maritime centres where Small-Scale Fishery has deeply rooted traditions in

its maritime history. Indeed, the SSF fleet in GSA 9 (included Tuscany) was represented by almost the 70% on the whole fleet. GSA9 is not referred only to Tuscany areas, then GSA 9 covering an area of 42,410 km^2, includes the Ligurian Sea and the central-northern Tyrrhenian Sea, and it encompasses 1,245 km of coastline, including the stretches of sea adjacent to Liguria, Tuscany, and Lazio (Northern).

Fishing activity in Tuscany, as in the entire Mediterranean, is influenced by the strong multispecific nature of available fishery resources and the possibility of employing vessels of various sizes armed with different fishing systems in the same fishing areas, thus suitable for catching multiple species. For these reasons, the Tuscan fleet is characterized by high mobility, with both local vessels from the archipelago ports and fishing units from other areas converging for fishing campaigns.

The fleet register of the Italian Ministry of Agriculture, Food and Forestry included 556 registered vessels in the maritime compartments of Tuscany, with a total tonnage of 4,612 GT, an average tonnage of 8.29 GT, a total engine power of 36,325.20 kW, and an average of 65.33 kW with a mean of LOA 8.97 (Reg. CE No. 1198/2006). Among the 556 vessels, the 80.75% (n= 449) was registered as Small Scale Fisheries vessels (<12 m of LOA). The 449 fishing vessels had a total tonnage of 982.00 GT an average tonnage of 2.19 GT and a total engine power of 16,551.08 kW, and an average of engine power 33.14 kW, and an average of LOA as 7.11 m. All SSF vessels were registered in the main fishing harbours of Tuscany: Isola di Capraia, Castiglioncello, Castiglione Della Pescaia, Cavo, Cecina, Follonica, Forte Dei Marmi, Isola del Giglio, Livorno, Marciana Marina, Marina Di Campo, Marina Di Carrara, Marina Di Grosseto, Marina Di Massa, Marina Di Pisa, Orbetello, Piombino, Porto Azzurro, Porto Ercole, Porto Santo Stefano, Portoferraio, Rio Marina, San Vincenzo, Talamone, Vada, and Viareggio (downloaded data from Fleet Register, December 31st 2023).

1.2. CETACEANS & HUMANS: relation over the years

Cetaceans, including dolphins and whales, have long held significant cultural and symbolic value in human history. This is reflected in prehistoric artifacts, myths, and literature from Greek and Roman philosophers. Some communities even erected statues and symbols to honour these creatures, sometimes attributing them with celestial qualities (Constantine, 2001). The word "cetacean" is derived from the Greek word "κῆτος, ketos," meaning sea monster, which in ancient Greek mythology referred to a goddess Pontos (the wave) and the daughter Gaia (the earth). Today, it refers to marine mammals like dolphins and whales. In ancient Greek culture, dolphins were seen as elegant creatures symbolizing favourable omens, while whales were perceived as monstrous and fearsome (Würtz and Repetto, 1998). Greek mythology often intertwined dolphins with the gods of Olympus, and these marine animals inspired art, literature, and symbolism, especially representing femininity and motherhood. Dolphins were also associated with gods like Poseidon, Apollo, Aphrodite, and Artemis (Redondo, 2015). The Greek philosopher Plutarch highlighted dolphins' loving nature, which was closely linked to human life. Dolphins were so revered that killing one was punishable by death. In Hellenistic culture and other coastal civilizations, dolphins were prominently featured in mosaics, vases, coins, and other artworks.

Figure 8 – Illustrations from ancient history regarding dolphins in human life. **A.** The Queen's Megaron, Palace of Knossos (Crete, Greece). **B.** Minoan art. **C.** Head of nymph Arethusa, Kingdom of Agathocles 317-289 B.C. (Sicily, Syracuse). **D.** Period of Pyrrhus: Taras and Phalantos on dolphin with small figure of Victory and trident, beneath a prow of a ship 302-281 B.C. (Calabria, Tarentum) **E.** Nereid riding dolphin ca 425-401 B.C. (The J. Paul Getty Museum, Malibu) **F.** Ancient Greek vase decoration with a man riding a dolphin. **G.** Mosaic in Houses of Dolphins (Delos). **H.** Metamorphosis of the Tyrrhenian pirates from Micali Painter ca 510-500 B.C. (Toledo Museum of Art, Ohio USA).

In ancient times, the dolphin, primarily featured in myths and legends, also gained attention from early scientists. Aristotle was the first to observe dolphins scientifically, noting their unique behavior and biology. In his book *Historia Animalia* (350 B.C.), he pointed out that dolphins were not fish, as commonly believed, since they breathe air, a remarkable observation for the time.

> *"Dolphins, Aristotle says, are supremely swift swimmers and voracious hunters. He says that they copulate and give birth to one or two live young and that they suckle via ventral slits. ... Sleeping dolphins to, however, snore — or so it's said. They live in male and female pairs for up to thirty years. We know this because fishermen nick their tails and then release them again — which seems to be an account of history's first mark-recapture study. Sometimes they strand themselves for no obvious reason at all.*
> *Most of this is accurate. That dolphins snore is dubious, but perhaps we'll let it go since they do, apparently, vocalize in their sleep. Some scholars think Aristotle must have dissected a dolphin. I don't for he also makes some serious mistakes."*

In the 20th century, research into dolphins advanced significantly. In the 1950s, Dr. John Lilly conducted experiments to establish communication with dolphins, believing they could perceive human language. He thought dolphins could perceive human language and tried to teach them to speak, but despite controversial and unsuccessful experiments, his efforts paved the path for more rigorous scientific study of dolphin behaviour. In the 1960s, Dr. D.L. Mech and Dr. K.R. Norris conducted a famous study on dolphin behaviour off the California coast, revealing their complex social structures and use of vocalizations for communication, including distinguishing pod members by unique calls. However, as human exploration and exploitation of marine habitats grew, interactions between humans and cetaceans evolved into a wide range of activities, both positive and negative (Whitehead et al., 2000). Humans have hunted cetaceans for resources and sometimes culled them due to competition for fish, while cetaceans have benefited from human activities, using boats for energy conservation, play, and foraging (e.g., food, bait, oil, and baleen). Conversely, cetaceans have utilized human activities for assistance in movement (e.g., using the wake of boats to conserve energy while swimming or riding the bow wave of ship), play (e.g., riding waves created by boats), and obtaining food (e.g., following fishing boats to feed on fish that escape from nets or are discarded by fishers) (Busnel, 1973; Shane et al., 1986; van Waerebeek and Reyes, 1994; Orams, 1997; Samuels and Tyack, 2000; Read, 2008).

Concerning the late 1700s, the Australian Aboriginal people began collaborating for whale hunting activities in Twofold Bay (New South Wales, Australia) becoming commercial whalers organized in a collaborative hunting partnership focusing on targeting humpback whales (*Megaptera novaeangliae,* Borowski, 1781) (Wellings, 1944). Advancements in technology during the late 19th and early 20th centuries brought about a substantial shift in human-cetacean interactions. Innovations like the harpoon cannon, industrialized fishing

fleets, and factory ships allowed longer sea expeditions and real-time catch processing, resulting in a substantial increase in both marine exploration by humans and the exploitation of marine life enhancing also fish captures. French oceanic explorer Jacques Cousteau's words emphasize this shift (Cousteau and Diol'e, 1972).

> *"Until the nineteenth century ...man's career as a killer of whales was limited by the relatively primitive means of pursuit and slaughter at his command – ships propelled by sails or oars, hand winches, flimsy ropes, and hand-thrown harpoons. At this time, size was a decided advantage to a whale, for a man could attack and kill only the smaller specimens. With the invention of the harpoon gun in 1864, however, the balance of power shifted."*

On one hand, whaling technology spread quickly, leading to the unsustainable and profit-focused exploitation of great whales causing the collapse of numerous whale populations and the subsequent decline of major commercial whaling enterprises during the 20th century (Figure 9). Another example of cetacean decline population regards not only whaling activity but also fisheries as it happened due to bycatch phenomenon in the Black Sea with the harbour porpoises (*Phocena phocena*, Linneaus 1758) populations that decreased by approximately 90% over the last fifty years. Or in the Mediterranean, particularly in Italy, in Sardinia, Liguria, and Tuscany, there was the practice of "*musciame*" which is the fillet of common bottlenose dolphin limited supplies on illegal markets (Di Natale, 1991; Cagnolaro and Notarbartolo di Sciara, 1992).

Taking this into account, about three decades ago, member states of the International Whaling Commission (IWC) imposed a moratorium on commercial whaling across all species. Consequently, commercial whaling is now largely considered obsolete as an industry. However, diverse forms of human-cetacean interactions, including whaling, have persisted beyond the 1980s encompassing a range of scenarios, not always motivated by commercial gains. For instance, Aboriginal communities in regions like Canada, Greenland, and the US continue traditional or subsistence whaling. The Japanese still engage in whale hunting under the pretext of "scientific" research, while different dolphin species are driven to coastal areas and killed for consumption, as part of culling efforts to mitigate competition for fish resources, or for display in aquariums. Commercial whale hunting remains ongoing in Norway and Iceland and in the Faroe Islands (Denmark) where witness regular "grinds" leading to the deaths of multiple pilot whales (*Globicephala melas,* Traill 1802) and other odontocete species. Also, Africa, Asia, South and Central America, the West Indies, and the South Pacific have been hunting cetaceans during this period (Whitehead et al., 2000).

On the other hand, during the same period, there was a significant expansion in tourism focused on observing free-ranging cetaceans (Hoyt, 2001; O'Connor et al., 2009). Many countries that formerly exploited cetaceans for consumption shifted from whaling to whale-

watching as a more environmentally friendly "exploitation" of this natural resource (Romero and Hayford, 2000; Parsons and Rawles, 2003; Kogi et al., 2004) (Figure 10). Whale-watching and dolphin watching not only have provided, but continue to provide, tangible advantages to local communities due to the encompass economic gains from visitor spending, job opportunities, enhanced infrastructure, exposure of visitors to unfamiliar wildlife habitats and natural areas, support for scientific research in terms of logistics and funding, marine environmental education, and the potential for a more sustainable approach to utilizing cetaceans compared to direct harvests (Orams, 1997, 2001; Hoyt, 2001; Bejder and Samuels, 2003; Garrod and Fennell, 2004).

In conclusion, based on Dr. Allen S.J. consideration (2014), over the time, humans have transitioned from a relationship based on cetacean exploitation (e.g., hunting, whaling, etc.) to a relationship based on adoration (e.g., whale watching, dolphin watching, ecotourism, etc.). This can be considered a transition towards a more sustainable lifestyle that humans have nature.

Figure 9 – **A.** Old whaling in the Bay of Biscay. From a picture in the coat of arms of Lequeitio (Graells, 1870). **B.** Blue whale in Cangas del Morrazo factory (Spain) in 1979. Credit: Manuel Hermelo/Jesús Cancelas, Massó Museum. **C.** Striped dolphin (*Stenella coeruleoalba*, Meyen 1833) photographed by a tourist on a boat in the Pelagos Sanctuary (Northern Tyrrhenian Sea, Italy) **D.** A researcher using the binoculars looking for a dorsal fin of common bottlenose dolphins close to the coast within Punta Campanella AMP during the Life DELFI "dolphin watching" activity expected by Action C4.

1.2.1. Common bottlenose dolphin biology

1.2.1.1. Phylogenesis of the species

Cetaceans and ungulates (such as hippopotamuses, pigs, and deer) share a 50-million-year phylogenetic relationship, belonging to the order Artiodactyla, supported by both paleontological and molecular studies. Biochemical analyses (Arnason et al., 1984) suggest that the two suborders of cetaceans, Mysticeti and Odontoceti, evolved from a common ancestor that went extinct 10-15 million years ago. These suborders are considered monophyletic, meaning they share a single common ancestor.

In this PhD project, the focal group of cetaceans is primarily centred around Delphinidae, with a particular emphasis on the species common bottlenose dolphin (*Tursiops truncatus,* Montagu, 1821). This dolphin is one of the eight regular cetacean species inhabiting the Mediterranean Sea with other species belonging to Delphinidae family which are: striped dolphin, common dolphin, Risso's dolphin, pilot whale, one species belonging to Ziphidae family which is Ziphius, one species belonging to Physeteriade family which is sperm whale, and only one species belonging to the Mysticeti suborder and to Balenidae family which is fin whale (Notarbartolo di Sciara, 2016).

The *Tursiops truncatus* (*T. truncatus*), also known with the common name "common bottlenose dolphin" is also the most studied species and most involved in human activities conducted both at sea in coastal fishing operations, in dolphin-watching activities, and in photo-ID campaigns, as well as on land, considering how much it is used as a charismatic species in aquariums and dolphinariums.

The common bottlenose dolphin of the *Tursiops* genus (Gervais, 1855) is a marine cetacean belonging to the subfamily *Delphininae* and, together with the subfamilies *Lissodelphininae*, *Globicelphalinae*, and *Orcininae*, it belongs to the family *Delphinidae* (Gray, 1821) (Figure 10).

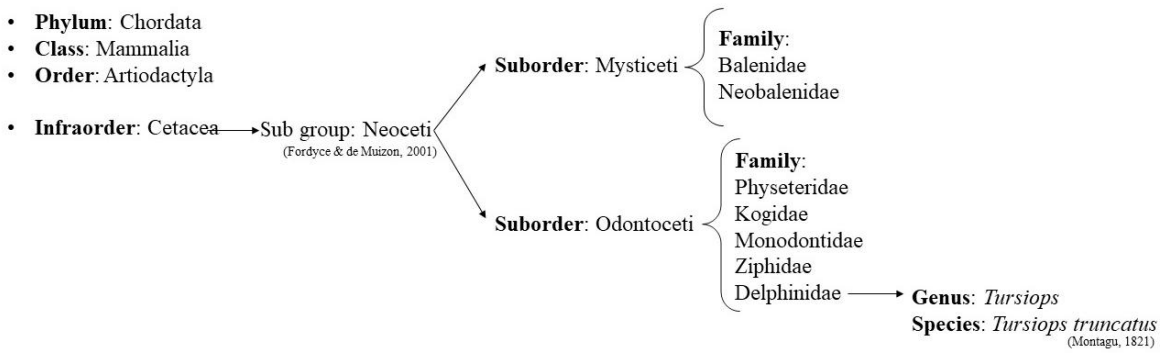


Figure 10 – The phylogenetic tree and taxonomic position of *Tursiops truncatus.* In terms of taxonomic position, *Tursiops truncatus* belongs to the order Cetacea, subgroup Neoceti (Fordyce and Muizon, 2001), suborder Odontoceti, family Delphinidae, genus *Tursiops*, and species *Tursiops truncatus* (Montagu, 1821).

1.2.1.2. Morphological and social features

Common bottlenose dolphins, belonging to the class of mammals, are lung-breathing vertebrates and are recognizable by their anatomical features: a robust, streamlined, with a prominent beak-like rostrum, and perfectly hydrodynamic body. Among cetaceans, they are considered a medium-sized species: the length of adult male's ranges from 2.5 to 4 meters with a weight of about 500 kg, while in adult females, the average length varies from 2 to 3.5 meters with an average weight of 250 kg. Common bottlenose dolphins exhibit a coloration which varies from light to dark grey on their dorsal side, transitioning to a lighter shade on their ventral side (Figure 11). The dorsal fin is well-developed and moderately curved and dark in colour, characterized by distinct markings called notches, which are missing parts of tissue along the trailing edge (Auger Méthé and Whitehead, 2007). These notches are considered individual as a fingerprint for each individual, commonly taken up an important role in photo-ID studies due to its unique shape, nicks, or scars. Analysis of growth layers in dentin and cement in their teeth has shown that female common bottlenose dolphins can live up to 57 years, while males can live up to 48 years (Cagnolaro et al., 2015). These morphological features may differ based on geographic location, not only due to their genetic variations (Bearzi et al., 2008) in Mediterranean Sea, for instance, common bottlenose dolphin specimens tend to be slightly smaller on average compared to those from other parts of the world such as the Atlantic Ocean and this difference can probably be attributed to regional variations in prey availability and environmental factors. Therefore, in Mediterranean Sea specimens may have lighter grey coloration probably influenced by water temperature, diet and genetics, and also the shape of the dorsal fin can be more triangular compared to those in some other regions which may have slightly more curved dorsal fins (Bearzi et al., 2005; Natoli et al., 2005).

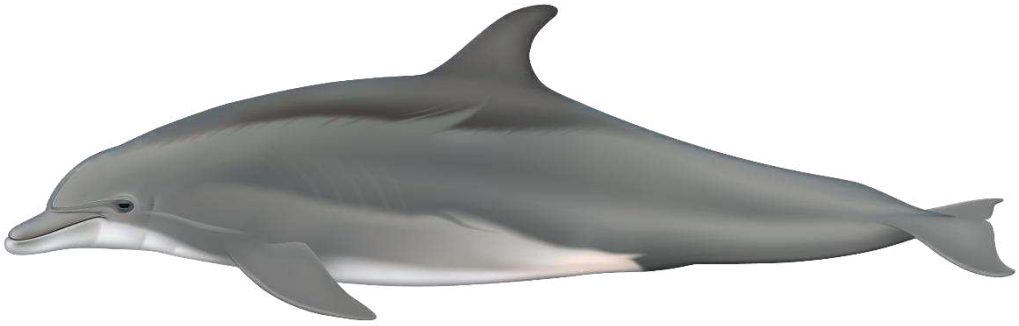


Figure 11 – Illustration of *Tursiops truncatus* (Montagu, 1821). Credits: Uko Gorter.

Common bottlenose dolphin, as other cetaceans, has evolved numerous adaptations to thrive in their aquatic environments. Among these, blubber the subcutaneous fat layer emerges as a multifaceted and indispensable asset playing a vital role for these marine organisms. Its

primary functions include acting as an excellent thermal insulator, enabling cetaceans to maintain a consistent body temperature in cold marine environments. This insulating layer retains metabolic heat, shielding them from the chilly water temperatures. Additionally, blubber serves as an energy reserve due to its high fat content, providing a source of energy during periods of fasting or food scarcity. The low density of blubber contributes to the buoyancy of cetaceans, aiding in swimming and maintaining position during rest or sleep. The thick layer of blubber also offers protection against predators, making it more difficult for them, such as sharks, to penetrate the muscle tissue of the cetacean. Moreover, blubber contributes to the hydrodynamics of the cetacean's body, minimizing water resistance during swimming, which is especially crucial for efficient movement during activities like hunting or escaping predators. In summary, blubber represents a fundamental evolutionary adaptation crucial for the survival of cetaceans in marine environments. Unfortunately, blubber being a lipid-rich tissue, tends to accumulate lipophilic (fat-loving) contaminants such as most of Persistent Organic Pollutants (POPs) and this characteristic makes it a target tissue for many of environmental contaminants affecting cetacean livelihood and compromising their health status.

Common bottlenose dolphins in the Mediterranean Sea are known for their complex social structure: they live in a matriarchal society, where mothers are tasked not only with parental care but also with cultural transmission. Group sizes vary and are not commonly seen interacting with other cetacean species, although there have been occasional sightings with common dolphins and long-finned pilot whales (Bearzi et al., 2009, Koemtzopoulos et al., 2019). Once male dolphins reach sexual maturity, they typically form groups of 2-3 mates, and they search for prey and adult females for potential mating. While females are generally spotted in groups of 5-7, maximum 10 individuals, consisting of adult females, sub-adults, and juveniles, but it is often possible to spot calves swimming alongside their mothers. The swimming alongside the mother is because the mother teaches the calf to live in the marine environment: how to swim, how to prey, how to communicate, and most importantly, how to breathe. Indeed, dolphins have voluntary respiration, and in the first few days of life, the mother's swimming helps giving the calf a little push towards the surface to exhale through the single blowhole (sometimes, you can even hear the calves cough when they need to learn, possibly because some water may have entered their airways). However, dolphins are excellent breath-holders thanks to their ability to store oxygen, which is facilitated by the protein myoglobin and well-organized *retia mirabilia* (Bonato et al., 2019). The spray we see is nothing more than water vapor emitted with a strong and swift jet out of the water

(lasting 0.1-0.3 seconds). This dolphin species can hold its breath for 3-4 minutes, up to a maximum of 7-8 minutes (Bearzi et al., 2009). Another important feature of their behaviour that impacts their social composition can also arise from the different social responses of various personalities within the group. Indeed, a study conducted in Sardinia (Italy) investigated on the *shy-bold* continuum, showing how different personalities within wild bottlenose dolphin groups can impact their social structure. Specimens with a preference for novelty (boldness), had stronger social bonds, central network positions, and spent more time near others, than specimens with a with a novelty-averse behaviour (shyness). This suggests they contribute more to group cohesion, information sharing, feeding opportunities, and mating success. Surprisingly, personality did not relate to exploration or interaction with human-related activities; in some case this divergence may be due to the rich food resources near a marine fin-fish farm, attracting all personality types (López, 2020).

1.2.1.3. Communication system of common bottlenose dolphin

Dolphin communication is intricate and influenced by context (Johnson, 1993). These marine mammals employ a wide range of signals for communication, encompassing both vocal and non-vocal forms (Würsig et al., 1990). This includes visual, tactile, kinaesthetic, and chemoreceptive signals, and they are known for their cross-modal communication abilities using a combination of vocalizations, body language, and other behaviours (Pack and Herman, 1995). Their communication is complex and serves various purposes within their social groups. Here are some of the ways they communicate:

1. **Body language**: dolphins communicate through various body movements and postures. They use their fins, tails, and bodies to signal intentions or emotions to other group members. For example, a playful dolphin may engage in acrobatic leaps and spins to signal its mood.
2. **Touch**: physical contact is another form of communication among dolphins. They may nuzzle, bump, or rub against each other to express affection or reinforce social bonds.
3. **Behavioural signals**: dolphins often use their behaviour to convey messages. For instance, they may engage in synchronized swimming, tail-slapping, or leaping out of the water as a group, which can be a way to coordinate activities, signal excitement, or establish dominance within the group. For example, if they are stressed and annoyed, they deliver powerful tail slaps with loud thuds to stun prey through cavitation (creating a vacuum). Moreover, jumping serves multiple purposes for dolphins. It can be for communication, play, predation, or even to communicate their position within the group. Alternatively, dolphins jump to shed

their skin, as they need to change it approximately 12 times in their life, this phenomenon is known as “the Gray’s paradox” or “the dolphin paradox” (Carpenter et al., 2000).

4. **Role in group behaviour**: the timing and coordination of behaviours within a group can convey information to other dolphins. For example, a coordinated hunting strategy may involve specific signals and roles for different group members. Moreover, in common bottlenose dolphin species, there is no dominant male, but rather there is a super-alliance among males that isolates the interested female through whistles, swimming, jumps, and so on (Connor et al., 2000). Dolphins are highly intelligent and social animals, and their communication is essential for maintaining group cohesion, coordinating activities, and expressing emotions within their complex societies. Researchers continue to study dolphin communication to better understand their social dynamics and cognitive abilities.
5. **Vocalizations**: dolphins are known for their wide range of vocalizations and their sounds are divided into three primary categories: clicks, whistles, and burst-pulse sounds, all produced in their blowholes. Dolphins produce two sounds simultaneously producing clicks on the right side and whistles on the left side (Madsen et al., 2013). The specific patterns and frequencies of these vocalizations can convey information about identity, location, and emotions.

- *Clicks*: clicks (including *echolocation click trains* and *buzzes*) are often used for echolocation, which is primarily used for navigation, orientation and hunting in their underwater environment (Au, 1993). Dolphins can emit echolocation clicks that carry information about their surroundings to other group members. Each click is a short, high-frequency sound that bounces off objects in the water and returns to the dolphin, providing information about the object’s size, shape, and distance. The clicks are transmitted through specialized acoustic fat with varying densities located in the front part of their head, known as the melon. This acoustic fat helps focus and direct the sound into a narrow, highly directional beam. Once emitted, these sound waves travel through the water until they encounter an object, such as prey or an underwater obstacle. When these sound waves hit an object, they bounce back as echoes. The returning echoes are primarily captured by the cetacean’s lower jaw, which contains fat that guides the received sound toward the complex inner ear structure (Figure 12). By emitting ultrasonic sound pulses, odontocetes effectively listen for these echoes, allowing them to detect objects beneath the water’s surface. In essence, they “visualize” their underwater environment by interpreting the reflected sound waves they generate.

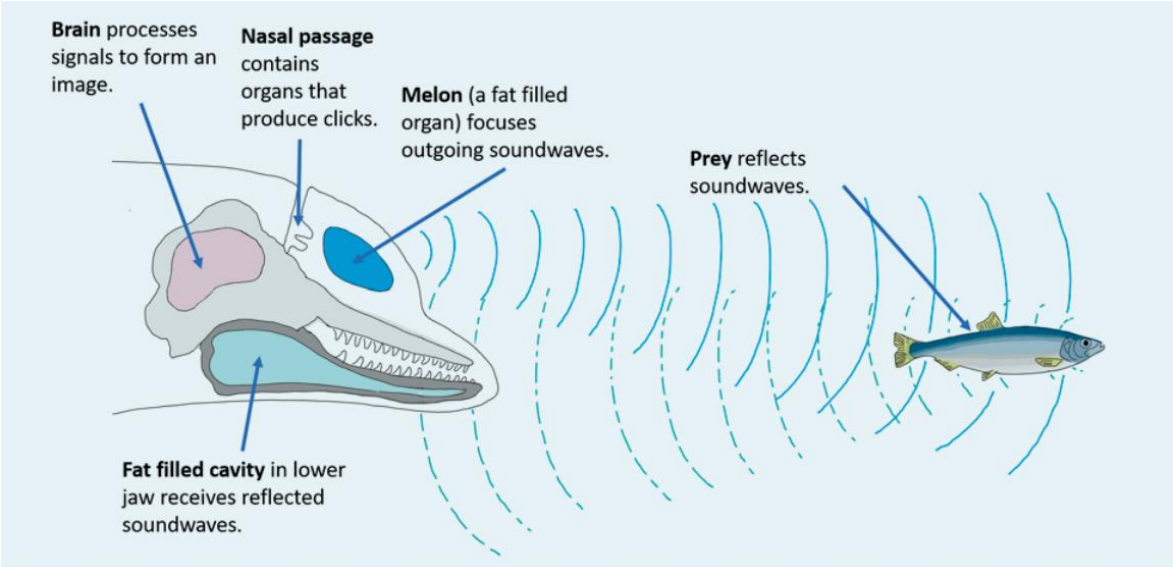


Figure 12 – Toothed dolphin as common bottlenose dolphin use echolocation to navigate and find prey. Sound production and reception. The blue structure in the forehead is the acoustic fat of the melon, which channels the emitted clicks (light blue line). The sound is reflected by the fish (light green dashed line) and mainly received thought the lower jaw. There shading indicates the mandibular acoustic fat close to the ear bone. Credits: Annika Toth and IWC.

Dolphins play dual roles in the marine ecosystem, serving as both predators (preying on fish and squid) and prey (vulnerable to sharks and orcas). They employ a combination of passive and active sonar techniques. Dolphins exhibit exceptional hearing sensitivity, and numerous species emit signals with bimodal frequency bands typically centred around 40 –50 kHz and 130 – 140 kHz (Au and Herzing, 2003). Common bottlenose dolphins produce short-duration broadband frequency clicks, reaching a peak-to-peak source level of up to 228 dB re 1 µPa at a distance of 1 m. These clicks have peak frequencies ranging from 115 to 121 kHz and an approximate 3 dB bandwidth of about 40 kHz. Notably, 75% of these signals exhibit a bandwidth exceeding 25 kHz. In Mediterranean Sea, common bottlenose dolphin emits signals in a band between 3 – 120 kHz (La Manna et al., 2020).

- *Whistles*: these are longer, tonal sounds that dolphins use for communication within their social groups, they include *frequency-modulated whistles*, *amplitude modulated whistles* and *whistle squawks*. They are narrowband sounds, principally used in social contexts, which in dolphins such as Tursiops *spp*. range between 0.8 and 28.5 kHz in frequency in duration from 0.5 to 8s (Schultz and Corkeron, 1994; May-Collado and Wartzok, 2008). Dolphins may also use whistles to coordinate group activities and express emotions. The whistle is emitted at the beginning and end of each predatory act and very often, young males acquire a signature whistle similar or identical to that of their mother, and once they are adults, they leave the family group to seek out a female to mate with. Therefore, a particular common bottlenose dolphin feature is that each dolphin has a unique whistle, often referred to as a "*signature whistle*" (1 – 38 kHz) which can serve as a form of identification because each

specimen has its own unique signature whistle (Herzing, 1996; Janik and Sayigh, 2013). These whistles are thought to play a crucial role in individual recognition within a social group and to identify themselves to others.

- *Burst-Pulse Sounds*: This type of vocalization includes *squawks*, *barks* and *pops*. They all are rapid sequences of clicks followed by a whistle. Burst clicks are similar to echolocation clicks but have a higher pulse rate used during social interactions for short-distance communicative purposes (Caldwell and Caldwell 1968, Lammers et al., 2003). *Burst-pulse sounds* are identified as synchronized vocalizations encompass a range of sounds such as squawks, screams, and brays, adding prosodic elements to dolphin communication. Dolphins also produce vocalizations in the air, including chuffs, raspberries, and non-vocal impulse sounds like jaw-claps, tail cavitation, tail slaps, and bubbles. These sounds are linked to social interactions and can express excitement or heightened arousal (Herzing, 2000).
- *Moan*: named also "meow", they are low frequency narrow band sounds emitted especially (van der Woude, 2009). Low frequency narrow-band (LFN) sounds which are short-duration (1 s) tonal sounds, usually under 1 kHz in frequency (Schultz et al., 1995; Simard et al., 2011). Like BP sounds, their function in the dolphin acoustic repertoire has yet to be resolved.

1.2.2. Common bottlenose dolphin ecology

1.2.2.1. Population, home range and habitat

Mediterranean common bottlenose dolphins are genetically distinct from those in the eastern North Atlantic Ocean and Scottish waters, with boundaries reflecting different habitats and eco-regions. Genetic analyses using mitochondrial and nuclear DNA show clear differentiation between these populations. Studies (Natoli et al., 2005) indicate separate populations in the Black Sea and Mediterranean, with significant genetic structure within the Mediterranean, showing differentiation between Eastern and Western populations. There is also differentiation within sub-regions of both basins, although some gene flow has occurred between these areas.

Recent estimates suggest that the Mediterranean subpopulation of common bottlenose dolphins' numbers over 60,000, though large areas, such as the North African coast and the Levantine basin, were not surveyed (ACCOBAMS, 2021). Trend data, mainly available at the local level, show relatively stable short-term trends, but the lack of historical data makes it difficult to assess long-term trends over three generations. Therefore, monitoring stranding rates is crucial to evaluate whether the positive trends indicate overall population stability (http://mammiferimarini.unipv.it/).

Common bottlenose dolphins exhibit varying home range and distribution varies due to factors like habitat, environmental conditions, prey availability, and human activity (Wells et al., 1999). While there are knowledge gaps in some Mediterranean areas, common bottlenose dolphins are commonly reported through sightings, strandings, or bycatch, throughout the basin: Albania, Algeria, Croatia, Cyprus, Egypt, France, Gibraltar (UK), Greece, Israel, Italy, Lebanon, Libya, Malta, Montenegro, Morocco, Slovenia, Spain, Syria, Tunisia and Turkey. They occur primarily in coastal and offshore waters with depth <100 m, but they can also be found in deeper waters. Their distribution shows potential gaps in areas with very narrow continental shelf and/or oceanographic fronts (Notarbartolo di Sciara and Demma, 2004; Reeves and Nortabartolo di Sciara, 2006; ACCOBAMS 2021) (Figure 13).

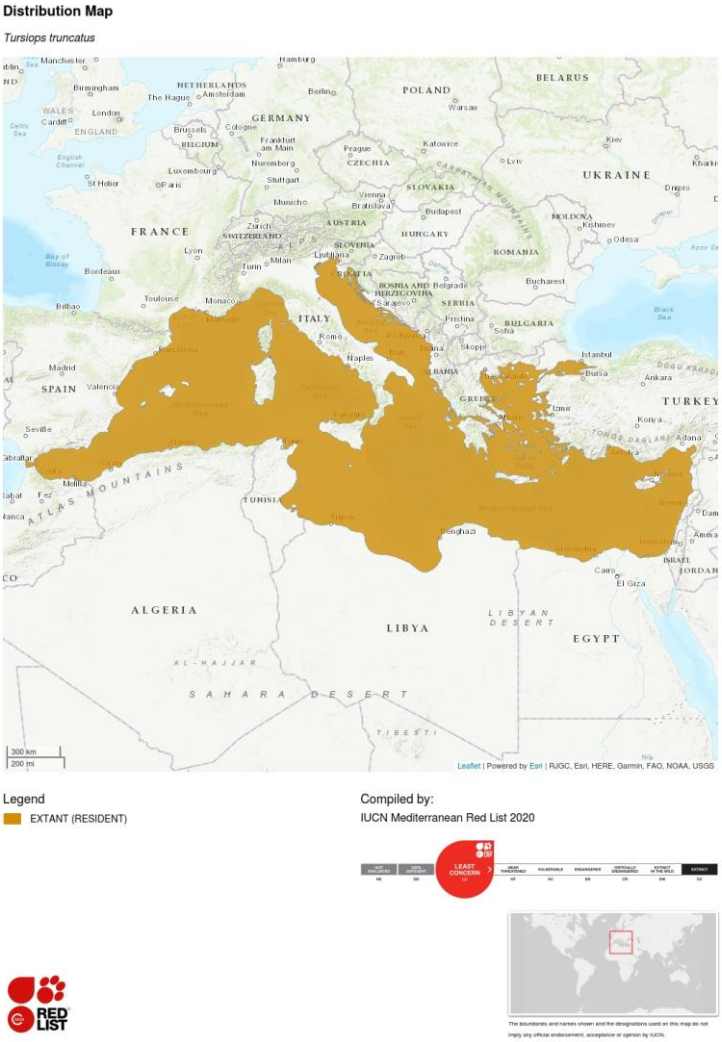


Figure 13 – The geographic range of common bottlenose dolphin for the Mediterranean sub-populations. Albania; Algeria; Bosnia and Herzegovina; Croatia; Cyprus; Egypt (Sinai, Egypt (African part)); France (France (mainland), Corsica); Gibraltar; Greece (Kriti, East Aegean Is., Greece (mainland)); Israel; Italy (Sicily, Sardinia, Italy (mainland)); Lebanon; Libya; Malta; Monaco; Montenegro; Morocco; Palestine, State of; Slovenia; Spain (Spanish North African Territories, Baleares, Spain (mainland)); Syrian Arab Republic; Tunisia; Turkey (Turkey-in-Asia, Turkey-in-Europe).

Their specific distribution along coastlines is influenced by physical features and seasonal patterns, likely related to prey distribution (Giannoulaki et al., 2017; Laran et al., 2017). Anthropogenic factors such as fisheries, fish aquaculture, recreational boat traffic, and underwater noise also impact their coastal distribution (Fortuna 2006; Rako et al., 2012; Bonizzoni et al., 2021).

In the Pelagos Sanctuary, common bottlenose dolphins prefer shallow waters less than 100 meters deep, typically found along the narrow continental shelf and shallow coastal plateaus (Cañadas et al., 2002; Forcada et al., 2004; Fortuna, 2006; de Stephanis et al., 2008; Bearzi et al., 2008; Aïssi and Yahia, 2011; Holcer, 2012; Pulcini et al., 2014; Pleslić, 2015; Santostasi et al., 2016; Carlucci et al., 2018; Fortuna et al., 2018; Pleslić, 2019). Seasonal variations occur, but they do not significantly affect their range. For example, in the north-western Mediterranean, there are higher winter densities in the northern Tyrrhenian Sea's offshore waters and higher summer densities in the Gulf of Lion and Corsica's coastal waters. In the northern Adriatic Sea, the opposite trend occurs, with higher coastal densities in winter and offshore densities in summer (Laran et al., 2017). In Spanish waters, they are spotted along the entire shelf, near the shelf edge, and in deeper waters (200-500 meters), particularly in the Alborán and Balearic Seas. In the Ionian and Adriatic Seas, they are found above the continental shelf and in various habitats, including the northern Adriatic continental shelf, southern Adriatic pelagic waters, and Croatian islands like Lošinj, Cres, Kornati, Vis, and Lastovo. In the Aegean Sea, they inhabit semi-enclosed seas, continental shelf waters, and deeper waters around islands and archipelagos. Around the Italian Peninsula, they prefer coastal waters less than 100 meters deep (Natoli et al., 2021).

Common bottlenose dolphins are commonly thought to exhibit strong site fidelity to particular areas, often referred to as “resident” behaviour. However, this perception may, in part, be influenced by the distribution and focus of cetacean researchers rather than the actual behaviour of the dolphins themselves. Recent evidence obtained by a study conducted in the Mediterranean Sea indicates that common bottlenose dolphins are capable of significant movements, sometimes over relatively short timeframes (Genov et al., 2022).

Their behaviour and diet further emphasize their adaptability. Their feeding behaviour involves long dives followed by recovery periods. Their diet is incredibly diverse, encompassing demersal species such as European hake (*Merluccius merluccius,* Linnaeus 1758), European conger (*Conger conger,* Linnaeus 1758), red mullet (*Mullus barbatus*, Linnaeus 1758), surmullet (*Mullus surmuletus,* Linnaeus 1758) and common cuttlefish (*Sepia officinalis* Linnaeus 1758), as well as semi-pelagic and epipelagic species like bogue

(*Boops boops,* Linnaeus 1758) and round sardinella (*Sardinella aurita,* Valenciennes 1847). In particular, stomach content analyses conducted on common bottlenose dolphin specimens stranded along the Tuscan coast (Italy), revealed that the diet composition consists of 60 species belonging to *Actinopterygii* and *Cephalopoda* classes (Neri et al., 2022). However, stable isotope analyses have indicated that their diet can shift depending on seasonal prey availability, transitioning from demersal to epipelagic fish (Fernández et al., 2011).
Therefore, common bottlenose dolphins are often drawn to fish farms or fishing gears, where they have adapted to forage opportunistically. As a matter of fact, a study conducted through stomach content analysis on stranded common bottlenose dolphins along the Tuscan coast (Italy), found out two specimens with pieces of set nets in the stomach, confirming the opportunistic feeding behaviour and the occurrence of fishing or fishing cages interactions with this cetacean species (Neri et al., 2022). This behaviour has been observed in various coastal areas of the Mediterranean, providing them with a new food resource.

1.2.2.2. Conservation status and anthropogenic threats

Various international, regional, and national agreements provide crucial protection for the common bottlenose dolphin. It is listed under Appendix II of the Bern Convention, which aims to conserve European biodiversity, and Annex II of the Barcelona Convention, which addresses environmental protection in the Mediterranean. The species is also protected by the Washington Convention (CITES), regulating international trade in endangered species. At the Mediterranean level, it is safeguarded by ACCOBAMS, established under the Bonn Convention. The common bottlenose dolphin is also protected under the European Habitats Directive (92/43/EEC), requiring conservation actions like the designation of Special Areas of Conservation (SACs). Additionally, the Marine Strategy Framework Directive (2008/56/EC) ensures the species' protection in European waters, requiring Member States to consider its conservation status when developing strategies for "Good Environmental Status" (GES).
Therefore, the common bottlenose dolphin species is among the 6,596 mammals of the 74,420 vertebrates that are listed on the Red List of the International Union for Conservation of Nature (IUCN) (IUCN, 2022). The IUCN regularly assesses the extinction risk of cetacean species worldwide, considering factors like population size, trends, habitat fragmentation, and geographic range. The IUCN Red List classifies common bottlenose dolphins as "Least Concern" on a global scale, however, the conservation status of common bottlenose dolphins varies by region and its assessment may differ; indeed, while some populations are considered stable, others can face significant threats (Hammond et al., 2008) (IUCN Red

List, 2021). For example, the Fiordland subpopulation and the Gulf of Ambracia subpopulation are classified as "critically endangered", with assessments conducted respectively in 2010 and in 2020 (Currey et al., 2011; Gonzalvo and Notarbartolo di Sciara, 2021). In contrast, the subpopulation in the Mediterranean Sea, which was previously categorized as "Vulnerable" based on the 2009 assessment, in 2021 has improved its status upgrading to "Least Concern" (Natoli et al., 2021) (Figure 14).

The common bottlenose dolphin faces numerous threats in the Mediterranean Sea, encompassing both natural and anthropogenic factors. While some natural elements, like epizootic outbreaks (e.g., *morbillivirus*) or bacterial and protozoan infections (e.g., *Brucella ceti* and *Toxoplasma gondii*), can indeed pose threats, the primary hazards are from human origin, occurring in areas that overlap with common bottlenose dolphin habitats, especially those in nearshore and coastal environments. The conservation of the common bottlenose dolphin is threatened by various anthropogenic activities, including military drills, maritime traffic and shipping, recreational marine activities, coastal urbanization, recreational exploitation of marine resources, artisanal fishery, overfishing, illegal fishing practices, historical culling campaigns and killings for food consumption (this last forbidden through an Agreement ACCOBAMS 1996, ratified 2018). These activities exert various pressures, resulting in issues such as strikes, acoustic disturbance, chemical pollution, presence of marine debris creating habitat degradation, potential impacts of climate change on their habitat and food sources, prey depletion, retaliation and harassment resulting from depredation by dolphins, and last but not least elevated levels of environmental contaminants.

- **CONTAMINANTS THREAT**

As common bottlenose dolphin is a species that occupies the top position in marine food webs and resides in close proximity to the coast, it is particularly susceptible to anthropogenic contamination. In the common bottlenose dolphins specimens that live in the Mediterranean Sea, contaminant levels, especially regarding organochlorine compounds (OCs), which are generally elevated compared to those reported in this species in other part of the world (Alzieu and Duguy 1979; Corsolini et al., 1995; Marsili and Focardi 1997; Aguilar et al., 2002; Fossi and Marsili 2003; Wafo et al., 2005; Borrell et al., 2006; Borrell and Aguilar 2007; Storelli et al., 2007; Shoham-Frider et al., 2009; Lauriano et al., 2014; Romanić et al., 2014; Jepson et al., 2016; Gonzalvo et al., 2016; Marsili et al., 2018; Genov et al., 2019). While organochlorine contamination is declining in some areas, it remains high in Mediterranean common bottlenose dolphins (Tolosa et al., 1997; Borrell and Aguilar

2007; Storelli et al., 2007; Jepson et al., 2016; Marsili et al., 2018; Genov et al., 2019; Grattarola et al., 2023). After decades of studies in the waters of the Mediterranean Sea, it is well-known that the state of the *Mare Nostrum* is not at its best. It possesses unique geomorphological characteristics as a semi-enclosed and shallow sea, while simultaneously facing an incredible number of anthropogenic pressures related to both basin-level factors (maritime traffic, fossil resource extraction, intensive fishing, etc.) and coastal factors (highly populated cities, industries, ports, etc.). For instance, concentrations of PCBs appear to follow a general geographical pattern, with a gradient from more industrialized to less industrialized areas (as reviewed by Genov et al. 2019), possibly linked to patterns of anthropogenic impacts (e.g., pollution and marine resource exploitation) in this region (Coll et al. 2012). Research on stranded cetaceans along its coasts has provided crucial information for monitoring the state of the Mediterranean Sea, demonstrating that, for instance, some contaminants, now internationally regulated, such as dichlorodiphenyltrichloroethane (DDT) or polychlorinated biphenyls (PCBs) or hexachlorobenzene (HCB), continue to be top-priority pollutants in these waters and its ecosystems.

Compounds like PCBs or PAHs have been associated with reproductive disorders, immune system suppression, and neoplasia (Lahvis et al., 1995; Reddy et al., 2001; Schwacke et al., 2002; Jaber et al., 2005; Hall et al., 2007; Centelleghe et al., 2019; Marsili et al., 2018; Grattarola et al., 2023). The effects of PCBs at the population level are still unknown, but maternal transfer from females to their offspring has been demonstrated and could potentially affect recruitment (Genov et al., 2019). In 2019, a series of deaths along the western Italian coast were attributed to morbillivirus and other pathogens (Grattarola et al., 2024). A link with the high levels of OCs accumulated in blubber, which may have impaired the immune response of the animals, cannot be excluded (Aguilar and Borrell 1994; Desforges et al., 2016). Then, other Persistent Organic Pollutants (POPs) evaluated in Mediterranean common bottlenose dolphins included polybrominated diphenyl ethers (PBDEs) (Pettersson et al., 2004; Barón et al., 2015) and fluorinated compounds (PFOS, FOSA, PFHxS, and PFOA) (Kannan et al., 2002). Various and sometimes high levels of heavy metals have been found in stranded specimens (e.g., Leonzio et al., 1992; Frodello and Marchand 2001; Roditi-Elasar et al., 2003; Shoham-Frider et al. 2009; Martínez-López et al., 2019). Mercury, known for its effects on the nervous and lymphoid tissues (Kershaw and Hall, 2019), can pose a serious health concern in these species due to its high concentration (Martinez-Lopez et al., 2019).

Stranding animals are considered very important scientific treasure on which many analyses can be conducted post-mortem. In scientific literature there are much more studies about environmental contaminants investigated on stranded dolphins, than studies conducted on free-ranging specimens. This data highlights the importance within the scientific community of maximizing and efficiently utilizing the death of an animal as an opportunity for non-destructive and non-invasive methods of investigation. Such methods can encompass a wide range of multidisciplinary research areas, including parasitology, virology, bacteriology, genetics, and toxicology. Therefore, sampling from animals that have already been found dead grants them another life: a scientific one. Through this scientific approach, it becomes possible to gather a wealth of information, not only to identify potential causes of the animal's demise but also to thoroughly investigate the overall health status of the animal and the ecosystem it serves as a bioindicator for. Finally, the appreciation of the deceased animal is often realized through museum preservation, which includes the preservation of certain parts (such as pelvic remnants, jaw, dentition, etc.) or, when possible, the entire skeleton (Figure 14).

Figure 14 – **A.** and **B**. Specimens of common bottlenose dolphin recovered stranded or at sea in Tuscany within the Framework of NATura NEtwork Toscana project founded by Tuscany Region. **C**. and **D**. RT179Tt in laboratory during necroscopy. D. RT163Tt. **E** and **F**. Skeleton and teeth of common bottlenose dolphin prepared for the museum of Accademia dei Fisiocritici (Siena). Credits: Cancelli F.

Cetacean strandings can be caused by both natural and anthropogenic factors. Natural causes include geomagnetic anomalies that disrupt migration (Vanselow et al., 2018), extreme weather events like storms and cyclones, and changes in ocean currents affecting prey distribution (Schumann et al., 2013). Anthropogenic threats can be direct, such as accidental fishing captures (Read et al., 2017) and vessel collisions (Laist et al., 2001), or indirect, like noise pollution from military sonars (Southall et al., 2016) and chemical pollution, including heavy metals (Fossi et al., 2000) and organochlorines (Fossi and Marsili, 2003). These factors weaken cetaceans, making them more susceptible to diseases and leading to stranding. Chemical contaminants, especially persistent organic pollutants (POPs), can impair immune function, increasing vulnerability to infectious diseases (Bossart, 2011; Mazzariol et al., 2012; Centelleghe et al., 2019). Emerging diseases affecting cetaceans include viral, bacterial, protozoan, and fungal infections (Van Bressem et al., 2009; Giorda et al., 2017). Climate change also affects cetaceans, particularly in coastal and river ecosystems, making coastal species like common bottlenose dolphins more vulnerable (Hoegh-Guldber and Bruno., 2010; Sousa et al., 2019; Sanderson and Alexander, 2020; van Weelden et al., 2021). As top predators, they accumulate toxic chemicals like organochlorines (PCBs, DDT) through the trophic chain (Fossi et al., 2006; Green and Larson, 2016; Neri et al., 2022). Studies show that stranded dolphins in the Mediterranean have higher levels of contaminants compared to living ones (Borrell et al., 2006; Gonzalvo et al., 2016; Jepson et al., 2016; Genov et al., 2019; Romanić et al., 2014; Wafo et al., 2019; Shoham-Frider et al., 2009; Grattarola et al., 2023). The *post-mortem* investigations in stranded specimens have shown an important correlation between high levels of these pollutants and the infectious diseases that were recognized as the most likely cause, of death of these marine mammals (Grattarola et al., 2016). This evidence is particularly documented in the Pelagos Sanctuary, an area for the protection of cetaceans covering 87,500 km^2 and 2022 km of coast of the northwestern Mediterranean Sea, established under an international agreement between France, Italy, and the Principality of Monaco (Italian Republic Legislative Decree No. 391/2001) (Figure 15). The Mediterranean area is a biogeographically distinct sub-section of the Large Marine Ecosystem (LME), characterized by diverse topography, hydrodynamics, and high primary productivity due to nutrient upwelling. These factors support the presence of eight species of marine mammals. However, coastal urbanization and industrialization are increasing, with agricultural practices releasing fertilizers, fungicides, and pesticides, and industries such as chemical, petrochemical, metallurgical, oil and gas refineries, and desalination plants contributing to

contamination by xenobiotics, metals, and polycyclic aromatic hydrocarbons. This raises contamination pressures on cetaceans in Marine Protected Areas (Panti et al., 2011; Fossi et al., 2013). To assess pollution impacts on cetacean health, it is essential to systematically investigate stranding events through post-mortem exams and diagnostic investigations. These studies help explore correlations between sex, age, sexual maturity, pathologies, levels of persistent organic pollutants (POPs), and the effects of various xenobiotics in relation to their toxicological properties.

Figure 15 – Pelagos Sanctuary for Mediterranean Marine Mammals. It starts from the West: from the line extending from Punta Escampobariou (western tip of the Giens Peninsula) (N 43°01'70 - E 06°05'90) to Capo Falcone (western end of the Gulf of Asinara) (N 40°58'00 - E 08°12'00), and extending from the East: from the line extending from Capo Ferro (northeastern coast of Sardinia) (N 41°09'18 - E 09°31'18) to Fosso del Chiarone (western coast of Italy) (N 42°21'24 - E 11°31'00).

Strandings events in Italy and in Tuscany

In Italy, since the 1980s, deceased cetaceans have been recovered and investigated to assess their health and potential causes of death, serving as bioindicators of their environment. This helps monitor environmental pressures, even those not currently concerning, which may become significant in the future, such as the accumulation of certain contaminants. In Tuscany, the regional government established the Tuscany Cetacean Observatory (OTC) (No. 247/2007) which later evolved into the Tuscany Cetacean, Sea Turtle, and Elasmobranch Observatory under various resolutions (No. 199/2011 and No. 472/2014). The Tuscany Biodiversity Observatory (OTB), formed in 2015 (No. 30/2015), coordinates the network of strandings and sightings through the Regional Environmental Protection Agency of Tuscany (ARPAT) and local entities like the University of Siena, the University of Pisa,

and the Zooprophylactic Institute for Lazio and Tuscany (IZSLT) (https://www.regione.toscana.it/osservatorio-toscano-per-la-biodiversit%C3%A0). The OTB compiles annual reports on species monitoring, strandings, and sightings (Ventrella, 2016). ARPAT coordinates recovery actions, while IZSLT handles autopsies which, in turn, is primarily responsible for preparing a health report on the causes of death of these marine animals. Among these entities, the analyses to be carried out on the recovered samples are divided: IZSLT, in addition to conducting autopsies on cadavers, also performs parasitological, bacteriological, virological, and histopathological analyses, and, in last, the University of Siena conducts toxicological analyses. The carcasses are then disposed of according to an established procedure, relying on local disposal companies (IZSLT, 2019). In cases of mass strandings or large animals, analyses are conducted on-site, while smaller specimens are sent to laboratories for further examination.

- **FISHERY ACTIVITIES**

Regarding the threats fishing activities can pose to the dolphin conservation, they can be viewed from multiple viewpoints: i) prey depletion ii) dolphin-fishery interaction and iii) illegal intentional killing.

i) prey depletion

Overfishing in the Mediterranean has significantly impacted ecosystems, leading to the decline of many fish stocks (Caddy and Griffiths, 1990; Stanners and Bourdeau, 1995; Garcia and Cochrane, 2005). The common bottlenose dolphin's diet overlaps with the catch of several commercial fisheries, but the extent of resource sharing between dolphins and fisheries is only partial (Scheinin et al., 2014; Milani et al., 2019). Overfishing and prey depletion are suggested as contributing factors to the decline of common bottlenose dolphins and other marine animals in certain areas (Bearzi, 2006; Bearzi et al., 2010). Fish stocks like European hake and red mullet, key to the dolphin's diet, are overfished in the Mediterranean and Black Sea (FAO, 2016; FAO, 2018). While small pelagic fish stocks are generally sustainably managed, some exceptions exist. The effects of prey depletion on dolphin populations are complex, especially due to the species' varied diet across different regions (Borrell et al., 2020).

ii) illegal intentional killing

Illegal fishing practices, such as using explosives (Tudela, 2004), retaliation (e.g., intentional killings and injuries), and harassment (e.g., firecrackers) due to dolphin depredation and damage to fishing gear, have been documented and still occur sporadically (Di Natale and

Notarbartolo di Sciara, 1994; Gazo et al., 2008). Since 2010, nine cases of targeted killings and injuries in the Tyrrhenian and Adriatic Seas have been reported, and in the Balearic Islands (1992-95), 30 dolphins were killed annually by fishermen (Bearzi et al., 2002). Gun shootings were also a major cause of mortality in French waters (Duguy et al., 1983), with instances of harpoon wounds and firearm injuries reported in Croatian and Venetian waters. Additionally, in parts of Italy, dolphins are killed for the production of *musciame* a fillet product, still sold illegally (Di Natale, 1991; Cagnolaro and Notarbartolo di Sciara, 1992). However, protective legislation and greater environmental awareness have significantly reduced intentional killings, including local consumption of dolphin meat, which was more common in the early 1990s (Di Natale, 1991; Di Natale and Notarbartolo di Sciara, 1994; La Repubblica, 2022).

Figure 16 – The filleted dolphin found on Su Barone beach (Orosei) in Sardinia (La Nuova Sardegna, 2022).

iii) dolphin-fishery interaction

Considering the overlap between their favoured habitat and various fishing areas utilized by both professional and artisanal fisheries, coupled with their opportunistic behaviour, particularly in terms of foraging tactics, common bottlenose dolphins face a heightened risk of becoming ensnared in various fishing equipment (ACCOBAMS, 2019). In 2008, during a regional workshop jointly organized by ACCOBAMS and the GFCM, it was confirmed that despite a lack of comprehensive data, anecdotal evidence, including reports from fishers and incidents involving stranded dolphins, indicated that both depredation (predation on caught fish) and accidental capture (bycatch) of this species were widespread issues across the region:

- **Depredation** can trigger illegal retaliatory actions by fishers, has been reported, particularly by small-scale fishers in various areas of the Mediterranean Sea, including the western Mediterranean (Brotons et al., 2008; Gonzalvo et al., 2008), Tyrrhenian Sea (Lauriano et al., 2004; López, 2006; Blasi and Pace, 2006; Buscaino et al., 2009; Lauriano et al., 2009; Pennino et al., 2015), Tunisian plateau (Zahri et al., 2004; Benmessaoud et al., 2014), Ionian Sea in Gulf of Taranto (Bearzi et al., 2011); Gulf of Ambracia and Inner Ionian Sea (Gonzalvo et al., 2015a); Gulf of Corinth (Bonizzoni et al., 2016), North Aegean Sea and Adriatic Sea (Figure 17). While the scientific community commonly used the term "depredation" to describe this phenomenon, a more suitable term "foraging around fishing gear" has been proposed to accurately convey the nature of these interactions (Bearzi and Reeves, 2022).

Figure 17 – Depredation occurs when dolphins approach fishing vessels and remove parts of the catch Credits: GFCM/Claudia Amico

- **Bycatch** was occurring at undisclosed levels in several countries, including Algeria, Croatia, France, Greece, Israel, Italy, Malta, Morocco, Slovenia, Spain, Tunisia, and Turkey (ACCOBAMS/GFCM, 2008). ACCOBAMS assessed a valuation involving experts in both fisheries and cetaceans, and concluding that common bottlenose dolphins were still unintentionally caught in various fishing methods, such as bottom trawlers (GSA 1, 5, 10, 13-16, 20, 27), driftnets (GSA 9, 10, 18, 19, 22), trammel nets (GSA 5, 8-11, 15, 16, 18, 19), unspecified gillnets (GSA 8, 10, 17, 20, 22, 27), set gillnets (GSA 9-11, 15, 16, 18-20), drifting longlines (GSA 9-11, 13, 15, 16, 18, 19, 21), purse-seines (10, 15, 16, 18, 19), and hooks and lines (10, 16, 19). Gillnets also included anti-predator gillnets with a mesh size of 15 cm, which were deployed in fish farms (López and Shirai, 2007). Since 2008, there has been little progress in implementing a systematic monitoring system for cetacean bycatch, and the available quantitative information on common bottlenose dolphin bycatch remains limited and patchy, both in terms of geographical scope and the types of fishing gear used (Gonzalvo et al., 2008; Fortuna et al., 2010; 2015).

Detrimental cetacean-fisheries interactions occur, or occurred, nearly throughout the Mediterranean Sea, involving most of the fishing activities and cetacean's species inhabiting the basin (Northridge et al., 2006). Common bottlenose dolphin is the most affected species, due to its coastal and pelagic distribution that largely overlaps to the majority of the Mediterranean fishing areas (in particular those exploited by the artisanal fleet) and its opportunistic foraging strategy. In addition, common bottlenose dolphin, as already aforementioned, has advanced learning abilities and high remarkable resilience, allowing this species to be highly adaptable to human activity (Chilvers and Corkeron, 2001).

The existing studies and circumstantial evidence for local populations continue to raise concerns, suggesting that annual fishery-induced mortality could be locally unsustainable or very close to being unsustainable in certain sub-regions (e.g., Feingold et al. 2005, Brotons et al. 2008) (Figure 18). Moreover, data from stranded dolphins along the northern Adriatic coast (2012-2015; NETCET project; Cre.Di.Ma. Annual Reports 2016-2021) have confirmed that between 18% and 33% of fully examined bottlenose dolphins likely died as a result of direct interactions with fishing gear.

Figure 18 – An example of lethal bycatch: an adult male of common bottlenose dolphin found dead along Tuscan coast in August 2023.

1.3. DOLPHIN – FISHERY INTERACTIONS: how to mitigate this harmful relationship

The interaction between dolphins and fisheries is causing increasing concern from environmental, economic, and societal perspectives, as it typically results in conflict that leads to severe adverse outcomes for both parties involved. On one side, dolphins can modify their feeding and predatory behaviour and can change their way of hunting, but in the worst cases, they can be injured or even die due to directly accidental capture, referred to as bycatch - *"any marine mammal adversely affected as a result of being unintentionally entangled, entrapped, ensnared, or caught by nets, lines, traps, or hooks, or otherwise impacted by fishing gear"* (Marine Mammal Commission - MMC; https://www.mmc.gov). Cetaceans bycatch and entanglement in fishing gears are recorded in almost all kinds of fishing operations, from large industrial to localised artisanal fisheries, but it also can result when fishing gear has been lost or discarded (i.e., ghost fishing) (ACCOBAMS, 2019b). Accidental capture usually results in lethal and sublethal consequences, including drowning (trapped animals cannot reach the surface to breathe), laceration and infection (ropes or lines bite through skin), and starvation (animals towing heavy fishing gear cannot feed effectively).

On the other side, those who suffer from these interactions are also the fishers. Indeed, dolphins are accused of negatively affecting fisheries by taking caught fish or bait and causing damage to fishing equipment. This interaction, referred to as depredation, involves predators harming or killing their prey, often seen as raids on fishing gear (Reeves et al., 2001) and this phenomenon has significant economic consequences in certain fisheries due to reduced catch quantity and/or quality (Lauriano et al., 2009; Rocklin et al., 2009). Moreover, it requires additional time and labour to replace or repair fishing gear (Gönener and Özdemir, 2012; Lauriano et al., 2009; Snape et al., 2018). Moreover, fishery depredation by dolphins often creates hostility in fishers, who may attempt to retaliate against cetaceans to protect their catch or gear (Bearzi, 2002; 2008). Other prominent issues resulting from dolphin-fisheries interactions include an indirect ecological competition with cetaceans, as both dolphins and fishers are insisting on similar food resources in the same area (Reeves et al., 2001).

1.3.1. Interactions between dolphin and different type of fishing gears

Providing a detailed description of the conditions that result in dolphin interactions with a specific type of fishery is crucial for gaining a clear understanding of when and how a

mitigation measure can effectively reduce these interactions. This understanding is vital because the effectiveness of mitigation measures can vary based on factors such as the type of fishing gear used, the nature of the interactions between dolphins and fisheries, their methods, and the resulting outcomes.

SET NETS (paragraph 1.1.1.1.)

Incidental catch in gillnet fisheries is widely acknowledged as a leading anthropogenic cause of mortality for numerous cetacean species worldwide (Read et al., 2003). It is estimated that over 75% of global odontocetes species are vulnerable to bycatch in gillnets (Reeves et al., 2013). Notably, the indiscriminate use of gillnets has pushed at least two dolphin species, the vaquita (*Phocoena* sinus; Slooten et al., 2006), and Maui's dolphin (*Cephalorhynchus hectori maui*; Rojas-Bracho and Reeves, 2013), to the brink of extinction. In the Mediterranean, the extensive use of bottom-fixed nets, particularly gillnets and trammels, can occasionally result in the entanglement of coastal species, primarily the common bottlenose dolphin. Despite the clear potential threat to common bottlenose dolphins, there is limited knowledge regarding bycatch rates and mortality trends in set-net fisheries. As pointed out by STETCF (2019), monitoring vessels of less than 15 meters (e.g., artisanal sector) within Regulation (EU) 812/2004 (repealed by Regulation (EU) 2019/1241) is insufficient, with inadequate focus on the gears (e.g., gillnets) that pose the highest bycatch risk. Additionally, fishers often remove dolphins incidentally caught at sea, either dead or alive, contributing to underreporting. Most data on set-net bycatch come from independent sources (e.g., observer programs), indirect evidence (e.g., strandings), or anecdotal observations. The annual number of common bottlenose dolphins caught in gillnets along the northeastern coast of Sardinia was approximately 1.47 n (López, 2006). Instead, stranding analyses have shown that entanglement in gillnets appeared to be the cause of mortality for several dolphins along the Mediterranean coast, with over 25 stranded common bottlenose dolphins on the Tunisian coast attributed to lethal interactions with gillnets (ACCOBAMS, 2019b). Another study involving 120 common bottlenose dolphin carcasses stranded between 1990 and 2008 along the Croatian Adriatic coast found that 12 had their larynx strangled by gillnets, while 4 also had mesh net in their stomachs; 8 other individuals had pieces of mesh in their stomachs but showed no signs of strangulation (Gomerčić et al. 2009) (Figure 19). The main factors contributing to entanglement and subsequent drowning in fixed set-nets include:

1. **Presence of potential dolphin prey in the nets**: dolphins may become entangled while attempting to forage on fishes already trapped in the nets, entangling various body parts such as flippers, dorsal fins, tail, or head (Rowe, 2007). Entanglement can occur within the netting panel or with the ropes (e.g., footrope, headrope, and those connecting the net to the buoys).
2. **Net detectability**: factors like water turbidity, human activities, environmental noise, and the small echo properties of nylon netting panels can make fishing gear less visible, reducing its detectability to echolocating animals.
3. **Net design**: set-nets are designed to be see-through and have nearly the same density as water, making them difficult to detect in the water column, especially at night (Kastelein et al., 2000). Net height (drop), slackness, and soaking time are significant predictors of gillnet bycatch (ICES, 2010).
4. **Experience**: juvenile or immature dolphins are considered more vulnerable to entrapment in nets due to their relative lack of experience, tendency to play, and extended time spent scouting. Unlike adults, they may lack the strength to tear through nets and escape (Bearzi, 2002).

Figure 19 – Gill-net part causing larynx strangulation and protruding from the mouth of a bottlenose dolphin (Credits: /Gomerčić et al., 2009).

DRIFTNET

Driftnets (FAO Code: GND), similar to gillnets, consist of a single vertical mesh panel held in place by a buoyant floatline at the top and a weighted leadline at the bottom. Unlike fixed set nets, driftnets drift freely with currents, either near the water's surface or a few meters below it. They are typically made of nylon with large mesh openings, reaching lengths of up to 20 km and heights of up to 35 m (Figure 20).

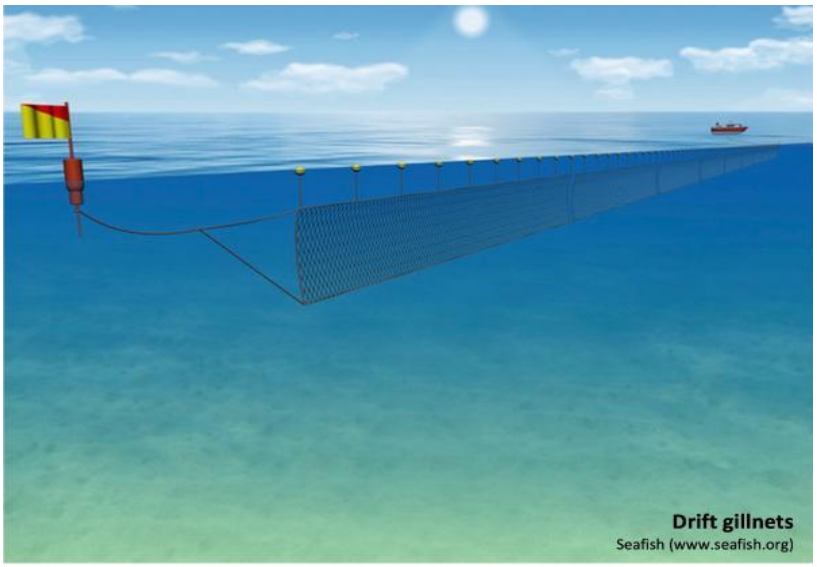


Figure 20 – A drift gillnet is a type of gillnet that is not fixed to the seabed but allowed to drift with the current. Credits: Seafish, 2021 © FAO.

In the 1980s and 1990s, driftnets gained popularity for catching large migratory pelagic species in the Mediterranean. However, due to environmental concerns, in 2022 the EU introduced Regulation 1239/98 in 2002, banning the use or possession of driftnets for capturing large pelagic species by EU vessels in EC waters. Despite some success in enforcing these bans on high seas driftnets, ongoing violations remain a significant issue.

In the Mediterranean Sea, driftnets, primarily used to target highly migratory species like bluefin tuna and swordfish, are unfortunately notorious for their high rates of bycatch, which includes cetaceans and many other protected species. During the peak of driftnet fishing in the late 1980s and early 1990s, before legislative measures that partially or completely banned this practice, it was estimated that more than 10,000 cetaceans were accidentally killed throughout the entire Mediterranean (IWC, 1994). For example, the Italian driftnet fleet, particularly known for its extensive operations, reported capturing a total of 1,682 cetaceans in 1991 alone using "*spadara*" nets (Di Natale, 1995). This included 1,363 striped dolphins, 132 pilot whales, 79 Risso's dolphins, 35 common bottlenose dolphins, and 62 other delphinids. The Moroccan fleet also had significant annual bycatch estimates,

amounting to 3,647 dolphins (50% common dolphin and 50% striped dolphin) in the Alboran Sea (Tudela et al., 2005). Driftnets also caused cetacean to bycatch along the French coast; for example, the "*thonaille*" a small pelagic driftnet used for catching tuna and swordfish by small-scale fishers (banned in 2007), led to the accidental capture of 93 striped dolphins from 2000 to 2003 (Bănaru et al., 2010). The unsustainability of this type of fishery was revealed by the high bycatch rate, with four boats catching 237 dolphins in eight months, averaging 0.64 dolphins per operation.

Despite international and national bans, illegal driftnet use persists in the Mediterranean Sea (David, 2005). In 2007, it was estimated that 500-600 illegal driftnet vessels were operating in various Mediterranean areas, including Italy, France, Morocco, Turkey, and Algeria (Baulch and Perry, 2014). Due to its illegality, the current extent of this illegal activity and its impact on cetacean populations are challenging to ascertain and cannot be adequately measured through existing fisheries monitoring programs.

TRAWLER

Trawl nets are actively towed by vessels and have a cone- or pyramid-shaped body with a cod-end at the back. They can extend their opening with wings or rigid frames. Horizontal opening is achieved using otter boards or variable-shaped frames. Trawls are categorized as bottom or pelagic trawls based on their towing depth (Figure 21):

- **Bottom trawls** are used for demersal or semi-demersal species and are classified into beam trawls and bottom otter trawls. Bottom otter trawls (FAO Code: OTB) have their mouth kept open by two otter boards, while vertical opening is controlled by floats, weights, and water flow. These trawl nets are about 60 meters long on average, with the majority in the body. Catching capacity depends on towing speed and the volume of water covered, influenced by depth and target species.
- **Pelagic trawl**, (FAO Code: PT) lighter and with a larger mouth than demersal trawls, operate across the water column (Figure 21). They can be towed near the surface or the seabed (semi-pelagic) and are controlled by warp length and vessel speed. Pelagic trawls are larger, with wide vertical and horizontal openings, and use otter boards or pair trawling to maintain horizontal opening and flotation, weights, and additional bridle weights for vertical opening. They target small pelagic species like anchovy, sardine, and mackerel, while semi-pelagic trawls catch demersal fish with semi-pelagic habits.

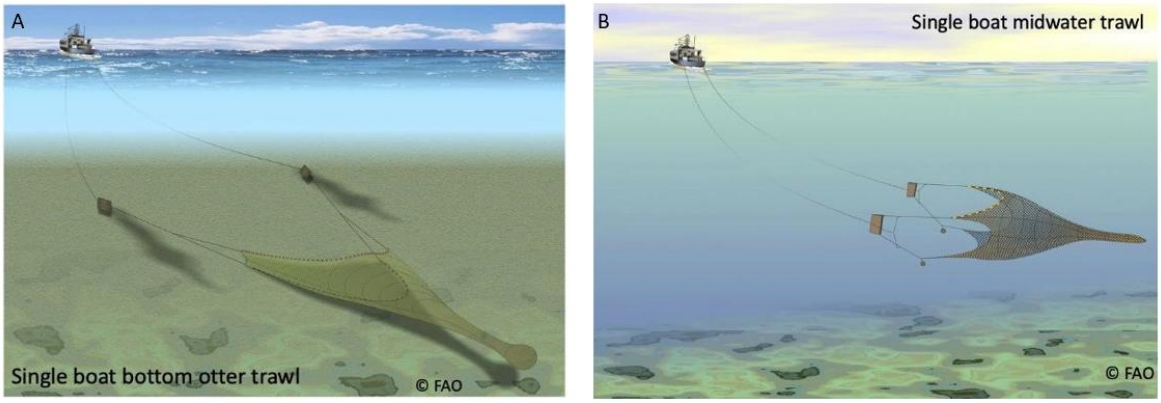


Figure 21 – **A**. A single boat bottom otter trawl is one cone-shape trawl towed on the seabed by one boat. Credits: FAO, 2021©. **B**. An example of pelagic trawler, specifically it is a single boat midwater otter trawl is a cone-shaped net that is towed in midwater by one boat. Credits: FAO, 2021©.

In various regions of the Mediterranean Sea, common bottlenose dolphins have developed a behaviour of trailing behind bottom trawlers to exploit fish stirred up or attracted by the nets or discarded at sea after the fishing operation (Figure 22). This behaviour has been studied in detail in the northern Adriatic Sea, where it's estimated that bottlenose dolphins spend approximately 5% of their time following trawlers (Bearzi et al., 1999). While these trawlers can provide a concentrated and easily accessible food source for dolphins, there is a risk of accidental dolphin bycatch resulting from their depredation behaviour. Dolphins may even intentionally enter the nets to forage on the catch (Wakefield et al., 2017). However, based on available data, bycatch incidents in trawling nets seem relatively uncommon in most Mediterranean areas. For instance, no bycatch was recorded during on-board monitoring of 460 commercial demersal trawling trips off Majorca between 2001 and 2004, despite the presence of several dolphins, mainly common bottlenose dolphins, in the vicinity of the trawlers during observations (Gonzalvo et al., 2008). A systematic monitoring program to assess cetacean bycatch in Italian pelagic trawlers has been in place since 2006 as part of the BYCATCH project, funded in compliance with Regulation (EC) No. 812/2004. Between 2006 and 2008, Fortuna et al. (2010) estimated a bycatch rate common bottlenose dolphin in the Adriatic Sea at 0.0006 individuals per haul, based on a total of 3141 hauls. However, 609 groups of common bottlenose dolphins were observed near the nets in over 30% of fishing operations, often interacting with the fishing operation, especially during net hauling when some of the catch escaped from the net.

Pelagic trawls have been affecting mostly striped dolphin with their large openings and often towed at relatively high speeds, with irregular and unpredictable changes in direction that increase the risk of dolphin entanglement. Indeed, reports of striped dolphin bycatch mainly come from the French pelagic trawler fleet, which targets small pelagic fish and hake. Under

the cetacean bycatch monitoring program established by EC Regulation 812/2004, four striped dolphins were bycaught by Gulf of Lions trawlers, and in the following year, one striped dolphin was caught during 150 trawling operations (Morizur et al., 2012).

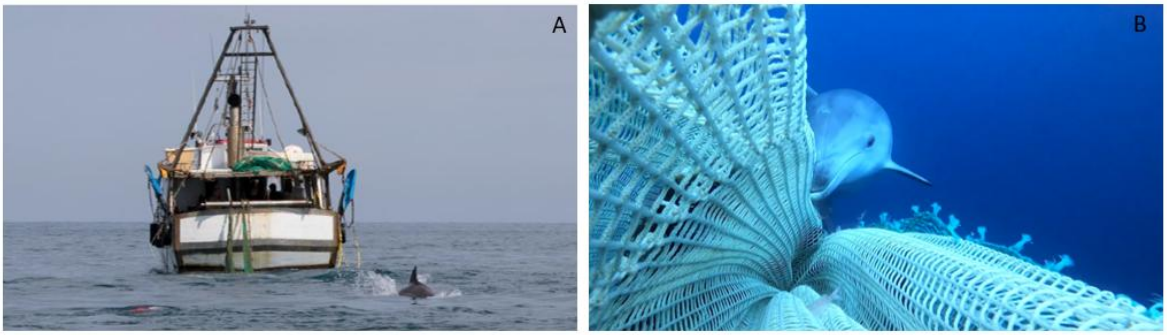


Figure 22 – **A**. Common bottlenose dolphins individual following a trawler in the Adriatic Sea (Bearzi and Bonizzoni, 2018). **B**. A specimen of common bottlenose dolphin outside an actively fishing trawler net. Credits: Life DELFI project.

PURSE SEINE

A purse seine (FAO Code: PS) is a rectangular netting with floatline and leadline, typically longer than it is deep. It has purse rings on the lower edge with a purse line for closing the net (Figure 23). Fishing involves encircling fish schools quickly to prevent escape, then hauling the net to collect the catch. In the Mediterranean, purse seining is mainly for shoaling pelagic species, using additional equipment like fish finders or attraction systems. Small pelagic seiners use light sources to attract and concentrate fish, while large pelagic seiners target free-swimming schools or fish attracted by floating aggregating devices (FADs), such as dolphinfish (*Coryphaena hippurus*).

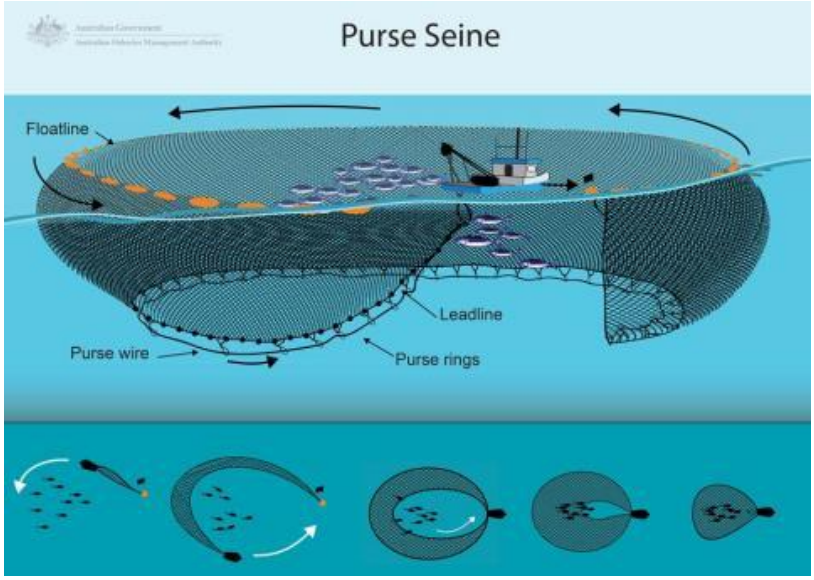


Figure 23 – Purse seine: principal components and purse seining operations (setting the net and hauling). Credits: Australian Fisheries Management Authority.

Dolphins' interaction with purse-seine fisheries occurs both in tuna and small pelagic fisheries across the Mediterranean Sea. Frequency, modalities, and types of interaction vary greatly between these two fisheries. Purse-seining for bluefin tuna involves the sporadic entrapment of different species of dolphins associated with tuna schools, even though mortality rates are generally considered negligible, as in most cases dolphin are released alive (Bearzi, 2002; ACCOBAMS, 2019b). Furthermore, bluefin tuna fishery in Mediterranean waters does not involve, as a general rule, the practice of setting nets around cetaceans, in contrast to the well-known case of the yellowfin purse seine fishery in the eastern tropical Pacific Ocean (Hall and Roman, 2013). In light of these observations, the impact of these nets on Mediterranean cetaceans is commonly considered to be negligible. The information available for the Mediterranean confirms sporadic and unintentional dolphin catches; Di Natale (1983) reported the capture of 21 specimens of striped dolphin in two separate incidents in the Ligurian Sea involving tuna purse seine nets. Magnaghi and Podestà (1987) recorded another incidental capture of 8 individuals in the same area. Lastly, 3 specimens were bycaught in the Gulf of Lions during 190 fishing day trips within the framework of the ICCAT Regional Bluefin Tuna Observation Programme (Fromentin and Farrugio, 2005).

On the opposite, certain Mediterranean purse seine fleets targeting small pelagic species may experience dolphin both depredation and accidental encirclement. This is particularly true for artisanal fleets, such as that operating along the Moroccan coast, as detailed within the framework of FAO COPEMED 2004 Project "Study of the interaction between common bottlenose dolphin and the purse seine fishery in the Moroccan Mediterranean". Common bottlenose dolphin presence affected 16 – 19% of the fishing survey by scaring and displacing fish schools or by producing large tears biting and pulling the net, in the attempt to depredate the fish crowd against the seine. As result of dolphins' presence, fishers are often forced to search for fish in more remote areas to avoid depredation, which results in waste of time and an increase in fuel consumption (COPEMED, 2004). The activity of the purse seine fleets targeting small pelagic fish in the Mediterranean does not seem to lead to high dolphin mortalities, at least in some areas, as generally dolphins are released alive after being accidentally encircled. However, a field study conducted under an EU-funded project estimated exceptionally high mortality of about 300 dolphins annually, the majority of them being common dolphins (University of Barcelona, 1995).

LONGLINE

A longline is a fishing gear composed of a mainline carrying multiple hooks on branch lines (snoods) of varying length and spacing depending on the target species. Longlines differ in material, hooks, baits, configurations, and practices that affect catch diversity, size, and amount. The mainline is thicker, branch lines are made of nylon or steel, and hooks are baited, with their size determining the targeted species. Longlines can be categorized as bottom-set (near the seabed) or pelagic (drifting in midwater or near the surface):

- **Bottom longlines** (FAO Code: LLS) are anchored on or near the seabed to target demersal species like hake and seabass. They are typically shorter and use fewer resistant materials and smaller hooks, commonly employed by coastal artisanal fleets.
- **Pelagic longlines** (FAO Code: LLD), widely used in the Mediterranean, target large pelagic species like swordfish, albacore, and bluefin tuna. They consist of a mainline with thousands of baited hooks suspended at various depths by buoyant lines attached to surface floats. Hooks catch fish at different depths, and soaking time depends on gear length, sea conditions, and fishing schedules (Figure 24).

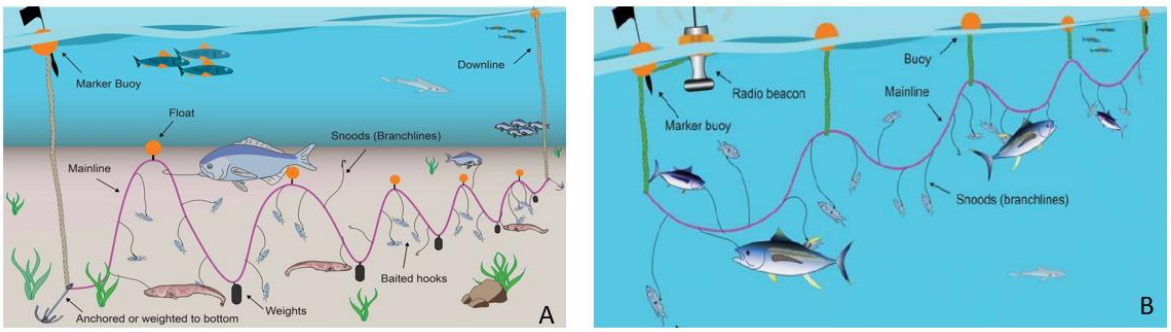


Figure 24 – **A.** Bottom (demersal) longlines. **B.** Pelagic (mid-water) longline. Credits: Australian Fisheries Management Authority.

With the exception of occasional instances involving bait and prey consumption or line entanglement, interactions between dolphins and longline fishing in the Mediterranean Sea are not well-documented, likely because dolphins are often released by fishers (Bearzi, 2002). Reported cases of cetaceans caught by pelagic longlines include a small number of striped dolphins, common bottlenose dolphins, Risso's dolphins, and false killer whales in Italy and Spain (Bearzi, 2002; ACCOBAMS, 2019b). An onboard observer program conducted by the Spanish Institute of Oceanography (IEO) confirmed a low occurrence of bycatch in pelagic longline fishing (López et al., 2012). Over the period from 2000 to 2009, out of 2587 sets in the Balearic Sea that were observed, only 52 (0.018%) fishing operations were found to have interacted with cetaceans, primarily involved those species inhabiting

pelagic waters beyond the continental shelf. In the waters of Italy, most reports of entanglement in longlines primarily concern striped dolphins, although documented cases also exist for common bottlenose dolphins (Di Natale, 1990; Mussi et al., 1998). Some of these individuals were discovered stranded with hooks in their mouths or fishing lines in their larynx, suggesting attempts to feed on bait or hooked fish (Bearzi, 2002). While there is limited quantitative data available on the extent of dolphin interactions with longlines in the Mediterranean Sea, this fishery appears to pose a minor threat in the region (Bearzi, 2002).

1.3.2. Possible solutions and mitigation methods for dolphin-fishery interactions

Over the past two decades, there has been heightened awareness and attention on the development of solutions to reduce cetaceans'-fisheries interactions (Reeves et al., 2001; Northridge et al., 2006; Rowe, 2007; Leaper and Calderan, 2018; ACCOBAMS, 2019a). Today, many of these strategies are contained in a range of fisheries and environmental legislation, including national and international regulation and guidelines. For example, the Food and Agriculture Organization of the United Nations (FAO, 2020) recently convened a workshop to draft "The technical guidelines to reduce bycatch of marine mammals in capture fisheries", containing a comprehensive review of the means to reduce marine mammal mortality in fisheries. According to this consultation, current techniques for preventing or minimizing interaction between cetaceans and fisheries can be categorized as follows: 1) time-area closures; 2) gear switching; 3) modifications to fishing gear or procedure; 4) deterrent devices (e.g., acoustic deterrents).

1) **Time-area closures**. Certainly, there is no doubt that time and area-based management strategies have the potential to effectively reduce cetacean by catch. This potential is particularly evident when such measures are applied in critical areas like breeding and nursery grounds, migration corridors, regions with seasonal prey abundance, and other areas where cetaceans tend to gather (FAO, 2019). Furthermore, these restrictions can be highly valuable when there is a consistent high rate of bycatch in specific areas and during particular seasons, as highlighted by Murray et al., in 2000. For instance, numerous countries, including Australia, New Zealand, Mexico, the United States, and parts of Europe (such as the Baltic Sea), have successfully implemented time and area-based closures to regulate gillnet fishing in response to concerns regarding cetacean bycatch (FAO, 2018). However, implementing such a strategy on a large scale in the Mediterranean Sea could present considerable challenges. From a socio-economic perspective, fishers tend to oppose spatial

restrictions on fishing areas, as this leads to their exclusion from preferred fishing grounds and a significant reduction in fishing revenue. Additionally, creating sufficiently extensive restricted areas to effectively reduce interactions may require a costly allocation of resources for enforcement and monitoring by regulatory authorities. In light of these considerations, it might be more feasible to implement temporal and spatial closures on a smaller scale, such as within protected areas. This approach may be particularly applicable in regions where bycatch poses a genuine risk to the survival or recovery of cetacean populations (Rojas-Bracho and Reeves, 2013).

2) **Gear switching**. Transitioning from fishing methods that pose a threat to dolphins, such as passive nets, to less impactful fishing gears represents another promising approach to mitigate harmful interactions between cetaceans and fisheries. Numerous trials focused on gear switching have demonstrated significant potential, especially when the catches of target species remain comparable to those of gillnets or the problematic fishing gear in question. Transitioning from fishing methods vulnerable to depredation and posing risks to marine mammals, like passive nets, to less impactful gears can help reduce these harmful interactions between dolphins and coastal fisheries. Trials involving gear switching explored alternatives such as longlines, light trawls, and pots. While longlines and trawls showed potential in limiting small cetacean by catch, they did not address depredation. Pots proved effective in reducing both bycatch and depredation, offering advantages like selectivity, minimal habitat impact, and low maintenance and, also, they maintain catch quality and can be commercially viable, encouraging fishers to switch to alternative gear for certain dolphin interaction-prone areas and periods (Königson et al., 2015) (Figure 25).

Figure 25 – **A**. A *Trapula* pot (three-chambers design) which is employed to catch fishes. **B**. Semi-ellipsoidal pot design employed to catch mantis shrimp.

3) **Modifications to fishing gear or procedure**. As it is shown in Figure 26, fishing gear can also be physically altered to minimize interactions with dolphins or to enable animals to

release themselves when they become hooked, entangled, or trapped. Consequently, these strategies are generally implemented to reduce direct mortality rather than preventing or discouraging the risk of contact with the fishing gear itself. There are numerous technical modifications and improvements in gear setup, some of which have been successfully tested while others are in use but lack adequate study. These modifications encompass various approaches, such as the use of passive reflector or the incorporation of bycatch reduction devices (BRDs). On this purpose, considering that gillnets are typically made from nylon monofilament, which has low acoustic reflectivity and weak target strength, making it hard for echolocating mammals to detect as a barrier, passive acoustic modifications have been proposed to enhance gillnet visibility to cetaceans, including the addition of reflective objects or the alteration of the net's acoustic properties with chemical compounds. While these modifications show promise in reducing dolphin and porpoise entanglement risks, their effectiveness in real-world fishing conditions is still unproven, as many studies were conducted in controlled environments without considering various environmental, behavioural, and economic factors. Early attempts to improve detectability by incorporating acoustic reflectors like air-filled or metallic components demonstrated potential, with requirements for effective reflectors being small size, omnidirectionality, and neutral buoyancy. Recent laboratory trials suggested that arranging acrylic spheres on the netting can significantly increase its target strength, making it more likely to be perceived as an impenetrable obstacle by cetaceans.

Adding a chemical filler to nylon gillnets to enhance acoustic reflectivity was tested to reduce harbour porpoise bycatch, but results varied. Larsen et al. (2007) saw lower porpoise bycatch, but it also reduced cod catch-per-unit effort, especially with iron oxide. Northridge et al. (2003) found higher porpoise bycatch in barium sulphate nets. Testing on common bottlenose dolphins in lab conditions showed that barium sulphate nets were detectable from certain angles (0° to 40°). However, doubts arose about acoustic materials as bycatch reduction tools, suggesting mechanical and visual factors, like stiffness and visibility, played a role. Metallic coatings increased net stiffness, preventing collapse around entangled animals, also seen in non-echolocating species like turtles and seabirds in barium sulphate nets (Trippel et al., 2003).

Another modification to the fishing gear is represented by the Marine Mammal Exclusion Devices (MMEDs) which were proposed in the mid-1990s to reduce bycatch of pinnipeds and small cetaceans in trawl fisheries. For dolphins, MMEDs use angled grids to prevent their entry into the net while allowing the target species to pass through. These grids direct

accidentally caught dolphins to escape openings in the net's top or bottom, similar to Turtle Excluder Devices (TEDs). Different grid types have been tested worldwide with mixed results. In one trial in Western Australia, a semi-flexible grid reduced bottlenose dolphin bycatch. Video footage showed that only a few dolphins intentionally entered the net, and some became distressed or died before escaping. Excluder devices were also tested in EU trawl fisheries, showing some bycatch reduction, but handling difficulties and commercial losses were observed. Other exclusion devices, like mesh barriers and ropes, were tested with inconclusive results in pelagic trawl fisheries due to marketable fish catch losses and increased drag. None of these exclusion devices have been tested in Mediterranean trawl fisheries, possibly due to development challenges and the relatively low dolphin bycatch rate in pelagic trawls (Fortuna et al., 2010). To reduce common bottlenose dolphin bycatch in trawl fisheries, studies suggest maintaining stable trawl gear to prevent net entrance collapse. Real-time monitoring systems like Marport's TrueTrawl™ can help ensure the net remains open, allowing dolphins to escape (Wakefield et al., 2017). These improvements are crucial in areas with frequent dolphin-trawl interactions, especially when deterrent systems like pingers are ineffective. For example, implementing otter-board sensors and avoiding sharp turns in an Australian fishery significantly reduced dolphin mortality by 20-59% (Allen et al., 2014; Wakefield et al., 2017). Auto-tensioning hydraulic devices, originally designed for efficiency, can also prevent dolphin entrapment (Baker et al., 2014). Additionally, considering factors like time of day, season, depth, and towing speed can help minimize dolphin bycatch in trawl fisheries. And last, the backdown manoeuvre, developed in the 1950s in the Eastern Pacific Ocean, allowed the intentional encirclement of dolphins in tuna purse seine fishing (now banned). It involves reversing the boat's engine to elongate the net into a channel, allowing dolphins to escape. A small mesh "Medina panel" at the end of the channel prevents entanglement. Measures like skiffs, speedboats, swimmers, and rafts are used to rescue trapped animals. This technique does not significantly impact tuna catches, as tuna tend to swim deeper.

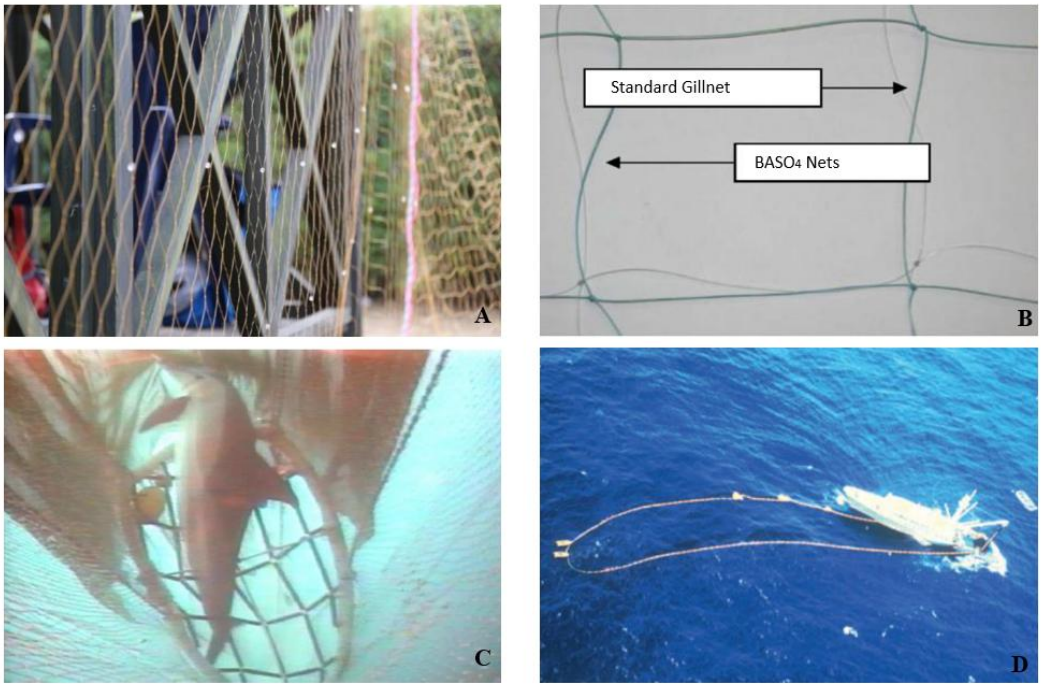


Figure 26 – **A**. Standard gillnet with acrylic spheres attached (Kratzer et al., 2020). **B**. A net impregnated BASO4 overlaid with a standard monofilament gillnet (Northridge et al., 2003). **C**. A common dolphin escaping in front of a rigid exclusion grid system inside a pelagic trawl (Von Marlen et al., 2007. **D**. A backdown procedure in progress (Gerordette, 2009).

4) **Deterrent devices**. Deterrent devices are non-lethal tools that are installed on or near fishing equipment with the aim of modifying cetaceans' behaviour to reduce their interactions with fishing gear. To accomplish this objective, these deterrents typically generate aversive stimuli that deter animals from approaching the fishing gear or employ methods to enhance their ability to detect and avoid collisions with it. Deterrent devices are regarded as a sensory ecology-based approach to mitigating negative interactions between cetaceans and fisheries because they capitalize on the sensory modalities through which animals perceive and respond to cues like light, sound, and smell (Schakner and Blumstein, 2013; Martin and Crawford, 2015). Among these systems, pingers are one of the most commonly used deterrent methods to address conflicts between dolphins and fisheries (Dawson et al., 2013; Hamilton and Baker, 2019). The challenge of marine mammals interacting with fisheries has driven the creation of non-lethal tools using aversive cues to discourage these interactions. Extensive efforts have been made to invent, deploy, and assess deterrents targeting various sensory aspects of marine mammals, such as touch-based disturbance, chemosensory repellents inducing fear or aversion, and visual and acoustic deterrence. Among these methods, acoustic techniques are widely used to mitigate detrimental interactions between cetaceans and fisheries, while the development of visual deterrents holds potential for further research.

1.3.2.1. Visual Deterrent Device (VDD)

Visual Deterrent Devices (VDDs), including LED lamps, are used to reduce unintentional captures of protected marine species, such as sea turtles and seabirds, in fishing nets (Figure 27). These devices rely on visual cues to influence animal behaviour, making them less susceptible to fishing gear. While LED lamps have been successful in reducing bycatch, the exact mechanism behind their effectiveness remains uncertain. It is believed that they may either scare away animals or make the fishing gear more visible, prompting avoidance. Dolphins, despite having well-developed vision, are less studied in terms of their response to visual cues. Recent research has extended the use of LED lamps to reduce dolphin interactions with fishing nets, showing promising results in reducing bycatch probabilities without affecting catch rates. LED lamps are favoured due to their brightness, durability, and ability to emit various wavelengths. They are considered cost-effective and can simultaneously reduce bycatch for multiple species in a fishery, making them a valuable tool. However, their effectiveness can be influenced by factors such as water turbidity, time of day, and depth. Future research should explore specific radiance and wavelengths for different dolphin species and test LED lamps in various fishing contexts, such as pair or bottom trawling.

Figure 27 – **A**. Electric LEDs lamp **B**. Chemical light sticks. **C**. LED employed on longline fishery **D**. UV-LED off and on.

1.3.2.2. Acoustic Deterrent Device (ADD)

Dolphin Deterrent Device or Acoustic Mitigation Device (AMD) can be grouped into two basic categories: Acoustic Harassment Device (AHD), which were initially developed to reduce depredation by pinnipeds, and Acoustic Deterrent Device (ADD), according to their sound intensity, functions and the species they were intended to deter cetaceans (Northridge et al., 2004; Reeves et al., 1996), respectively with first ones with <185 dB and >185 dB re 1 µPa 1 m (Long et al., 2015; ACCOBAMS, 2019).

The unregulated yet legal use of AHD in the Mediterranean Sea, permitted under EU fishery regulations and recommended by regional intergovernmental organizations (e.g., GFCM recommendation GFCM/36/2012/2, EU Regulation 2019/1241), is also a source of concern too (Natoli et al., 2021), and links to a significant threat, noise pollution (IUCN, 2023).

- The **Acoustic Harassment Devices** (AHDs) are powerful instruments that emit intense signals within the frequency range of 5 to 30 kHz, often exceeding 185 dB re 1 μPa at 1 meter (example: Figure 28). They are specifically designed to disrupt or cause discomfort to animals, with the primary purpose of deterring pinnipeds from approaching facilities like aquaculture farms, earning them the nickname "seal scarers". The effectiveness of these devices in deterring pinnipeds and unintended species has been evaluated with varying degrees of success, dependent on factors such as species, locations, and the specific AHD used. However, the high sound pressure levels produced by AHDs are believed to pose a potential risk of causing lasting harm to cetaceans. This harm could range from damage to their auditory systems to enduring physiological and behavioural changes, as well as disturbance of their activities and displacement from critical areas. Theoretical models suggest that the acoustic signals emitted by AHDs could be audible to harbour porpoises at distances of up to 12 km, causing significant disturbance and discomfort within a 1-km range. Despite some efforts to investigate the potential harm of AHDs on small cetaceans, such as harbour porpoises, there is limited knowledge about their impact on the behaviour and health of Mediterranean dolphins. To the best of our knowledge, only one study has attempted to assess the influence of AHDs on common bottlenose dolphins near a fish farm off the coast of Sardinia, Italy in which results partially contradicted previous findings related to small cetaceans, as AHDs appeared ineffective in deterring common bottlenose dolphins, which continued to approach the fish cages due to the abundance of prey. Nevertheless, the study did not rule out the possibility of long-term and harmful side effects induced by the acoustic device on dolphins (López and Mariño, 2011).

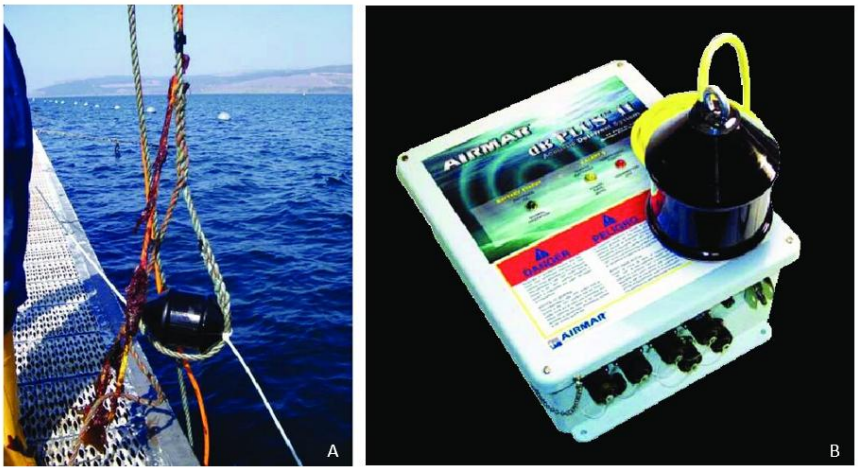


Figure 28 – **A**. Airmar dB Plus II calibration trials 2003. **B**. Airmar (dB Plus II) system (www.airmar.com in Lepper et al., 2014).

- The **Acoustic Deterrent Devices (ADD)** also known as pingers are battery-powered devices designed to minimize depredation or unintended capture of marine mammals in fishing gear, primarily used in set-nets. These devices emit relatively low-intensity sound levels (with a Sound Pressure Level - SPL of less than 185 dB re 1 μPa at 1 m) (Reeves et al., 1996; Werner et al., 2006). In general, these devices operate by emitting various acoustic signals within the middle to high frequency range (10 – 180 kHz). The high-frequency signals are intended to be detected by animals with keen high-frequency hearing abilities, such as delphinids (e.g., the most sensitive range for T. truncatus is between 15 and 110 kHz; Johnson, 1967). Depending on the manufacturer's specifications, each device has its own operational range and emits different acoustic signals, including pure tones, amplitude-modulated tones, frequency sweeps, broadband pulsed sounds, and sequences of multiple sounds. Pingers were initially developed to prevent small cetaceans, particularly harbour porpoises, from getting trapped in gillnets, reducing fishery-related mortality. EU Regulation 812/2004 mandated their use in specific EU waters.

  There are at least four main hypotheses to explain how these pingers work in reducing negative interactions between dolphins and fishing gear (Dawson et al., 2013):

  - the signals are generally aversive and function by pushing animals away from the vicinity of the pingers;
  - pinger sounds encourage echolocation or alert animals to the presence of the fishing net, enhancing their ability to avoid it;
  - acoustic stimuli disrupt the animals' sonar, causing them to leave the area;
  - pingers act as a deterrent to prey species (e.g., herring) rather than directly affecting cetaceans (e.g., harbour porpoises).

Among these hypotheses, the first two are the most supported by scientific evidence (Carlström et al., 2002; Culik et al., 2001; Leeney et al., 2007). However, there are no published studies specifically addressing whether pingers function by interfering with or reducing the effectiveness of echolocation in the current literature. Therefore, the fourth hypothesis, proposed by Kraus et al. (1999), was not supported by subsequent observations. On the contrary, several studies demonstrated that pinger sounds may have no adverse impact on the catch (Goetz et al., 2014). Numerous evidence to date suggested that pingers offer a simple and effective solution for reducing harbour porpoise bycatch in set-net fisheries (Dolman et al., 2016; Larsen et al., 2007; Trippel et al., 1999). Additionally, pingers are most likely to be successful in reducing bycatch of species that are generally neophobic or easily startled, such as harbour porpoises, although there are no definitive results for other species (Dawson et al., 2013). Since the marine mammals have different hearing sensitivities and may exhibit wide variation in responses to sound stimuli, the acoustic devices span a range of power output (measured in decibels [dB]) and frequencies (Hz); also, their duty cycle may be regular, random, or triggered by echolocating animals. For instance, high-frequency outputs are usually aimed to be detected by animals with good high-frequency hearing such as delphinids (e.g., best sensitivity in common bottlenose dolphin is between 15 and 110 kHz (Johnson, 1967). Then, pingers are classified as ADDs as they work by broadcasting a range of acoustic signals at relatively low intensity (Sound Pressure Level - SPL < 180 dB re 1 μPa at 1 m), regardless the species they are intended to deter (Long et al., 2015). And, in the end, depending on the manufacturer's brand specification, each pinger has its signal duration, silent intervals between signals (inter-pulse interval or minimum silent interval between signals), as well as produces different acoustic signals (e.g., pure tones, amplitude-modulated tones, or frequency sweep (Figure 29).

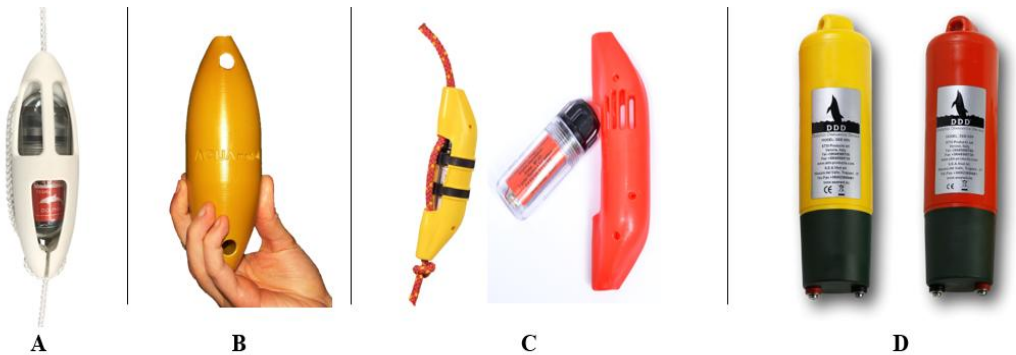


Figure 29 – Some examples of pingers: **A**. Netsheild pinger (Future Oceans) **B**. Aquamark 100 (Aquatek). **C**. Dolphin Anti-Depredation pinger (Fishtek Marine). **D**. DDDs model (STMm Products S.r.l.).

Regarding common bottlenose dolphins, most studies conducted in gillnet fisheries focus on reducing depredation and damage to set-nets rather than bycatch mitigation or the deterrent

effect of pingers. Therefore, the effectiveness of pingers is usually assessed by comparing commercial catches, fish damage, and net damage between control and "active" nets (i.e., those equipped with pingers). Studies may also include visual observations (e.g., behavioural observations *in situ*, photo-identification) and acoustic recordings (hydrophone recordings of dolphin echolocation signals) to evaluate the behavioural response to acoustic deterrent devices (Waples et al., 2013). Several experiments conducted across the Mediterranean Sea in the distribution range of common bottlenose dolphin have shown a significant reduction in net damage and minimal loss of commercial catches when pingers are used correctly. For example, experiments conducted in the gillnet fishery of the Egadi Archipelago (Sicily, Italy) using DDD-02 pingers (Buscaino et al., 2009 revealed that nets equipped with pingers experienced significantly less damage (31%) and contained more catch biomass (28%) than control nets and during the study, dolphins were recorded in 11 out of 29 hauls (38%). In a large-scale trial around the Balearic Islands (Spain) from 2001 to 2003, a significant reduction in dolphin-net interactions in active nets, ranging from 49% to 70% depending on the brand of devices used, was observed. However, there was no significant effect on profit per unit of effort (PPUE) (Brotons et al., 2008). In the same area, it was recorded an 87% decrease in holes attributed to common bottlenose dolphin depredation in trammel nets equipped with Aquamark 100 pingers compared to nets without pingers (Gazo et al., 2008). In the Aeolian Archipelago (Sicily, Italy) it was tested the effectiveness of FishTech Banana Pingers® (175dB) on coastal gill and trammel nets indicating an increase in yield and a reduction in interactions, along with decreased catch spoilage, in nets equipped with pingers (Bonanno Ferraro et al., 2018). In Greece, it was recorded significantly fewer holes (69%) attributed to dolphin depredation in trammel nets equipped with DolphinSaver pingers compared to nets without them (Northridge et al., 2003a). And a similar study in Sinop Bay (Turkey) showed significant differences between active and control nets in terms of catch per unit effort (CPUE) and net damage (Gönener and Özdemir et al., 2012). In the end, SaveWaves ADDs were effective in deterring dolphins from interacting with Spanish mackerel gillnets in North Carolina (Western Atlantic Ocean); however, they did not completely eliminate interactions, as observed from the research vessel (Waples et al., 2013). Notably, no dolphins were caught in any of the aforementioned studies, whether in nets equipped with pingers or control nets. This suggests that common bottlenose dolphins may have the ability to detect gillnets from a sufficient distance to avoid entanglement (Kastelein et al., 2000). Collectively, these studies indicate that while pingers may not completely eliminate interactions, they can significantly reduce their adverse effects.

1.3.2.2.1. General limitation and possible side effects of pingers

Whenever technological devices are used, it is important to evaluate general limitation and potential side effects, and so, using pingers, the following considerations should be taken into account:

- **Habituation**. While pingers have been effective in deterring bottlenose dolphins and other cetaceans from fishing gear interactions, concerns have arisen about habituation. Habituation occurs when animals become accustomed to a repeated stimulus and may reduce the effectiveness of pingers. Dolphins could interpret pinger sounds as an indicator of an easy food source, thus approaching fishing gear. To address this, some pingers emit signals at randomized intervals or modulate frequencies.
- **Habitat Exclusion**. Pinger use has raised concerns about habitat exclusion, particularly in areas with species having restricted distributions. Displacement effects are more pronounced in neophobic species like harbour porpoises. For bottlenose dolphins, the evidence is less clear, as they are often observed near pingers without showing escape behaviour. Displacement on a larger scale seems less problematic for dolphins with broader distributions and varied habitats.
- **Noise Pollution**. Pinger use may contribute to noise pollution in already noisy marine environments. The combined effect of many pingers might impact the physiology and auditory systems of cetaceans. The potential negative effects on dolphin hearing remain unclear and depend on factors such as exposure duration, sound level, and spectral content.
- **Economic Concerns**. Pingers can be expensive (around 200 - 1000€ per device), especially for small-scale fisheries requiring multiple devices along a net. Louder pingers, like DDD-03, can help reduce costs by requiring fewer devices. Battery life and management are secondary economic concerns. Rechargeable devices are easier to manage, but ensuring charged batteries for many devices can be logistically challenging. Guidelines and procedures have been developed to assist fishers in deploying and maintaining pingers.

1.3.3. Legal framework and policies on cetaceans' conservation and fisheries management

The common bottlenose dolphin is subject to numerous regulations that govern its conservation and highlight its ecological role. At the same time, there are several laws that regulate fishing and small-scale artisanal fishing. Below is a summary of the regulations at different levels, from global and European to national and regional levels, where agreements, regulations, and directives emphasize their importance for proper management and conservation (Figure 30).

At global level:

- **International Whaling Commission (IWC) Resolutions**: established in 1946, the IWC has adopted measures to monitor and manage interactions between fisheries and cetaceans, emphasizing the importance of minimizing bycatch and protecting critical habitats. At the following link is the ICRW The International Whaling Regulation Commission: https://iwc.int/convention.
- **The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)**: signed in 1973, entered into force in 1975 it regulates the international trade of cetaceans, including common bottlenose dolphins, to ensure their protection and conservation. The convention aims to prevent over-exploitation of these species through controlled trade and ensures that any trade does not threaten their survival in the wild.
- **Convention on Migratory Species (CMS)**: signed in 1979, entered into force in 1983, through the Bonn Convention, cetaceans, including common bottlenose dolphin, are listed under Appendix I and II of CMS, ensuring strict protection and international cooperation to reduce bycatch and conserve habitats.
- **The International Maritime Organization (IMO):** established in the 1948, in into force by 1958, the IMO regulates shipping and maritime traffic, including initiatives to reduce ship strikes on cetaceans. Ships are required to adhere to speed limits and routing measures in areas where cetaceans are known to be at risk.
- **FAO Code of Conduct for Responsible Fisheries**: since 1995 it has been providing global guideline promoting practices that minimize bycatch, reducing ecosystem impacts, and supporting sustainable artisanal fisheries.
- **Regional Fisheries Management Organizations (RFMOs):** RFMOs are international organizations responsible for the management and conservation of fish stocks in specific regions created in the late 60s. These bodies help coordinate efforts to ensure sustainable

fisheries practices and equitable access. RFMOs set fishing quotas, rules on fishing gear, and conservation measures for fisheries within their jurisdiction. While many RFMOs focus on industrial fisheries, small-scale fisheries often rely on these agreements for the conservation of shared fish stocks. Some RFMOs are beginning to integrate more inclusive approaches to SSF management.

- **International Labour Organization (ILO) and Fisheries** (188/2007, into force in 2017)**:** the International Labour Organization (ILO) plays a key role in setting labor standards in the fishing industry. It specifically addresses the decent work in fishing. This convention establishes standards for working conditions, safety, and social protection for workers in the fishing sector, which includes small-scale fishers. It ensures that small-scale fishers are not subject to exploitative working conditions and that their labour rights are protected, including access to decent living standards and health care.

At European level:

- **Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea, and Contiguous Atlantic Area (ACCOBAMS):** ACCOBAMS is a global agreement (signed on November 24th, 1996 and entered into force on June 1st, 2001) aimed at the conservation of cetaceans by reducing threats such as bycatch, habitat degradation, and overfishing. It promotes the use of sustainable fishing techniques to mitigate interactions between fisheries and cetaceans.
- **The Habitat Directive (92/43/EEC) and Natura 2000 Network**: this EU directive ensures the conservation of natural and semi-natural habitats and wild species of flora and fauna. Cetaceans, including common bottlenose dolphin, are classified as species of community interest, strictly protected against capture, disturbance, and killing.
- **The Marine Strategy Framework Directive (2008/56/EC):** this EU directive sets a framework for protecting and restoring the marine environment, aiming for "Good Environmental Status" (GES). It includes explicit objectives for cetacean conservation and sustainable management of human activities, including fisheries, that affect marine ecosystems.
- **Common Fisheries Policy (170/1983/EU)** with following reforms 2371/2002/EU and 1380/2013/EU): the EU's Common Fisheries Policy provides the legal framework for sustainable fisheries management. It encourages artisanal fishing and includes measures to protect cetaceans and reduce bycatch.

- **Technical Measures Regulation (2019/1241/EU):** this regulation defines technical measures to minimize the impact of fishing on marine ecosystems, with provisions to reduce bycatch of protected species, including cetaceans. It replaced the 812/2004 and it aims to establish a framework for technical conservation measures to ensure the sustainable management of fish stocks in the European Union. It provides rules for fishing gear, methods, and other technical measures designed to protect marine biodiversity, promote sustainable fishing, and reduce bycatch. this regulation establishes measures to reduce incidental catches of cetaceans in fisheries, including the mandatory use of acoustic deterrent devices (pingers) in specific fisheries to prevent bycatch.
- **The EU Biodiversity Strategy for 2030 (COM/2020/380)**: it aims to restore biodiversity and address the ongoing loss of ecosystems in Europe. A key focus of this strategy is the conservation and sustainable management of marine and freshwater ecosystems, including fisheries.
- **FEAMPA (Fund for European Aid for Maritime Affairs and Fisheries) Regulation 2021/1139/EU**: it is a key financial instrument that supports the European Union's maritime and fisheries policies, particularly those aligned with the Common Fisheries Policy (CFP) and the EU Biodiversity Strategy.
- **The EU Action Plan: Protecting and Restoring Marine Ecosystems for Sustainable and Resilient Fisheries (COM/2023/102)**: it is a strategic initiative by the European Commission, adopted on February 21, 2023. This plan aims to achieve the targets set in the EU Biodiversity Strategy for 2030, notably protecting 30% of EU seas, with one-third under strict protection.

At national level:

- **Framework Law on Parks and Nature Reserves (Law 394/1991):** this Italian law governs the protection of natural protected areas, including coastal and marine habitats critical for species like cetaceans. It promotes sustainable management of natural resources in protected areas and includes specific biodiversity conservation measures.
- **Homothermic wildlife and hunting (157/1992):** while primarily addressing terrestrial wildlife, this law includes provisions for the sustainable management of marine fauna and minimizing the impacts of human activities like fishing on protected species, including cetaceans.
- **The Pelagos Sanctuary (Law No. 391/2001)** is a special marine protected area established to protect marine biodiversity, particularly cetaceans (whales, dolphins, and porpoises), in the

Mediterranean Sea. It was created through an international agreement between Italy, France, and Monaco.

- **Presidential Decrees 357/1997 and 120/2003:** these decrees transpose the Habitat Directive into Italian law, establishing specific measures for protecting marine habitats and species. All cetaceans are subject to strict protections, with prohibitions on activities that could harm their populations or habitats.
- **Law 152/2001 – Sustainable Development of Fisheries and Aquaculture:** this Italian law regulates fisheries and aquaculture, emphasizing artisanal fisheries. It provides incentives and support measures for local fishing communities, promoting sustainable practices and the valorisation of fishery products.
- **Legislative Decree 154/2004:** this decree regulates fishing activities in Italy, establishing criteria for sustainable management of fishery resources. It includes provisions for protecting vulnerable marine species, such as cetaceans, and incentivizes artisanal fisheries.
- **Directorate General Decree No. 319453 of July 17, 2024:** it issued by the Ministry of Agriculture, Food Sovereignty, and Forests (MASAF), sets the resources and criteria for providing aid to fishing enterprises that decide to permanently cease their activity, in accordance with Article 20 of Regulation (EU) 2021/1139 (FEAMPA).

At regional level:

- **The DPR (Decree of the President of the Republic) No. 22 of July 22, 1996**: it pertains to the Tuscan Archipelago National Park (Parco Nazionale Arcipelago Toscano) in Italy. It is one of the largest marine and terrestrial protected areas in Europe and includes a series of islands off the coast of Tuscany, such as Elba, Giglio, and Capraia, as well as the surrounding seas.
- **The Site of Community Importance (SCI) "Protection of *Tursiops truncatus*"**: it was officially established with the Regional Council Resolution No. 2 of January 14, 2020. This SCI, identified by the Natura 2000 code IT5160021, is dedicated to the protection of the bottlenose dolphin (*Tursiops truncatus*).
- **The Tuscany Observatory for Biodiversity (OTB):** it is a regional initiative established under Regional Law No. 30 of March 19, 2015, titled "Norms for the conservation and enhancement of the regional naturalistic-environmental heritage." The OTB coordinates the collection of data on marine biodiversity, including strandings, sightings, and recoveries of cetaceans, sea turtles, and elasmobranchs. This network involves collaboration among the

regional environmental protection agency (ARPAT), universities, research centres, museums, aquaria, environmental associations, and fishers.

- **The Regional Law No. 30 of June 22, 2009:** it titled "New Discipline of the Regional Agency for Environmental Protection of Tuscany (ARPAT)", outlines the functions and responsibilities of ARPAT, including environmental monitoring activities. ARPAT has been actively involved in monitoring marine biodiversity, including cetaceans, sea turtles, and large cartilaginous fish. This includes recording strandings, sightings, and recoveries of these species along the Tuscan coast.
- **The Regional Law No. 52 of 2000 and Regional Law No. 7 of 2005** are key pieces of legislation in Tuscany aimed at regulating and protecting fishing activities. The Regional Law No. 52 of 2000 focuses on the conservation and enhancement of the regional naturalistic-environmental heritage, including the protection of aquatic ecosystems and fish populations. It establishes guidelines for the sustainable management of fishery resources, aiming to balance ecological preservation with the needs of fishing communities. The Regional Law No. 7 of 2005 specifically addresses the management of fish resources and the regulation of fishing in inland waters. It outlines the planning and management of fishing activities in inland waters, including the division into fishing zones, criteria for the establishment and management of fishing institutions, and measures to ensure the conservation and sustainable use of fish populations.

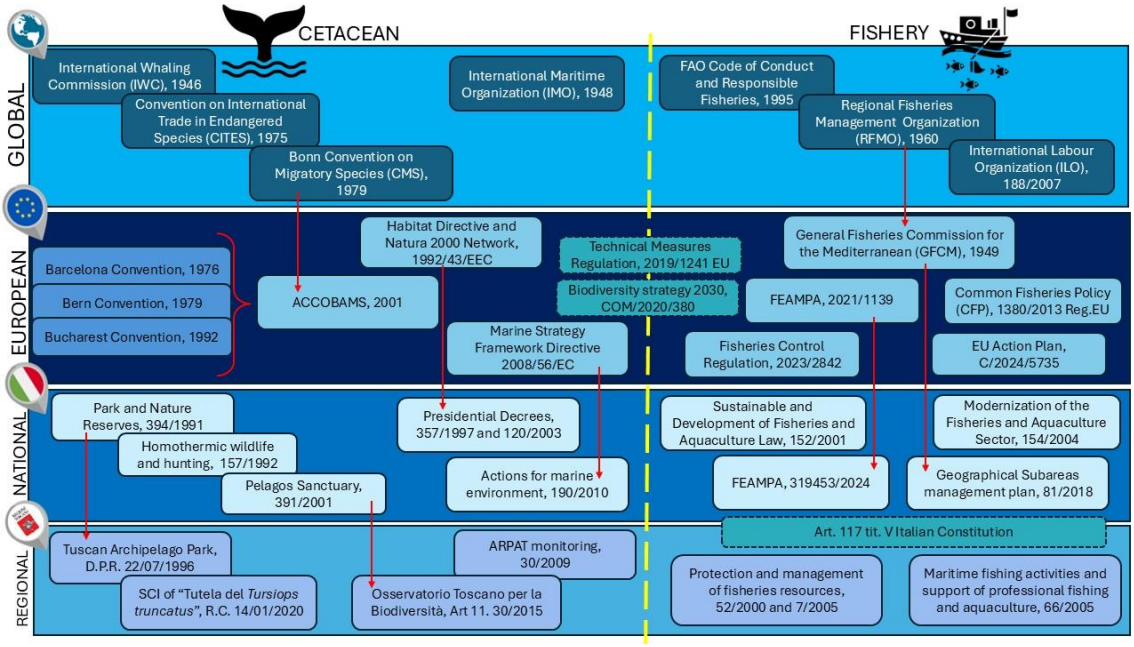


Figure 30 – Summarized chart cetaceans and fishery. In the "Cetaceans" section, the main laws, regulations, policies, and strategies are collected, which govern the protection of these marine mammals, their conservation, and the measures to be implemented. It also includes general laws on marine biodiversity and the protection of protected areas. In the "Fishery" section, the main laws, regulations, policies, and strategies regarding the management of professional and small-scale artisanal fishing are listed. The red arrows indicate the direct link between laws at different levels (i.e., the implementation of a law from one regulatory level to another), while the green sections with dashed outlines indicate that those laws apply to both sections.

1.3.4. Life DELFI project and the use of pingers

This PhD thesis is the result of three years of a project co-financed equally by the University of Siena and the Life DELFI project (co-financed by the European Community under the Life programme LIFE18 NAT/IT/000 942). Starting from the same meaning of the project acronym, "Dolphin Experience Lowering Fishing Interaction", it is possible to deduce the centrality of the purpose, which is to deepen knowledge about the interactions between dolphins and fishing activities with their reduction. The project areas (including 4 Marine Protected Areas) are: Punta Campanella, Egadi Islands, Tuscany coast (Northern Tyrrhenian Sea), Aeolian Islands, Tavolara Island, Veneto coast (north of the Po Delta), Torre del Cerrano (Abruzzo coast), Central Adriatic (Marche coast), Istria and Cres in Croatia. The target areas of the project have been chosen on the basis of several studies that reported both the presence of dolphins and the problem of a high mortality rate of these species, due to interactions with the fishing industry. One of the principal solutions proposed by Life DELFI that interested also this PhD project, is to experiment a new developed generation pinger (Dolphin Interactive Dissuader – DiD01®, manufactured by STM Products S.r.l.) mounted on fishing nets to reduce interactions with dolphins. So, the main aims of this PhD thesis related to the Life DELFI project were intended to: i) test Dolphin Interactive Deterrents (DiD01®), an interactive pinger, on set nets to keep common bottlenose dolphin far from fishing activities; ii) evaluate differences in terms of catch per unit effort per weight ($CPUE_W$) and number of individuals ($CPUE_N$); iii) evaluate differences in terms of richness and occurrence of species caught by nets with pingers and without pingers; and iv) evaluate the effectiveness and the efficiency of DiD01® in reducing harmful interactions such as the occurrence of catch and net damages.

Chapter 2 METHODS

The focus of this PhD thesis was on the following activities:

1. bottom- up analysis through *ex ante* and *ex post* monitoring (paragraph 2.2.1);
2. acoustic deterrent devices investigations using DiD01® and statistical data elaboration (paragraph 2.2.2);
3. strandings data elaboration (paragraph 2.2.3).

As was regular in a research plan, the first step involved conducting a thorough and detailed literature review. The bibliographic research was undertaken in order to collect information on: dolphin-fishery interactions and their modalities, bycatch rates, anthropogenic threat affecting common bottlenose dolphin livelihood and possible mitigation solutions to reduce detrimental dolphin-fishery interactions. It has been using a range of sources including peer-reviewed journals, reports, magazine articles, conference papers, master's and phd's thesis and information from government and non-government organizations. The bibliographic research was conducted primarily by consulting web search engines such as PubMed, Scopus, Google Scholar and Web of Science. Search strings included terms, such as "bycatch, interaction, depredation and/or mitigat*" combined with: "fisher*, trawl, purse seine, longline, gillnet, pot, trap, line, cetacean, dolphin, *Tursiops truncatus*, common bottlenose dolphin". Regarding the strandings events affecting common bottlenose dolphin, the strings included terms such as "common bottlenose dolphin, dolphin, *Tursiops truncatus*" combined with: "stranding*, stranded animal*, death animal*".

2.1. The study area

The study area is the one selected within the LIFE DELFI project, and the operational ports are the most significant in southern Tuscany, where the fishers most willing to support the implementation of the study and project have been identified. The study area holds high conservation value due to the presence of numerous important protected zones within or near its boundaries. First and foremost, it lied within the Pelagos Sanctuary, officially known as the Sanctuary for Marine Mammals which is the largest Specially Protected Area of Mediterranean Importance (SPAMI) in the Mediterranean. It is also ideal habitat for the common bottlenose dolphin (*Tursiops truncatus*), whose presence has been confirmed by the latest IUCN report (Natoli et al., 2002). Additionally, the study area was located within the Tuscan Archipelago National Park, a protected area that includes vast marine zones of great ecological significance. Furthermore, the fishing area in the south, especially off the coast of Talamone, were adjacent to the Maremma Regional Park, another highly valuable

natural area and many Natura 2000 sites such as “Padule della Trappola, Bocca d'Ombrone” (IT51A0039) and “Scoglio dell’Argentarola” (IT51A0038). Lastly, the Piombino area was within the Site of Community Importance (SCI) for the common bottlenose dolphin, recognized for the stable presence of this dolphin species along its coasts (Natura 2000 code IT516002—Regional Council Decision No. 2, of January 14th, 2020).

In this study area, five fishing harbours with a majority of vessels of Small-Scale Fisheries (SSF) operating mainly in areas overlapping with common bottlenose dolphin distribution (as reported by fishers interviewed during Life DELFI Action C1 and D1 project bottom-up surveys (Li Veli et al., 2023) were selected (Figure 31). The five study areas were selected from the main fishing communities of southern Tuscany, taking into account the operational ports of the fishermen who actively participated in the study, as well as their fishing areas.

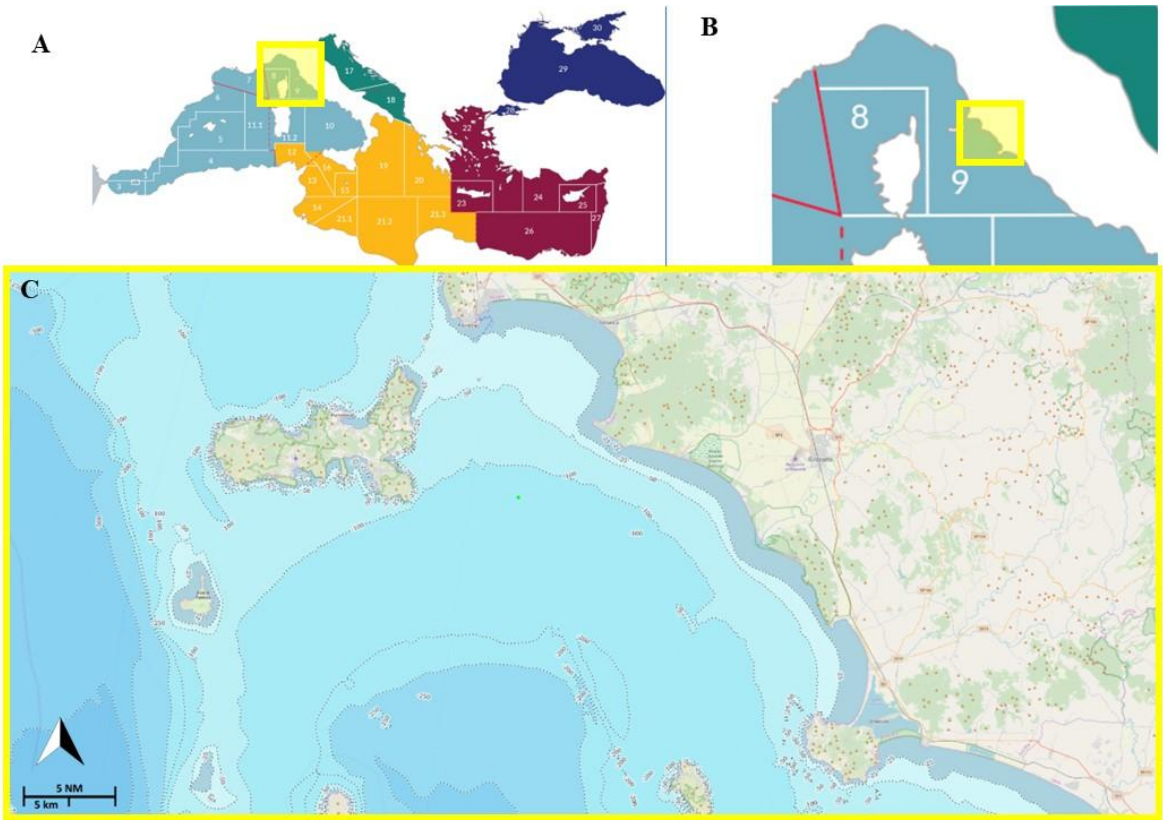


Figure 31 – Study area map showing the Geographical Sub-Areas selected by the GFCM with the highlighted GSA9 (**A**), the zoomed GSA9 with the highlighted study area in the Southern Tuscany (**B**) and the study area of the Northern Tyrrhenian Sea from Piombino to Porto Ercole (**C**).

2.2.1. *Ex ante* and *ex post* monitoring

Ex ante and *ex post* surveys have been conducted within the Action A3 and D3 of the Life DELFI project to assess respectively the occurrence of dolphin-fishery interaction first, and then, to evaluate the impacts of the activities implemented by the project three years later.

Ex ante interview surveys were conducted to collect FEK data on the interactions between dolphins and fishing activities in the study areas. The survey aimed to understand the fishers’

perspectives on (i) the nature and extent of interactions between fishing and dolphins, (ii) the economic impact of these interactions on dolphin populations, and (iii) the use of acoustic deterrent devices (pingers) to deter dolphins from fishing gear.

Ex post interview surveys were directed to fishers involved in some of the project activities and it was conducted to collect FEK data on the interactions between dolphins and fishing activities in the study areas three years later the project activities. The survey aimed to understand the fishers' perspectives (i) if the nature and the extent of interactions between fishing and dolphins has been changed in the years of the project, (ii) the possible advantages and the efficiency of the mitigation methods proposed by the project (e.g., acoustic deterrent devices, visual deterrent devices, pods, etc.) to deter dolphins from fishing gear, and (iii) the possible problematic issues encountered using mitigation methods.

The interview surveys were conducted in the study area (Tuscan harbours) as part of the Life DELFI project partner. Trained interviewer (the researcher) met the fishers at the harbours, onboard fishing vessels, and during *ad hoc* meetings with fishers' associations. The interviewer was left free to choose the most appropriate technique for collecting information from the fishers based on three different approaches:

- **Option 1: Question–answer interview**. This option was the most convenient, since it allows respondents to precisely fill in the questionnaire entries, however it required the fisher to be very keen in terms of time to reply. The data entries were collected through printed forms or a smartphone/tablet using Google Forms.
- **Option 2: Colloquial interview**. This option was preferable when the fisher was not completely available for the interview because it may take too much time. In this way, instead of following the question–answer structure, the interviewer could chat in person or talk on the phone with the fisher to obtain useful information.
- **Option 3: Direct data entry by the fisher**. This approach has been adopted only when the questionnaire was distributed during dedicated events or meetings to maximize time and resources. In this case, at least one person was required to support the data entry.

A "snowball" sampling technique was used for the interviews. Briefly, randomly chosen fishers indicated future study subjects from among their acquaintance (Biernacki and Waldorf, 1981; Faugier and Sargeant, 1997). Each questionnaire, given to the interviewee, consisted of 19 questions for the *ex ante* and of 20 for the *ex post* questionnaires, both with multiple answers grouped into 3 sections (about 15 min; supplementary materials S1 and S2).

Regarding *ex ante* questionnaire, before administering it to the fishers, they were shown fact sheets on the three dolphin species regularly present in the Mediterranean i.e., common bottlenose dolphin, short-beaked common dolphin and striped dolphin, for obtaining information about the species to which they interact the most. Only data from Sections 1 and 2 were considered for the analyses of the *ex ante* survey, instead, Section 3 was useful in order to gather information concerning the possible involvement into other activities of the project such as the tasting of acoustic/visual deterrent devices or alternative fishing gear. Sections S1 and S2 mainly consisted of closed ended questions to collect quantitative and factual information; respondents were also required to give an opinion on a certain topic. Section S1 focused on obtaining all the necessary information on the dolphin presence and interaction with all of the fisheries and fishing methods; Section S2 focused on the respondent's opinion towards pingers as mitigation devices, since they represent the most common devices produced on a commercial scale and are already employed by fishers (STECF, 2019).

Regarding *ex post* questionnaire, first of all, it should be noted that it was administered to those fishers who volunteered to conduct some activities within the Life DELFI project, such as the use of acoustic and/or visual deterrents, the use of alternative fishing gear, or involvement in alternative economic activities such as dolphin watching. Subsequently, a questionnaire was administered for each of the activities the fisher participated in. Only data from Sections 2 and 3 were considered for the analyses of the *ex post* survey, instead, Section 1 was useful in order to gather information regarding the type of involvement the fisher ha in the project activities. Sections S2 and S3 mainly consisted of closed ended questions to collect quantitative and factual information; respondents were also required to give an opinion on a certain topic. Section S3 aimed to gather all the necessary information regarding the use of deterrents, evaluating their effectiveness and identifying any advantages and/or issues encountered by fishers during fishing activities. Section S3 focused on the opinion and willingness of the fisher to transition from traditional fishing activities to more sustainable economic alternatives, promoting responsible fishery.

For both *ex ante* and *ex post* questionnaires any extra information was reported in a specific section "Interviewer's note", where personal opinions about the following points were reported (if any):

• Feelings about the honesty of the fisher in answering the questions;

• Feelings about the interest and involvement of the fisher;

• Feelings about the precision of the fisher in answering the questions;

• Useful details for the questionnaire's goals.

This additional information was considered in the following data treatment to validate each questionnaire.

The information obtained from the survey conducted in Tuscany (within the GSA9) has been primarily divided by fishing gear and for the PhD elaboration data only those fishers that used passive nets were taken into account. Data was elaborated with descriptive statistic values such as mean and standard deviation.

2.2.2. Acoustic Deterrent Devices

During the PhD project DiD®01 (Dolphin Interactive Deterrents) manufactured by STM Products S.r.l. Verona, Italy (Figure 32) was tested. It is a device designed in collaboration with prestigious research centers, such as the Institute of Marine and Environmental Research (IRMA) of the CNR of Mazara del Vallo and the Institute of Marine Research in Moscow. First, it had not been tested in only one study documented in the literature, who's the PhD candidate was first author (Ceciarini et al., 2023). Second, it was unique in terms of its technical features, which were believed to be especially effective in mitigating harmful interactions between dolphins and fisheries. In fact, this device was considered an evolution of the DDD models, producing ultrasound only when the presence of the marine mammals in the area was detected, through a special circuit, that "hears" the clicks emitted by them.

Figure 32 – DiD01® STM Products S.r.l Verona, Italy.

Dolphin Interactive Deterrents (DiD®01) set up. DiD®01 acoustic deterrent devices used in the trials, are specifically designed to emit signals only in response to dolphin echolocation clicks. This implies that the pinger is typically in a standby or hearing mode and only activated when an integrated hydrophone detects clicks originating from a dolphin. The output signals are emitted from 5 kHz up to 500 kHz at 168 dB re 1 μPa at 1 m as random high-speed tones FM ranging from 100 μs up to seconds (Table 1). The emission radius of a

single device is 250m, thus covering a horizontal space of 500 m, and extends 80 m downward, with an approximately toroidal emission field, as shown in Figure 33 and well-explained in the user manual (Cod 2629006 - Rev. 04.03 - 12.10.2020). The user manual provided by the manufacturer contain the following warning: "*do not place a DiD®01 at less than 600-800 m from another DiD®01*". In addition, the technical features of the dispositive is given in another section of the manual and confirmed that the horizontal spacing between two devices must be 600-800m. To further maximizes the acoustic coverage, the first device is usually placed approximately 300 m from the start of the nets. Its sound frequencies range were only emitted when in close proximity to dolphins since this technology utilised a special circuit that was activated by the clicks emitted by them. Fishes were insensitive to the frequencies emitted; therefore, it did not produce any harm to them nor to the dolphins. This system decreases the possibility of habituation. Since they only emit sound in the presence of cetaceans, there battery charge has an increased duration.

Table 1 – DiD®01 technical sheet (STM Products S.r.l., Verona, Italy).

TECHNICAL FEATURES	
Emission frequency	From 5 to 500 kHz
Emission power	168 dB re 1 µPa at 1 m
Maximum reception capability	125 dB re 1 µPa at 1 m in the 50 – 70 kHz
Maximum reception distance	800 – 1200 m with echolocation pulses > 200 dB
Minimum operative depth	10 - 20 m
Maximum operative depth	200 m
Horizontal spacing	600 – 800 m
Power internal source	5 rechargeable 1.2 NiMH batteries
Batteries autonomy	> 300 hours in hearing mode. ~12 hours in continuous emission
Average lifetime	500 – 1000 battery charge/discharge cycles
Dimension	210 x 61 mm
Weight	990 g

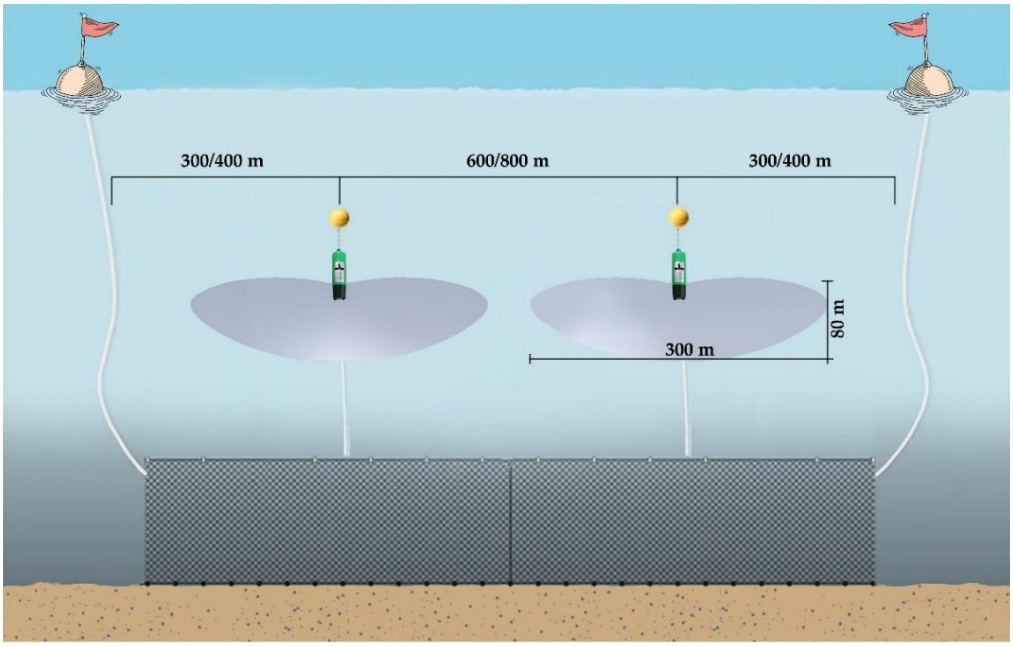


Figure 33 – The setup of the DiD®01 on a trammel net shows the correct distance between the buoyant signal and each pinger. The emission-range of the pinger is also shown in grey.

The pingers were deployed on the net using floating branch lines whose length varies according to the depth of the study area. The branching lines are made of polyethylene ropes (Ø = 8 mm), with two stainless steel snaps fasteners at both ends, to easily connect them to the net and the float. The latter is needed to neutralize the weight of the pinger (990 g). PVC deep water buoy (Ø = 400 mm; net buoyancy = 2 kg) was used to provide positive buoyancy. An additional lead weight (1 kg) was placed on the guideline for each branch, to prevent the net from detaching from the seabed due to water currents. Finally, the pinger was connected to the buoy by a snap. The setup of DiD®01 on the trammel net is shown in Figure 32. All technical issues related to device charging and battery measurement were managed by the researchers, who, over the three years of the study, maintained constant communication with the manufacturer, STM Products S.r.l. Italy which provided advice and solutions to address technical problems and assess the operational status of the devices. For instance, the battery was regularly monitored using the Voltester supplied by STM. When the pingers are fully charged, they emit a continuous, regular, and closely spaced sound. Upon use, if they come into contact with water on the electrode area, they produce a prolonged deep beep, confirming that they are functioning correctly. This was the instructed method for their proper use. In this way, fishers could verify that the deterrents were ready for use and ensured their effectiveness. The maintenance of the deterrent devices was entrusted to the fishers, who received specific training including procedures such as washing the device in freshwater and thoroughly drying it to prevent rust formation. Defective or broken devices were sent back to the manufacturer for proper disposal.

Data collection. All data were collected from both fishers and researchers in two different logbooks called respectively: “fisher logbook” and “observer logbook” shown in the supplementary material S3. A properly qualified observer of the Department of Physical Sciences, Earth, and Environment, (University of Siena) collected the data whenever it was possible to get on board. Otherwise, when, for some reasons, such as technical issues or weather conditions, there was not the possibility to get onboard, data was collected directly from the fishers. Then, after being initially checked by researchers, the data obtained via fishers’ logbook was then incorporated into the database using a data entry programme. Data were collected during the normal progression of fishing operations, without interference from the scientists on board. Experimental trials were conducted using setnets (i.e., trammel nets, combined nets and gillnets), usually set during sunset, and hauled just before or after sunrise, as in commercial fishing activities. Trials were divided into nets without pingers called “CTRL” and nets fitted with pingers called “TEST”, and so, in order to minimize

differences due to patchy species distribution, the two types of nets were deployed, when possible, simultaneously, close to each other maintaining the distance between TEST and CTRL net at least of 1000 m.

Type of setnet, target species, net meshes, net height were, net length, soaking time and depth were all data recorded. Maps of study area and TEST and CTRL trial distribution maps were made by using QGIS program 3.28.0 version. In accordance with the Life DELFI project guidelines, the deployment of nets was intended to be evenly divided between CTRL and TEST. However, due to the fishers' resistance and reluctance to use the control nets, it was sometimes only possible to deploy the TEST nets, as they feared being attacked by dolphins when using the control nets. This led, during data analysis, to a distinction between "matched" nets, where both CTRL and TEST were deployed simultaneously, and "unmatched" nets, where one of the two nets, either CTRL or TEST, was absent. Both type of trials was organized alternated (i.e., changed regularly) and randomized (i.e., arranged randomly). Alternation or randomization is important to avoid systematic bias. In other words, if the nets were not distributed randomly or alternately, there might be errors in the experiment's results due to uncontrolled factors affecting only one type of net (for example, a preferred position or an external factor that impacts only one type of net).

At the beginning of the trial, the geographical coordinates of the net position, date and time, net feature (i.e., mesh size in mm, length in m, and height in m), water depth in m, and number of pingers employed for test nets were recorded. At the end of the trial, the date and time, the weight and number of specimens, and the scientific name of fish species caught using, when possible, FAO code according to the ASFIS List of Species for Fishery Statistic Purposes 2022 version were recorded (ASFIS-FAO, 2023). Note: The ASFIS method considers species even in cases where there are groups of species or subspecies (e.g., *Brachyura*, *Cruscatcea*, or *Diplodus spp*).

During the fishing trials, interactions with dolphins were also recorded. The "interactions" were operationally defined as instances of dolphin presence, both direct and indirect. Direct interactions occurred when dolphins were visually observed (Direct Observation of Dophins, DDO (La Manna et al., 2024) during the hauling and setting phases, within a maximum distance of 500 meters from the fishing vessel (the observer's field of view), or when dolphins were involved in bycatch (see paragraph 1.1.1.) (referred to as direct interactions). Indirect interactions, on the other hand, were inferred from the presence or absence of damage to the nets or catch caused by dolphins (referred to as indirect interactions). The criteria for defining these interactions were as follows:

- direct interactions: documented by photographs or video taken by the fishers or the onboard observer, instances of bycatch (dead or alive) landed and analysed *post-mortem*.
- indirect interactions: assessed based on the number of holes in the net caused by dolphins and the number of individuals damaged by dolphin bites (Lauriano et al., 2004), accompanied by photographic evidence.

Regarding the dolphin interactions, interaction maps were created using QGIS software version 3.28.0 "Firenze" (http://qgis.org) and the "point cloud" command. These maps highlighted hotspot areas with a darker and more pronounced colour gradient, indicating coves where more interactions have been recorded, conversely, lighter colour represented areas with fewer interactions.

Economic loss due to damage to gear (number and size of holes) was estimated by fishers based on cost and time requested for repairing nets. Moreover, the economic loss due to the catch damages was calculated considering the potential economic value of the damaged fraction. These data were recorded in logbooks and throughout photos in order to assess if the damages were due to dolphin interaction or other causes. Damages both to the catch or gear due to dolphin interactions and other species interactions were considered for the economic loss evaluation. Damaged fish were considered as in Lauriano et al. (2004). All pictures of fishing trials and fishers were taken during the PhD project after obtaining a written informed consent from all human subjects. All subjects agreed to be photographed during fishing operations and gave their informed consent to have their identifying details (including photos) published.

2.2.2.1. Statistical analyses and modelling CPUEw data

To objectively and consistently evaluate fishing data, it is essential to use a standardized parameter. Raw catch numbers and weight alone lack meaningful context, as fishing outcomes depend on various factors, including effort intensity, equipment used, and environmental conditions. To account for this variability and ensure comparability, the parameter known as Catch Per Unit Effort (CPUE) is used. CPUE measures the amount of catch relative to the effort invested, standardizing results for more accurate analysis.

In this study, the most effective and useful CPUE—also the most commonly used in the literature—is the one that considers the catch quantity in terms of both weight and number of individuals, in relation to the length of the net and the duration of its immersion in water. To compare CTRL and TEST net results, catch data were first standardized since the total length and the soak time [calculated as (DD/MM/YYYY, hh:mm hauling time) — (DD/MM/YYYY, hh:mm setting time)] between CTRL and TEST nets were different.

Catches from each fishing trial were standardized using CPUE as in Lucchetti et al. (2019). CPUE in terms of weight ($CPUE_W$) and in terms of number of individuals ($CPUE_N$) were calculated as follows:

$CPUE_W = W_c$ /[(NetLength/1000 m) (NetSoakTime/12 h)]

$CPUE_N = N_c$ /[(NetLength/1000 m) (NetSoakTime/12 h)]

where N_c and W_c are respectively the total number and total weight of captured individuals. Above all, the catch per unit effort (CPUE) method was used to standardize the data and minimize any possible discrepancies in catch performance in terms of weight (kg) and the number of individuals (n), in order to overcome potential biases that could affect all trials such as weather conditions, dolphin behaviour, net disparities, and pinger activity.

Descriptive statistics were used to summarize the main characteristics of the control and test trials. The Mann–Whitney U non-parametric test was implemented to detect differences between CTRL and TEST for the $CPUE_W$. Boxplots were then used to display graphically results.

Sørensen index (Sc) was used to assess the species similarity between the CTRL and TEST nets.

The equation for Sc is as follows:

$$Sc = \frac{2c}{S_{CTRL} + S_{TEST}}$$

where c is the number of species common to both net captures and S_{CTRL} and S_{TEST} are the number of species captured by CTRL and TEST nets, respectively.

This index takes values from 0 to 1: the closer to 1 the value is, the more similar the CTRL and TEST nets captures are.

Shannon Equitability Index (EH) was used to measure the evenness of species in CTRL and TEST nets' captures. Evenness refers to how similar the abundances of different species are in the CTRL and TEST net captures.

The Shannon Equitability Index (EH) is given by:

$$E_H = \frac{-\sum_{i=1}^{S} p_i ln p_i}{\ln (S)}$$

where pi is the relative abundance of one species on the total number of individuals captured, ln is the natural log, and S is the number of species. This index ranges from 0 to 1 where 1 indicates complete evenness.

Linear regression analysis was used to study the determinants of $CPUE_W$ (Mayers et al., 2012; Montgomery et al., 2021). The linear regression model is a statistical tool used to understand how a dependent variable (in this case, CPUE) was influenced by one or more independent variables (e.g., water temperature, fishing effort, time of year, or other environmental characteristics).

2.2.3. Cetacean strandings data

In order to evaluate the occurrence of dolphin mortality, particularly for the species of interest in this PhD thesis, such as the common bottlenose dolphin, in Italy and especially in Tuscany, the BDS (Stranding Italian Data Bank) database was utilized (https://mammiferimarini.unipv.it/). This database has been systematically recording all cetacean strandings from 1986 to nowadays and still ongoing. The data were opportunistically used, and analyses were conducted to understand the occurrence of the common bottlenose dolphin strandings in Italy and Tuscany, and to identify the reasons why dolphins died especially those with clear evidence of anthropogenic causes, in particular those related to fishing activities.

The BDS website was accessed with an internal user login, thanks to Professor Letizia Marsili, who is one of the coordinators of this cetacean stranding monitoring in Tuscany (Osservatorio Toscano per la Biodiversità, OTB, L.R. No.. 30/2015 art.11) and holds the access credentials. Once inside the database, several queries were made on the portal to analyse the deaths by species, location (i.e., region), year, and cause of death, etc.

Moreover, a schema of the various entries in the database with the possible combinations for of the most frequent causes of death or observable signs linked to the presence of humans, or their fishing activities was built. The following scheme combinations with different variables (Table 2).

Table 2 – All observable sings of cause of death of cetaceans related to human activities with all possible combinations. In the data sheet of BDS (Stranding Italian Data Bank), all of these categories can be filled by biologists, veterinarians and experts.

OBSERVABLE SINGS OF CAUSE OF DEATH RELATED TO HUMAN ACTIVITIES	COMBINATION
Bycatch	A
Sing of fishing gear	B
Presence of net	C
Presence of hook	D
Firearm injuries	E
Collision	F
Bycatch and sing of fishing gear	AB
Bycatch, sing of fishing gear and presence of net	ABC
Bycatch and presence of net	AC
Bycatch, presence of net and presence of hook	ACD
Bycatch and presence of hook	AD
Bycatch and firearm injuries	AE
Bycatch and collision	AF
Sing of fishing gear and presence of net	BC
Presence of net and presence of hook	CD

Results were also presented in the same order as methods, with their respective subsections.

3.1. *Ex ante* and *ex post* monitoring

The *ex ante* and *ex post* monitoring expected by Actions A3 and D3 of the Life DELFI project were also conducted by the partner of the University of Siena throughout the Tuscan harbours located within the GSA9 area. Therefore, in continuity with the paper published, in which the candidate is a co-author (Figure 34), the results presented in this PhD thesis focused on the questionnaires obtained solely from the Tuscany coast. Moreover, *ex post* monitoring was carried out as expected from the Life DELFI project in order to assess how the experimentation activated have progressed.

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Article

Fishers' Perception on the Interaction between Dolphins and Fishing Activities in Italian and Croatian Waters

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Abstract: Interactions between fishing and dolphins can be detrimental, since on one hand dolphins can be lethally entangled by nets and trawls, and on the other dolphins can predate fish caught by nets. For dolphins, this interaction can be dangerous as they can be wounded or accidentally killed; for fishers, the predation of their catch results in economic losses due to reduced quantity and/or quality of catches and damage to fishing gear. During July and November 2020, we surveyed the "dolphin–fisheries conflict" through compiling 209 fisher interviews from nine locations in Italy and Croatia. Fishers mentioned the common bottlenose dolphin (*Tursiops truncatus*) as the species primarily interacting with fishing, with the major issue being catch damage by predation. The interaction probability varied among gears and seasons, with some fishing activities (e.g., passive nets) more affected than others (e.g., bottom trawls), especially in terms of economic loss (1000–10,000 €/year on average). More than 70% of the fishers claimed that dolphin populations have increased over the last 10 years, in different degrees and based on different areas. Dolphin bycatch rates are generally low; however, 34.6% of respondents reported having captured at least one dolphin during their career. The fishers' attitude towards acoustic deterrents ("pingers") as a mitigation measure revealed that few of them were aware of these devices or were using them.

Keywords: dolphin–fisheries interaction; bottlenose dolphin; fishers' ecological knowledge (FEK); bycatch; Mediterranean Sea

Figure 34 – Abstract of the paper published regarding the *ex ante* monitoring carried out within the Life DELFI project. Diversity 2023, 15(2), 133; https://doi.org/10.3390/d15020133

3.1.1. *Ex ante* monitoring in Tuscany

Among the 209 questionnaires obtained, managed, and analysed by the Life DELFI project, 35 were administered in Tuscany. Among these 35 questionnaires, only 18 were taken into account for the elaboration of this PhD thesis because were administered to those fishers that used setnets.

Among these18 fishers, the 44.44% practiced its activity in some harbours located in the North part of Tuscany (Livorno n=6, Marina di Pisa n=1 and Viareggio n=1) and the remaining 55.56% practiced its activity in others in harbours located in the South of Tuscany (Piombino n=2, Scarlino n=3, Castiglione della Pescaia n=1, Talamone n=2, Porto Santo Stefano n=1 and Porto Ercole n=1).

The average age of the interviewed fishers was 57.61 ± 8.44 years old, with the oldest being 72 years old and the youngest being 46 years old. On average, these fishers spent at sea 202 ± 68.21 fishing days/year. When asked how frequently they observed dolphins during their fishing activities, the 61.11% responded "*often*", the 22.22% stated that they "*always*" observed them, and the 16.67% answered "*occasionally*". None of the interviewed fishers responded that they had "*never*" observed dolphins during fishing operations. Fishers reported that dolphins damaged fishing gear ins some different modalities: stole fish from the nets (100%), damaged entangled fish (33%), and scared fish away from the nets (14.29%).

Then it was asked whether the presence of dolphins had increased over the years, the 83.33% of the fishers responded affirmatively. The fishers were then asked if they had ever caught a dolphin during their fishing activities, to the 61.11% (n=11) fishers responded negatively, while the 33.33% (n=6) of them responded affirmatively. The remaining 5.56% (n=1) did not answer to this question. Among the 6 fishers who had experienced a dolphin bycatch, 2 reported that the accidentally caught dolphins were still alive, while the other 4, the dolphins were already dead. For all 6 fishers who had encountered accidental dolphin catches, the presence of the dolphin had hindered the normal conduct of fishing activities, causing damage to the gear for 27.78% and to both the gear and the catch for 11.11%.

Regarding damages, fishers estimated on average damages caused by interactions with dolphin amounting to €4,800.00 ± €3,392.80.

Regarding the sighting period, fishers were asked to rate the seasons with the highest sightings on a scale from 1 (fewest sightings) to 4 (most sightings). The 18 fishermen interviewed were asked how frequently they spotted dolphins each season, using a scale from 1 to 4. The season with the most frequent sightings was summer, followed by spring, autumn, and winter (Figure 35).

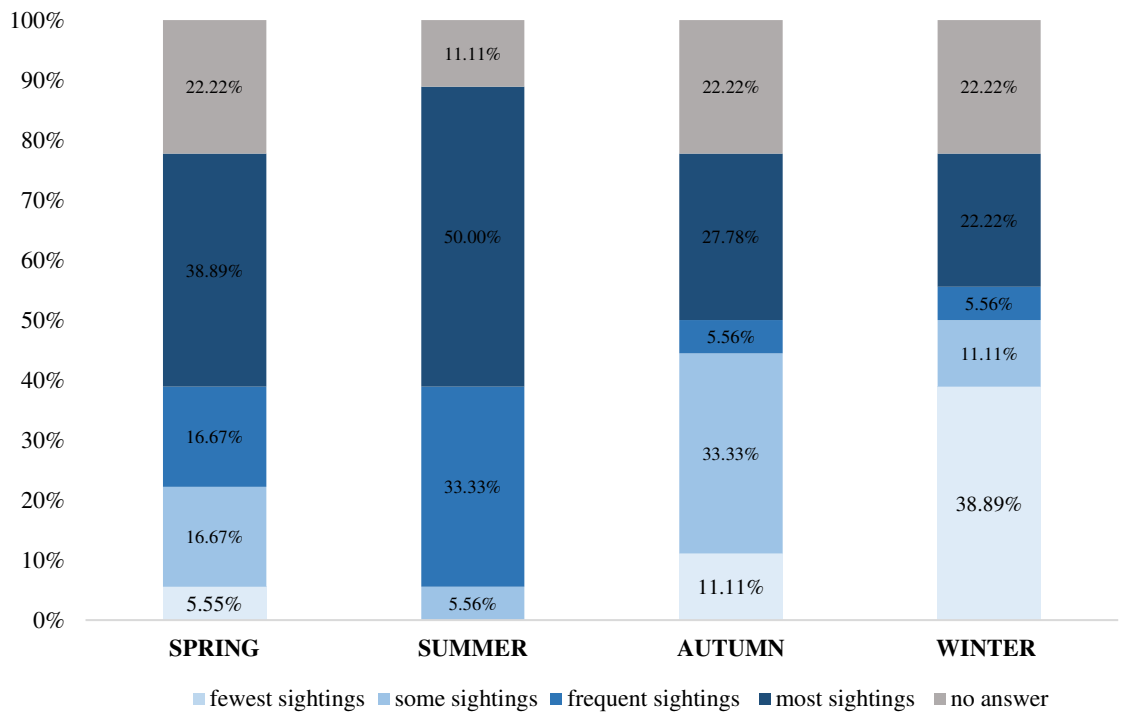


Figure 35 – Graphs showing the frequency of dolphin sightings for each season where 1 is fewest sightings and 4 is most sightings.

The 16.67% of fishers believed that dolphins were not important resources in the marine environment, while the 77.78% believed that they were. The remaining 5.55% answered they did not know.

Focusing on the main aims of the project, the fishers were asked what their experiences with the use of some mitigation methods as the use of deterrent devices were. Among the 18 fishers interviewed 15 have ever used a dolphin deterrent device, while one fisher stated that he has been used occasionally, and, in the end, one fisher responded that the pingers initially work but then lead to dolphin habituation, while one fisher did not answer.

Finally, the interviewer asked the fishers if they have never believed something could be done to solve the issue of harmful dolphin-fishery interactions. For 88.89% of the respondents, the answer was affirmative, while the remaining 11.11% stated that there would never be a solution.

At the end, they were asked if they were willing to participate in project activities such as the use of new generation deterrents like the DiD01® model, engaging in dolphin watching or fishery and tourism activities, and finally, if they would appreciate the establishment of a quality label for the catch. Among the 18 fishermen interviewed, the willingness to implement these project proposals was distributed as follows:

- **Testing acoustic deterrent devices**: 77.78% “yes”, 16.67% “no”, and 5.55% did not respond to the question.

- **Dolphin watching activities**: 50.00% “yes”, 38.89% “no”, 5.55% “yes but the vessel is too small”, and 5.56% did not respond to the question.
- **Fishery tourism (on boat)**: 27.78% “yes”, 33.33% “no”, 16.67% “already practicing”, 11.11% “yes but the vessel is too small”, and 11.11% did not respond to the question.
- **Fishery tourism (at fisher’s house):** 33.33% “yes”, 55.56% “no”, 5.55% “already practicing”, 5.56% did not respond to the question.
- **Catch quality label:** 50.00% “yes”, 38.89% “no”, 5.56% “only if it is useful”, 5.55% did not respond to the question.

3.1.2. *Ex post* monitoring in Tuscany

As expected by the project plan, the activates of the final year included an *ex post* evaluation through the administration of questionnaires to fishers in order to evaluate the project’s activities. In the Tuscany area, hence the PhD study area, 18 questionnaires were administered. Among these 18 questionnaires, all fishers used passive nets as the principal fishing gear during the experimentation of the acoustic deterrent devices. Among these 18 fishers, the 16.67% practiced its activity in some harbours located in the North part of Tuscany (Isola d’Elba n=2 and Livorno n=1) and the remaining 83.33% practiced its activity in others in harbours located in the South of Tuscany (Piombino n=1, Follonica n=1, Castiglione della Pescaia n=1, Marina di Grosseto n=2, Porto Ercole n=5, Porto Santo Stefano n=3, Talamone n=2). The average age of the 16 interviewed fishers was found to be 51.19 ± 13.37 years old, with the oldest being 76 years old and the youngest being 29 years old. Only four fishermen responded to the question regarding how many fishing days per year they dedicated to the Life DELFI activities. Among these four fishers the fishing days/year were 187.5 ± 94.65.

Among these 18 interviewed fishers, 15 used the Acoustic Deterrent Devices, two the alternative fishing gear (i.e., pots) and only one the Visual Deterrent Devices. Afterwards, they were asked if they had ever used, before the project activities, mitigation devices in order to reduce dolphins’ interactions: 14 had never used them, two had used other models but not regularly, and only one had used these deterrents regularly. They were also asked how many times, with the use of deterrents, they had observed dolphin interactions during fishing activities. On a scale from 1 to 5, where 1 is “never” and 5 is “most frequently” they responded as it is shown in the graph (Figure 36). Hopefully fishers observed that while using deterrent devices dolphin interactions were mostly reduced, in fact “*never*” were responded in the

61.11% of cases, comparing to the fishing activities without deterrents where observations of dolphin interactions were more frequently (45.90% and 24.59%).

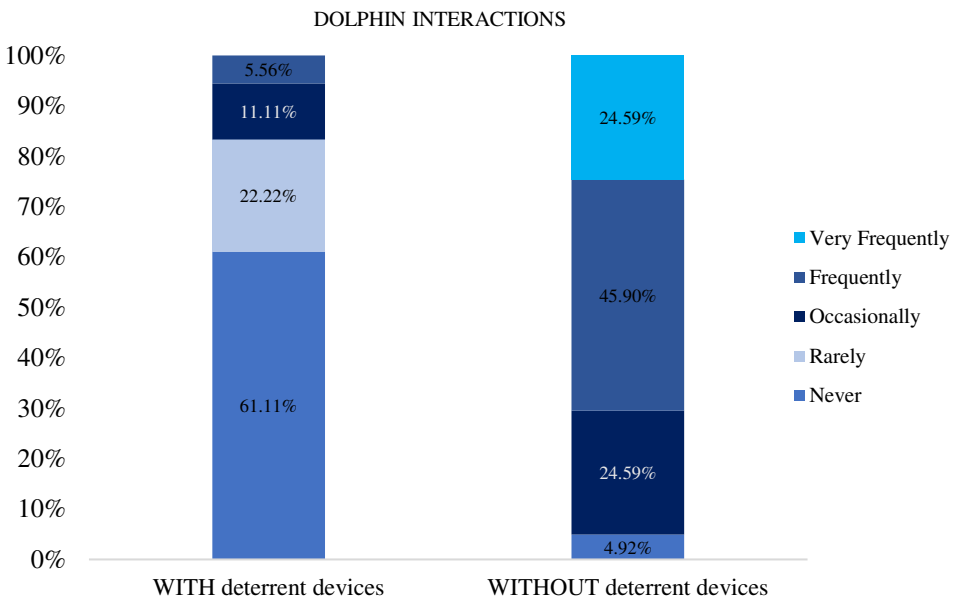


Figure 36 – Chart showing the frequency of observations of dolphin interactions during fishing activities with and without deterrent devices.

Then, it was asked to the fishers if they observed a change in the damages occurred to the catches or to the gear by the dolphin interactions and in the graph, it is shown the percentages (Figure 37 and 38).

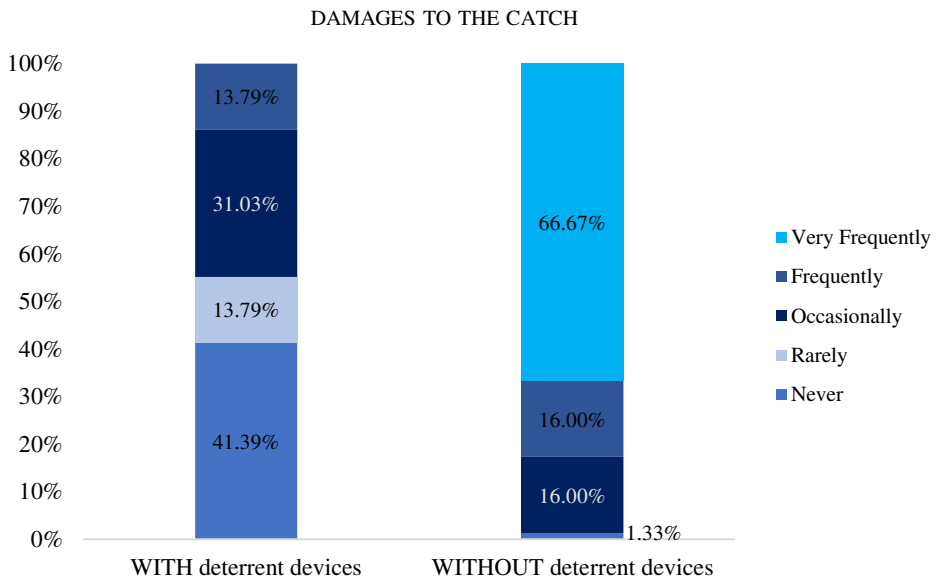


Figure 37 – Graph showing the frequency of damages to the catch during fishing activities with and without deterrent devices.

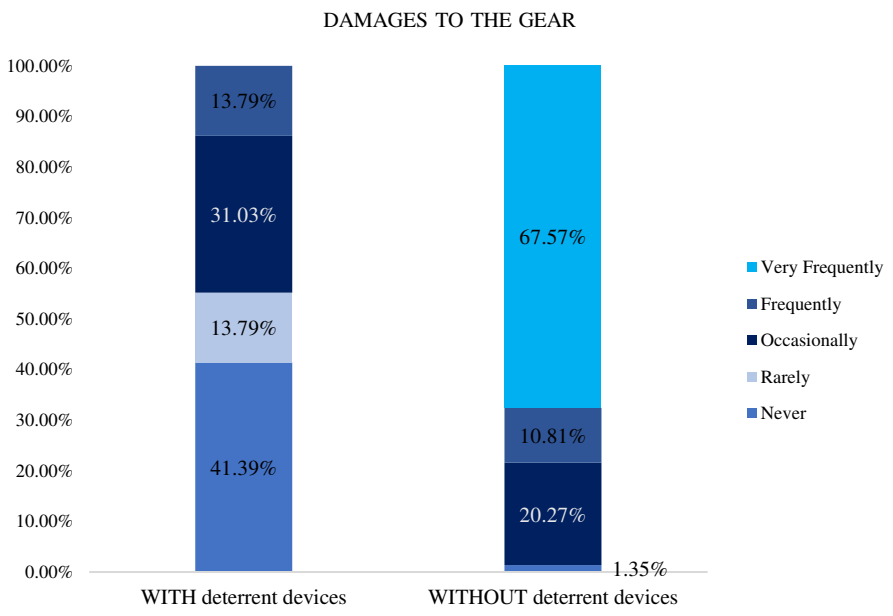


Figure 38 – Graph showing the frequency of damages to the gear during fishing activities with and without deterrent devices.

The 50% of the fishers responded that they had gained considerable economic benefit from using the deterrents, while 22% reported having gained a significant economic benefit. The 16.67% responded that they had not gained any economic benefit, and the other 5.56% did not know how to answer this question and did not absolutely reveal an economic benefit using deterrent devices. The 61.11% of the fishers believed that the use of deterrents has changed their way of fishing either considerably (11.11%) or a lot (16.67%), while others believe it has changed their way of fishing only a little (11.11%).

The majority of the fishers found the use of deterrents to be simple and practical (83.33%), while the remaining 16.67% found it either slightly practical or not practical at all, respectively 11.11% and 5.56%.

This was confirmed by their responses to the question about their satisfaction with using the deterrents. The 83.31% was very or fairly satisfied with the use of the deterrents, respectively with 27.75% and 55.56%. The 11.11% were not satisfied at all, while 5.56% were slightly satisfied.

After the experience conducted within the Life DELFI project, 77.78% of the interviewed fishermen would continue to use acoustic deterrents to keep dolphins away from their nets. Of these, 33.34% would buy another model of deterrent, while the remaining 44.44% would purchase the same model. The 22.23% would not buy deterrents again because they find their use pointless, actually what it is important is that the 50.00% of fishers said that it

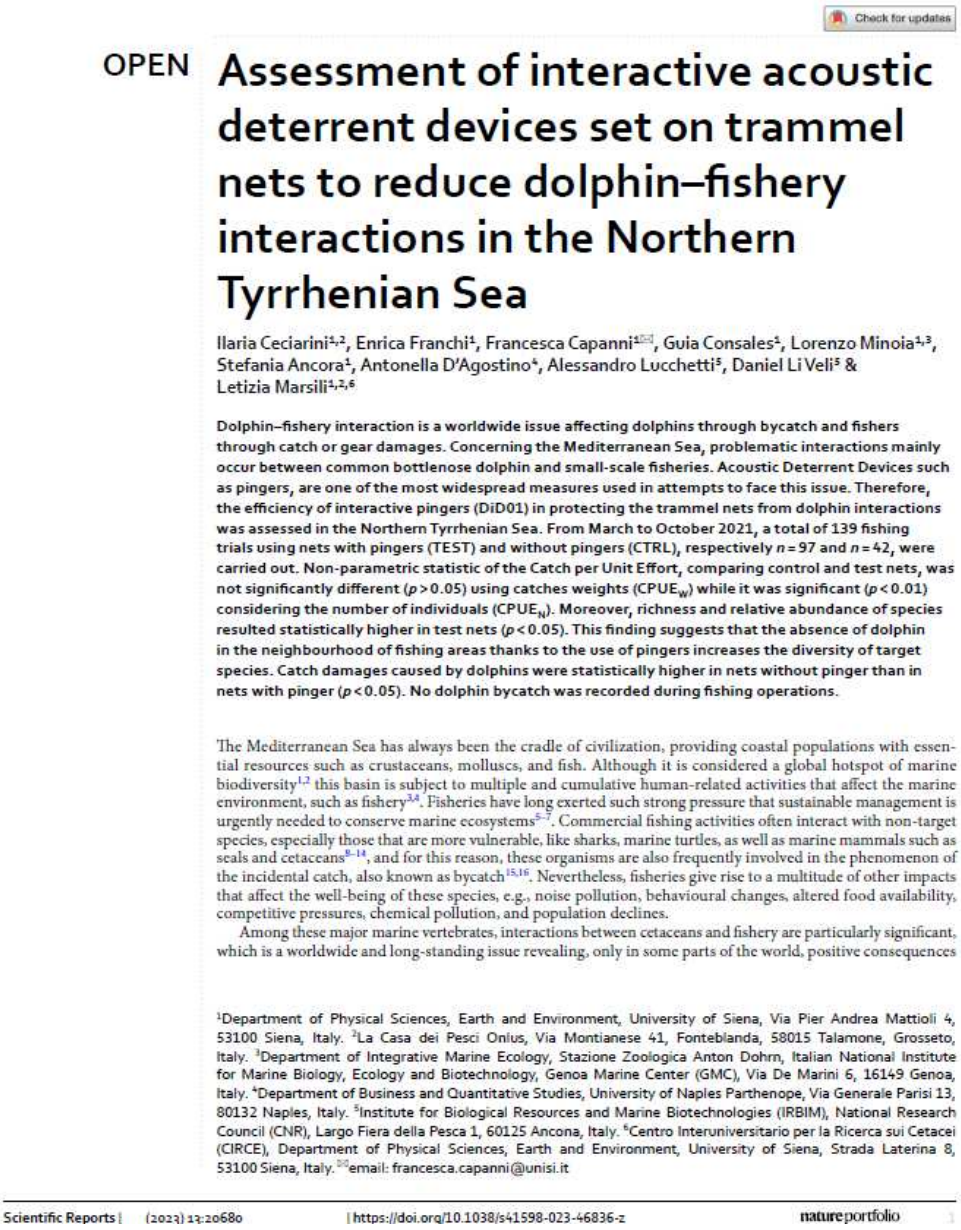
would be very important to change the recharge modalities in order to make the device much more efficient.

At the end, they were asked if they have been participating in project activities such as the use of new generation deterrents like the DiD01® model, engaging in dolphin watching or fishery and tourism activities, and finally, if they would appreciate the establishment of a quality label for the catch. Among the 18 fishers interviewed the answers were:

- **Other collaboration in project regarding sustainable fisheries**: 94.44% "yes" and 5.56% "no"
- **Dolphin watching training course participation**: 50.00% "yes" and 50.00% "no"
- **Dolphin watching activities**: 66.67% "yes", 27.78% "no" and 5.55% "already practicing"
- **Fishery tourism (on boat)**: 44.44% "yes", 27.78% "no", 27.78% "already practicing"
- **Fishery tourism (at fisher's house):** 33.33% "yes", 55.56% "no", 5.55% "already practicing", 5.56% did not respond to the question.
- **Catch quality label:** 100.00% "yes".

3.2. Acoustic Deterrent Devices

The discussion of the results regarding the use of deterrents is aligned with the framework of the paper already published in Nature Portfolio regarding data about the first year of experimentation 2021. Therefore, the following section discusses the results by integrating the information from all three years, following the processing methods used in the published article (Figure 39).



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Assessment of interactive acoustic deterrent devices set on trammel nets to reduce dolphin–fishery interactions in the Northern Tyrrhenian Sea

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Dolphin–fishery interaction is a worldwide issue affecting dolphins through bycatch and fishers through catch or gear damages. Concerning the Mediterranean Sea, problematic interactions mainly occur between common bottlenose dolphin and small-scale fisheries. Acoustic Deterrent Devices such as pingers, are one of the most widespread measures used in attempts to face this issue. Therefore, the efficiency of interactive pingers (DiD01) in protecting the trammel nets from dolphin interactions was assessed in the Northern Tyrrhenian Sea. From March to October 2021, a total of 139 fishing trials using nets with pingers (TEST) and without pingers (CTRL), respectively $n = 97$ and $n = 42$, were carried out. Non-parametric statistic of the Catch per Unit Effort, comparing control and test nets, was not significantly different ($p > 0.05$) using catches weights ($CPUE_W$) while it was significant ($p < 0.01$) considering the number of individuals ($CPUE_N$). Moreover, richness and relative abundance of species resulted statistically higher in test nets ($p < 0.05$). This finding suggests that the absence of dolphin in the neighbourhood of fishing areas thanks to the use of pingers increases the diversity of target species. Catch damages caused by dolphins were statistically higher in nets without pinger than in nets with pinger ($p < 0.05$). No dolphin bycatch was recorded during fishing operations.

The Mediterranean Sea has always been the cradle of civilization, providing coastal populations with essential resources such as crustaceans, molluscs, and fish. Although it is considered a global hotspot of marine biodiversity[1,2] this basin is subject to multiple and cumulative human-related activities that affect the marine environment, such as fishery[3,4]. Fisheries have long exerted such strong pressure that sustainable management is urgently needed to conserve marine ecosystems[5–7]. Commercial fishing activities often interact with non-target species, especially those that are more vulnerable, like sharks, marine turtles, as well as marine mammals such as seals and cetaceans[8–14], and for this reason, these organisms are also frequently involved in the phenomenon of the incidental catch, also known as bycatch[15,16]. Nevertheless, fisheries give rise to a multitude of other impacts that affect the well-being of these species, e.g., noise pollution, behavioural changes, altered food availability, competitive pressures, chemical pollution, and population declines.

Among these major marine vertebrates, interactions between cetaceans and fishery are particularly significant, which is a worldwide and long-standing issue revealing, only in some parts of the world, positive consequences

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Figure 39 – Published article withing NaturePortfolio in Scientific Reports journal. The doi is: https://doi.org/10.1038/s41598-023-46836-z.

3.2.1. Control and test trials

During the three years of PhD project (2021-2022-2023), 20 vessels and 25 fishers of the Small-Scale Fisheries were involved within the Life DELFI and PhD projects in order to conduct trials using the DiD01®. The vessels and the fishers have been operating in the five different harbours from the southern to the northern part of the study area. The fishing areas involved in testing pingers were named: AREA 1 for Porto Ercole (GR), AREA 2 for Porto Santo Stefano (GR), AREA 3 for Talamone (GR), AREA 4 for Marina di Grosseto (GR), and AREA 5 for Piombino (LI). They were distributed: two vessels and two fishers in AREA 1, seven vessels and nine fishers in AREA 2, five vessels and seven fishers in AREA 3, five vessels and five fishers in AREA 4, and one vessel and two fishers in AREA 5.
Trials were conducted from March 1st, 2021, to November 14th, 2023, in nearshore waters along the southern Tuscan coast in the Northern Tyrrhenian Sea (Figure 40).

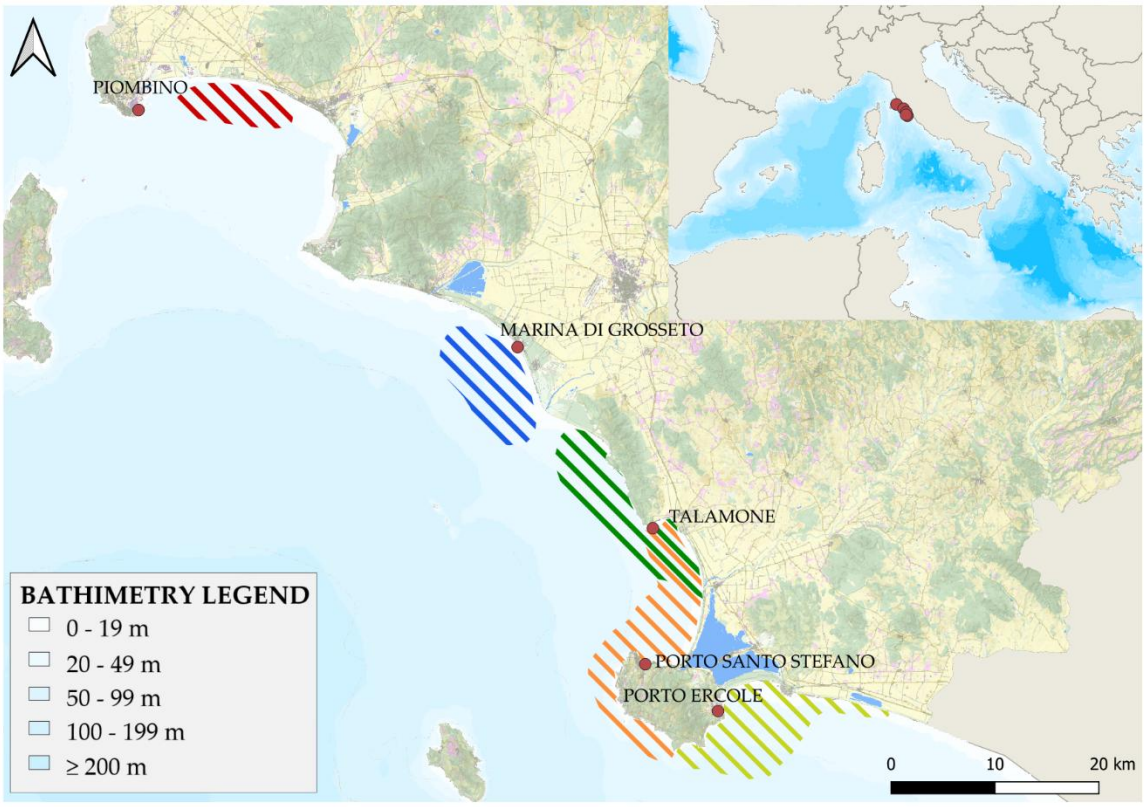

Figure 40 – Study area map showing the five Tuscan harbours and related study areas in the Northern Tyrrhenian Sea (Italy): "yellow" AREA 1 (Porto Ercole, GR), "orange" AREA 2 (Porto Santo Stefano, GR), "green" AREA 3 (Talamone, GR), "blue" AREA 4 (Marina di Grosseto, GR), and "red" AREA 5 (Piombino, LI). Bathymetry legend shows the depth in various shades of colour from the lightest to the darkest. Map created with QGIS software version 3.28.0 "Firenze" (http://qgis.org).

The colouring of the map was done by considering the areas where the fishing spot coordinates were located from each port during the three years of the project. The area of Porto Santo Stefano and Talamone in some part overlapped because some fishers from Porto Santo Stefano moved within the area usually frequented by fishers from Talamone. The

whole study area covers around 150 km of coastline from Ercole (GR) to Piombino (LI). All fishing areas were within 12 miles off the coast, as expected by D.M. 12/7/2016, Art.1. Italian Regulation regarding the Italian SSF policy. In each area fishers with small scale fisheries vessels interested in testing pingers were selected from the *ex ante* questionnaire survey.

A total of 868 fishing trials were carried out from March 1st, 2021, to November 14th, 2023. The total was 295 CTRL and 573 TEST trials. In Table 3 information regarding all trials carried out in each area for each year (2021, 2022, and 2023) were reported. The number of trials has been increasing over the three years with the following trend: 138, 244, 486. The difference in the number of fishing trials between the three years was primarily due to the fact that, first of all, in 2021 the activity started in March and, more importantly, because initially, the testing activities started from a single harbour with the involvement of only one fisher (Paolo Fanciulli). He showed greater willingness and availability to use the new model of acoustic deterrent devices. Thanks to the initial positive feedback that the fisher himself experienced, it was possible to involve other fishers in other fishing harbours still in southern Tuscany such as Porto Santo Stefano, Marina di Grosseto, and Piombino. Furthermore, this positive *word-of-mouth* among the fishers not only increased the numbers of boats and therefore fishers to involve in the testing activities but also expanded the experimentation area. So much so that in the following years, namely in 2022 and 2023, a new area like Porto Ercole was included with two new fishers.

Most trials were conducted in AREA 1 (n = 225) followed by AREA 2 (n = 217), AREA 3 (n = 216), AREA 5 (n = 138), and AREA 4 (n = 72). It is important to specify some point about the following data: first in AREA 1 there were not present data for the 2021 because fishers of this harbours had not been involved yet but only from 2022. Then, observer logbooks were not always available because not always researchers had the possibility to get on board. This was especially for AREA 5 were not ever available because it was impossible for researchers to get on board (boarding was not allowed since the boat lacked authorization to accommodate more than two individuals as per safety regulations, and the onboard staff already consisted of two fishers).

Table 3 – Number of trials conducted in each area along the southern Tuscan coast between March 1st, 2021, to November 14th, 2023, divided between control (CTRL) and test (TEST) trials and type of data collection (fisher or observer logbook). The number of vessels, fishers employed, and experimental period were also shown for each year. Abbreviations: Jan=January, Mar=March, Apr=April, May=May, Jun=June, Jul=July, Sep=September, Oct=October, Nov=November, Dic=December. The symbol "-" indicated that the gear was not used.

	CTRL logbook		Tot. CTRL trials	TEST logbook		Tot. TEST trials	Tot. TRIALS
	FISHER	OBSERVER		FISHER	OBSERVER		
AREA 1	**73**	**19**	**92**	**126**	**7**	**133**	**225**
2021	-	-	-	-	-	-	-
2022 Vessel (n=2) Fisher (n=2) Period (Jun-Dic)	27	-	27	69	-	69	96
2023 Vessel (n=2) Fisher (n=2) Period (Jan-Nov)	46	19	65	57	7	64	129
AREA 2	**41**	**1**	**42**	**167**	**8**	**175**	**217**
2021 Vessel (n=1) Fisher (n=2) Period (May-Oct)	1	1	2	8	8	16	18
2022 Vessel (n=5) Fisher (n=7) Period (Apr-Dic)	2	-	2	33	-	33	35
2023 Vessel (n=7) Fisher (n=9) Period (Jan-Nov)	39	13	52	50	5	55	107
AREA 3	**50**	**28**	**78**	**92**	**46**	**138**	**216**
2021 Vessel (n=3) Fisher (n=3) Period (Mar-Jul)	6	13	19	17	29	46	65
2022 Vessel (n=3) Fisher (n=4) Period (May-Oct)	5	2	7	25	12	37	44
2023 Vessel (n=3) Fisher (n=3) Period (Jan-Oct)	39	13	52	50	5	55	107
AREA 4	**14**	**2**	**16**	**45**	**11**	**56**	**72**
2021 Vessel (n=2) Fisher (n=2) Period (May-Sep)	8	2	10	12	11	23	33
2022 Vessel (n=2) Fisher (n=2) Period (May-Jun)	-	-	-	7	-	7	7
2023 Vessel (n=4) Fisher (n=5) Period (May-Sep)	6	-	6	26	-	26	32
AREA 5	**67**	**-**	**67**	**71**	**-**	**71**	**138**
2021 Vessel (n=1) Fisher (n=2) Period (Jun-Oct)	10	-	10	12	-	12	22
2022 Vessel (n=1) Fisher (n=2) Period (Mar-Oct)	31	-	31	31	-	31	62
2023 Vessel (n=1) Fisher (n=2) Period (Mar-Oct)	26	-	26	28	-	28	54
Total	**245**	**50**	**295**	**501**	**72**	**573**	**868**

In regard to the period of the year during which the trials were conducted, it has been taken into account the seasonality of the Mediterranean region which divides the year into four seasons: spring (lasting from March 23rd to June 14th), summer (lasting from June 15th to September 7th), autumn (lasting from September 8th to December 2nd) and winter (lasting from December 3rd to March 22nd) (Kotsias et al., 2020). Considered this, all trials were distributed differently throughout the seasons over the years. For CTRL trials the pattern of seasonality was summer>autumn>spring>>winter with the respectively percentages among all the 295 CTRL trials: 34.20%, 27.10%, 26.80%, and 11.90%. Instead for TEST trials it was summer>spring>autumn>winter with the respectively percentages among all the 573 TEST trials: 34.20%, 34.00%, 19.50% and 12.20%. It is important to note that the months with fewer trials conducted were November, December, January, and February. This was due to several factors, including adverse weather conditions, that especially during autumn and winter, make difficult to navigate with small vessels. Additionally, during these months, three vessels involved in the experimentation in AREA 2, AREA 3, and AREA 5 were engaged in a type of fishing using a particular modified purse seine called "sciabichella" that does not interact with dolphins. Those months were dedicated to fishing for transparent goby (*Aphia minuta*, Risso 1810), as expected by a specific plan which is "National Management Plan for the GSA 9 area", which is notified by MASE "The Italian Ministry of the Environment and Energy Security" under the authority of the European Commission (Council Regulation (EC) No. 1967/2006). Soaking time, depth and net length were recorded (Table 4). The average of soaking time was bit lower for CTRL nets than for TEST nets across all locations, with respectively 893.11 ± 507.91 min and 908.15 ± 639.63 min. The average water depth for CTRL trials was 14.25 ± 8.62 m, whereas it was 17.63 ± 10.98 m for TEST trials, indicating that all fishers frequently fished in shallow seas close to shore, confirming that this type of fishing was conducted in grounds that are close to the coast (within 12 nautical miles) and that can be reached in a short time, thus involving a limited number of hours at sea. Moreover, the average of net length employed in all trials was almost double for TEST nets than CTRL nets, respectively 1839.31 ± 1157.06 m and 903.62 ± 485.00 m. This difference in net length between the CTRL and TEST groups is due to the fact that, once the fishermen observed the beneficial effects of the pingers in reducing interactions with dolphins, they were very reluctant to deploy the control net without the deterrent, fearing damage to their gear or catch. Additionally, when they did deploy a control net, they would use an older and shorter one to avoid damaging a new (often hand-stitched net).

Table 4 – Average of soaking time in minutes ("min"), depth and net length in meters ("m") were reported showing mean values and standard deviation for each area for both CTRL and TEST trials for each year 2021, 2022 and 2023. The symbol "-" indicated that data was not available.

	SOAKING TIME (min)	DEPTH (m)	NET LENGTH (m)
CTRL			
AREA 1	**601.60 ± 372.06**	**15.61 ± 11.70**	**1018.70 ± 502.30**
2021	-	-	-
2022	615.41 ± 257.46	15.62 ± 5.19	1088.89 ± 318.45
2023	595.86 ± 412.05	15.60 ± 13.56	881.85 ± 355.08
AREA 2	**924.88 ± 503.66**	**17.64 ± 11.06**	**1229.76 ± 634.10**
2021	1092.50 ± 229.81	13.00 ± 1.41	1050.00 ± 636.40
2022	915.00 ± 106.07	21.50 ± 6.36	1600.00 ± 565.69
2023	916.58 ± 527.04	17.69 ± 11.50	1219.74 ± 645.52
AREA 3	**1293.97 ± 659.61**	**10.25 ± 3.74**	**980.13 ± 515.37**
2021	2076.84 ± 811.33	10.36 ± 6.40	1447.37 ± 415.49
2022	959.29 ± 598.38	10.00 ± 2.31	1357.14 ± 377.96
2023	1052.98 ± 282.00	10.24 ± 2.44	758.65 ± 415.49
AREA 4	**944.94 ± 282.58**	**16.20 ± 7.29**	**1115.00 ± 597.44**
2021	888.90 ± 210.39	18.67 ± 8.31	1324.00 ± 477.94
2022	-	-	-
2023	1038.33 ± 378.33	12.08 ± 1.69	766.67 ± 653.20
AREA 5	**837.67 ± 153.07**	**14.49 ± 2.47**	**500.00***
2021	743.90 ± 317.58	14.95 ± 2.77	500.00
2022	812.26 ± 59.91	14.68 ± 2.48	500.00
2023	904.04 ± 111.09	14.26 ± 8.59	500.00
TEST			
AREA 1	**506.65 ± 325.42**	**19.78 ± 16.15**	**1479.17 ± 598.35**
2022	462.25 ± 299.27	17.93 ± 6.26	1514.49 ± 398.81
2023	554.52 ± 347.45	21.78 ± 22.28	1441.09 ± 758.70
AREA 2	**804.65 ± 492.71**	**20.65 ± 11.35**	**1698.69 ± 653.34**
2021	1082.50 ± 410.58	16.28 ± 5.23	1525.00 ± 450.92
2022	894.52 ± 507.60	25.55 ± 16.42	1965.15 ± 476.07
2023	745.83 ± 486.05	19.92 ± 9.89	1650.95 ± 697.75
AREA 3	**1499.07 ± 812.34**	**14.80 ± 6.17**	**1151.09 ± 524.87**
2021	2423.28 ± 737.80	20.81 ± 6.34	1608.70 ± 396.56
2022	1164.05 ± 320.63	12.91 ± 3.18	1097.30 ± 477.54
2023	959.82 ± 258.77	11.05 ± 2.99	804.55 ± 336.41
AREA 4	**1022.54 ± 317.55**	**14.69 ± 5.91**	**1694.64 ± 540.51**
2021	931.96 ± 215.71	16.54 ± 6.75	1665.22 ± 676.63
2022	837.86 ± 205.28	12.67 ± 0.69	1600.00*
2023	1152.50 ± 368.94	13.60 ± 5.58	1746.15 ± 483.51
AREA 5	**645.48 ± 177.11**	**13.84 ± 2.67**	**4492.96 ± 198.08**
2021	681.17 ± 285.25	14.79 ± 3.65	4583.33 ± 194.62
2022	634.68 ± 187.74	13.71 ± 2.56	4500.00*
2023	642.14 ± 91.12	13.57 ± 2.28	4446.43 ± 283.47
ALL AREAS			
CTRL	**893.11 ± 507.91**	**14.25 ± 8.62**	**903.62 ± 485.00**
2021	1367.10 ± 808.54	13.46 ± 6.74	1167.62 ± 536.15
2022	746.88 ±275.81	14.77 ± 4.31	859.70 ± 427.66
2023	838.16 ± 418.68	14.24 ±10.07	859.35 ± 475.70
TEST	**908.15 ± 639.63**	**17.63 ± 10.98**	**1839.31 ± 1157.06**
2021	1650.93 ± 938.63	18.37 ± 6.39	1979.38 ± 1087.33
2022	737.97 ± 428.83	17.33 ± 9.33	2037.36 ± 1229.01
2023	771.24 ± 426.76	17.56 ± 12.88	1679.18 ± 1114.50

*In AREA 5 and in AREA 4 (for 2023) all CTRL trials were conducted using a net long 500m. Also, in AREA 4 for the year 2022 the TEST nets were always 1600m and in AREA 5 for the year 2022 the TEST nets were always 4500m.

Testing activities of the acoustic deterrent devices were mainly accomplished on board of small vessels belonging, as already said, to the small-scale fishery segment and operating

with set nets. In supplementary materials (Table S1) some net technical features such as mesh size and net height all the three setnets employed were reported. In these three years the type of set nets used were divided in: trammel nets (GTR), gillnets (GNS) and combined nets (GTN). Among the 868 total of trials 777 were conducted using trammel nets (CTRL n=267 and TEST n=510), 58 were conducted using combined nets (CTRL n=19 and TEST n=39), and the remaining 33 were carried out using gillnets (CTRL n=9 and TEST n=24). Trammel nets were used in all five areas, combined nets were only used in AREA 1, AREA 2 and AREA 3, and gillnets were employed only in AREA 1 and AREA 4. Net meshes and net height were equal between CTRL and TEST nets. All measures adopted by fishers involved related to seasonal fishing periods, fishing operating areas, and technical measures such as minimum conservation reference sizes and gear dimensions (maximum net length and net height) complied with and were in line with European regulations (EU) 1967/2006 and (EU) 2019/1241.

The figures below showed the locations recorded with coordinates where CTRL and TEST trials were carried out for each year separated for each area: AREA 1 (Figure 41), AREA 2 (Figure 42), AREA 3 (Figure 43), AREA 4 (Figure 44), and AREA 5 (Figure 45).

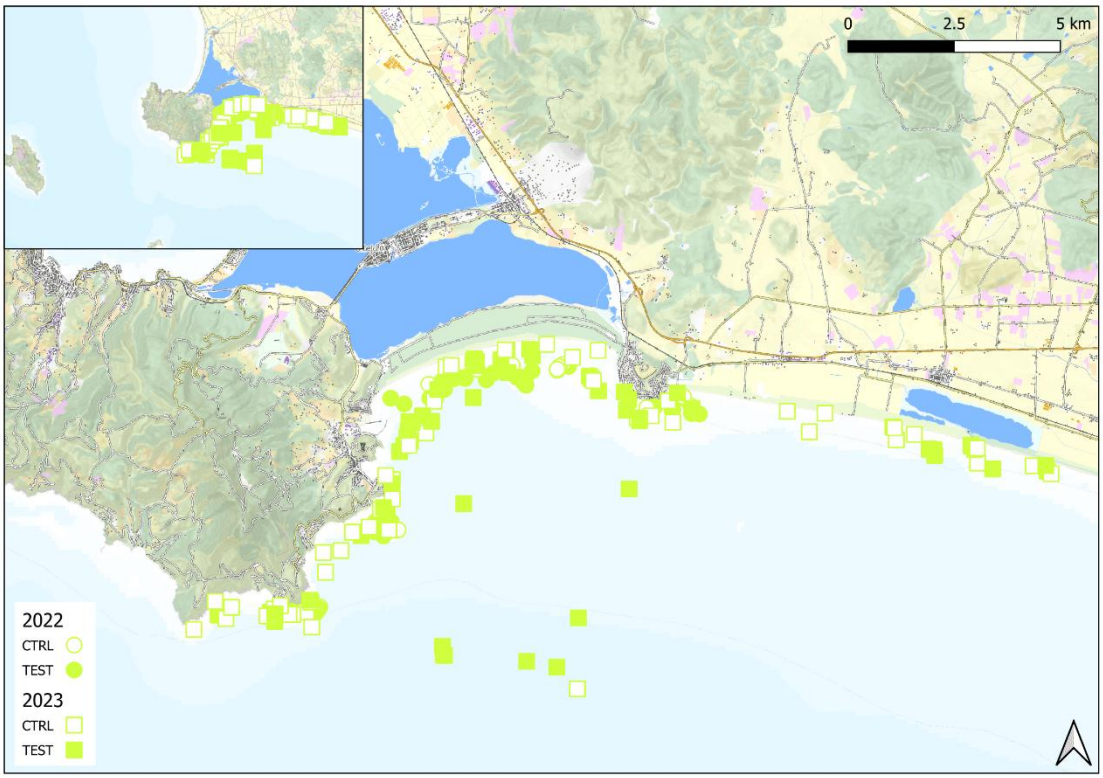

Figure 41 – Map of the study area representing both CTRL (○ and □) TEST (● and ■) trials for AREA 1 (Porto Ercole) for 2022 trials were indicated with a circle shape and for 2023 trials were indicated with a square shape. Map created with QGIS software version 3.28.0 "Firenze" (http://qgis.org).

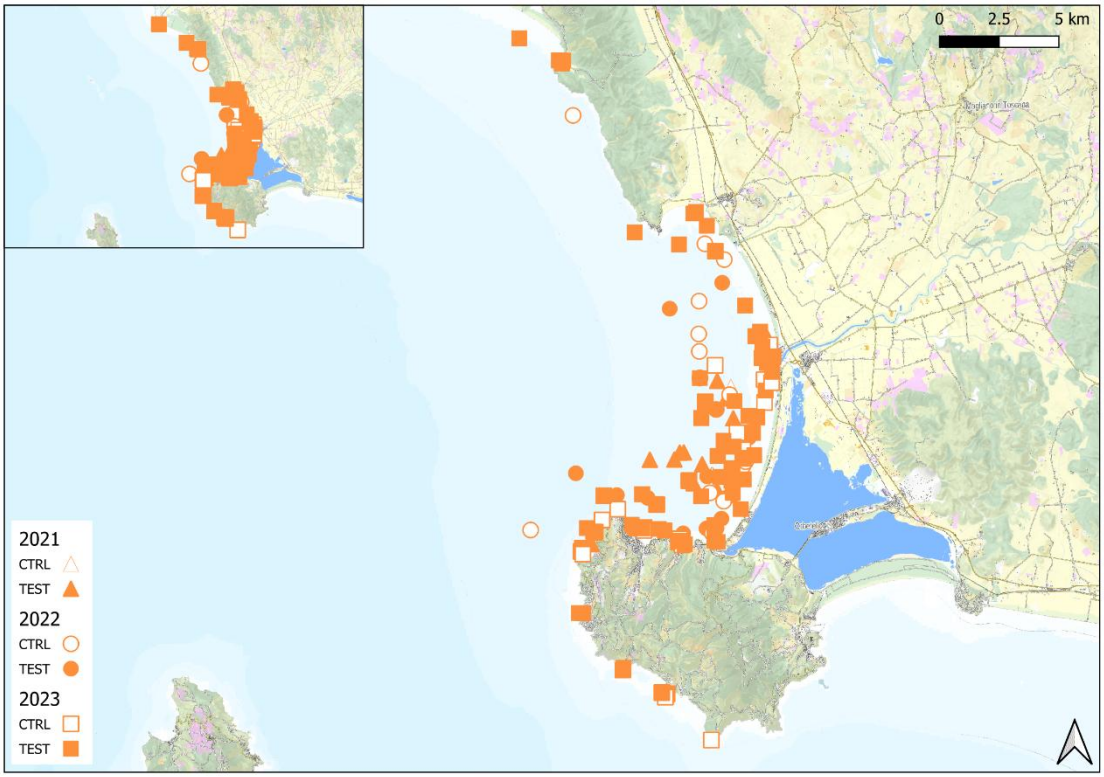

Figure 42 – Map of the study area representing both CTRL (Δ, ○ and □) TEST (▲,● and ■) trials for AREA 2 (Porto Santo Stefano) for 2021 trials were indicated with a triangle shape, for 2022 trials were indicated with a circle shape and for 2023 trials were indicated with a square shape. Map created with QGIS software version 3.28.0 "Firenze" (http://qgis.org).

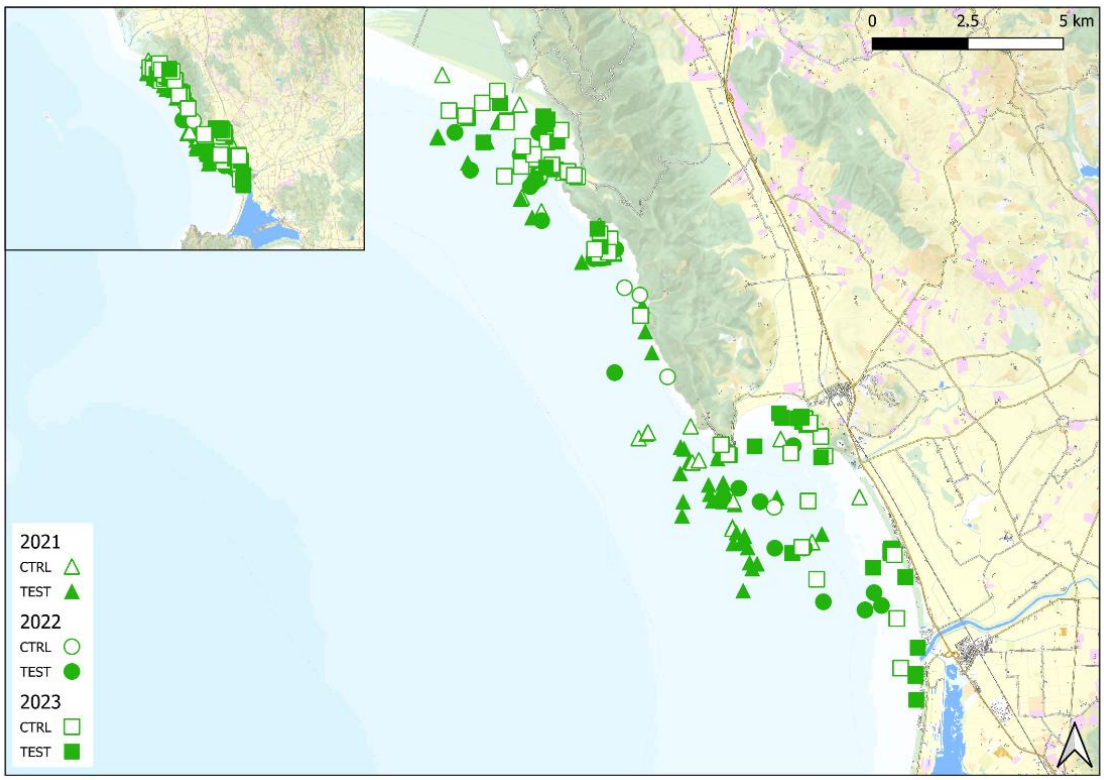

Figure 43 – Map of the study area representing both CTRL (Δ, ○ and □) TEST (▲,● and ■) trials for AREA 3 (Talamone) for 2021 trials were indicated with a triangle shape, for 2022 trials were indicated with a circle shape and for 2023 trials were indicated with a square shape. Map created with QGIS software version 3.28.0 "Firenze" (http://qgis.org).

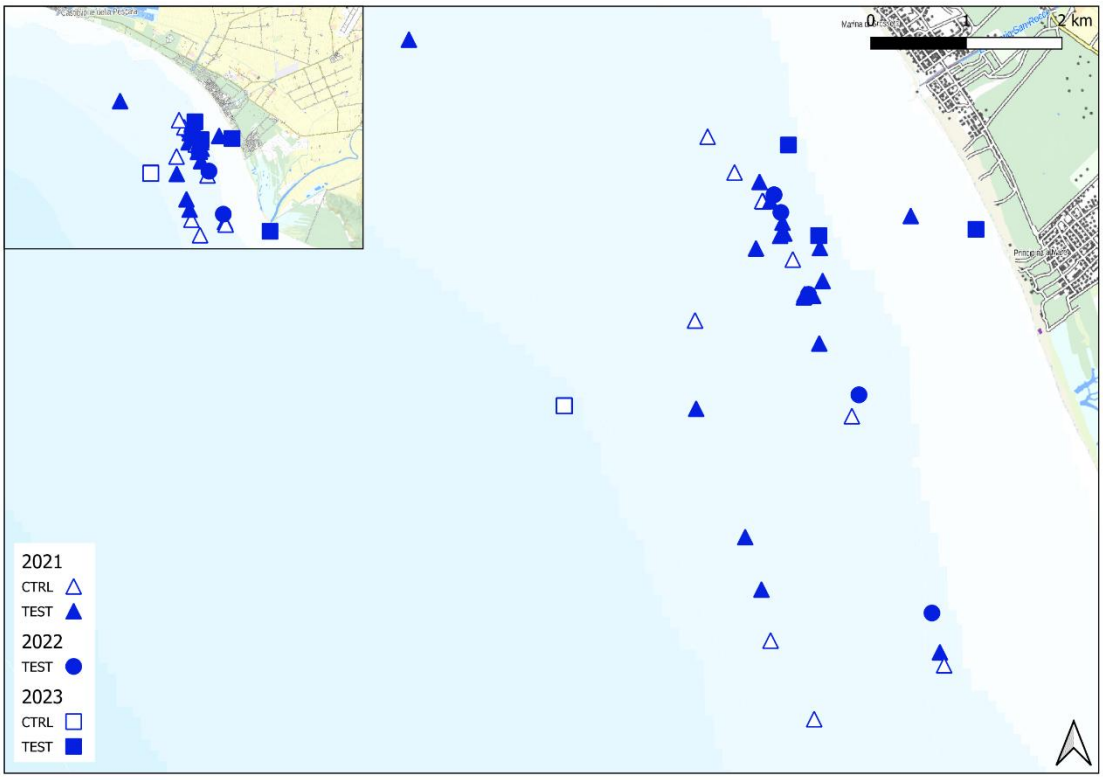

Figure 44 – Map of the study area representing both CTRL (Δ and □) TEST (▲,● and ■) trials for AREA 4 (Marina di Grosseto) for 2021 trials were indicated with a triangle shape, for 2022 trials were indicated with a circle shape and for 2023 trials were indicated with a square shape. Map created with QGIS software version 3.28.0 "Firenze" (http://qgis.org).

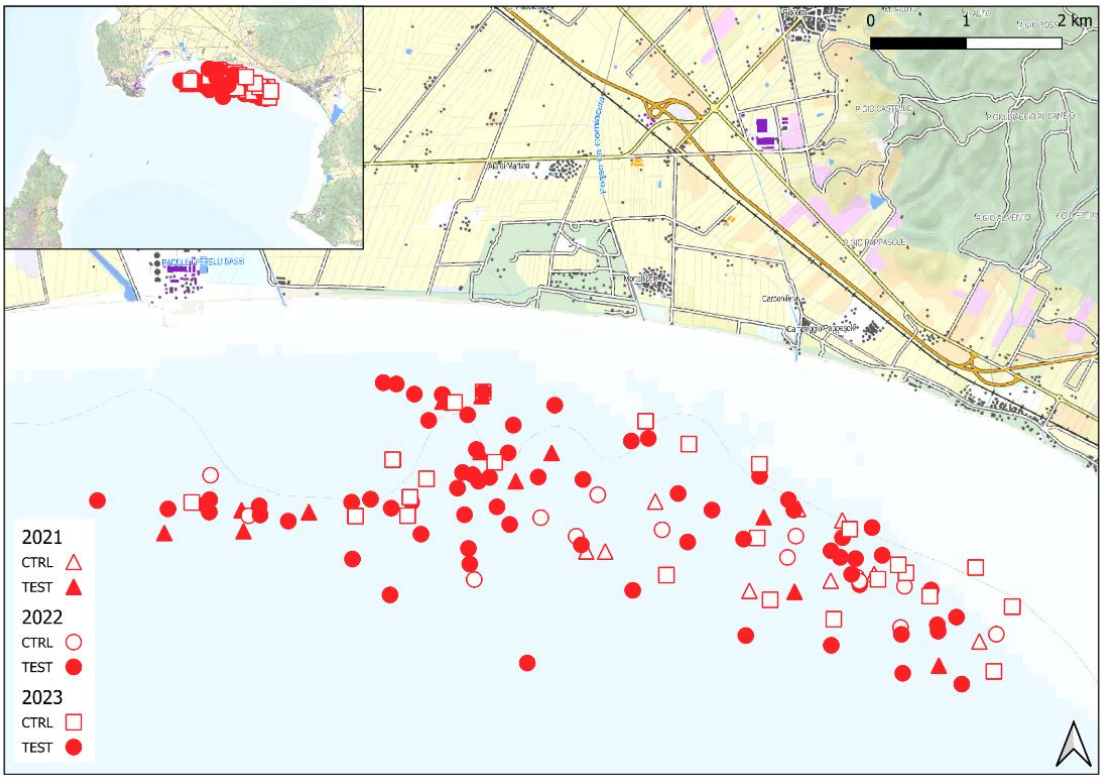

Figure 45 – Map of the study area representing both CTRL (Δ, ○ and □) TEST (▲,● and ■) trials for AREA 5 (Piombino) for 2021 trials were indicated with a triangle shape, for 2022 trials were indicated with a circle shape and for 2023 trials were indicated with a square shape. Map created with QGIS software version 3.28.0 "Firenze" (http://qgis.org).

3.2.2. Effect of acoustic deterrent device on species composition and captures

The total species and group richness in all samples was 83. All catches identified by fishers or observers during trials, were reported in Table 5.

Among the 83 species, 6 of these include a wider group of species (i.e., *Actinopterygii* or *Osteichthyes, Brachyura*, *Crustacea*, *Diplodus* spp., *Loligo* spp., *Raja* spp.), meanwhile, the other 77 species refer to a specific single species. It should be pointed out that *Centrolophus niger* (CEO) and *Engraulis encrasicolus* (ANE) were among the 83 species caught, but they were not considered marketable because they were caught with damages.

Among the 83 species, 72 were caught using CTRL nets of which 6 species were only captured during these trials (*Engraulis encrasicolus* - ANE, *Boops boops* - BOG, *Centrolophus niger* - CEO, *Crustacea* - CRU, *Pagrus pagrus* - RPG, and *Loligo* spp. - SQC) and 77 species were captured using TEST nets of which 11 species exclusively caught during TEST trials (*Lophius budegassa* - ANK, *Brachyura* - CRA, *Parapenaeus longirostris* - DPS, *Trachurus mediterraneus* - HMM, *Zeus faber* - JOD, *Raja asterias* - JRS, *Mustelus asterias* - SDS, *Loligo forbesi* - SQF, *Loligo vulgaris* - SQR, *Diploddus* spp. - SRG, and *Scilyorhinus canicula* - SYC). The remaining 66 species were captured using both CTRL and TEST nets. The results regarding the species were useful also to obtain the evidence and, hence, support the thesis of intraspecific competition between artisanal fishers and common bottlenose dolphins that have been competing for the same resources. In Table 6 all species caught during CTRL and TEST trials were compared to the species part of the diet of the common bottlenose dolphin (Neri et al., 2023; Neri, 2024). The paper by Neri et al. (2023) and the PhD thesis of Neri (2024) which analysed the stomach contents of stranded common bottlenose dolphins along the Tuscan coast, revealed the presence of a highly diversity of species (up to 60 different species) in the diet of this marine mammal. Among these species, the 41.67% correspond to the same species captured by artisanal fishers involved in the study, whether using CTRL or TEST nets.

Table 5 – List of species captured during experimental trials conducted between March 1st, 2021 and November 14th,2023 in nearshore waters along the southern Tuscan coast. FAO Code named with "Code", Scientific Name & Author following the systematic use of parentheses, Common English name as expected by ASFIS List of Species for Fishery Statistics Purposes downloaded from 2024 version (©FAO 2024. ASFIS List of Species for Fishery Statistics Purposes. Fisheries and Aquaculture Division. Rome. [Cited Tuesday, February 6th, 2024] https://www.fao.org/fishery/en/collection/asfis/en) were also provided.

Code	Scientific Name & Author	Common Name
SHELLFISH		
Molluscs		
CTC	*Sepia officinalis* Linnaeus 1758	Common cuttlefish
OCC	*Octopus vulgaris* Cuvier 1797	Common octopus
SQC	*Loligo spp.* Lamarck, 1798	Myopsid squid species
SQF	*Loligo forbesii* Steenstrup 1856	Veined squid
SQR	*Loligo vulgaris* Lamarck, 1798	Mediterranean squid
Crustaceans		
CRA	*Brachyura* Latreille, 1802	Short-tailed crabs
CRU	*Crustacea* Brünnich, 1772	Crustaceans
DPS	*Parapenaeus longirostris* (Lucas 1846)	Deep-water rose shrimp
LBE	*Homarus gammarus* (Linnaeus 1758)	European lobster
MTS	*Squilla mantis* (Linnaues 1758)	Spottail mantis squillid
SLO	*Palinurus elephas* (Fabricius 1787)	Common spiny lobster
TGS	*Penaeus kerathurus (Forsskål 1775)*	Caramote prawn
FINFISH		
Bony fishes		
AMB	*Seriola dumerili* (Risso 1810)	Greater amberjack
ANE	*Engraulis encrasicolus* (Linnaeus, 1758)	European anchovy
ANK	*Lophius budegassa* Spinola 1807	Blackbellied angler
ANN	*Diplodus annularis* (Linnaeus 1758)	Annular seabream
BBS	*Scorpaena porcus* Linnaeus 1758	Black scorpionfish
BLL	*Scophthalmus rhombus* (Linnaeus 1758)	Brill
BLU	*Pomatomus saltator* (Linnaeus 1766)	Bluefish
BOG	*Boops boops* (Linnaeus, 1758)	Bogue
BON	*Sarda sarda* (Bloch 1793)	Atlantic bonito
BRF	*Helicolenus dactylopterus* (Delaroche 1809)	Blackbelly rosefish
BSS	*Dicentrarchus labrax* (Linnaeus 1758)	European seabass
CBM	*Sciaena umbra* Linnaeus 1758	Brown meagre
CBR	*Serranus cabrilla* (Linnaeus 1758)	Comber
CEO	*Centrolophus niger* (Gmelin 1789)	Rudderfish
COB	*Umbrina cirrosa* (Linnaeus 1758)	Shi drum
COE	*Conger conger* (Linnaeus 1758)	European conger
CTB	*Diplodus vulgaris* (Geoffroy St. Hilaire 1817)	Common two-banded seabream
DEC	*Dentex dentex* (Linnaeus 1758)	Common dentex
JOD	*Zeus faber* Linnaeus, 1758	Peter's fish
LEE	*Lichia amia* (Linnaeus, 1758)	Leerfish
LTA	*Euthynnus alletteratus* (Rafinesque 1810)	Little tunny (=Atl.black skipj)
MGA	*Liza aurata* (Risso 1810)	Golden grey mullet
MLR	*Chelon labrosus* (Risso 1827)	Thicklip grey mullet
MAC	*Scomber scombrus* Linnaeus, 1758	Atlantic mackerel
MMH	*Muraena helena* Linnaeus 1758	Mediterranean moray
MON	*Lophius piscatorius* Linnaeus, 1758	European angler
MSF	*Arnoglossus laterna* (Walbaum 1792)	Mediterranean scaldfish
MSP	*Tetrapturus belone* Rafinesque, 1810	Mediterranean spearfish
MUF	*Mugil cephalus* Linnaeus 1758	Flathead grey mullet
MUR	*Mullus surmuletus* Linnaeus 1758	Surmullet
MUT	*Mullus barbatus* Linnaeus 1758	Red mullet
MZZ	*Actinopterygii*	Marine fishes
PAC	*Pagellus erythrinus* (Linnaeus 1758)	Common pandora
POP	*Trachinotus ovatus* (Linnaeus, 1758)	Silverfish
RPG	*Pagrus pagrus* (Linnaeus, 1758)	Red porgy
RSE	*Scorpaena scrofa* Linnaeus, 1758	Red scorpionfish
SAA	*Sardinella aurita* Valenciennes 1847	Round sardinella
SBA	*Pagellus acarne* (Risso, 1827)	Spanish sea-breamaxillary
SBG	*Sparus aurata* Linnaeus 1758	Gilthead seabream
SBS	*Oblada melanura* (Linnaeus 1758)	Saddled seabream
SHR	*Diplodus puntazzo* (Walbaum, 1792)	Sharpsnout seabream
SLM	*Sarpa salpa* (Linnaeus 1758)	Salema
SMD	*Mustelus mustelus* (Linnaeus, 1758)	Common smooth hound
SNQ	*Scorpaena notata* Rafinesque 1810	Small red scorpionfish
SOL	*Solea solea* (Linnaeus 1758)	Common sole
SOS	*Pegusa lascaris* Ben-Tuvia 1990	Sand sole
SRG	*Diplodus spp.* Rafinesque, 1810	Seabream species
SRK	*Serranus scriba* (Linnaeus, 1758)	Painted comber
SSB	*Lithognathus mormyrus* (Linnaeus 1758)	Sand steenbras
SYC	*Scyliorhinus canicula* (Linnaeus, 1758)	Lesser spotted dogfish
SWA	*Diplodus sargus* (Valenciennes 1830)	White seabream
TUR	*Psetta maxima* (Linnaeus 1758)	Turbot
UUC	*Uranoscopus scaber* Linnaeus 1758	Stargazer
WEG	*Trachinus draco* Linnaeus 1758	Greater weever
YFC	*Symphodus cinereus* (Bonnaterre, 1788)	Grey wrasse

DOL	*Coryphaena hipporus* Linnaeus, 1758	Common dolphinfish	YRS	*Sphyraena sphyraena* (Linnaeus 1758)	European barracuda
EZS	*Scorpaena elongata* Cadenat 1943	Slender rockfish	**Cartilaginous fishes**		
GPW	*Epinephelus aeneus* (Geoffroy St. Hilaire 1817)	White grouper			
GUU	*Chelidonichthys lucerna* (Linnaeus 1758)	Tub gurnard	JRS	*Raja asterias* Delaroche 1809	Mediterranean starry ray
GFB	*Phycis blennoides* (Brünnich 1768)	Greater forkbeard	RJC	*Raja clavata* Linneaus 1758	Thornback ray
HKE	*Merluccius merluccius* (Linnaeus 1758)	European hake	RJO	*Dipturus oxyrinchus* (Linneaus 1758)	Longnosed skate
HMM	*Trachurus mediterraneus* (Steindachner 1868)	Mediterranean horse mackerel	SDS	*Mustelus asterias* Cloquet 1821	Starry smooth hound
HOM	*Trachurus trachurus* (Linnaeus, 1758)	Atlantic horse mackerel	SKA	*Raja spp.* Linnaeus, 1758	Skate's fishes
LDB	*Lepidorhombus boscii* (Risso 1810)	Four-spot megrim	TTV	*Torpedo torpedo* (Linnaeus 1758)	Common torpedo

Table 6 – List of species about common bottlenose dolphin diet species (Neri et al., 2023), CTRL/TEST nets, TEST and CTRL nets separately. In **bold** species matched between Tt diet and captures.

***Tursiops truncatus* diet**	**CTRL/TEST SPECIES**	**TEST nets**	**CTRL nets**
Arnoglossus sp.	***Arnoglossus laterna***	*Brachyura*	***Boops boops***
Abralia veranyi (Rüppell, 1844)	***Chelidonichthys lucerna***	*Diplodus spp*	*Centrolophus niger*
Alloteuthis spp.	*Chelon labrosus*	***Loligo forbesi***	*Crustacea*
Ancistroteuthis lichtensteinii (Férussac [in Férussac and d'Orbigny], 1835)	***Conger conger***	***Loligo vulgaris***	*Engraulis encrasicolus*
Argonauta argo Linneaus, 1758	*Coryphaena hippurus*	*Lophius budegassa*	***Loligo spp***
Ariosoma balearicum (Delaroche, 1809)	***Dentex dentex***	*Mustelus asterias*	*Pagrus pagrus*
Boops boops (Linneaus, 1758)	***Dicentrarchus labrax***	*Parapenaeus longirostris*	
Bothus podas (Delaroche, 1809)	***Diplodus annularis***	*Raja asterias*	
Callionymus risso Lesueur, 1814	*Diplodus puntazzo*	*Scyliorhinus canicula*	
Callionymus sp. Linneaus, 1758	*Diplodus sargus*	***Trachurus mediterraneus***	
Cepola macrophthalma (Linneaus, 1758)	***Diplodus vulgaris***	*Zeus faber*	
Chelidonichthys cuculus (Linneaus, 1758)	*Dipturus oxyrinchus*		
Chelidonichthys lucerna (Linneaus, 1758)	*Epinephelus aeneus*		
Chelon ramada (Risso, 1827)	*Euthynnus alletteratus*		
Citharus linguatula (Linneaus, 1758)	*Helicolenus dactylopterus*		
Conger conger (Linneaus, 1758)	*Homarus gammarus*		
Dentex dentex (Linneaus, 1758)	*Lepidorhombus boscii*		
Dicentrarchus labrax (Linneaus, 1758)	*Lichia amia*		
Diplodus annularis (Linneaus, 1758)	***Lithognathus mormyrus***		
Diplodus vulgaris (Geoffroy Saint-Hilaire, 1817)	*Liza aurata*		
Eledone cirrhosa (Lamarck, 1798)	*Lophius piscatorius*		
Eledone moschata (Lamarck, 1798)	*Merluccius merluccius*		
Engraulis encrasicolus (Linneaus, 1758)	*Mugil cephalus*		
Gnathophis mystax (Delaroche, 1809)	***Mullus barbatus***		
Gobius niger Linneaus, 1758 B	***Mullus surmuletus***		
Gobius spp.	*Muraena helena*		
Heteroteuthis dispar (Rüppell, 1844)	*Mustelus mustelus*		
Histioteuthis reversa (Verrill, 1880)	*Oblada melanura*		
Illex coindetii (Vérany, 1839)	***Octopus vulgaris***		
Lesueurigobius sp.	*Osteichthyes*		

Lithognathus mormyrus (Linneaus, 1758)	*Pagellus acarne*		
Loligo sp.	***Pagellus erythrinus***		
Loligo vulgaris Lamarck, 1798	*Palinurus elephas*		
Merluccius merluccius (Linneaus, 1758)	*Penaeus kerathurus*		
Micromesistius poutassou (Risso, 1827)	***Phycis blennoides***		
Mullus barbatus Linneaus, 1758	*Pomatumus saltator*		
***Mullus* sp.**	*Psetta maxima*		
Octopus vulgaris Cuvier, 1797	*Raja clavata*		
Onychoteuthis banksii (Leach, 1817)	*Raja spp*		
Ophidion barbatum Linneaus, 1758	*Sarda sarda*		
Pagellus acarne (Risso, 1827)	***Sardinella aurita***		
Pagellus erythrinus (Linneaus, 1758)	*Sarpa salpa*		
***Phycis* sp.**	*Sciaena umbra*		
Pomadasys incisus (Bowdich, 1825)	*Scomber scombrus*		
Sardina pilchardus (Walbaum, 1792)	*Scophthalmus rhombus*		
Sardinella aurita Valenciennes, 1847	*Scorpaena elongata*		
Serranus cabrilla (Linneaus, 1758)	*Scorpaena notata*		
Serranus sp.	*Scorpaena scrofa*		
Solea solea (Linneaus, 1758)	*Scropaena porcus*		
Solea sp.	*Sepia officinalis*		
Sparus aurata Linneaus, 1758	*Seriola dumerili*		
Sphyraena sphyraena (Linneaus, 1758)	***Serranus cabrilla***		
Spicara flexuosa Rafinesque, 1810	***Serranus scriba***		
Spicara smaris (Linneaus, 1758)	***Pegusa lascaris***		
Spondyliosoma cantharus (Linneaus, 1758)	***Solea solea***		
Synodus saurus (Linneaus, 1758)	***Sparus aurata***		
Trachurus mediterraneus (Steindachner, 1868)	***Sphyraena sphyraena***		
Trachurus sp.	*Squilla mantis*		
Trisopterus capelanus (Lacepède, 1800)	*Symphodus cinereus*		
Umbrina cirrosa (Linneaus, 1758)	*Tetrapturus belone*		
	Torpedo torpedo		
	Trachinotus ovatus		
	Trachinus drago		
	Trachurus trachurus		
	Umbrina cirrosa		
	Uranoscopus scaber		

In all five areas during all period of the project from March 1st, 2021, to November 14th, 2023, the first four most caught species in terms of number of individuals were the same for both CTRL and TEST nets represented by *Mullus barbatus* (MUT), *Melicertus kerathurus* (TGS), *Squilla mantis* (MTS), and *Sepia officianlis* (CTC) counting respectively with a total of 16,189, 15,683, 7,012, and 6,778 number of individuals. Instead, taking into account the total kilograms, only one species, the *Sepia officianlis* (CTC), resulted the most caught species in both type of nets for all areas during all three years, respectively with a total of 608.69 kg for CTRL nets and 2,327.74 kg for TEST nets.

Now it has been taken into account the frequency represented by the number of times that in all five areas a species has been captured differently using CTRL and TEST nets. The cuttlefish (*Sepia officinalis* – CTC) and gilthead seabream (*Sparus aurata* - SBG) emerged as the two most frequently caught species both among the 72 species captured with CTRL nets and among the 77 species captured with TEST nets. For cuttlefish, the frequency of being caught with both CTRL and TEST nets was 4.60% and 3.50% respectively. For gilthead seabream, the percentages were 3.83% for CTRL nets and 3.25% for TEST nets, as well as octopus (*Octopus vulgaris* – OCC) in the case of TEST nets (Figure 46 and 47).

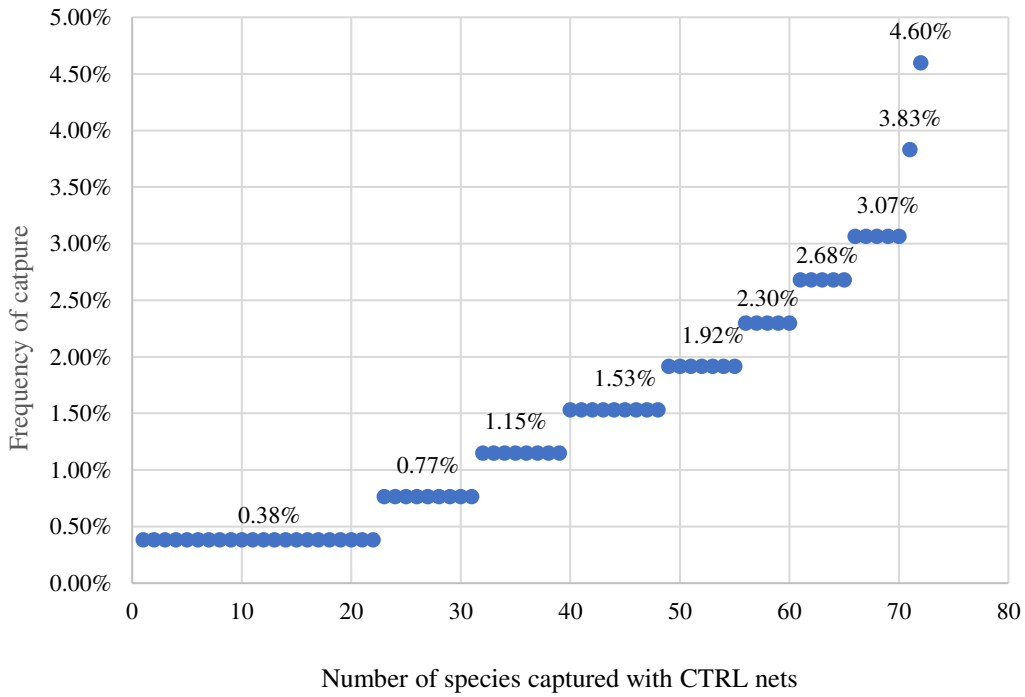

Figure 46 – Graph showing the frequency of capture of the 72 species caught using CTRL nets considering all areas: 0.38% (ANE, BOG, BRF, CEO, CRU, DOL, LBE, LDB, MAC, MON, MSP, RJO, RPG, SAA, SBA, SKA, SMD, SQC, SRK, TUR, WEG, and YFC), 0.77% (CTB, GFB, GPW, HOM, LEE, POP, TTV, SHR, and YRS), 1.15% (ANN, BBS, EZS, GUU, LTA, MSF, SBS, and SLO), 1.53% (AMB, BLU, COE, MGA, MLR, MMH, MTS, RJC, and SOS), 1.92% (BON, BSS, CBR, SNQ, SSB, TGS and UUC), 2.30% (BLL, HKE, MUF, MZZ, and SWA), 2.68% (CBM, COB, PAC, RSE, and SLM), 3.07% (DEC, MUR, MUT, OCC, SOL and SBF), 3.83% (SBG) and 4.60% CTC. Total of times species has been captured using CTRL nets was equal to 261.

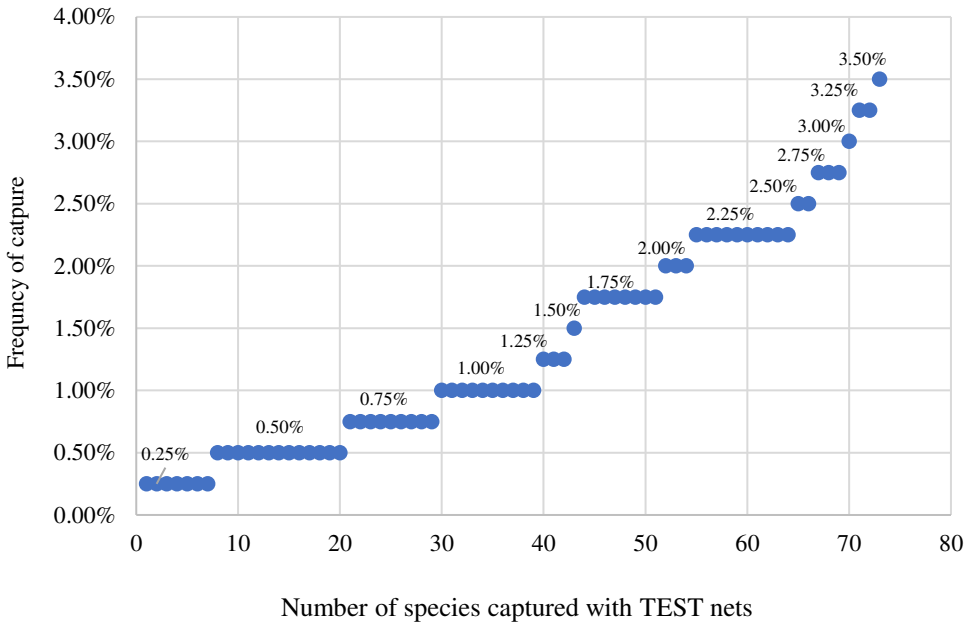

Figure 47 – Graph showing the frequency of capture of the 77 species caught using TEST nets considering all areas: 0.25% (CRA, JOD, JRS, LDB, MAC, RJO, SDS, SQR, SRG, SRK, and TUR), 0.50% (ANK, DOL, DPS, GPW, HMM, MSP, SAA, SBA, SHR, SKA, SYC, and WEG), 0.75% (BBS, BRF, COE, LEE, POP, SBS, SMD, SOS, and YFC), 1.00% (CTB, EZS, HKE, HOM, LBE, LTA, MLR, SQF, TTV, and TTV), 1.25% (ANN, GFB, and MMH), 1.50% (CBR), 1.75% (BSS, CBM, GUU, MGA, MSF, RJC, RSE, and SNQ), 2.00% (AMB, UUC, and SWA), 2.25% (BLU, BON, COB, MUF, MUR, SLM, SLO, SSB, TGS, and UUC) and 2.50% (BLL and MTS), 2.75% (DEC, PAC, and SOL), 3.00% MUT, 3.25% (OCC and SBG), and 3.50% CTC. Total of times species has been captured using CTRL nets was equal to 400.

The following part of the results showed all species captured in each area (AREA 1, AREA 2, AREA 3, AREA 4, and AREA 5) per year (2021, 2022 and 2023) distinguishing between CTRL and TEST nets showing all important data such as: number of individuals (n), kilograms (kg), number of individuals damaged (n) and kilograms of catches damaged (kg).

AREA 1 (Porto Ercole)

During the two years when trials were carried out (2022 and 2023) the species most caught in CTRL nets in terms of number of individuals (> 500 n) were: caramote prawn (TGS), surmullet (MUR), red mullet (MUT), and cuttlefish (CTC), respectively with a total number of 1,635, 927, 832, and 508. The species most caught in CTRL nets in terms of kilograms (> 100 kg) were: gilthead seabream (SBG), surmullet, bluefish (BLU), cuttlefish and thick lip grey mullet (MLR), respectively with a total of 163.50 kg, 141.95 kg, 114.50 kg, 107.02 kg, and 105.00 kg. Regarding the damages occurred to the catches during the two years (2022 and 2023) using CTRL nets for number of individuals were recorded in surmullet (n=3), cuttlefish, red mullet and painted comber (SRK) for each with n=2, while damages to the catch recorded in terms of kilograms were for surmullet and for red mullet, respectively with a total of 0.41 kg and 0.16 kg.

Regarding TEST nets during the two year (2022 and 2023) the species most caught in terms of number of individuals (> 1000 n) were: caramote prawn, red mullet, surmullet and cuttlefish respectively with a total number of 9490, 5170, 1673 and 1221. The most caught species in terms of kilograms (> 200 kg) were: red mullet, caramote prawn, cuttlefish, surmullet and gilthead seabream, respectively with a total of 500.77 kg, 344.80 kg, 268.71 kg, 225.17 kg and 212.90 kg. Regarding the damages occurred only 2 individuals of cuttlefish were recorded during the two years using the nets employed with pingers (TEST nets). All species caught in AREA 1 in number of individuals and in kilograms during the two years were charted in the treemaps for CTRL nets in Figure 48 and 49 and for TEST nets in Figure 50 and 51. Moreover, detailed data were reported in supplementary materials Table S1 and S2.

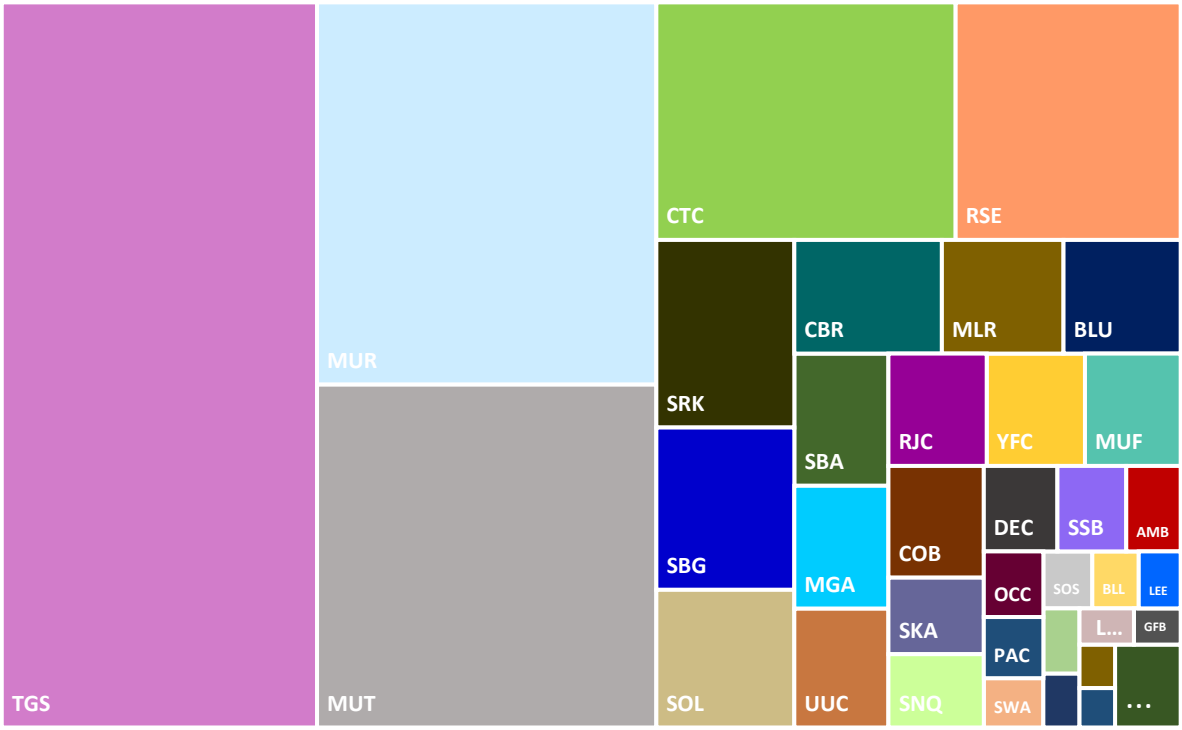

Figure 48 – Treemap of species caught in AREA 1 using CTRL nets, represented by the number of individuals captured. Each rectangle represented a different species, with the size proportional to the number of individuals caught (n=6,112). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: SLM (n=17), CBM (n=14), and RPG, POP, MZZ, YRS, CTB SMD, BON, SHR, BSS, HKE, SBS, WEG, MAC, MON, SLO, SQC (n=≤13).

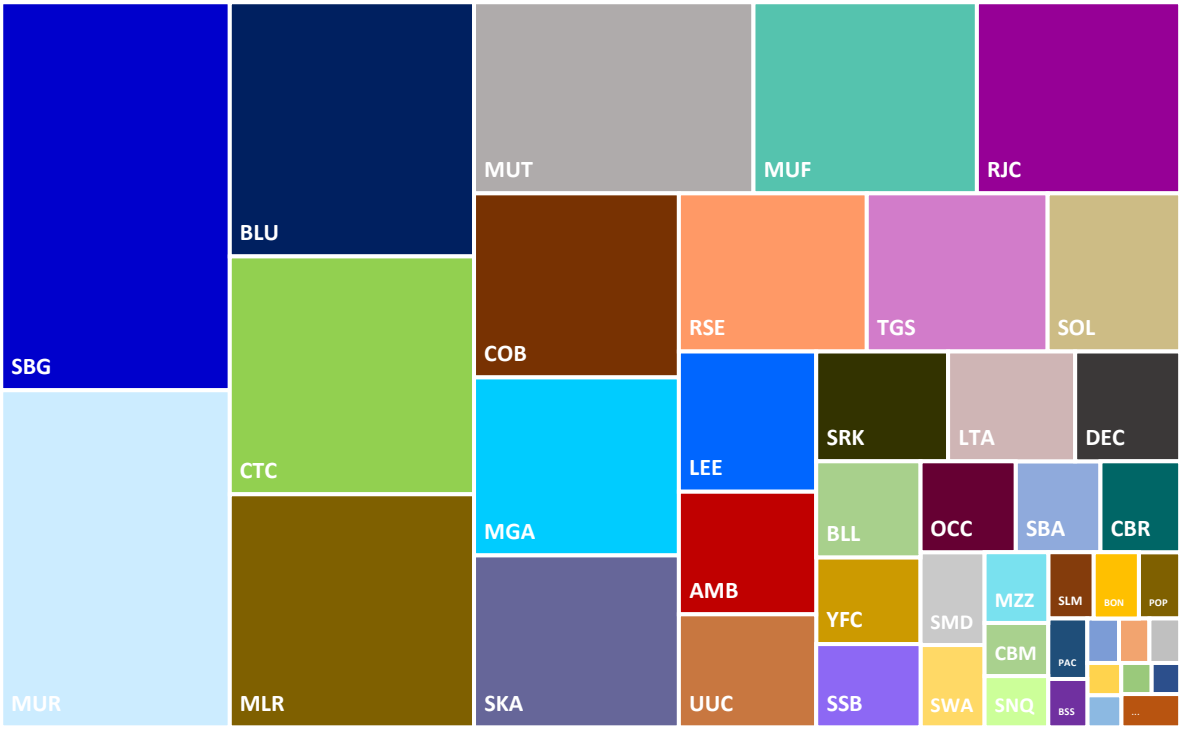

Figure 49 – Treemap of species caught in AREA 1 using CTRL nets, represented by the kilograms captured. Each rectangle represented a different species, with the size proportional to the kilograms caught (1,575.12 kg). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code readable were: HKE (2.6 kg), GFB (2.5 kg), SOS (2.5 kg), YRS (2.01 kg), MON (2.00 kg), and RPG, CTB, SHR, SLO, WEG, SBS, MAC, SQC (< 2 kg).

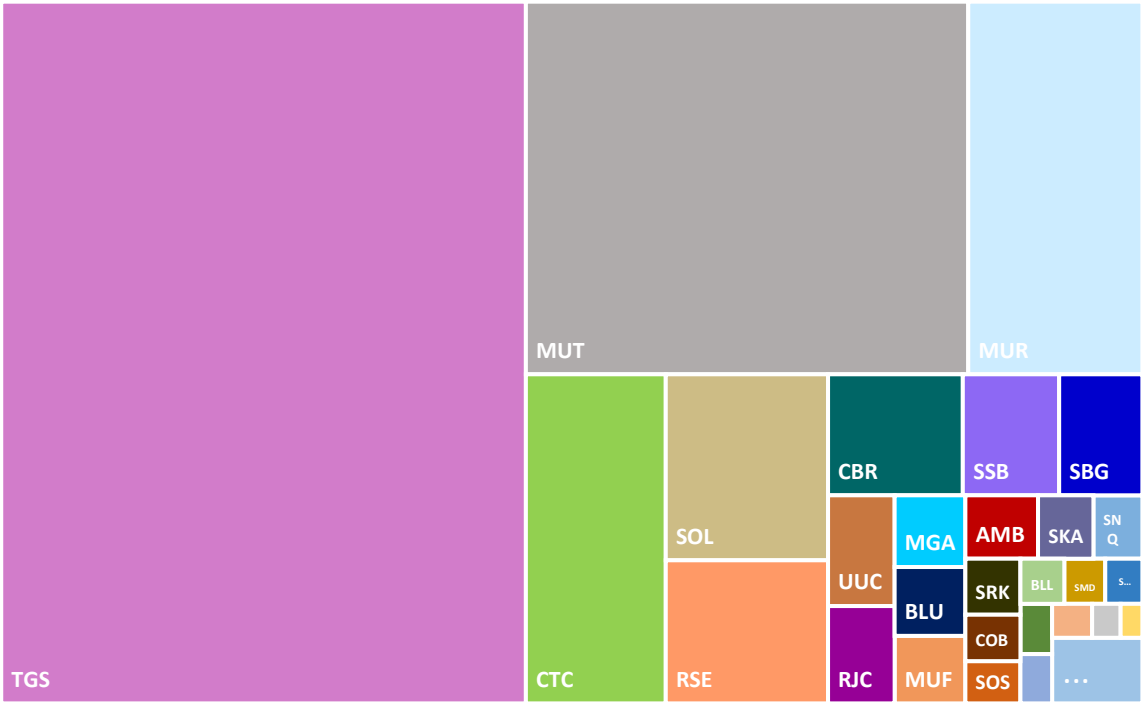

Figure 50 – Treemap of species caught in AREA 1 using TEST nets, represented by the number of individuals captured. Each rectangle represented a different species, with the size proportional to the number of individuals caught (n= 0,637). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code readable were: LTA (n=41), MLR (n=40), LEE (n=35), SWA (n=25), GUU (n=19), and DEC, SYC, MON, MTS, YRS, TTV, BON, CBM, OCC, YFC, POP, PAC, SLM, SRG, CTB, GFB, MMH, MZZ, SBS, SLO, SQF, SQR (n=≤15).

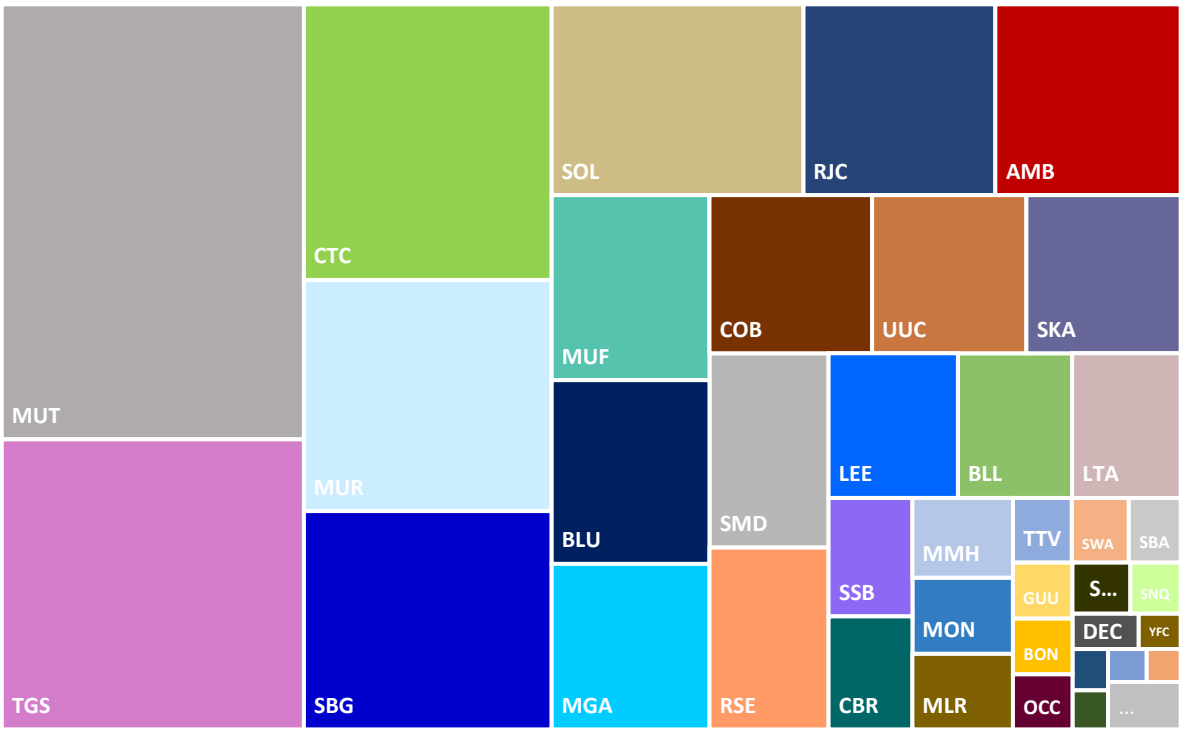

Figure 51 – Treemap of species caught in AREA 1 using TEST nets, represented by the kilograms captured. Each rectangle represented a different species, with the size proportional to the kilograms caught (3,362.47 kg). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code readable were: MZZ (5.8 kg), CBM (5.5 kg), SYC (5.00 kg), (YRS 4.4 kg), and POP, PAC, SOS, SLM, CTB, MTS, SLO, SRG, GFB, SBS, SQR, SQF (<3 kg).

AREA 2 (Porto Santo Stefano)

During the three years when trials were carried out (2021, 2022 and 2023) the species most caught in CTRL nets in terms of number of individuals (> 100 n) were: red mullet, spottail mantis squillid (MTS), cuttlefish, surmullet, flathead grey mullet (MUF), and red scorpionfish (RSE), respectively with a total number of 690, 399, 272, 123, 112, and 100. The species most caught in CTRL nets in terms of kilograms (> 50 kg) were: greater amberjack (AMB), cuttlefish, and red mullet, respectively with a total of 131.50 kg, 71.80 kg, and 65.80 kg. Regarding the damages occurred to the catches using CTRL nets during the three years (2021, 2022 and 2023) in terms of number of individuals (> 5 n) were recorded in European hake (HKE), annular seabream (ANN), surmullet, flathead grey mullet, common sole (SOL), rudderfish (CEO), respectively with a total number of 17, 12, 12, 8, 7, and 6, while damages to the catch recorded in terms of kilograms were for European hake, rudderfish, surmullet, sand steenbras (SSB), common sole, annular seabream, and Atlantic bonito (BON), respectively with a total of 6.00 kg, 2.00 kg, 1.90 kg, 1.40 kg, 1.30 kg, 1.20 kg and 1.00 kg.

Regarding TEST nets during the three years (2021, 2022 and 2023) the species most caught in terms of number of individuals (> 1000 n) were: redmullet, spottail mantis squillid, and cuttlefish respectively with a total number of 6760, 2689, and 1207. The most caught species in terms of kilograms (> 200kg) were red mullet, greater amberjack, cuttlefish, and common sole, respectively with a total of 790.75 kg, 377.70 kg, 323.55 kg, and 211.39 kg. Regarding the damages to the catch in terms of number of individuals (> 15 n), these occurred in red mullet, Mediterranean scaldfish (MSF), common sole and annular seabream, with respectively with a total number of 122, 55, 16, and 15, while regarding the damages in terms of kilograms (> 5 kg) the species were: red mullet and Mediterranean scaldfish with a total of 12.9 kg and 5 kg.

All species caught in AREA 2 in number of individuals and in kilograms during the three years were charted in the treemaps for CTRL nets in Figure 52 and 53 and for TEST nets in Figure 54 and 55. Moreover, detailed data were reported in supplementary materials Table S3, S4 and S5.

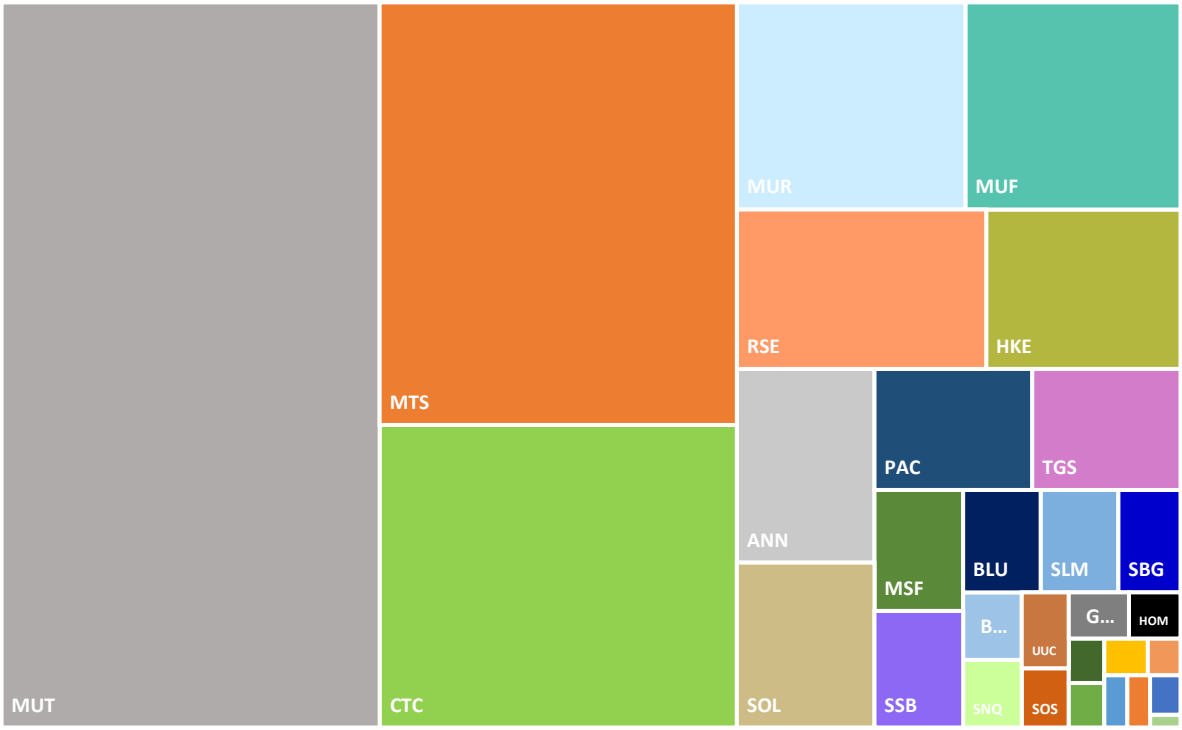

Figure 52 – Treemap of species caught in AREA 2 using CTRL nets, represented by the number of individuals captured. Each rectangle represented a different species, with the size proportional to the total number of individuals caught (n=2,151). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: OCC, COB, BON (n=4), BLL, RJC, BSS, AMB (n=3) and DEC (n=1).

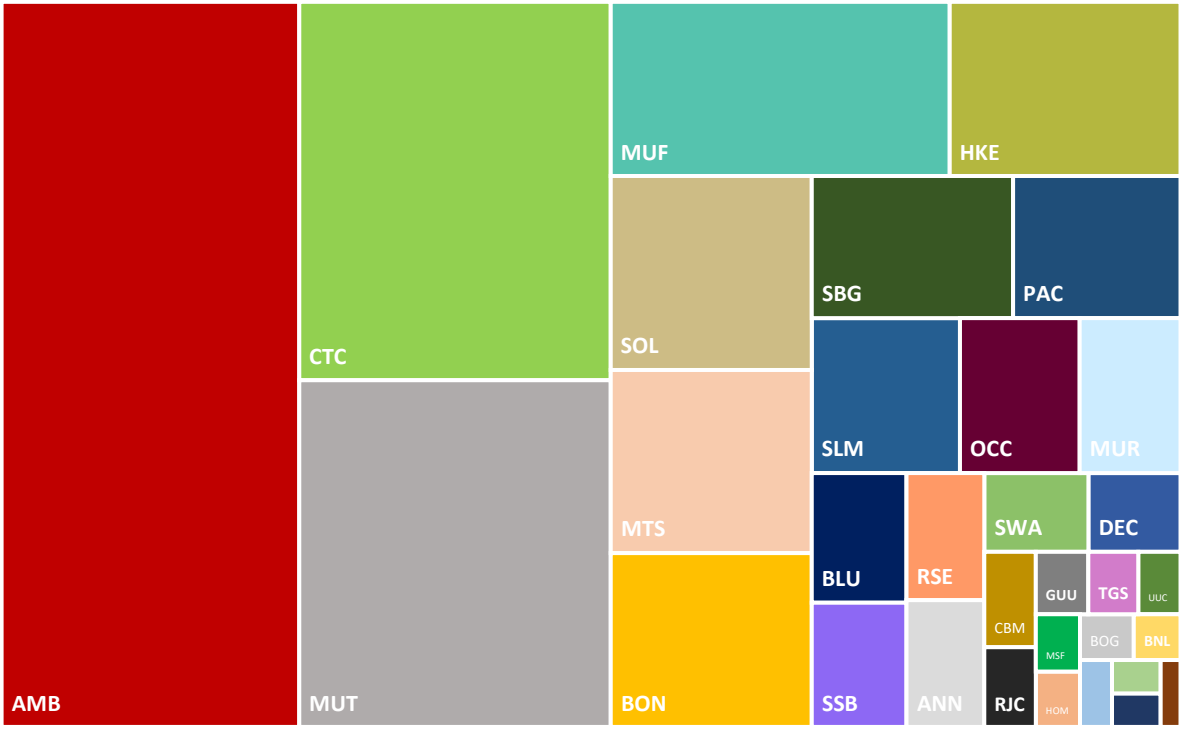

Figure 53 – Treemap of species caught in AREA 2 using CTRL nets, represented by the kilograms captured. Each rectangle represented a different species, with the size proportional to the total kilograms caught. (520.7 kg). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: SNQ (1.3 kg), BSS and COB (1 kg), and SOS (0.8 kg).

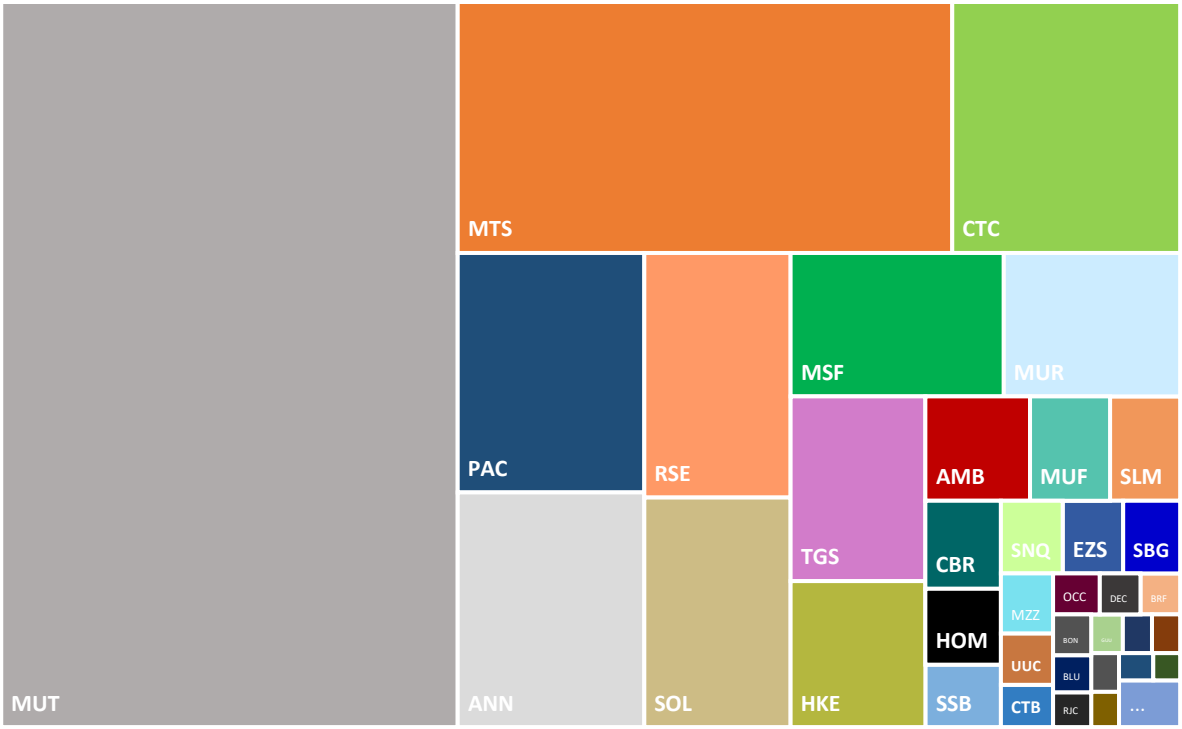

Figure 54 – Treemap of species caught in AREA 2 using TEST nets, represented by the number of individuals captured. Each rectangle represented a different species, with the size proportional to the total kilograms caught. (n=1,7410). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: SWA (n=23), BLL and CRA (n=22), LTA(n=20), COB (n=19), SBS (n=15), MAC (n=11), MMH, SYC, MSP, ANK, GFB, SLO, SQF, MLR, TTV, GPW, TUR, HMM, and JRS (n=<10).

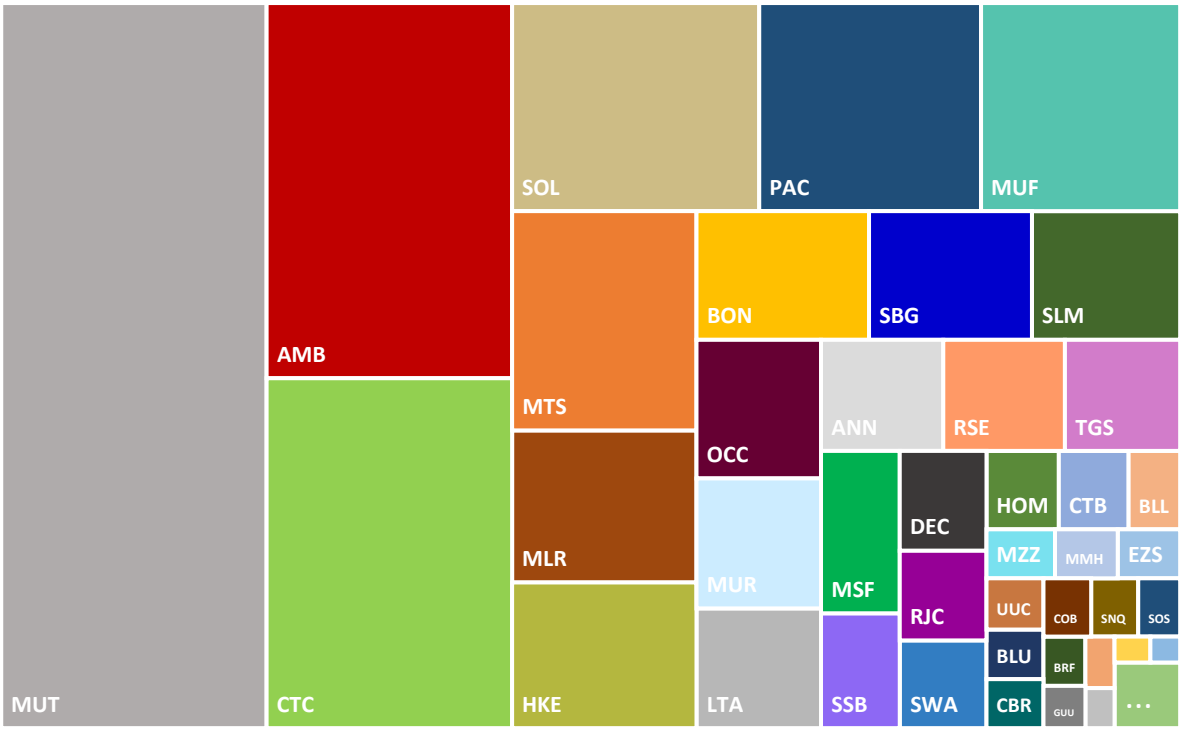

Figure 55 – Treemap of species caught in AREA 2 using TEST nets, represented by the kilograms captured. Each rectangle represented a different species, with the size proportional to the total kilograms caught. (35,090.79 kg). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: ANK (6.2 kg), SBS (4.8 kg), MSP (3.8 kg), DPS (3.15 kg), and LEE; CRA, GFB, GPW, MAC, TTV, SAA, SYC, SLO, SQF, TUR, JRS, HMM (≤ 3kg).

AREA 3 (Talamone)

During the three years when trials were carried out (2021, 2022 and 2023) the species most caught in CTRL nets in terms of number of individuals (> 100 n) were: cuttlefish, gilthead seabream, greater amberjack, shi drum (COB), and flathead grey mullet, respectively with a total number of 735, 427, 118, 118, and 104. The species most caught in CTRL nets in terms of kilograms (> 50 kg) were: cuttlefish, gilthead seabream, shi drum, flathead grey mullet and greater amberjack, respectively with a total of 249.10 kg, 181.30 kg, 74.50 kg, 69.50 kg, and 55.5 kg. Regarding the damages occurred to the catches using CTRL nets during the three years (2021, 2022 and 2023) in terms of number of individuals (> 4 n) were recorded in cuttlefish and in European anchovy (ANE), respectively with a total of 8 n and 4 n, while damages to the catch recorded in terms of kilograms were for brown meagre (CBM), cuttlefish, and crustaceans, respectively with a total of 1.50 kg, 1.20 kg, and 1 kg.

Regarding TEST nets during the three years (2021, 2022 and 2023) the species most caught in terms of number of individuals (> 500 n) were: cuttlefish and common sole, respectively with a total number of 2867 and 563. The most caught species in terms of kilograms (> 100kg) were cuttlefish, gilthead seabream, greater amberjack, common sole and shi drum, respectively with a total of 768.80 kg, 145.90 kg, 139.20 kg, 119.02 kg and 105.00 kg. Regarding the damages to the catch in terms of number of individuals (> 10 n), these occurred in cuttlefish and in red mullet respectively with a total of with a total of 22 n and 13 n, while regarding the damages in terms of kilograms (> 2 kg) the species were: cuttlefish, common torpedo (TTV) and common pandora (PAC), respectively with a total of 4.5 kg, 3 kg, and 2.65 kg.

All species caught in AREA 3 in number of individuals and in kilograms during the three years were charted in the treemaps for CTRL nets in Figure 56 and 57 and for TEST nets in Figure 58 and 59. Moreover, detailed data were reported in supplementary materials Table S6, S7 and S8.

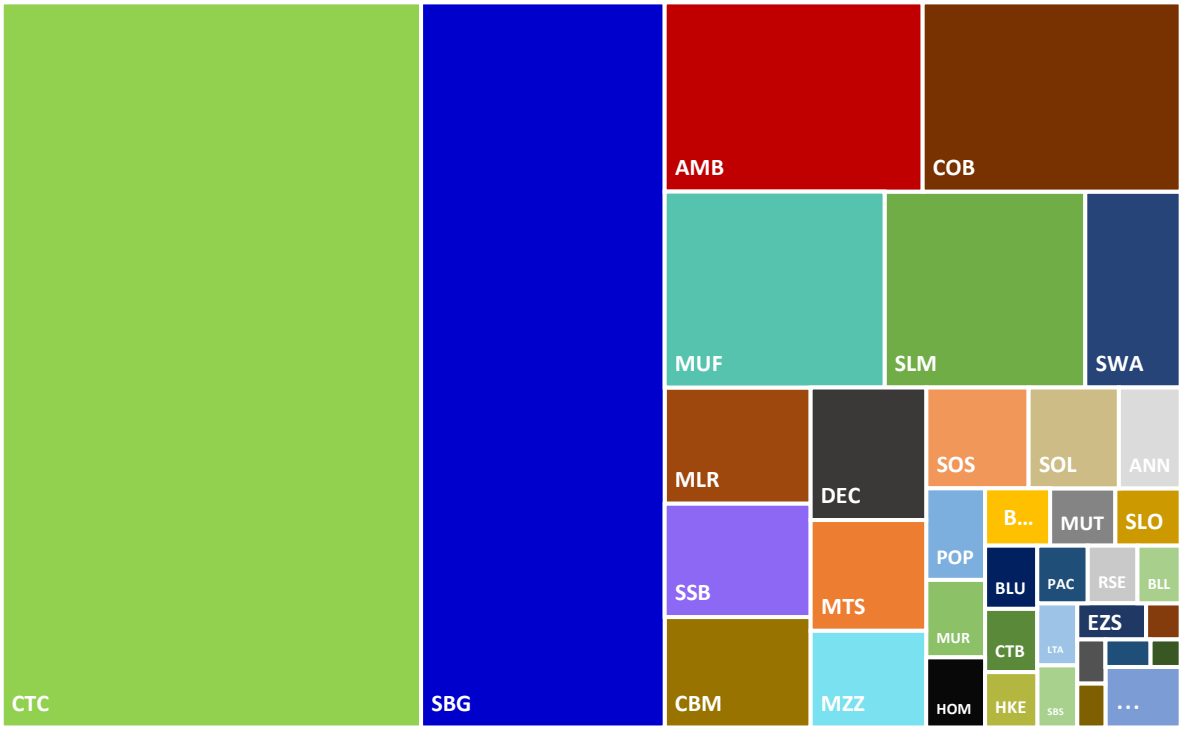

Figure 56 – Treemap of species caught in AREA 3 using CTRL nets, represented by the number of individuals captured. Each rectangle represented a different species, with the size proportional to the total number of individuals caught. (n=2,066). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: MSF, TTV, GPW, CRU (n=3), OCC (n=2), and GUU, MMH, MPS, BSS, GFB, SHR, COE, and SAA (n=≤2).

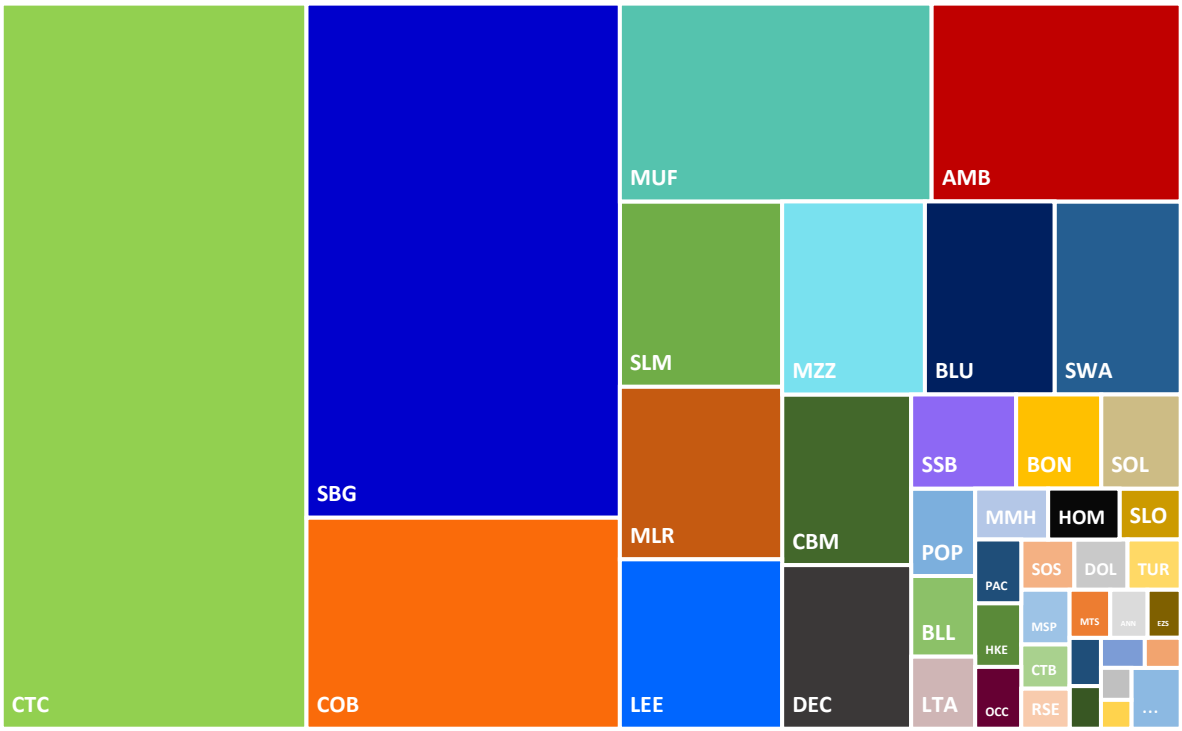

Figure 57 – Treemap of species caught in AREA 3 using CTRL nets, represented by the kilograms captured. Each rectangle represented a different species, with the size proportional to the total kilograms caught. (962.85 kg). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: GPW (1.7 kg), COE (1.5 kg), MUR (1.48 kg), SBS (1.2 kg), GUU (1.1 kg), MUT (1.00 kg), and TTV, SHR, SAA, BSS, GFB, MSF (<1kg).

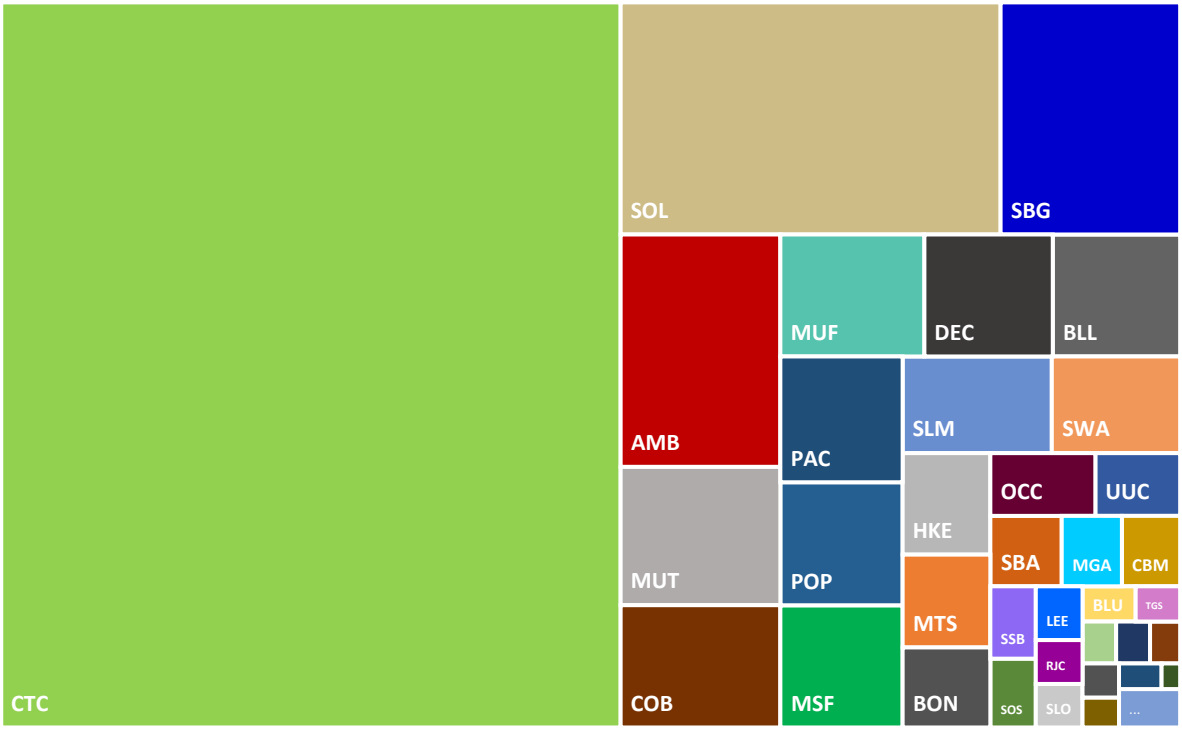

Figure 58 – Treemap of species caught in AREA 3 using TEST nets, represented by the number of individuals captured. Each rectangle represented a different species, with the size proportional to the total number of individuals caught. (n=5,456). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: RSE and HOM (n=9), BSS and MZZ (n=8), GUU and ANK (n=7), LBE (n=3), and GPW, CTB, GFB, SAA, DOL, MLR, MUR, SHR, HMM (n= ≤3).

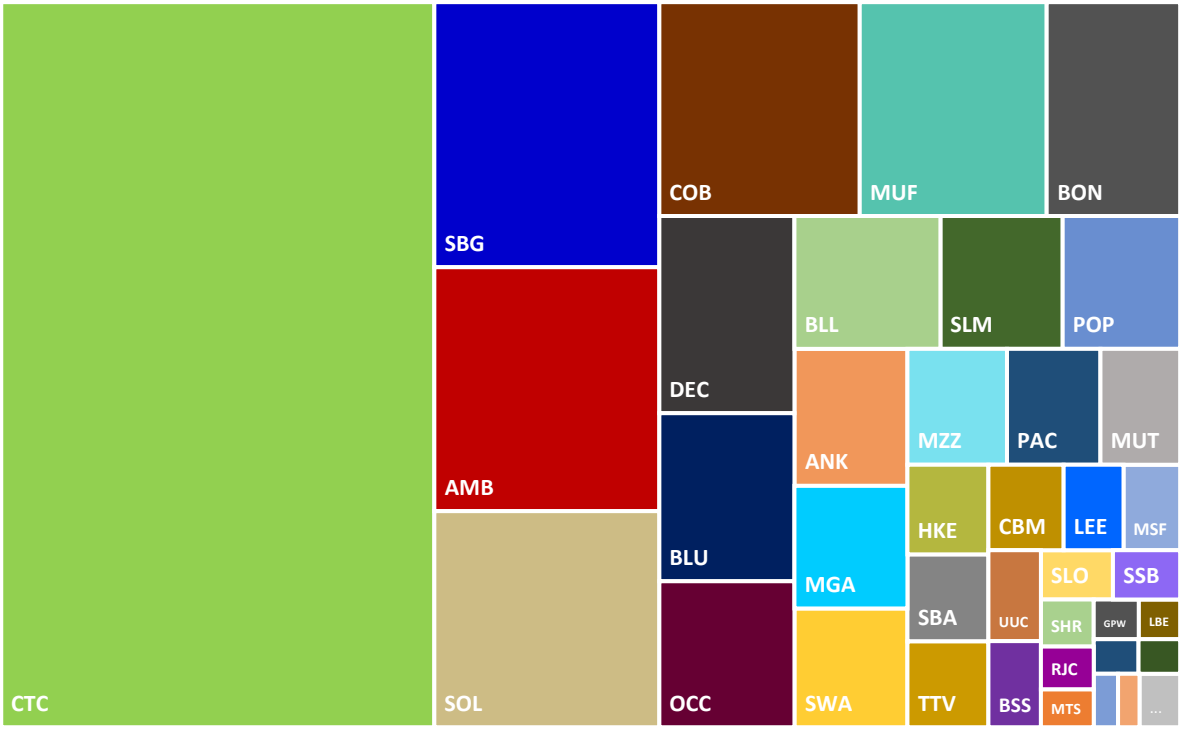

Figure 59 – Treemap of species caught in AREA 3 using TEST nets, represented by the kilograms captured. Each rectangle represented a different species, with the size proportional to the total kilograms caught. (2,091.91 kg). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: DOL (3.80 kg), HOM (3.50 kg), RSE (3.20 kg), SOS (2.80 kg), and SAA, GUU, TGS, GFB, CTB, MUR, MLR, HMM (<2kg).

AREA 4 (Marina di Grosseto)

During the three years when trials were carried out (2021, 2022 and 2023) the species most caught in CTRL nets in terms of number of individuals (> 100 n) were: spottail mantis squillid, red mullet, cramote prawn, common sole and flathead grey mullet, respectively with a total number of 1033, 756, 680, 166, and 120. The species most caught in CTRL nets in terms of kilograms (> 10 kg) were: cramote prawn, red mullet, spottail mantis squillid, and common sole, respectively with a total of 42.25 kg, 38.20 kg, 24.40 kg, and 16.80 kg. Regarding the damages occurred to the catches using CTRL nets during the three years (2021, 2022 and 2023) only red mullet were recorded with a total of 20 individuals for 2 kg. Regarding TEST nets during the three years (2021, 2022 and 2023) the species most caught in terms of number of individuals (> 500 n) were: caramote prawn, red mullet, spottail mantis squillid, and common sole, respectively with a total number of 3498, 3409, 3105, and 570. The most caught species in terms of kilograms (> 100kg) were red mullet, caramote prawn and spottail mantis squillid, respectively with a total of 485.40 kg, 354.00 kg, and 152.80 kg. Regarding the damages to the catch, only two species recorded: the red mullet and the octopus (OCC) respectively with a total of n=4 and 0.20 kg, and with n=2 and 1.60 kg.
All species caught in AREA 4 in number of individuals and in kilograms during the three years were charted in the treemaps for CTRL nets in Figure 60 and 61 and for TEST nets in Figure 62 and 63. Moreover, detailed data were reported in supplementary materials Table S9, S10 and S11.

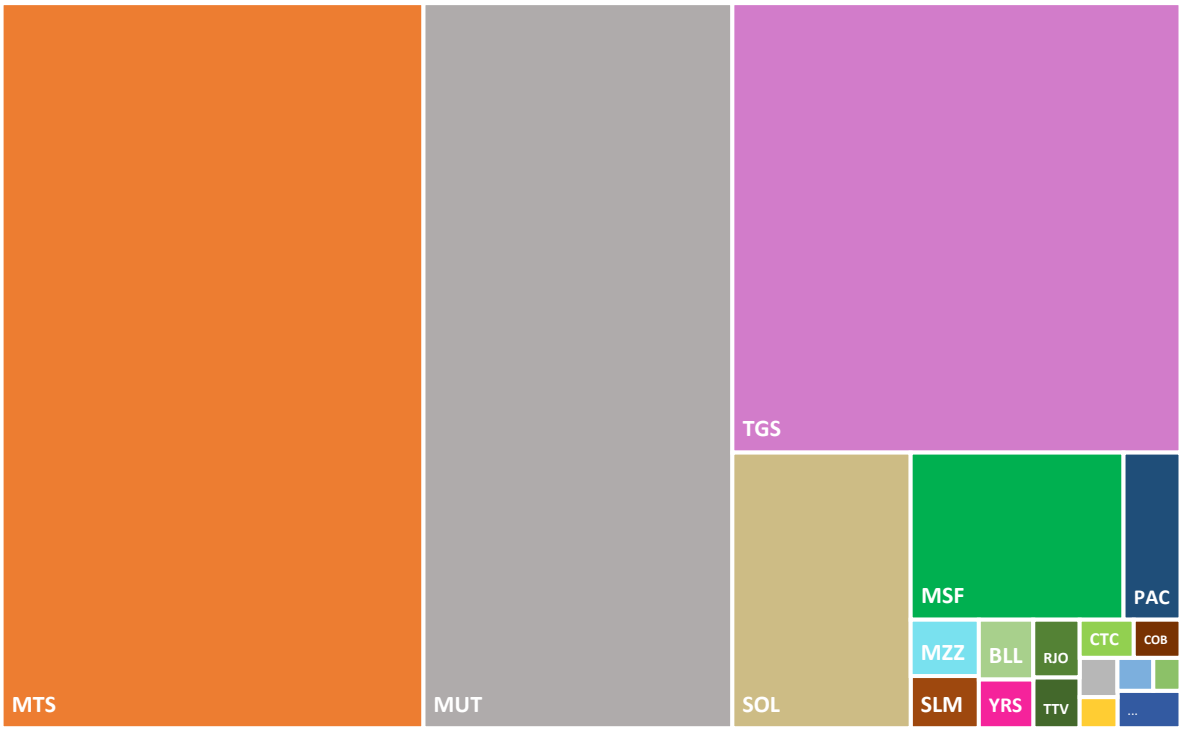

Figure 60 – Treemap of species caught in AREA 4 using CTRL nets, represented by the number of individuals captured. Each rectangle represented a different species, with the size proportional to the total number of individuals caught. (n=2,886). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: SSB, (n=5), OCC and UCC (n=4), LDB (n=3) SOS and BRF (n=2), MUR, RJC, SBG, and GUU (n=1).

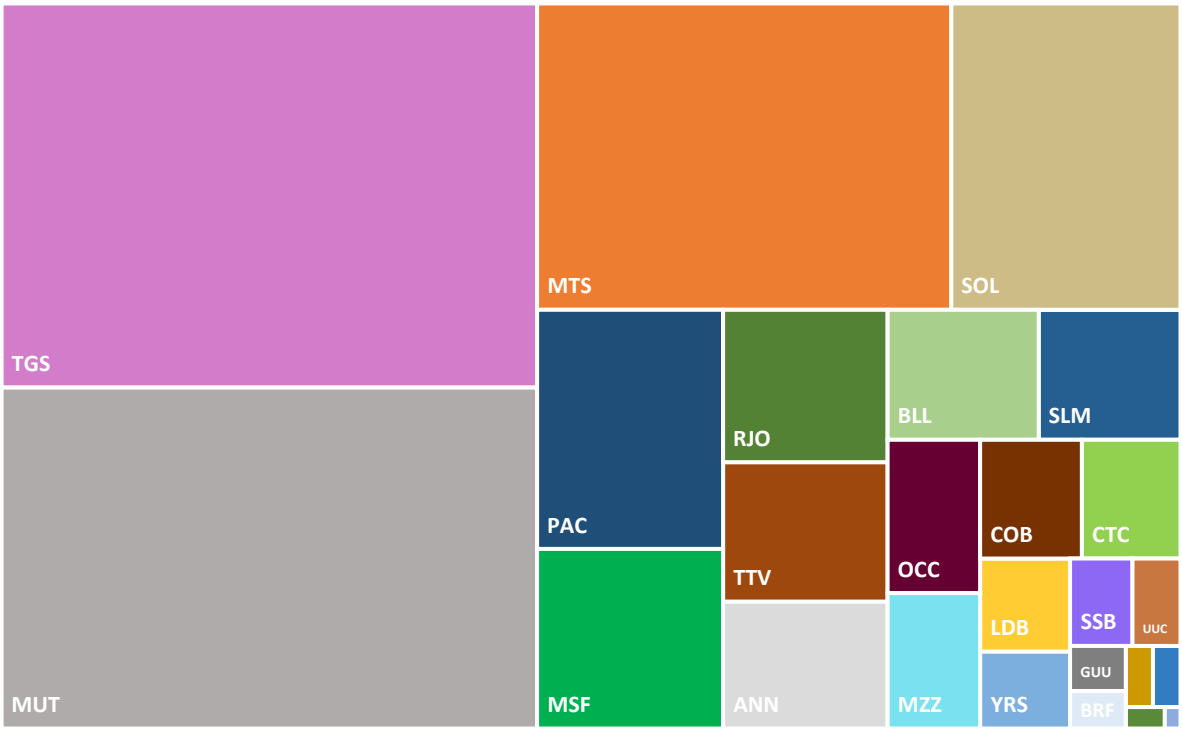

Figure 61 – Treemap of species caught in AREA 4 using CTRL nets, represented by the kilograms captured. Each rectangle represented a different species, with the size proportional to the total kilograms caught. (204.63 kg). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: MUR (0.8 kg), RJC and SBG (0.4 kg), and SOS (0.2 kg).

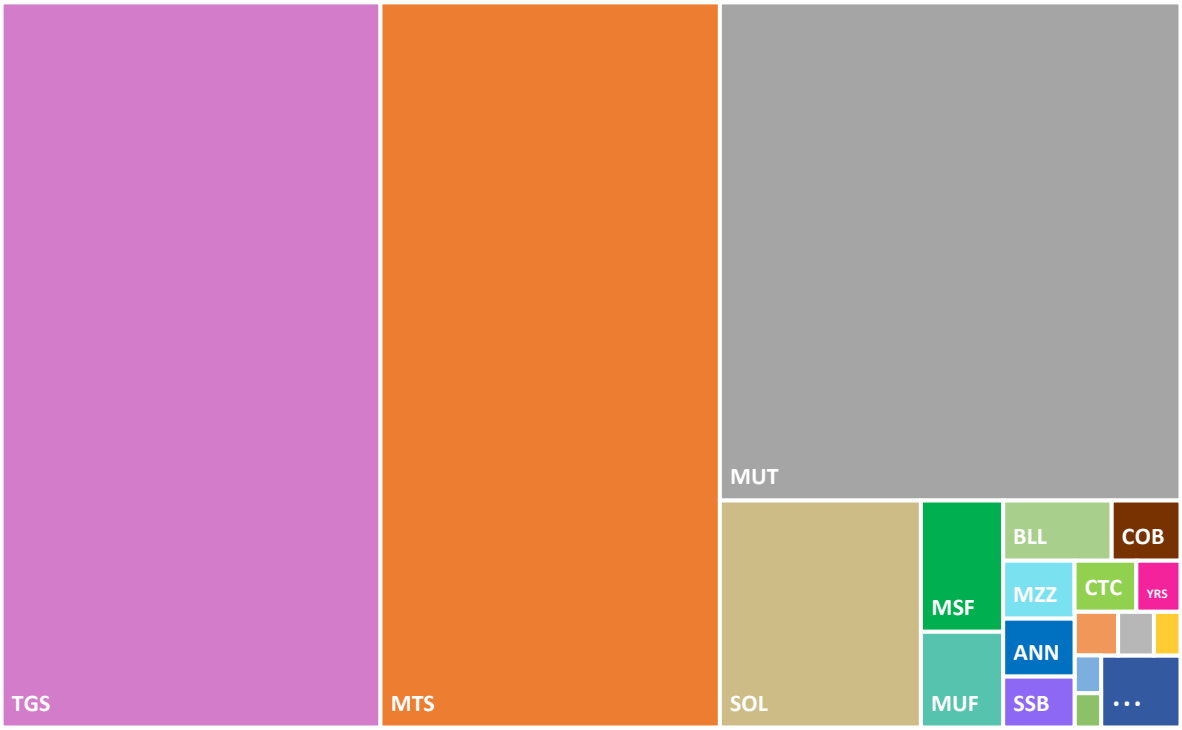

Figure 62 – Treamap of species caught in AREA 4 using TEST nets, represented by the number of individuals captured. Each rectangle represented a different species, with the size proportional to the total number of individuals caught. (n=2,886). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: EZS (n=23), UUC (n=19), PAC (n=14), SLM (n=12), LDB (n=11), and SBG, SQF, OCC, BSS, RJO, GFB, MLR, TTV, BLU, RJC, SLO, WEG, GUU, and BRF (n=≤10).

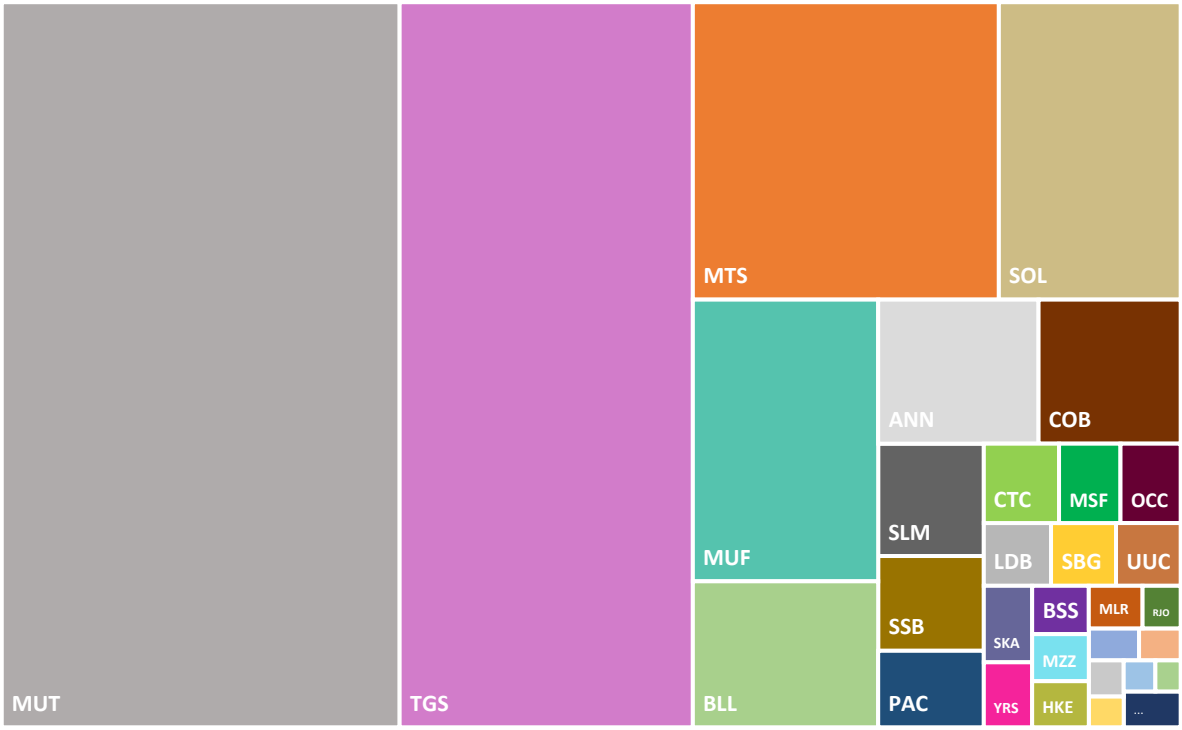

Figure 63 – Treamap of species caught in AREA 4 using TEST nets, represented by the kilograms captured. Each rectangle represented a different species, with the size proportional to the total kilograms caught. (1,434.42 kg). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: TTV (2.7 kg), EZS (2.25 kg), MSP (2.1 kg), RJC (1.8 kg), GFB (1.65 kg), BLU, SQF, SLO, GUU, WEG, BRF (≤ 1kg).

AREA 5 (Piombino)

During the three years when trials were carried out (2021, 2022 and 2023) the species most caught in CTRL nets in terms of number of individuals (> 10 n) were: Mediterranean moray (MMH), octopus, golden grey mullet (MGA), European conger (COE), brown meagre, and red scorpionfish, respectively with a total number of 37, 28, 22, 19, 12, and 10. The species most caught in CTRL nets in terms of kilograms (> 50 kg) were: cuttlefish, small red scorpionfish (SNQ), surmullet, black scorpionfish (BBS), and comber (CBR), respectively with a total of 177.97 kg, 143.79 kg, 82.15 kg, 66.44 kg, 63.95 kg, and 50.35 kg. Regarding the damages occurred to the catches using CTRL nets during the three years (2021, 2022 and 2023) in terms of number of individuals (> 20 n) and in terms of kilograms (> 1.5 kg) were recorded: surmullet, Mediterranean moray, comber, brown meagre, and European conger, respectively with a total of 144 n and 19.65 kg, 34 n and 3.96 kg, 33 n and 3.8 kg, 20 n and 3 kg, and 20 n and 1.8 kg.

Regarding TEST nets during the three years (2021, 2022 and 2023) the species most caught in terms of number of individuals (> 30 n) were: Mediterranean moray, common octopus, brown meagre, European conger, and common dentex, respectively with a total number of 62, 58, 47, 38, and 35. The most caught species in terms of kilograms (>100kg) were: cuttlefish, small red scorpionfish, surmullet, black scorpionfish, comber and Mediterranean moray, respectively with a total of 927.63 kg, 586.61 kg, 384.97 kg, 193.26 kg, 173.35 kg, and 133.03 kg. Regarding the damages to the catch, no damages were recorded using nets employed with pingers (TEST nets).

All species caught in AREA 5 in number of individuals and in kilograms during the three years were charted in the treemaps for CTRL nets in Figure 64 and 65 and for TEST nets in Figure 66 and 67. Moreover, detailed data were reported in supplementary materials Table S12, S11 and S12.

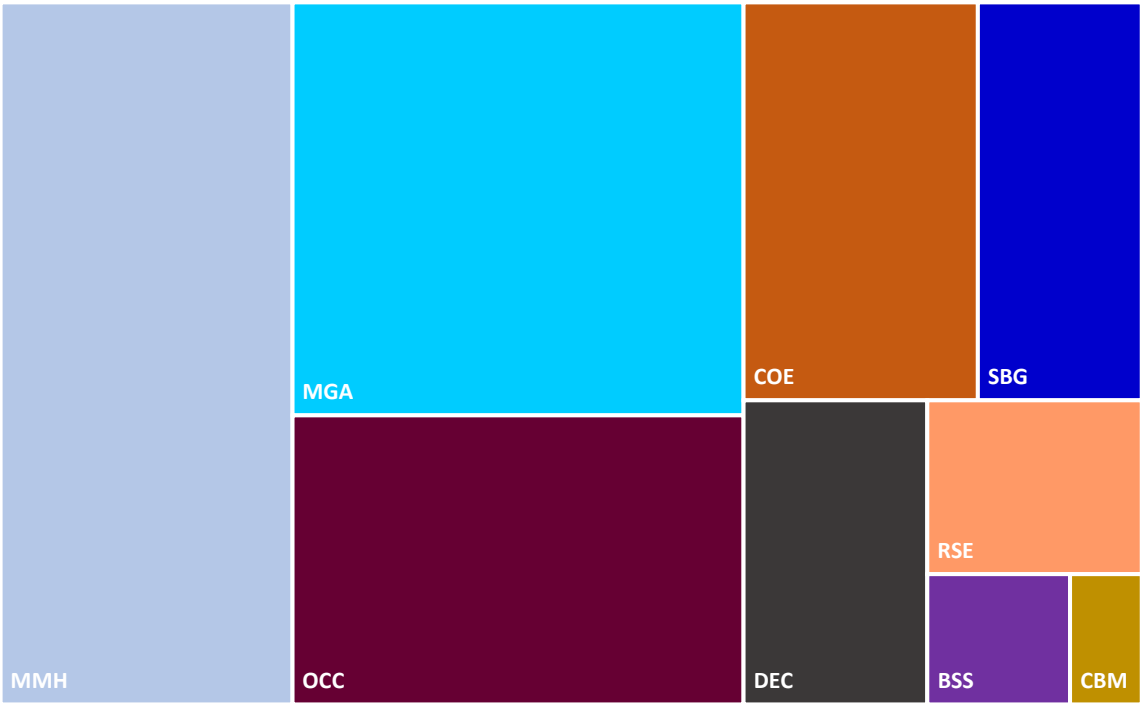

Figure 64 – Treemap of species caught in AREA 5 using CTRL nets, represented by the number of individuals captured. Each rectangle represented a different species, with the size proportional to the total number of individuals caught. (n=86). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area.

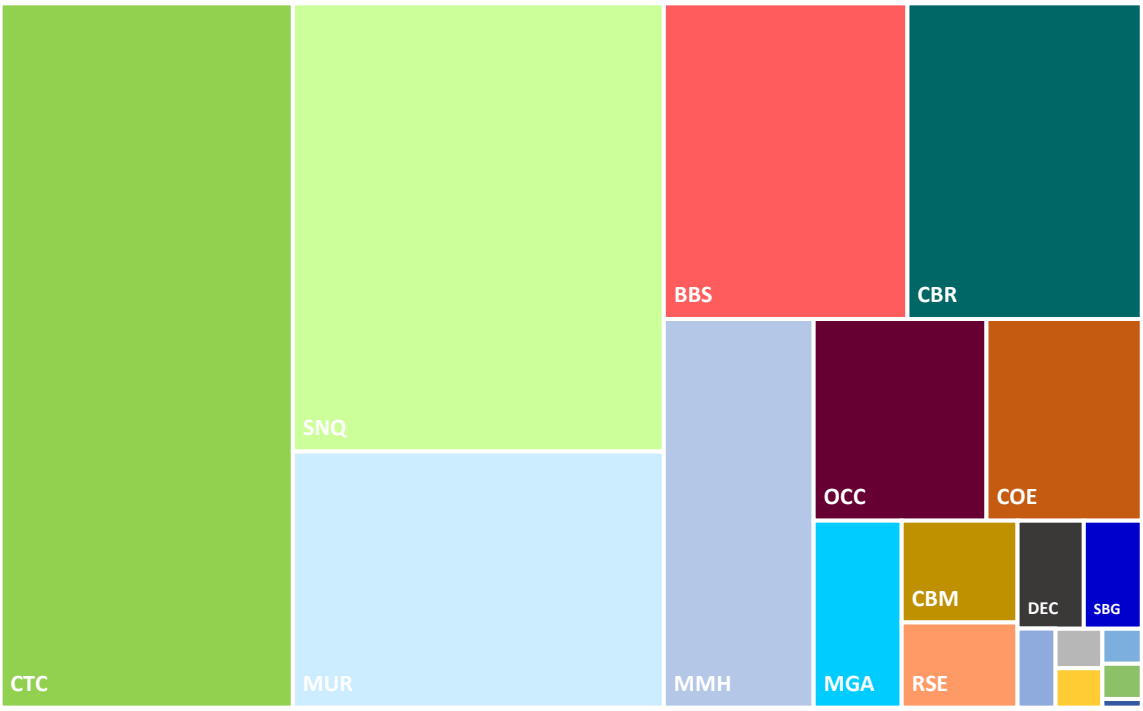

Figure 65 – Treemap of species caught in AREA 5 using CTRL nets, represented by the kilograms captured. Each rectangle represented a different species, with the size proportional to the total kilograms caught. (694.84 kg). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: BSS (2.58 kg), EZS (1.61 kg), SLM (1.60 kg), SBS and LBE (1.20 kg), and MUT (0.29 kg).

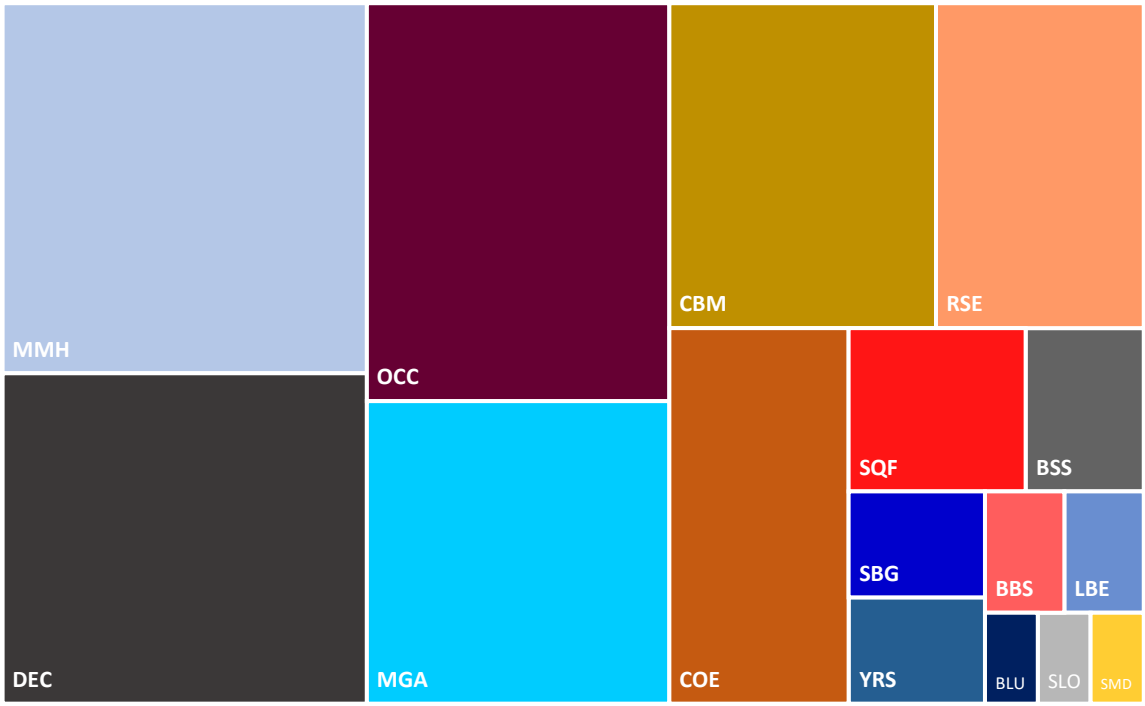

Figure 66 – Treemap of species caught in AREA 5 using TEST nets, represented by the number of individuals captured. Each rectangle represented a different species, with the size proportional to the total number of individuals caught. (n=166). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area.

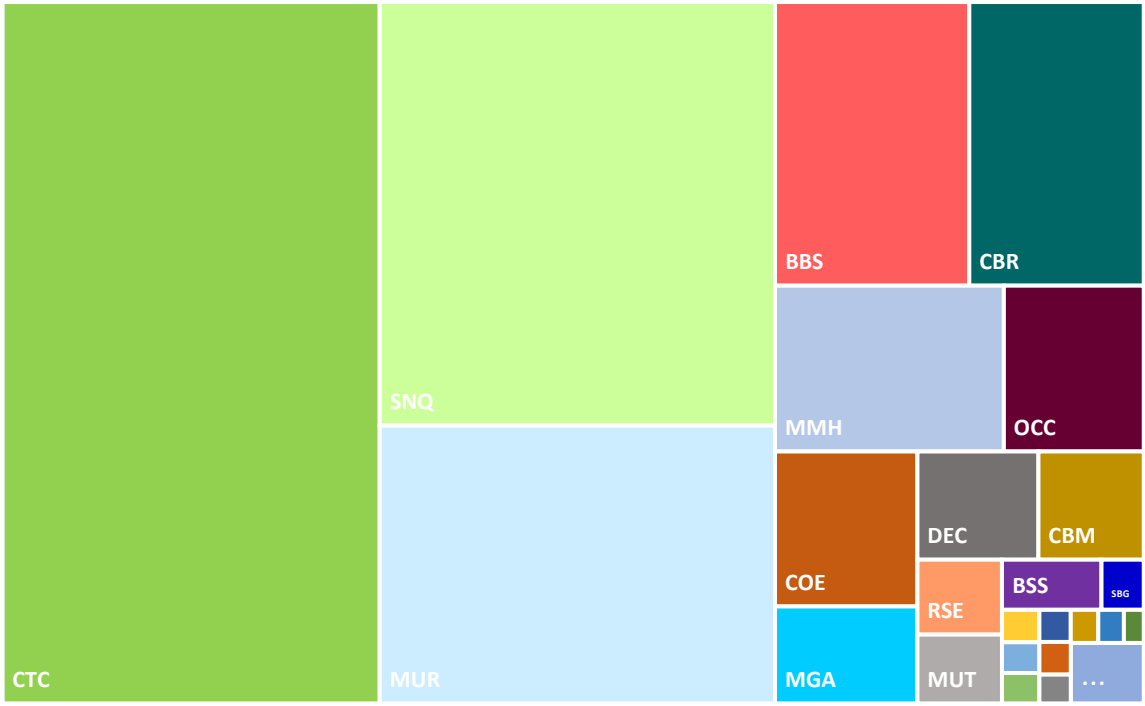

Figure 67 – Treemap of species caught in AREA 5 using TEST nets, represented by the kilograms captured. Each rectangle represented a different species, with the size proportional to the total kilograms caught. (2,805.93 kg). Species with higher catch numbers were displayed with larger rectangles, allowing for quick identification of the most abundant species in the area. Those rectangles without the FAO code were: SWA (4.3 kg), SMD and YFC (4 kg), SDS and LBE (3.6 kg), BRF and HOM (3.2 kg), SBS (3.00 kg), and PAC, SLM, BON, EZS, JOD, SLO, BLU, YRS, DOL, AMB, SQF (≤3 kg).

Considering the analyses discussed above, 21 most caught species were identified both in terms of the number of individuals and weight (in kg), for CTRL and TEST trials. The species were: within molluscs group cuttlefish (CTC) and octopus (OCC), within crustaceans group spottail mantis squillid (MTS) and cramote prawn (TGS), and within bony fishes greater amberjack (AMB), black scorpionfish (BBS), brill (BLL), comber (CBR), shi drum (COB), European conger (COE), dentex (DEC), golden grey mullet (MGA), thicklip grey mullet (MLR), Mediterranean moray (MMH), flathead grey mullet (MUF), surmullet (MUR), red mullet (MUT), red scorpionfish (RSE), gilthead seabream (SBG), small red scorpionfish (SNQ), and common sole (SOL). The dot plot graphs took into account these species clearly showing that, although these species were among the most commonly caught, their distribution varies significantly from one area to another (Figure 68, 69, 70 and 71). Notably, AREA 5 has reported a higher number of species differed to the other four areas, which could suggest that fishers in Piombino targeted a different fishing area compared to the four areas further south of Tuscany, besides the fact that they use a fishing method more specific to combers (CBR) and scorpionfishes (BBS, RSE, and SNQ).

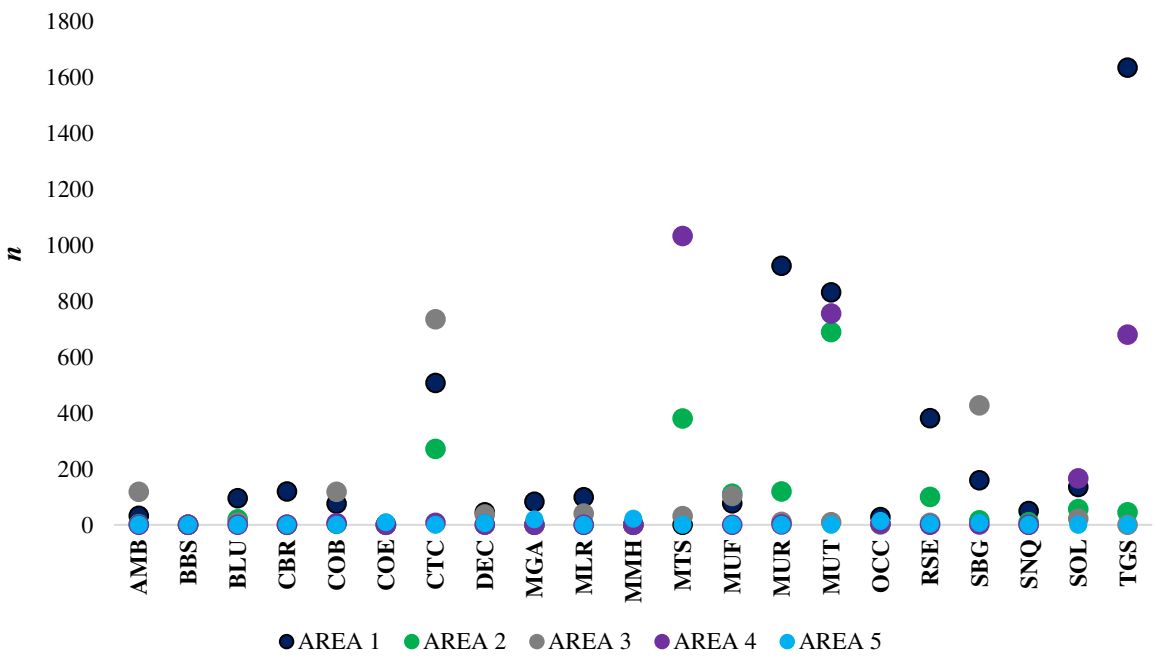

Figure 68 – Dot plot of the 21 most commonly caught species across different five areas, based on the number of individuals captured using CTRL nets. Each dot represented the number of individuals of a specific species caught in each area showing which species were predominant in each zone.

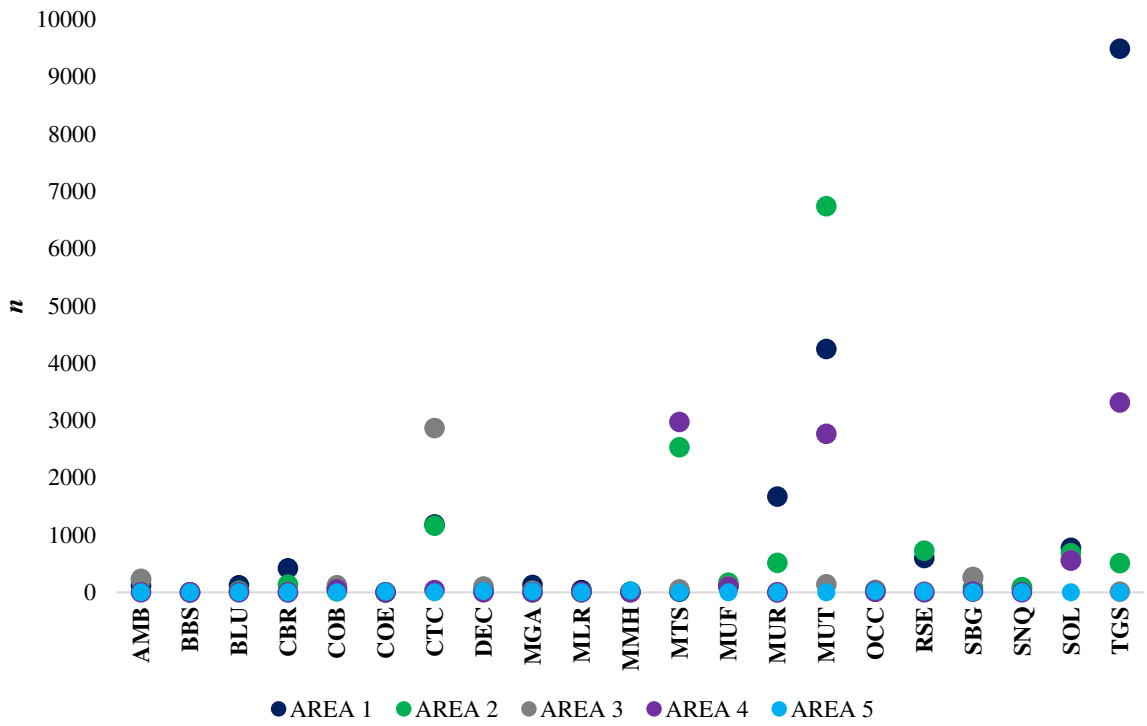

Figure 69 – Dot plot of the 21 most commonly caught species across different five areas, based on the number of individuals captured using TEST nets. Each dot represented the number of individuals of a specific species caught in each area showing which species were predominant in each zone.

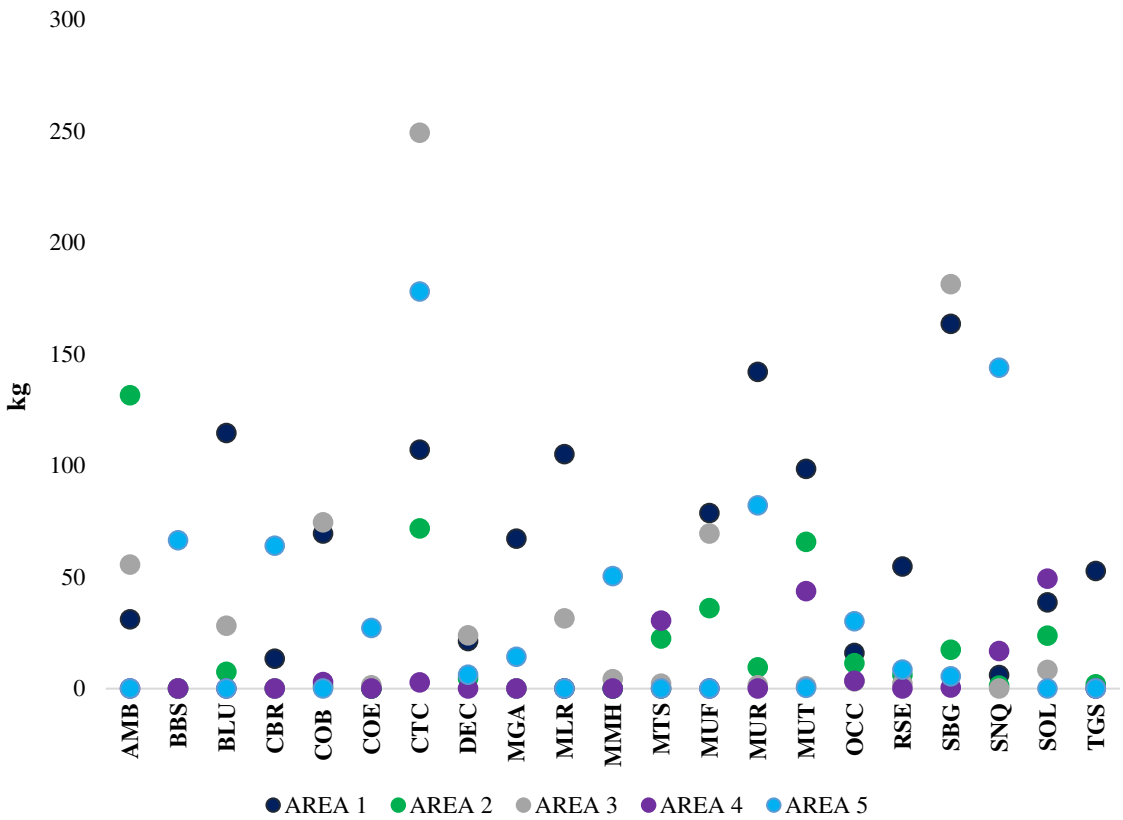

Figure 70 – Dot plot of the 21 most commonly caught species across different five areas, based on the kilograms using CTRL nets. Each dot represented the number of individuals of a specific species caught in each area showing which species were predominant in each zone

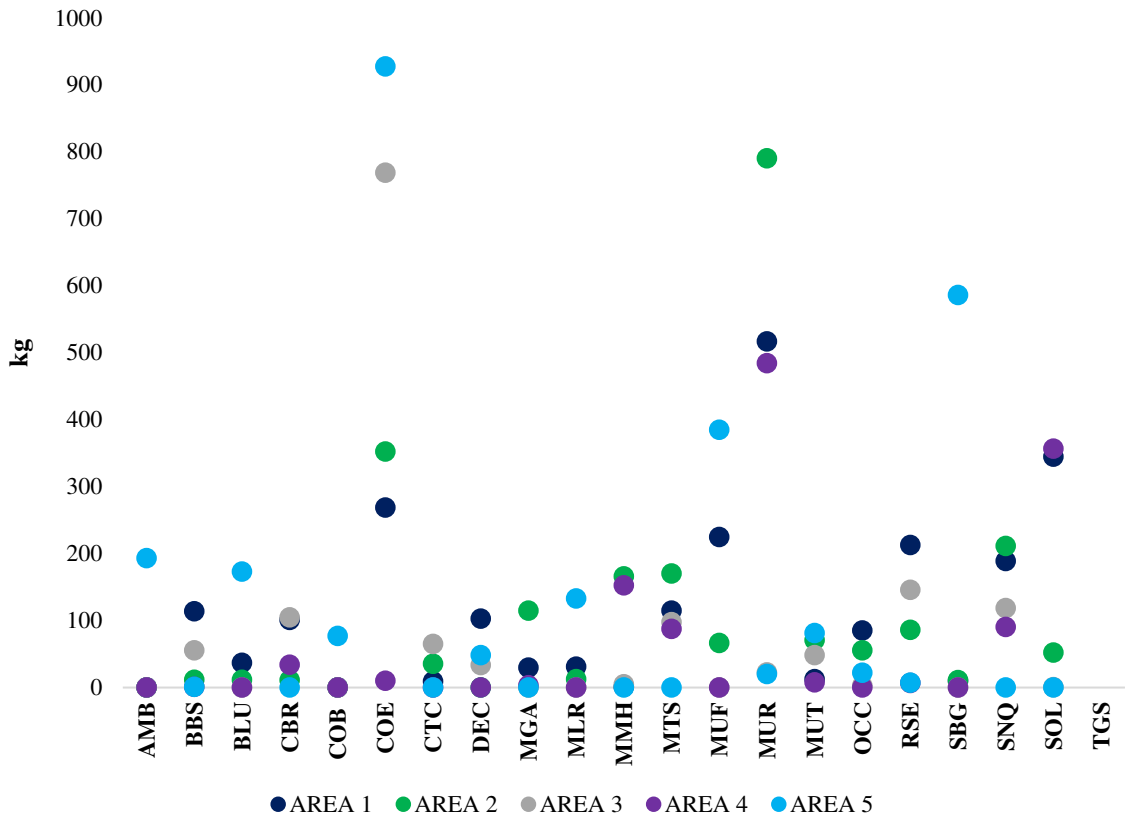

Figure 71 – Dot plot of the 21 most commonly caught species across different five areas, based on the kilograms captured using TEST nets. Each dot represented the number of individuals of a specific species caught in each area showing which species were predominant in each zone

3.2.2.1. Index on species composition

Considering the total number of species caught over the three years (2021, 2022 and 2023) in all five areas, the total species richness was 83. However, it was important to consider the variables of year, area, and type of net to analyse the differences in specie composition in the different nets and area.

Therefore, the diversity of species between the two types of nets was first evaluated, considering all areas and all years together through the Sørensen index that was 0.89, suggesting a change in species assemblages between CTRL and TEST nets.

Then, this index was analysed considering comparing area by area and also each area individually (Table 7).

- **Areas with greater similarity**: AREA 1, AREA 4, and AREA 5 show higher Sørensen index values, respectively 0.71, 0.70, and 0.72, indicating a higher similarity in species caught by both CTRL and TEST nets in these regions. This means that in these areas, the two nets captured similar species.
- **Areas with greater difference**: AREA 2 (0.58) and AREA 3 (0.67) have lower Sørensen index values, suggesting that the species caught by the CTRL and TEST nets differ more

significantly. This could be due to local factors such as environmental variability or differences in the nets' effectiveness in relation to the species present in those areas.

Table 7 – Number of species per type of net indicated in each area and the values needed for the elaboration of the index were also reported.

	AREA1	**AREA2**	**AREA3**	**AREA4**	**AREA5**	**all areas**
N. of species in CTRL&TEST nets	57	58	56	37	34	83
N. of species in CTRL nets	49	33	48	25	19	72
N. of species in TEST nets	50	54	46	35	34	77
N. of species common both CTRL&TEST nets (*c*)	35	25	31	21	19	66
2c	70	50	62	42	38	132
$S_{CTRL}+S_{TEST}$	99	86	93	60	53	149
Sørensen index	**0.71**	**0.58**	**0.67**	**0.70**	**0.72**	**0.89**

The Shannon index was used to evaluate the equitability, or how evenly the species were distributed between the two nets. The values reported were 0.67 for CTRL nets and 0.52 for TEST nets. These values indicate that in the CTRL nets, the distribution of species was more even compared to the TEST nets. Although both nets showed some degree of equitability, the CTRL nets tend to have a more balanced distribution of species. This could be explained by the fact that the CTRL nets were standardized control nets, designed to reflect normal conditions, while the TEST nets might be more specific or experimental, selectively capturing certain species.

The Sørensen index and the Shannon index provided complementary information. The Sørensen index showed how similar the species caught by the two nets are in each area, while the Shannon index evaluated how evenly species are distributed across the catches. The analyses revealed that while CTRL and TEST nets generally capture fairly similar species (especially when combining data from all areas), there were significant local differences. This suggested that different nets capture different species depending on the area, and while there was overall similarity, local factors such as environmental conditions or the specific design of the nets could cause variations in species composition

3.2.2.2. Fishing effort in CTRL and TEST nets

In the data processing phase, both for number of individuals (n) and for weight (kg) CPUE (Catch Per Unit Effort) were calculated, which served as an abundance index used to monitor the available biomass of a resource (Maunder and Punt, 2004). Regarding the CPUE (Catch Per Unit Effort) based on the number of individuals, it was important to note that this data have not

been consistently recorded by all fishers due to the perception that counting every individual captured was very time-consuming. On the contrary, the total weight of the catch was always a present data according to the delivery to the Harbor Office as expected by the Commission Implementing Regulation (EU) No 404/2011 of 8 April 2011 lays down detailed rules for the implementation of Council Regulation (EC) No 1224/2009, which establishes a community control system to ensure compliance with the rules of the Common Fisheries Policy (see on Supplementary Materials S4). In Figure 72 $CPUE_W$ means ± standard deviation was reported for each area during the three years. Analysing the CPUE based on weight ($CPUE_W$), it was observed that using CTRL nets in:

- 2021, the highest fishing effort was recorded in AREA 5>AREA 2>AREA 4>AREA 3 having respectively a CPUEw equal to 10.70 ± 7.38, 9.87 ± 0.65, 9.24 ± 6.20 and 4.01 ± 2.00. (Note: AREA 1 did not carry out trials in this year).
- 2022, the highest fishing effort was recorded in AREA 3>AREA 1>AREA 5>AREA 2, having respectively a CPUEw equal to 22.48 ± 22.04, 20.37 ± 23.04, 18.42 ± 6.53, and 2.59 ± 0.63 (Note: AREA 4 did not carry out CTRL trials in this year).
- 2023, the highest fishing effort was recorded in AREA 1>AREA 2>AREA 5> AREA 4> AREA 3, having respectively a CPUEw equal to 37.33 ± 31.57, 21.64 ± 42.35, 19.95 ± 7.47, 10.71 ± 5.55, and 10.04 ± 7.79.

Analysing the CPUE based on weight ($CPUE_W$), it was observed that using TEST nets in:

- 2021, the highest fishing effort was recorded in AREA 2>AREA 4>AREA 5>AREA 3 having respectively a CPUEw equal to 15.19 ± 16.64, 14.32 ± 13.21, 9.89 ± 3.43 and 4.43 ± 2.69. (Note: AREA 1 did not carry out trials in this year).
- 2022, the highest fishing effort was recorded in AREA 1>AREA 4>AREA 2>AREA5>AREA3, having respectively a CPUEw equal to 39.72 ± 54.77, 15.33 ± 8.99, 14.05 ± 20.30, 10.32 ± 4.12, and 9.05 ± 7.44.
- 2023, the highest fishing effort was recorded in AREA 1>AREA 2>AREA > AREA 5> AREA 4, having respectively a CPUEw equal to 45.99 ± 64.61, 28.81 ± 46.86, 11.24 ± 9.29, 9.59 ± 2.79, and 8.26 ± 4.06.

In Table 8 all $CPUE_N$ and $CPUE_W$ for all the three years for both CTRL and TEST trials were reported.

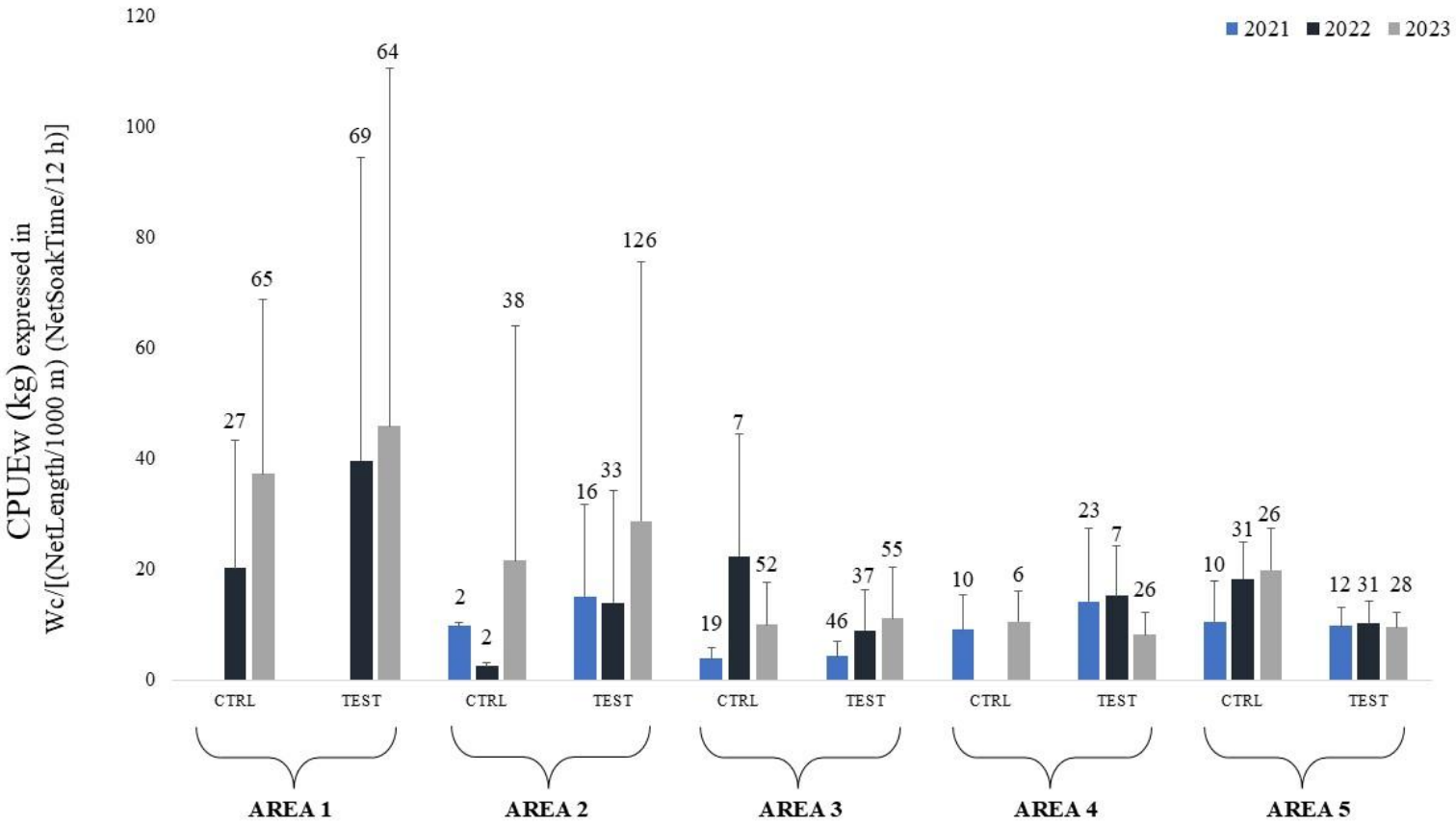

Figure 72 – Graph showing the $CPUE_W$ (mean ± st.dev.) expressed in expressed in Wc/[(NetLength/1000 m) (NetSoakTime/12 h)] for each year (2021, 2022, and 2023) in all five areas (AREA, 1, AREA 2, AREA 3, AREA 4, and AREA 5). In AREA 1 the year 2021 was missing because the fishers in this area have not been involved yet and in AREA 4 in the year 2022 fishers did not carry out CTRL trials. Numbers above the st.dev. symbol reported number of trials conducted in each area for both CTRL and TEST nets.

What can be observed in Figure 71 was that the trend of CPUEw in all areas was higher in the TEST trials compared to the CTRL trials, with the exception of Area 5 (Piombino), where the CPUEw of the TEST nets was lower than that of the controls.

Table 8 – Mean ± st.dev. of $CPUE_N$ and $CPUE_W$ in CTRL and TEST nets for each year in all five areas were reported for every vessel with their own registration number. The symbol "-" means that data were not available and " * " means that was not possible to calculate the st.dev. because n=1.

	$CPUE_N$	**$CPUE_W$**
AREA 1		
CTRL n=92	179.86 ± 235.50	32.35 ± 30.22
2022 n=27	176.25 ± 258.63	20.97 ± 23.04
2023 n=65	181.30 ± 227.72	37.33 ± 31.57
TEST n=133	310.86 ± 462.65	42.74 ± 59.57
2022 n=69	294.20 ± 270.03	39.72 ± 54.77
2023 n=64	328.30 ± 603.89	45.99 ± 64.61
AREA 2		
CTRL n=42	200.88 ± 545.15	20.17 ± 40.51
2021 n=2	23.33*	9.87 ± 0.65
2022 n=2	-	2.59 ± 0.63
2023 n=38	206.43 ± 552.92	21.64 ± 42.35
TEST n=175	265.82 ± 537.56	24.78 ± 41.47
2021 n=16	50.22 ± 66.94	15.19 ± 16.64
2022 n=33	68.22 ± 65.50	14.05 ± 20.30
2023 n=126	327.33 ± 599.42	28.81 ± 46.86
AREA 3		
CTRL n=78	18.26 ± 13.08	9.69 ± 10.09
2021 n=19	11.69 ± 6.67	4.01 ± 2.00
2022 n=7	29.00*	22.48 ± 22.04
2023 n=52	20.50 ± 14.13	10.04 ± 7.79
TEST n=138	19.06 ± 13.75	8.38 ± 7.72
2021 n=46	15.86 ± 11.18	4.43 ± 2.69
2022 n=37	19.40 ± 10.66	9.05 ± 7.44
2023 n=55	21.61 ± 16.28	11.24 ± 9.29
AREA 4		
CTRL n=16	189.67 ± 208.84	9.79 ± 5.72
2021 n=10	207.22 ± 211.42	9.24 ± 6.20
2023 n=6	14.22*	10.71 ± 5.55
TEST n=56	17.77 ± 143.27	11.63 ± 9.81
2021 n=23	186.28 ± 131.49	14.32 ± 13.21
2022 n=7	291.48 ± 145.85	15.3 ± 8.99
2023 n=26	22.05 ± 13.57	8.26 ± 4.06
AREA 5		
CTRL n=67	-	17.86 ± 7.52
2021 n=10	-	10.70 ± 7.38
2022 n=31	-	18.42 ± 6.53
2023 n=26	-	19.95 ± 7.47
TEST n=71	-	9.96 ± 3.50
2021 n=12	-	9.89 ± 3.43
2022 n=31	-	10.32 ± 4.12
2023 n=28	-	9.59 ± 2.79

3.2.3. Effects of acoustic deterrent devices on dolphin interactions

3.2.3.1. Frequency of interactions

Among the 868 total trials (295 CTRL and 573 TEST) conducted over the three years (2021, 2022, and 2023) in all five areas, the 19.81% of trials recorded both direct dolphin interactions as sightings or indirect interactions as damages to the catch or to the gear (represented by the presence of holes in the net) from dolphins or other species.

Among these 172 harmful trials, the 65.70% (n=113) were using CTRL nets and the 34.30% (n=59) using TEST nets. In the pie charts below percentage of each area where with direct and/or indirect interactions occurred using CTRL nets (Figure 73) and TEST nets (Figure 74) were reported.

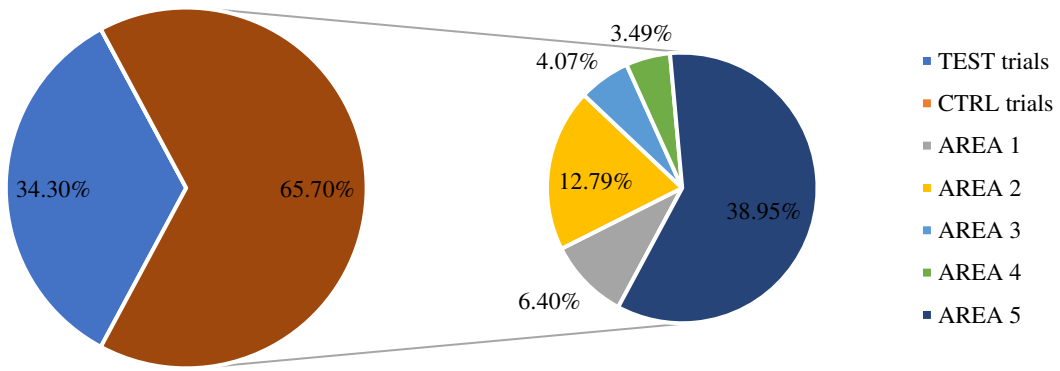

Figure 73 – Pie chart shows the occurrence of harmful interactions between CTRL and TEST trials. For the subset of CTRL trials, it also displays the occurrence for each area.

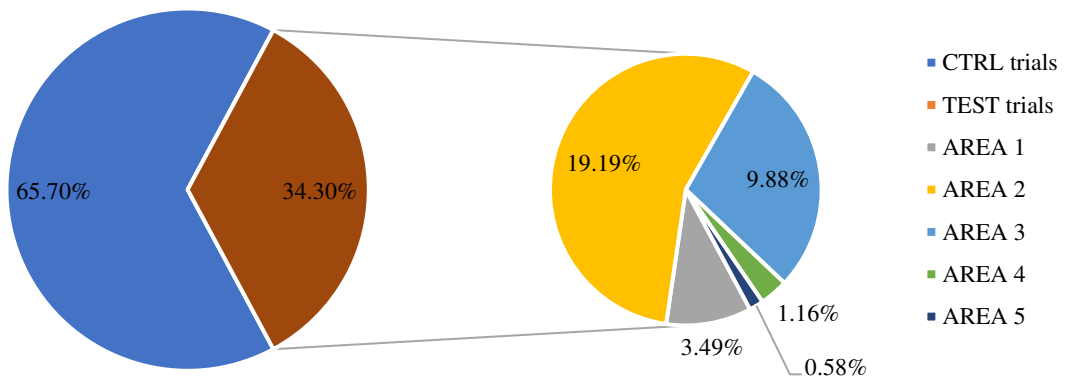

Figure 74 – Pie chart shows the occurrence of harmful interactions between CTRL and TEST trials. For the subset of TEST trials, it also displays the occurrence for each area.

Among these 172 trials, the 16.86% (n=29) was affected by damages to the catches from other species such as octopus or moray eel and not from dolphins, instead in the rest of 83.14% of trials (n=143) recorded both dolphin sightings or damages to the catch or to the gear caused by dolphin.

Considering only the trials where dolphins interactions occurred, in the 5.81% only dolphin sightings were recorded (n=10), while the other 77.33% of total harmful trials recorded both dolphin sightings during setting and hauling time and damages to the gear or to the catch (n=133) (Figure 75).

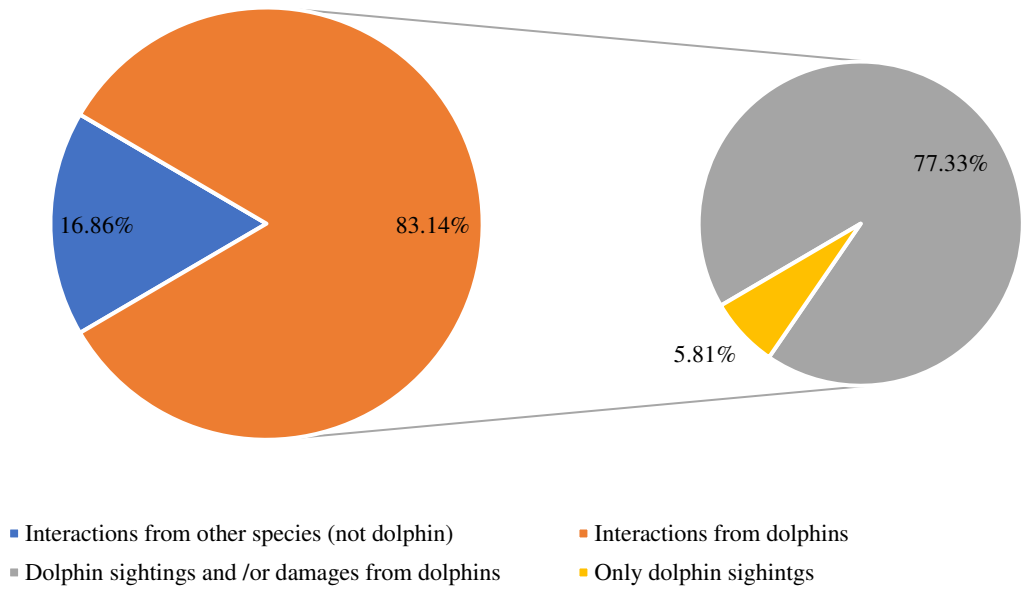

Figure 75 – Pie chart shows the 172 trials where harmful interactions occurred divided by those from other species and those from dolphins. Moreover, the subset distinguishes between interactions with only dolphin sightings and those where sighing and/or damages occurred.

The following maps showed for each area the occurrence of dolphin interactions (Figure 76, 77, 78, 79, and 80). The hotspot areas were obtained by cross-referencing the geographical coordinates of the fishing area that had recorded interactions with dolphins, whether direct (sightings) or indirect (damages to the catch and/or to the fishing gear). The "point cloud" command typically referred to the visualization and analysis of a set of points in a 3D space. However, when points with geographical coordinates were plotted with a variable like dolphin interactions, it was likely referring to the process of creating a point layer on a 2D map using those coordinates and then applying a colour gradient to represent the values of

that variable (in this case, dolphin interactions). Since there were three ways in which the variable "dolphin interactions" was expressed (dolphin sightings, damages to the catch from dolphin and damages to the gear from dolphin), the colours were determined by whether an area exhibited one to all three variables. The more intensely coloured (dark red) an area was, the more both direct and indirect interactions have occurred there. In contrast, the lighter and opaquer the colour (matt red), the more likely it was that only one type of interaction has occurred in that area.

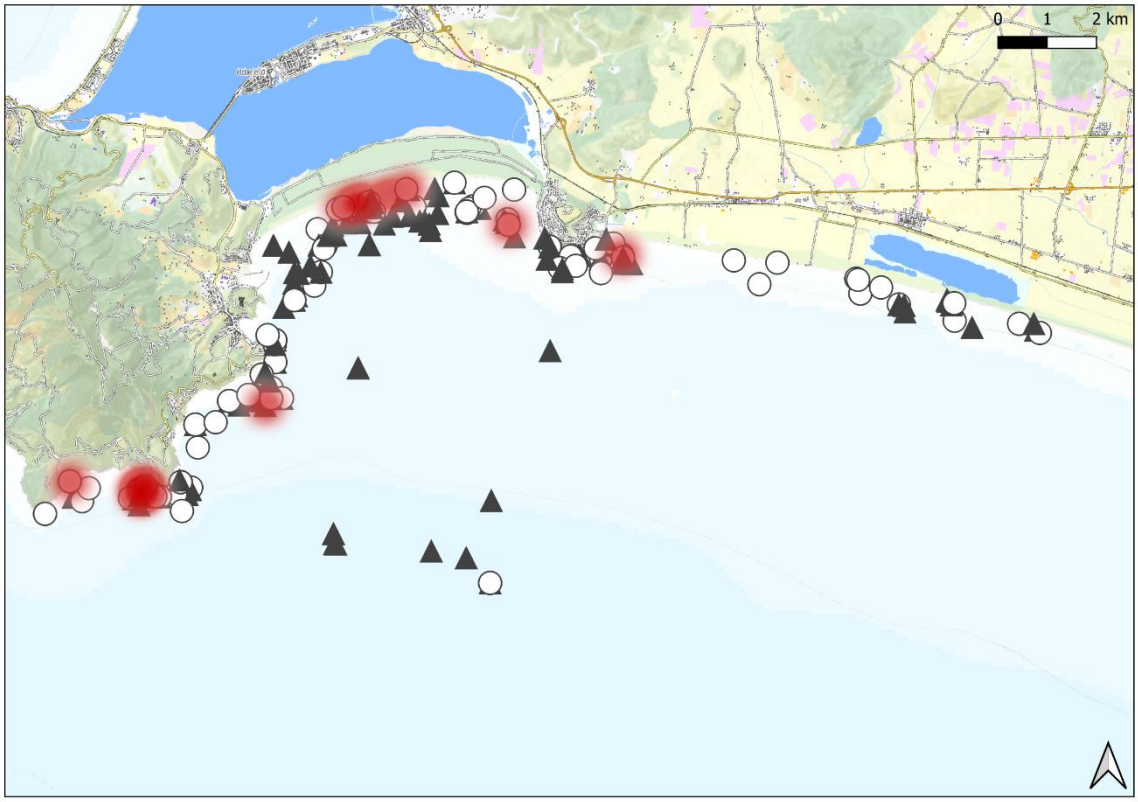

Figure 76 – Locations of the trials carried out in AREA 1 (Porto Ercole) with both CTRL and TEST trials of all three years (2021, 2022, and 2023). The heatmaps around the trials qualitatively indicated the areas with dolphin interactions (dark red: more interactions, matt red: less interactions). The symbol ○ referred to CTRL trials and the symbol ▲ referred to TEST trials. Map created with QGIS software version 3.28.0 "Firenze" (http://qgis.org).

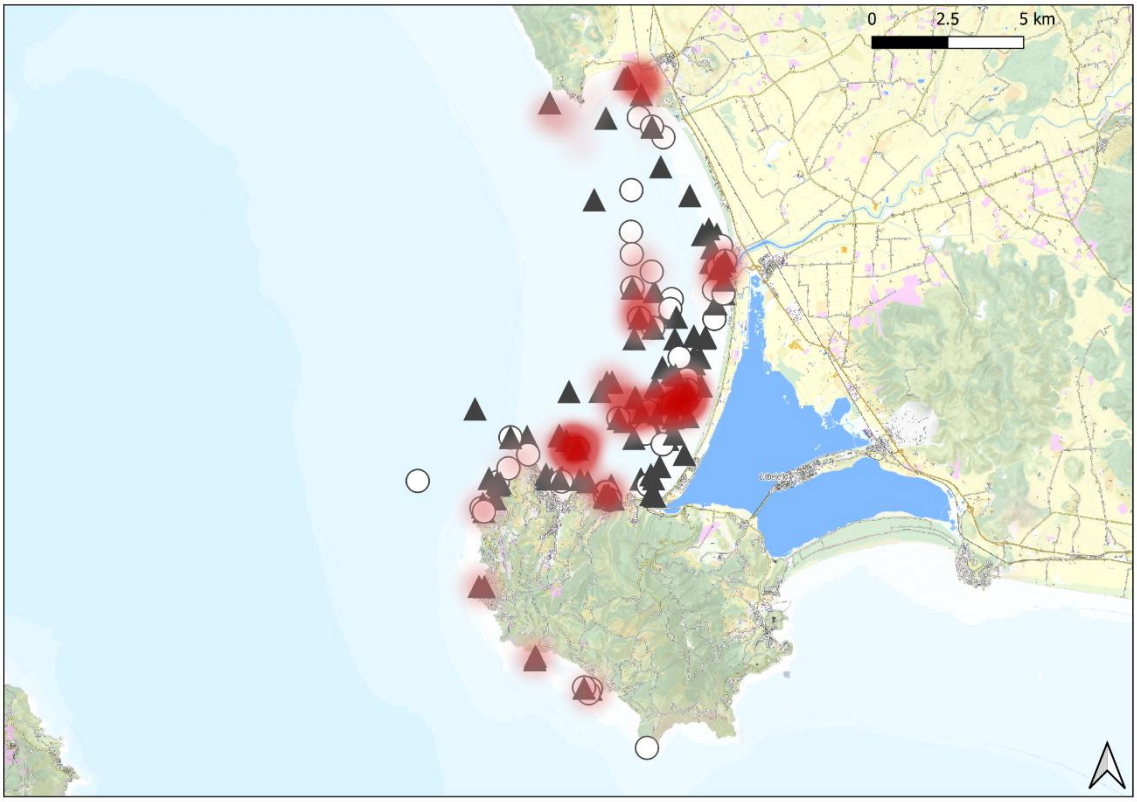

Figure 77 – Locations of the trials carried out in AREA 2 (Porto Santo Stefano) with both CTRL and TEST trials of all three years (2021, 2022, and 2023). The heatmaps around the trials qualitatively indicated the areas with dolphin interactions (dark red: more interactions, matt red: less interactions). The symbol ○ referred to CTRL trials and the symbol ▲ referr8d to TEST trials. Map created with QGIS software version 3.28.0 "Firenze" (http://qgis.org).

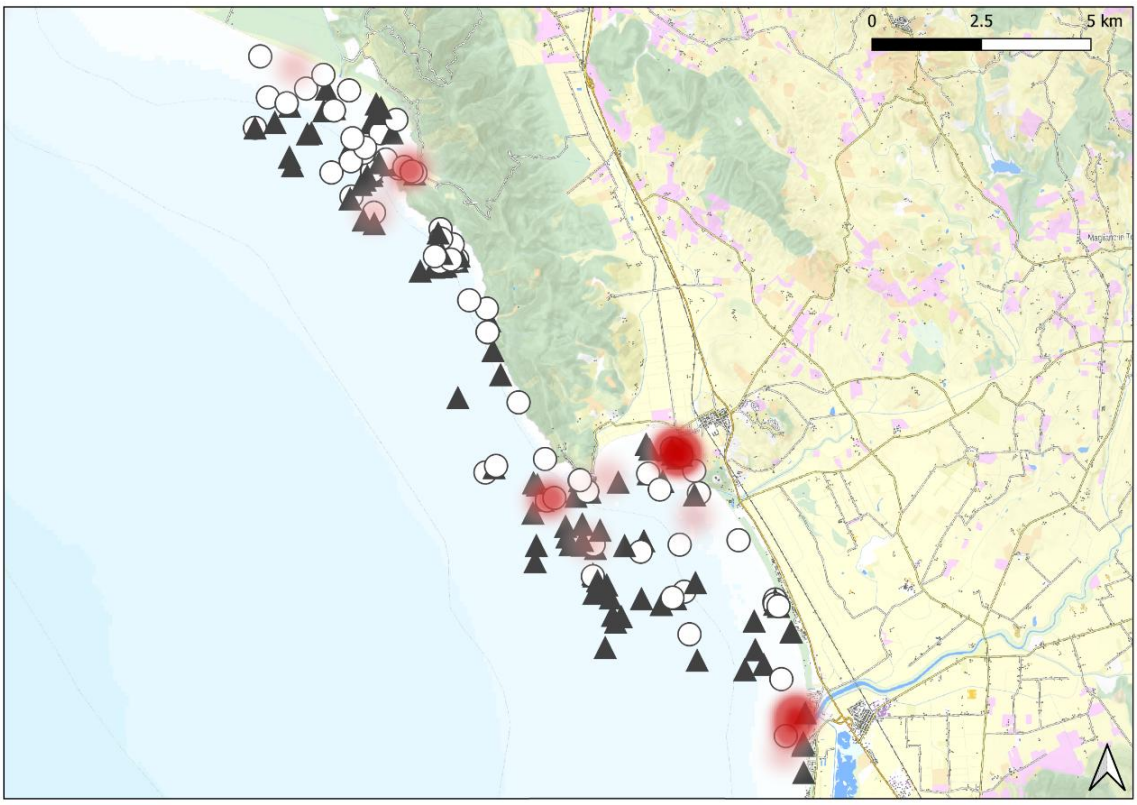

Figure 78 – Locations of the trials carried out in AREA 3 (Talamone) with both CTRL and TEST trials of all three years (2021, 2022, and 2023). The heatmaps around the trials qualitatively indicated the areas with dolphin interactions (dark red: more interactions, matt red: less interactions). The symbol ○ referred to CTRL trials and the symbol ▲ referred to TEST trials. Map created with QGIS software version 3.28.0 "Firenze" (http://qgis.org).

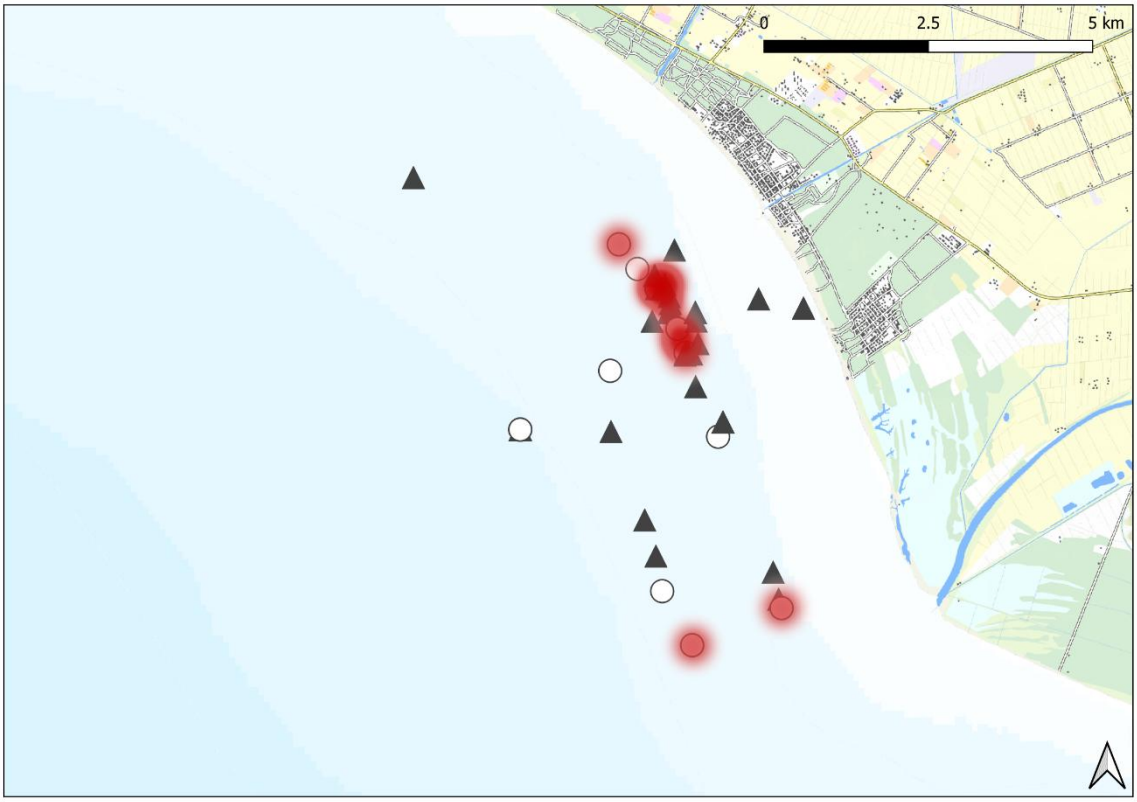

Figure 79 – Locations of the trials carried out in AREA 4 (Marina di Grosseto) with both CTRL and TEST trials of all three years (2021, 2022, and 2023). The heatmaps around the trials qualitatively indicated the areas with dolphin interactions (dark red: more interactions, matt red: less interactions). The symbol ○ referred to CTRL trials and the symbol ▲ referred to TEST trials. Map created with QGIS software version 3.28.0 "Firenze" (http://qgis.org).

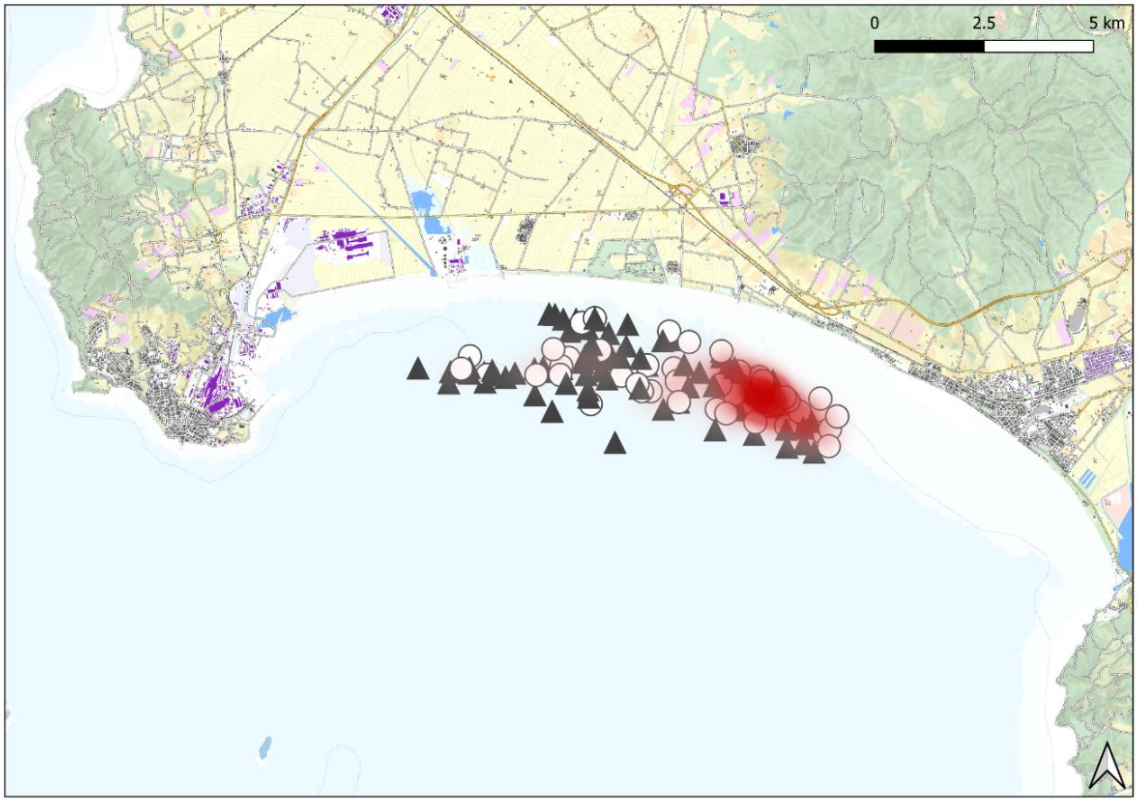

Figure 80 – Locations of the trials carried out in AREA 5 (Piombino) with both CTRL and TEST trials of all three years (2021, 2022, and 2023). The heatmaps around the trials qualitatively indicated the areas with dolphin interactions (dark red: more interactions, matt red: less interactions). The symbol ○ referred to CTRL trials and the symbol ▲ referred to TEST trials. Map created with QGIS software version 3.28.0 "Firenze" (http://qgis.org).

3.2.3.2. Occurrence of catch damages from common bottlenose dolphin or other species

Among the 868 total trials conducted in all five areas during the three years (2021, 2022, and 2023), the damages to the captures were recorded in the 15.81% of total trials (n=138), distinguishing that in the 21.00% (n=29) of trials damages were occurred from other species such as common octopus, sea fleas, moray eel or conger (≠ dolphins) and in the 79.00% (n=109) of trials damages were recorded from direct dolphin interaction. Taking into account the type of net employed among the 138 trials, damages occurred in 97 trials using CTRL nets (70.29%) and in 41 trials using TEST nets (29.71%).

In general, comparing with the total of CTRL and TEST trials (respectively n=295 and n=573), during the three years (2021, 2022, and 2023) in all five areas, damages to the catch caused by other species (≠ dolphins) occurred to the 2.71% (n=8) of total CTRL trials and for the 3.67% (n=21) of the total TEST trials. Whereas damages to the catches occurred directly by common bottlenose dolphin interactions were recorded for the 30.17% in CTRL nets (n=89) and for the 3.49% in nets employed with acoustic deterrent devices (TEST nets) (n=20) (Figure 81).

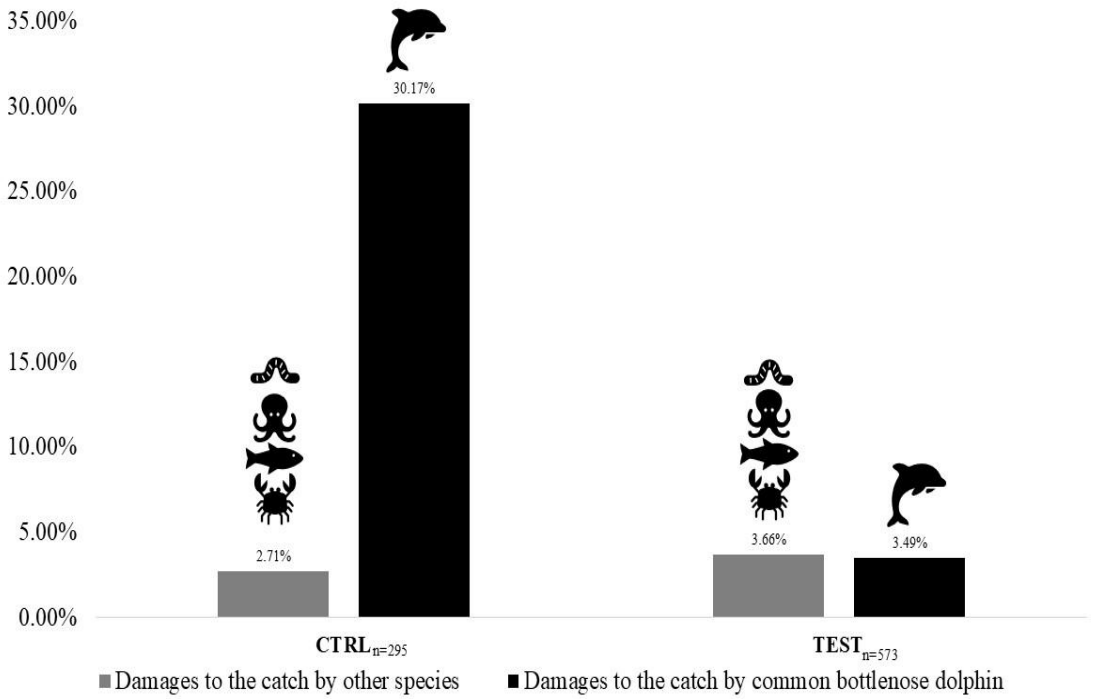

Figure 81 – Graph showing the percentages of damages to the catch occurred among the total CTRL (n=293) and TEST (n=580) nets during the three years of the study (2021, 2022, and 2023) in all five study areas (AREA 1, AREA 2, AREA 3, AREA 4, and AREA 5). The damages are referred both to the ones caused by other species such as common octopus, sea fleas, moray eel or conger (≠ dolphins), both damages caused by common bottlenose dolphin.

Taking into account the occurrence of damages occurred during the three years to the catch also data regarding not only the occurrence but also the number of individuals and the kilograms damaged was recorded on logbooks. Some catches, indeed, were not no longer marketable.

Considering the total number of individuals caught and damaged, and the total kilograms caught and damaged, damage rates were calculated by distinguishing between the two types of nets, CTRL and TEST, with a specific analysis for each area. The results showed that, in general, the damage rate (catch damage rate) in the TEST nets was 0.58% for the number of damaged individuals and 0.45% for the weight of damaged individuals. In the CTRL nets, which did not use the pinger, these rates were significantly higher: the damage rate for the number of damaged individuals reached 2.98%, while for the weight of damaged individuals it was 1.49% (Table 9).

Regarding CTRL trials, in Piombino (AREA 5) was recorded the higher catch damages rate both for number of individuals and for kg and the area with a catch damages rate lower was Porto Ercole (AREA 1). Instead, for TEST trials the highest catch damage rate was recorded in Porto Santo Stefano (AREA 2) both for number of individuals and for kg, instead the lowest catch damages rate was in Marina di Grosseto (AREA 4), instead in Piombino in TEST trials no damages to the catch were recorded.

Table 9 – Catch damage rates were calculated for both number of individuals damaged and kilograms damaged. The total of individuals counted number of individuals captured + number of individuals damaged, and total of kg counted kg captured + kg damaged. The symbol "*" indicated that in AREA 5 no damaged to the catch during CTRL trials occurred.

	TOTAL OF INDIVIDUALS (number of individuals captured + number of individuals damaged)	**CATCH DAMAGE RATE (%)**	**TOTAL OF KG** (kg captured + kg damaged)	**CATCH DAMAGE RATE (%)**
CTRL	13,710	2.98	4,017.97	1.49
AREA 1	6,119	0.11	1,575.69	0.04
AREA 2	2,229	3.50	537.00	3.04
AREA 3	2,089	1.10	967.30	0.46
AREA 4	2,906	0.69	206.63	0.97
AREA 5	367	76.57	731.35	4.99
TEST	54,308	0.58	13,264.34	0.45
AREA 1	2,0639	0.01	3,373.28	0.32
AREA 2	1,7658	1.40	3,540.51	0.87
AREA 3	5517	1.11	2,108.41	0.78
AREA 4	10,328	0.06	1,436.22	0.13
AREA 5	166	*0.00	2,805.93	*0.00

The following pictures showed some photos that has been taken during trials carried out with observer on board. Based on the study of Lauriano et al. (2004), the damages to the catches were recorded recognizing those occurred by other marine organisms such as common octopus, sea fleas, moray eel or conger (≠ dolphins) (Figure 82) or directly by dolphin interactions (Figure 83). The damages to the catches amounted of a total 1,251.25 kg for all CTRL and TEST trials, respectively with 1,189.23 and 62.02 kg. Considering the 72 species captured using CTRL nets, 44 species were found damaged, while among the 77 species caught with TEST nets, 26 species were found damaged. For CTRL trials the most damaged species (>50 kg) were *Sparus aurata*, *Seriola dumerili*, *Umbrina cirrosa*, *Sarpa salpa* and *Mugil cephalus*, respectively with a total of 420.00, 118.00, 113.00, 87.50, 87.00 kg. While using TEST nets the most caught species (≥5 kg) were *Mullus barbatus* and *Arnoglossuss laterna*, respectively 14.35 and 5.00 kg.

Figure 82 – Damages to the catch: **A**. Knot of conger, **B**. Gilthead seabream damaged by octopus' bite. **C**. Moray eel caught alive with a *Diplodus* spp. In the mouth taken from the net. **D**. *Diplodus* sp. bitten by conger, Vestigial damages by caused by scavenging organisms (mostly Isopoda) occurred on common pandora (**E**) and greater amberjack (**F**).

Figure 83 – **A**. Bite of a dolphin to a common sole. Head (**B**) and body (**C**) of a red mullet which was notable positively correlated with the presence of dolphins. Mediterranean hake damaged by dolphins (**D**). These two are target species of common bottlenose dolphin. Type of catch damages inspired by Lauriano et al., 2004.

From economic point of view, a data collected on logbook was also the economic loss regarding the damages occurred to the catch both occurred by dolphins or other species. Among the 139 trials that recorded a damage to the gear indicating also how much in terms of euros (€) was the economic loss. First of all, the economic loss due to damages to the catch during the three years in all five areas amounted to a total of €2,112.00 for damages occurring in trials where CTRL nets were used (n=98), and €840.00 for those occurring in trails where TEST nets were used (n=41). On average, the economic damage amounted differently area by area as it is shown in Table 10.

Each fishers provided an estimate of the damage in monetary terms (€), revealing that fishers in AREA 2 and AREA 5 experienced the greatest economic losses, followed by AREA 3, AREA 1, and AREA 4.

Table 10 – Data regarding number of trials (n) when damages occurred to the catch both caused by common bottlenose dolphin and those caused by other species are reported showing the economic loss (total amount and mean ± st.dev.) different between the two types of nets employed in each area. This symbol "-" means that it is not possible to obtain the mean because n=1.

	TRIALS WITH CATCH DAMAGES BY OTHER SPECIES (n)	**TRIALS WITH CATCH DAMAGES BY DOLPHINS (n)**	**ECONOMIC LOSS (€)**	
			Total	Mean ± St.Dev.
CTRL	9	89	2,112.00	21.55 ± 24.68
AREA 1	6	0	48.00	8.00 ± 7.04
AREA 2	2	17	868.00	45.68 ± 38.28
AREA 3	1	4	290.00	58.00 ± 40.87
AREA 4	0	1	30.00	-
AREA 5	0	67	876.00	13.07 ± 5.65
TEST	21	20	840.00	31.10 ± 26.05

AREA 1	2	0	15.00	7.5 ± 3.54
AREA 2	7	16	464.00	20.17 ± 21.92
AREA 3	12	1	291.00	22.38 ± 17.67
AREA 4	1	1	60.00	30.00 ± 28.28
AREA 5	0	1	10.00	-

3.2.3.3. Occurrence of net damages from common bottlenose dolphin

Among the 868 trials (295 CTRL and 573 TEST) carried out over the three years (2021, 2022, and 2023) in the five areas, the 14.74% of trials (n=128) recorded at least one damage to the gear, which was represented by a presence of hole in the net panel (Figure 54).

The total number of holes occurred in the 78.90% of CTRL trials (n=101) and in the 21.09% in the TEST trials (n=27). The total holes recorded was equal to 838, respectively 2,112 for the CTRL nets and 840 for the TEST nets. The highest number of trials where holes were recorded in the net was in AREA 5 followed by AREA 2, AREA 3, AREA 4, and AREA 1, respectively with n=68, n=41, n=9, n=6, and n=4 trials.

From economic point of view, a data collected on logbook was also the economic loss regarding the damages occurred to the fishing gear. Moreover the 128 trials indicated how much in terms of euros (€) was the economic loss. First of all, the economic loss amounted to a total of €20,991.00 divided into €12,696.00 for damages occurring in CTRL nets (n=98), and €8,295.00 for those occurring in TEST nets (n=24). On average, the economic damage amounted to €125.70 ± 343.09 for the 101 CTRL trials and €307.22 ± 461.71 for the 24 TEST trials (Table 11).

It was important to consider that in the estimation of fisher's economic losses, not only the assessment of lost materials was included but also the time taken to repair the gear. In fact, looking through the written note present logbook, many fishers emphasized the time spent on repairs, which could range from 2 to 5 hours per damaged net (Figure 84).

Nevertheless, the fishers responded differently, indicating that during the CTRL trials, gear damage was much more economically severe in AREA 2 and AREA 3, where the largest economic losses related to the equipment occurred, followed by AREA 5, AREA 4, and AREA 1. During the TEST trials, they reported major economic losses in AREA 2 and AREA 3, followed by much smaller amounts in AREA 4 and 5, while AREA 1 did not record any gear damage in the nets equipped with pingers.

Table 11 – Data regarding number of trials (n) when damages occurred to the fishing gear were reported showing the number of holes (n) and the mean ± st.dev. of the holes diameter (cm) and the economic loss (total amount and mean ± st.dev.) different between the two types of nets employed in each area. This symbol "-" means that data was not obtained and *n=1 so mean and st.dev. could not be calculated.

	TRIALS WITH GEAR DAMAGES (n)	HOLES (n)	HOLES DIAMETER (cm)	ECONOMIC LOSS (€)	
				Total	Mean ± St.dev.
CTRL	101	582.00	130.74 ± 110.06	12,696.00	125.70 ± 343.09
AREA 1	4	26.00	140.00 ± 151.00	410.00	102.50 ± 87.70
AREA 2	20	161.00	187.00 ± 140.23	4,320.00	216.00 ± 166.52
AREA 3	5	36.00	154.00 ± 63.87	6,150.00	1,230 ± 1,005
AREA 4	5	28.00	286.00 ± 330.50	850.00	170.00 ± 90.83
AREA 5	67	331.00	100.07 ± 31.66	966.00	14.42 ± 24.05
TEST	27	256.00	165.65 ± 134.29	8,295.00	307.22 ± 461.71
AREA 1	-	-	-	-	-
AREA 2	21	214.00	162.02 ± 129.14	5,200.00	247.62 ± 152.05
AREA 3	4	24.00	192.50 ± 205.49	3,000.00	750.00 ± 1,166.00
AREA 4	1	8.00	100.00	75.00	*
AREA 5	1	10.00	200	20.00	*

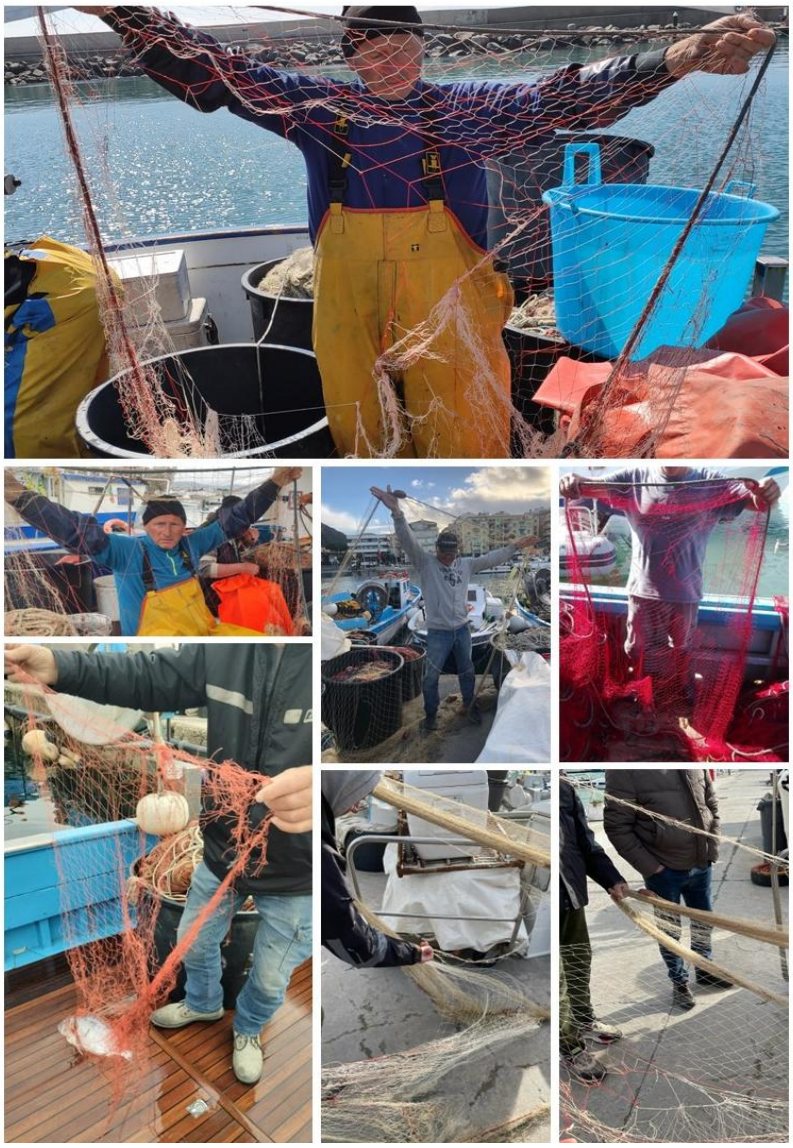

Figure 84 – Fishers involved in the study showed the holes occurred in the net from dolphin interactions.

3.2.3.4. Occurrence of common bottlenose dolphin sightings

According to data recorded on logbooks among the 868 trials (295 CTRL and 573 TEST), the 19.59% (n=172) of trials recorded dolphin interactions, among these in 24 trials dolphin were sighted during hauling and setting time in 50% CTRL and 50% TEST trials. Among the 24 trials where dolphins were sighted, 13 recorded holes in nets, 4 of which, were with pinger equipped on the net (TEST trials) and the other did not have the pinger on the net (CTRL trials).

Dolphins were sighted more were AREA 1 and AREA 2 both using CTRL and TEST nets, respectively 20 and 16 and 28 and 36 (Table 12). In AREA 3, AREA 4 and AREA 5 during TEST trials no dolphins were sighted, while in AREA 3 during CTRL trials no dolphin were sighted.

Table 12 – Number of dolphins sighted in each area both during CTRL and TEST trials.

Type of trials in each area	n.
CTRL trials	
AREA 1	20
AREA 2	28
AREA 3	0
AREA 4	7
AREA 5	2
TEST trials	
AREA 1	16
AREA 2	36
AREA 3	0
AREA 4	0
AREA 5	0
Total common bottlenose dolphins sighted	**109**

The average sighting distance was 97.75 ± 142.40 m for the control nets, while it was 590.42 ± 721.11 m for the TEST nets. This difference, with the TEST nets showing sightings at distances approximately 6 times further away, is due to the activation of the acoustic deterrent device when dolphins were in the neighbourhood of the nets.

Among the 24 trials where dolphins were sighted, 11 trials (3 CTRL and 8 TEST) did not record any damages to the gear such as presence of holes, nor any other damages to the catch caused by dolphins. For the remaining 14 hauls (9 CTRL and 5 TEST), damages to both the catch and the gear were recorded simultaneously, with the exception of one trial where only damages to the catch were recorded and two trials where only damages to the gear were recorded (Figure 85).

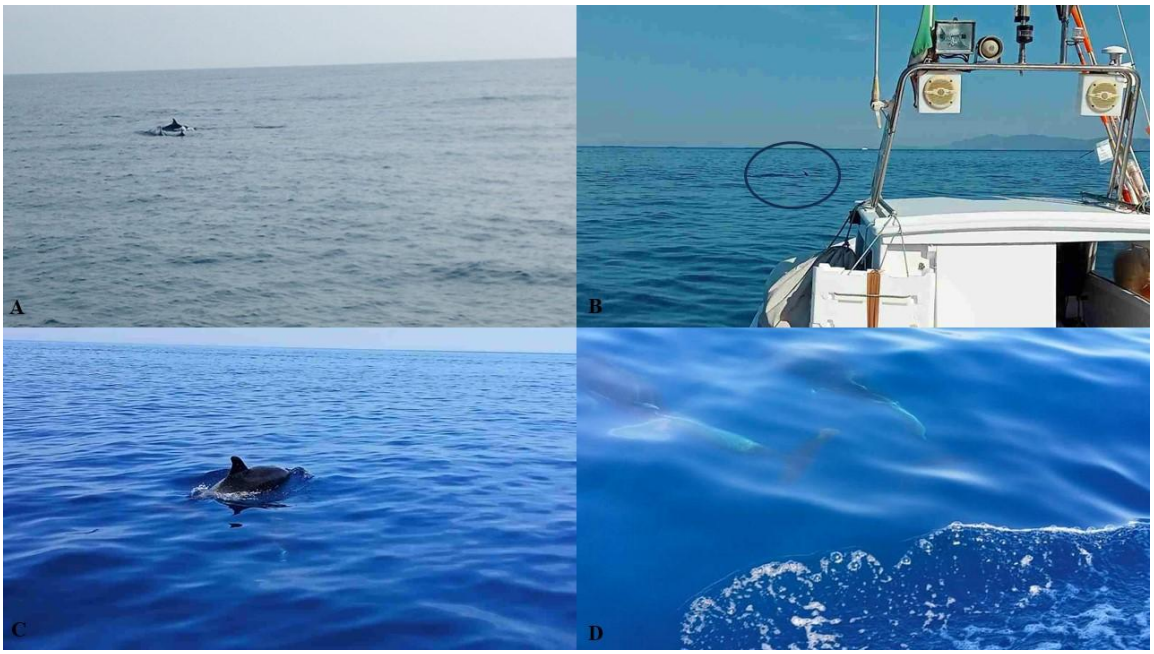

Figure 85 – Dolphin sighting during fishing operation from a distance around 100-200 m (**A** and **B**), then common bottlenose dolphin specimen approached the vessel (**C**) until it was right under the boat (**D**). The fisher wrote in the notes that as soon as he put the acoustic deterrent device in the water, the dolphin moved away.

3.2.4. Statistical analysis and modelling $CPUE_W$ data

The $CPUE_W$ was calculated for each trial. For the statistical analyses, only $CPUE_W$ was used, as $CPUE_N$, as previously explained in paragraph 3.2.2.2, was not a complete and comprehensive enough dataset to be used for binomial statistical analysis and for plotting the linear regression model.

Before performing statistical analysis, it was verified whether there were any differences in $CPUE_W$ based on the type of fishing gear used or whether the trials were matched or unmatched, in order to determine if all observations could be analysed together, regardless of net type or pairing.

Regarding the type of fishing gear, on all 868 observations, 777 were conducted using trammel nets, 58 with combined nets, and 33 with gillnets. Kruskal-Wallis test revealed no significant differences were found ($z = 0.14$; $p > 0.05$) between $CPUE_W$ obtained using different type of fishing gear, so we could confidently treat all observations as part of a unified dataset for further analysis (Figure 86).

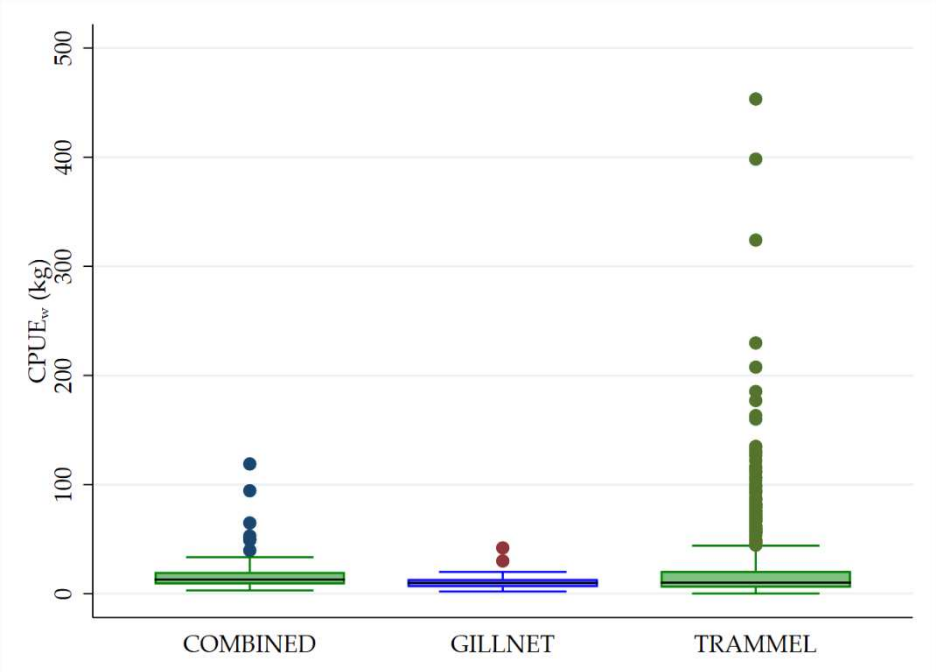

Figure 86– Boxplots of $CPUE_W$ expressed in Wc/[(NetLength/100m)(NetSoakTime/12h)] calculated for type of setnets employed during the three years (2021, 2022 and 2023) in all five areas.

As the number of trials using the control (CTRL) nets was much lower than the number of trials using the TEST nets because the fishers were skeptical and resistant to deploying nets without the acoustic deterrent device, a distinction was made during data processing distinguishing between "matched" and "non-matched" trials.

"Matched" trials were those in which both CTRL and TEST nets were deployed simultaneously, allowing for a direct comparison. On the contrary, "non-matched" trials were those in which there was no pairing of CTRL and TEST nets deployed at the same time.

After comparing the $CPUE_W$ and the $CPUE_N$ of each trial of these two groups matched (n=420) e non-matched (n= 868), through Mann-Whitney test emerged that there were no statistical differences ($z = 0.22$; $p > 0.05$), indicating that it was possible to consider the entirety of the observations (non-matched), not just the matched ones, especially to achieve a larger sample size.

It is important to highlight that matched data allow the observations of the causal effect of pinger on catch per unit effort, while considering all trials, including the unmatched ones, shifted the observer's perspective to whether the presence or absence of the pinger can influence CPUE.

Comparing $CPUE_W$ between CTRL and TEST nets over all three years (2021, 2022 and 2023), both considering all observations together (Figure 87) and considering the matched

ones (Figure 88), the results showed statistically significant differences ($z = 0.00$; $p < 0.001$).

Observing year by year considering only all observations (unmatched and matched) the results showed:

- In 2021, as already published in the paper by Ceciarini et al. (2023), the difference between CTRL and TEST nets was not significant in terms of $CPUE_W$ ($z = 0.79$; $p > 0.05$).
- In 2022, the difference between CTRL and TEST nets was not significant in terms of $CPUE_W$ ($z = 0.98$; $p > 0.05$).
- In 2023, the difference between CTRL and TEST nets was significant in terms of $CPUE_W$ ($z = 0.01$; $p < 0.05$).

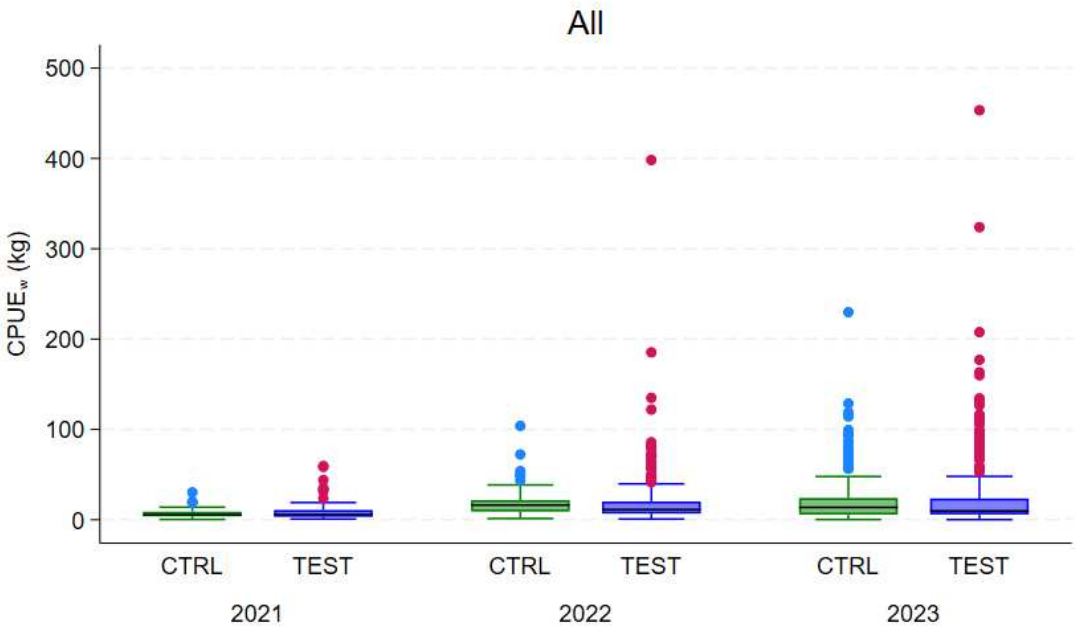

Figure 87 – Boxplot regarding statistical analysis comparing the CPUEw expressed in Wc/[(NetLength/100m)(NetSoakTime/12h)] of all unmatched CTRL and TEST trials over the three years (2021, 2022, 2023).

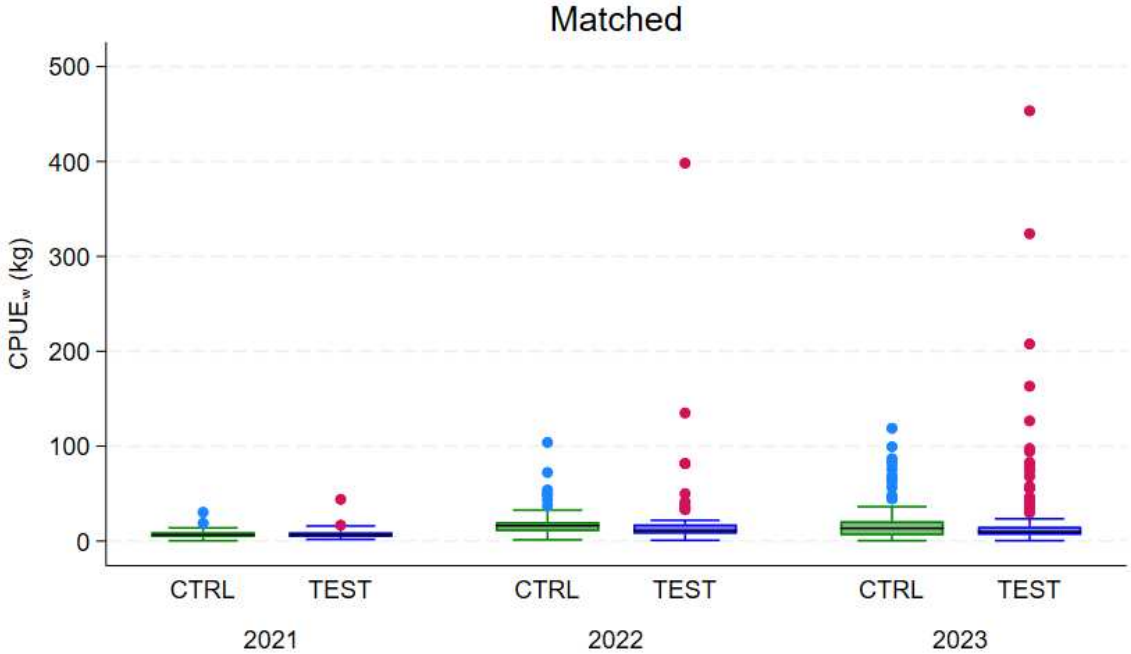

Figure 88 – Boxplot regarding statistical analysis comparing the CPUEw expressed in Wc/[(NetLength/100m)(NetSoakTime/12h)] of all unmatched CTRL and TEST trials over the three years (2021, 2022, 2023).

Observing the five areas and comparing the $CPUE_W$ between CTRL and TEST trails both unmatched, so all observations together (Figure 89) and matched (Figure 90), it resulted that in both cases the statistical analyses were significant ($z = 0.00$; $p < 0.001$).

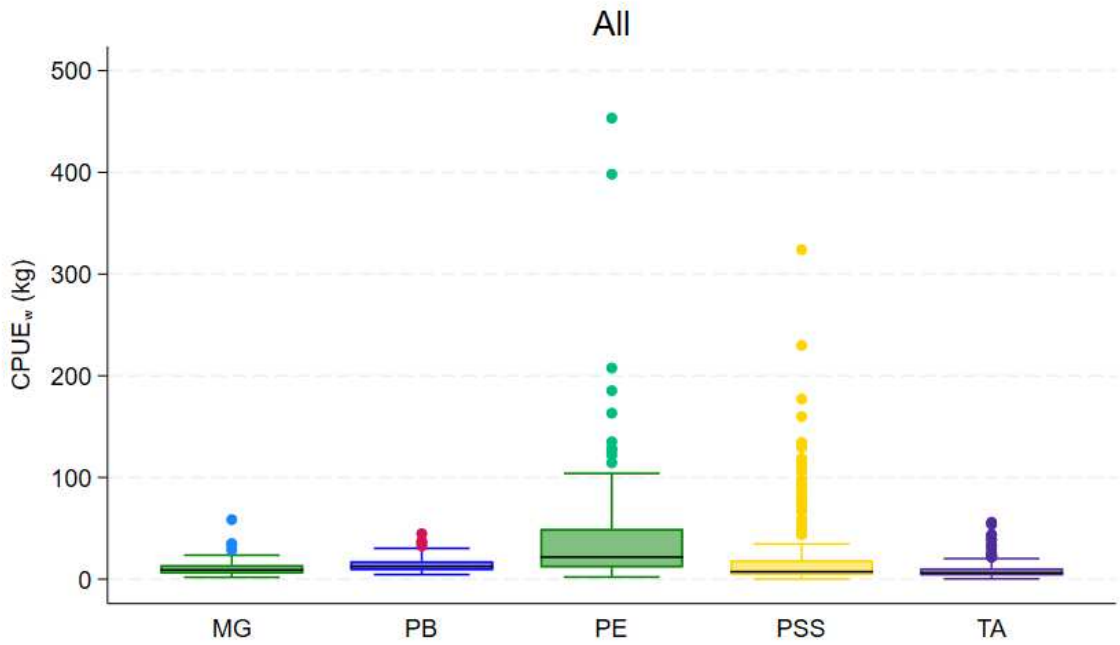

Figure 89 – Boxplot regarding statistical analysis comparing the CPUEw expressed in Wc/[(NetLength/100m)(NetSoakTime/12h)] of all unmatched CTRL and TEST trials over the three years (2021, 2022, 2023).

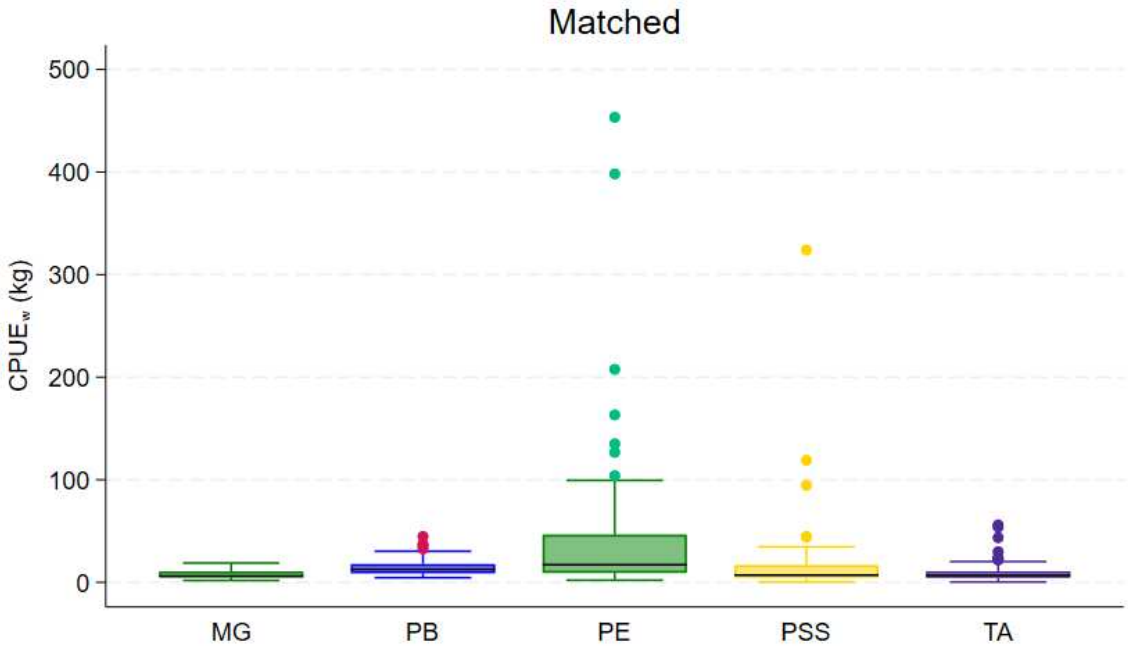

Figure 90 – Boxplot regarding statistical analysis comparing the CPUEw expressed in Wc/[(NetLength/100m)(NetSoakTime/12h)] of all unmatched CTRL and TEST trials over the three years (2021, 2022, 2023).

Linear regression model was used to evaluate whether CPUEw could be influenced by factors other than the type of haul, specifically using CTRL or TEST nets. This model helped understand the relationship between a dependent variable (the one we wanted to predict, in this case was CPUEw) and multiple independent variables (those we used for the prediction, such as season, depth, latitude, longitude, and dolphin interactions both direct and indirect). The dependent variable used in the analysis was the natural logarithm of CPUEw ($logCPUE_W$). The attached graph displayed the empirical distribution of $logCPUE_W$ compared to a normal distribution (Figure 91). The empirical distribution appeared reasonably symmetrical, supporting the assumption of normality in the data. To assess the assumption of homoscedasticity, a graph comparing the fitted values from the model with the residuals was analysed. The graph showed that the residuals are randomly distributed around zero, without any apparent patterns or trends (Figure 92). This behaviour supports the assumption that homoscedasticity was not violated.

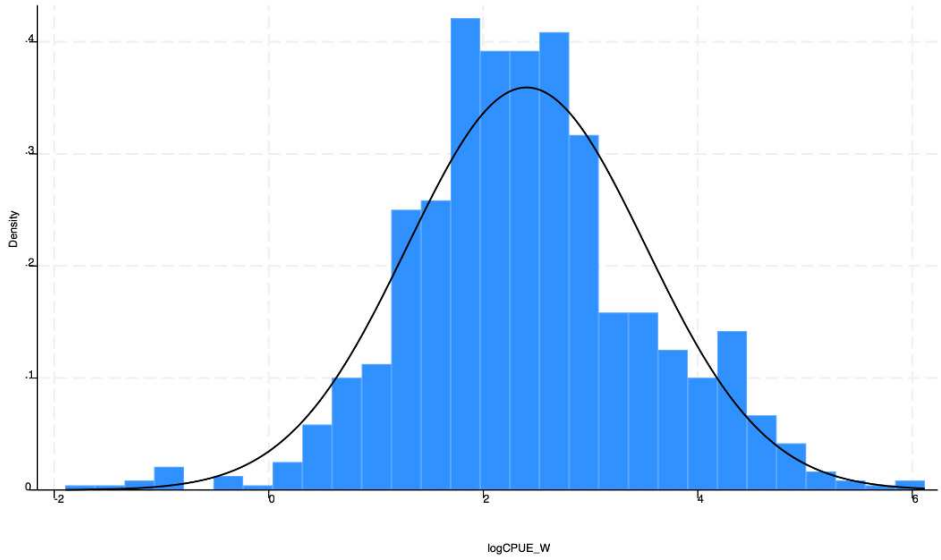

Figure 91 – The graph displayed the empirical distribution of logCPUEw compared to a normal distribution.

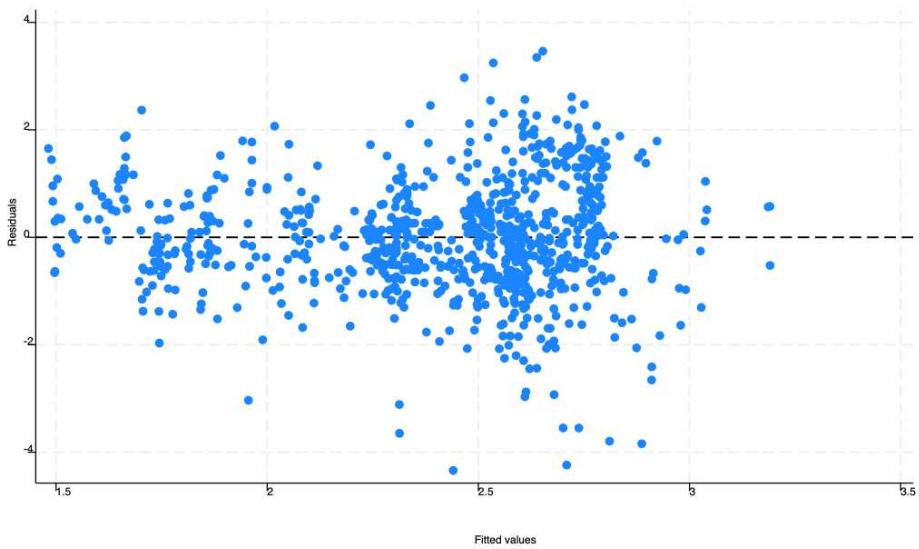

Figure 92 - The graph showed that the residuals are randomly distributed around zero, without any apparent patterns or trends. The homoscedasticity was not violated.

In Table 13 covariates used in the regression model were described.

Table 13 – List of covariates included in the regression model, along with a brief description of each and how they are measured. The covariates represent key factors such as the year of data collection, season, geographical location (latitude and longitude), water depth, and the presence of dolphin interactions, which were considered in the model to analyse their effect on CPUEw.

COVARIATE	DESCRIPTION	MEASUREMENT
YEAR	Year of data collection	Categorical variable (2021, 2022, 2023)
SEASON	Season of the year	Categorical variable (autumn, winter, summer,
LATITUDE	Latitude of fishing trial	Numeric variable (degrees of latitude)
LONGITUDE	Longitude of the fishing trial	Numeric variable (degrees of longitude)
DEPTH	Water depth of the fishing trial	Numeric variable (meters)
INTERACTIONS	Dolphin interactions during trial	Categorical variable (yes, no)

In the linear regression model, one category within each categorical variable was set as the reference. In the linear regression model, variables were treated differently depending on whether they were categorical (nominal) or numerical. For categorical variables, such as season, the model selected one of the categories as a reference. The other categories were then compared to this reference category. This allowed the model to indicate whether there were significant differences between year, seasons, and interactions in their effect on $CPUE_W$. Whereas, for numerical variables, such as latitude, longitude, and depth, the model worked differently. Instead of comparing categories, the model directly estimated the effect of each unit of change in the variable on the dependent variable. The coefficient associated with these numerical variables indicated the effect of an incremental change in the variable on $CPUE_W$: a positive coefficient meant $CPUE_W$ increased, while a negative coefficient meant it decreased. In summary, the model compared categories against a reference for categorical variables, while for numerical variables, it measured the direct impact of continuous changes on $CPUE_W$. The results showed:

Year: comparing 2022 and 2023 to 2021, there was a significantly higher $CPUE_W$ in 2022 and 2023 (for both, $z = 0.00$; $p < 0.05$).

Season: compared to autumn, the $CPUE_W$ was significantly lower in winter ($z=0.00$; $p < 0.05$), while there were no significant differences in summer ($z = 0.91$; $p > 0.05$) and spring ($z = 0.09$; $p > 0.05$) compared to autumn.

Latitude: There were differences in $CPUE_W$, which increased as latitude decreased, meaning that fishing in the north yielded significantly lower catches than in the south ($z = 0.00$; $p < 0.05$).

Longitude: there were not statistical differences in $CPUE_W$ regarding the increasing or decreasing of longitude ($z = 0.52$; $p > 0.05$).

Depth: the $CPUE_W$ was statistically higher in shallower waters than in deeper waters ($z = 0.05$; $p < 0.05$).

Interactions: the CPUEW was not statistically different comparing trials with and without pingers ($z= 0.07$; $p > 0.05$).

The model was developed taking all areas into account; however, as shown in Figure 71, in the Piombino area, the $CPUE_W$ in the control was consistently significantly lower than in the test, indicating a different trend compared to the other areas studied. In fact, when excluding the Piombino data from the linear model analysis, a statistically significant difference (z =

0.03; $p < 0.05$) is observed, with $CPUE_W$ proving to be lower in the presence of dolphins. This finding highlights how the interactions between dolphins and fishing nets, as well as their effects on $CPUE_W$, are strongly linked to the specific characteristics of the site where the hauls were conducted. When comparing this study with other similar research, it emerged that many authors, in processing the data, used models such as GLMs (Generalized Linear Models) and GAMs (Generalized Additive Models). These models were particularly useful for analysing complex, often nonlinear data with non-normal distributions, which were common in this type of context. Both models offered flexible statistical approaches to explore the relationships between predictor variables (such as location, type of fishing gear, or fishing practices) and response variables (e.g., the number of depredation incidents or bycatch mortality). Specifically, GLMs and GAMs allowed for modelling complex and interactive effects between variables, such as environmental conditions (e.g., water temperature and salinity), fishing practices, and cetacean behaviour. One example of application could be analysing how fishing depth interacts with seasons to determine depredation risks by dolphins (Brotons et al., 2008; Cruz et al., 2016; Revuelta et al., 2018). These models can also be used to predict interactions between cetaceans and fishers, for instance, predicting the number of depredation incidents based on factors like the type of fishing gear, cetacean density in an area, or the presence of other species. In this study, however, the linear regression model was considered the most appropriate for analysing CPUE (Catch Per Unit Effort) in relation to specific variables.

3.2.4.1. Variability of $CPUE_W$ and other data between fisher and observer logbook

The involvement of non-specialized personnel (e.g., fishers) in data collection aboard fishing vessels raised questions about the quality and standardization of observations. While collaboration with industry operators was certainly commendable, it was essential to clarify the percentage of samples collected by qualified observers and any differences this might introduce in results and subsequent data analyses. In this study, out of a total of 868 trials, 746 were recorded by fishers, representing 85.00% of the data collected, while 122 trials were documented by qualified observers, accounting for 14.05% of the total. Given this difference in the proportion of data collected, it was important to assess whether there were differences in estimates or data quality in terms of weight using $CPUE_W$ as a comparison parameter. Overall $CPUE_W$ mean considering all trials was 21.28. Then, considering type of data sources the $CPUE_W$ obtained through fishers' logbook was meanly 21.83 ± 36.02 and $CPUE_W$ obtained through observer logbook was 17.88 ± 28.97. When analysing the trials separately based on the use of pingers, a similar trend emerged considering CTRL trials

$CPUE_W$ mean was 20.30 ± 24.94 and 19.21 ± 26.73, respectively for fishers (n = 245) and observers' (n = 50) logbooks. Instead considering TEST trials $CPUE_W$ mean was 22.59 ± 40.35 and 16.95 ± 30.58, respectively for fishers (n = 501) and observers' (n = 72) logbooks. Moreover, statistical analysis comparing $CPUE_W$ between logbook "observer" and logbook "fisher" were conducted. The Shapiro-Wilk test indicated that the data, both when considering only matched trials and when considering all trials, did not follow a normal distribution. Therefore, the Kolmogorov-Smirnov test was applied, revealing a statistically significant difference in CPUEW between the logbook recorded by fishers and the logbook recorded by observers, with $p < 0.005$ for matched data and $p < 0.001$ when considering all trials.

3.3. Cetacean strandings data

Thanks to the systematic collection of information on marine mammal strandings on the Italian coasts, which began in 1986 due to the efforts of the Cetacean Studies Center and the volunteers associated with it, it is possible to consult, only for authorized users, the rich database that contains data dating back to 1713. For this PhD thesis, indeed, data and information from a temporal trend from January 1st, 1713, to December 31st, 2023, regarding strandings, particularly of the common bottlenose dolphins, were analysed to assess the incidence of accidental capture and the impact of these animals with fishing activities.

Over these 310 years, information has been collected on 6,433 stranded or found dead animals at sea. However, strandings do not have a uniform distribution throughout space and time. For example, each year can be so much different one to another mostly due to the fact that peaks are observed in periods ranging from late spring to summer when there was a more frequent human presence on the coasts, which increased the number of reports. Of these 6433 can be elaborated which species was most involved, in which Italian region most strandings occurred, and how the anthropogenic activities affect the cetaceans' deaths. The chart in the Figure 93 shows the timeline of stranded cetaceans recorded over these 310 years.

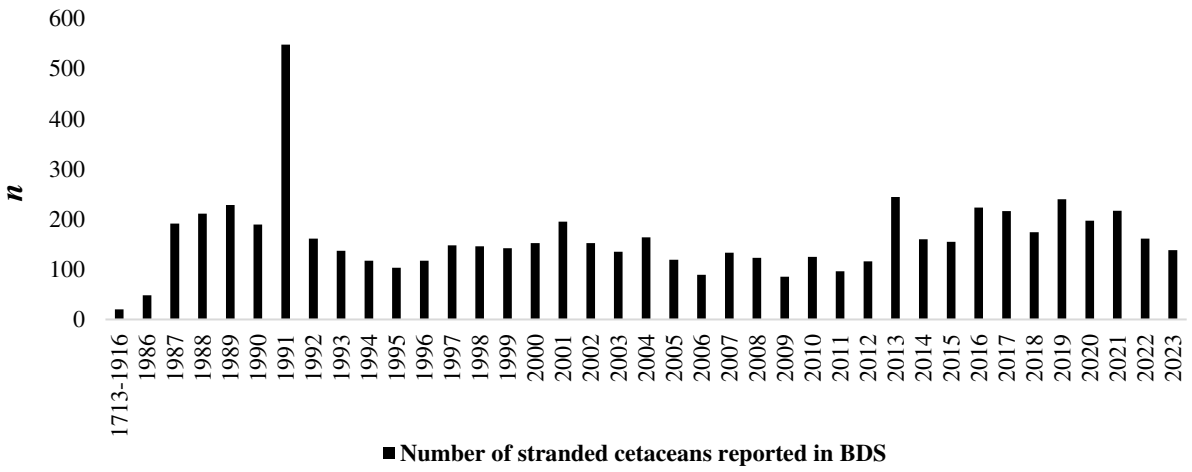

Figure 93 – The temporal trend from January 1st, 1713, to December 31st, 2023, showed the number of cetaceans strandings for each year. The years from 1713 to 1916 were grouped together due to the missing data for some years until 1896 when Cetacean Studies Center was established, and a systematic collection was started.

The data from 1713 to 1916 were grouped together due to missing years and limited data collection during that period. Conversely, data for each year from 1986 onwards have been presented individually. This marks the founding year of the Cetacean Studies Center, initiating a more organized and extensive systematic data collection. A relatively consistent chronological trend was observed with a mean of 158.35 ± 46.97 dead animals (with a minimum n=51 in 1986 and maximum n=245 in 2013), except for the notable peak in the

year 1991, where the number of cetaceans recorded was significantly higher compared to other years, reaching 548 animals. While the annual fluctuations aligned with what has been consistently observed over the past 33 years, from 1990 to the present year 2023.

3.3.1. Occurrence of cetacean strandings in Italian regions

Moreover, Figure 94 shows the Italian regions where stranding events occurred during this temporal trend of 310 years, from 1713 to 2023. Among the 20 Italian regions, only 15 had a stretch of coastline (~7,500 km) facing the various marine territories of the Mediterranean Sea such as the Ligurian Sea, Tyrrhenian Sea, Sardinian Sea, Sicilian Sea, Ionian Sea, and Adriatic Sea. Indeed, the regions involved are Liguria, Tuscany, Lazio, Campania, Calabria, Basilicata, Sicily, Sardinia, Apulia, Abruzzo, Molise, Marche, Emilia-Romagna, Veneto, and Friuli-Venezia Giulia. Each of these regions overlooked different seas, each with distinct geological, morphological, and oceanographic characteristics, that could influence the likelihood and manner of a cetacean stranding events. The regions most involved in the phenomenon of cetacean strandings are Sicily, Apulia, Sardinia and Tuscany with highest percentages, respectively: 15.22%, 14.18%, 12.14%, and 11.99%, instead lowest percentages of strandings occurred in Friuli Venezia Giulia and Basilicata with respectively 0.40% and 0.42%. In minor percentage it was considered also part of strandings occurred abroad for instance in Corsica, France or other international waters representing the 0.20% of all recordings.

Figure 94 – The map showed the Italian regions with different percentages of cetacean stranding events occurred from January 1st, 1713, to December 31st, 2023. The other two areas not included in the maps are "abroad" and "Ligurian Sea" with respectively 0.20% and 0.85%.

In Figure 95 the graph showed of which species strandings occurred since 1713 to 2023. In these 310 years, all eight cetacean regular species that live in the Mediterranean Sea were involved in stranding events with different percentages. The *Stenella coeruleoalba* species resulted the most involved in stranding events with the highest percentage of 40.95%, followed by *Tursiops truncatus* with 28.22%. The other significant percentage is represented by the "undetermined" class, which includes specimens for which it was not possible to identify the species, mostly due to the deteriorated conditions of the carcasses. Being in an advanced state of decomposition, indeed, they are often disposed of directly without undergoing necropsy analyses. Furthermore, they may include all those specimens reported stranded or dead at sea but not recovered, and for which it was not possible to determine the species. This is often because they were identified by non-scientific personnel lacking expertise in the field. The class "other species" represented in less percentage with 0.40% included all no regular Mediterranean cetacean species of which were recorded only one specimen or less more: *Megaptera novaeangliae* (n=1), *Mesoplodon europaeus* (n=1), *Kogia sima* (n=3), *Pseudorca crassidens* (n=5), *Balaenoptera acutorostrata* (n=8), *Steno bredanensis* (n=8).

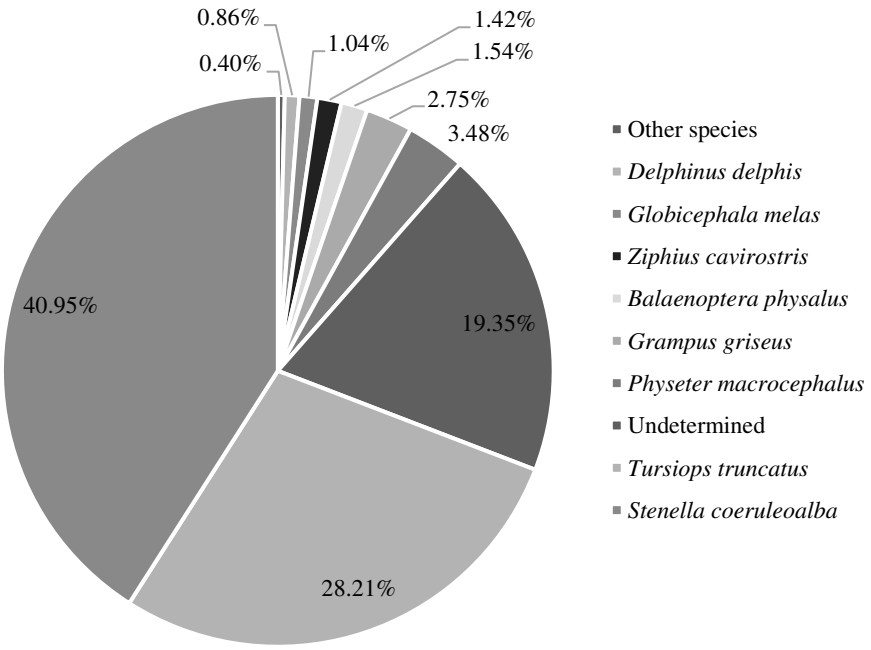

Figure 95 – Pie chart represented the species involved in stranding events from January 1st, 1713, to December 31st, 2023. "Other species" category referred to: *Megaptera novaeangliae* (n=1), *Mesoplodon europaeus* (n=1), *Kogia sima* (n=3), *Pseudorca crassidens* (n=5), *Balaenoptera acutorostrata* (n=8), *Steno bredanensis* (n=8) and "Undetermined" category referred to all specimens for which it was not possible to identify the exact species.

Cross-referencing data between Italian regions and the most frequently encountered species revealed a distinctive pattern where the discovery of one species predominates over another in certain regions. For instance, as depicted in Figure 96, Sicily stands out as the region with the highest number of identified specimens (n=979) and also distinguishes itself as the region with the greatest number of striped dolphin specimens (n=416). However, this does not imply the same for all other species; for example, the Emilia-Romagna region is notable for having the highest number of identified common bottlenose dolphin specimens with n=291, closely followed by Tuscany with n=236. Alternatively, for instance, in the region defined as the "Ligurian Sea", referring to all those animals found dead at open sea and, where the condition of the carcass allowed, recovered for disposal or necropsies, it was possible to observe that the most prevalent species was the "Undetermined" class with n=33, compared to other less represented species such as the striped dolphin with n=11, the pilot whale with n=6, the beaked whale with n=3, and the sperm whale with n=1 (Table 14).

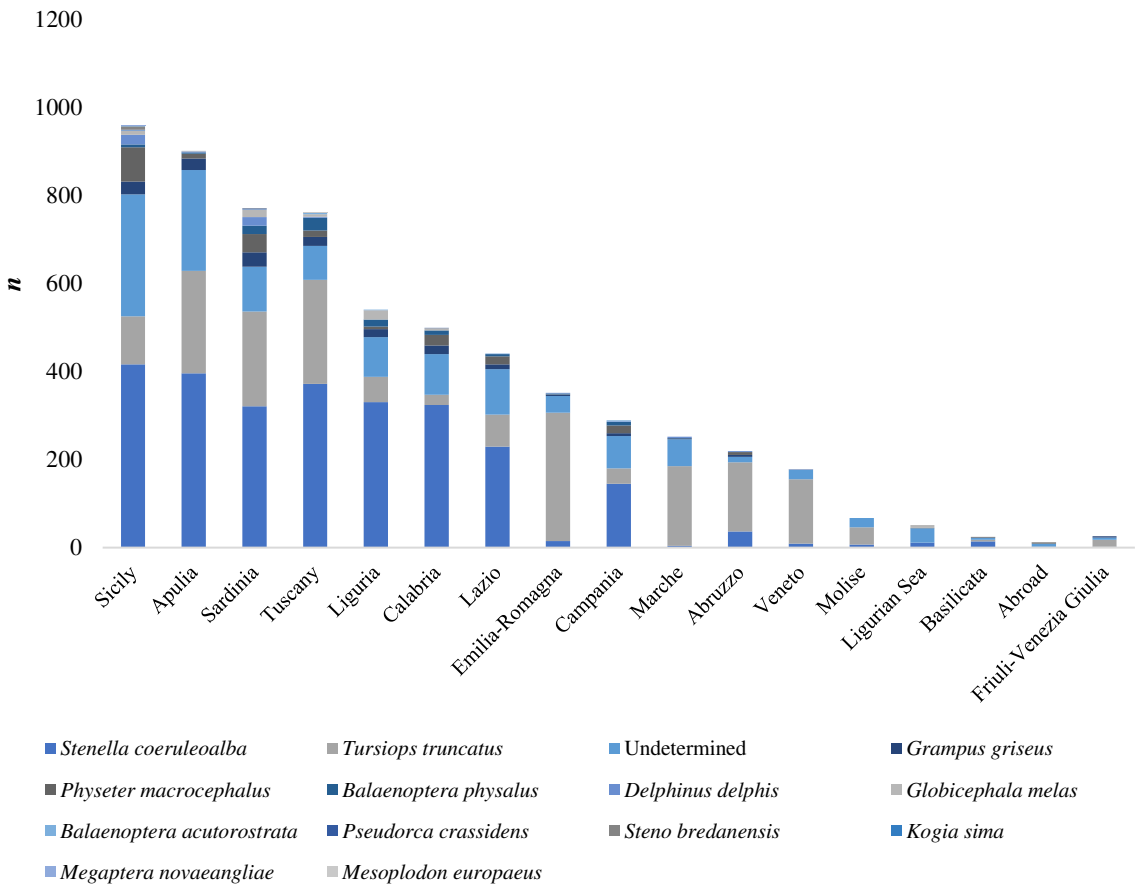

Figure 96 – The chart represents the crossing data between each Italian region and the cetacean species recovered stranded or dead at sea from 1st January 1713 to 31st December 2023 "Undetermined" category referred to all specimens for which it was not possible to identify the exact species.

Table 14 – All specimens for each cetacean species stranded or recovered dead at sea in BDS in each Italian Region from 1st January 1713 to 31st December 2023. "Abroad" referred to all France and Corsica territories and international waters. "Undetermined" category referred to all specimens for which it was not possible to identify the exact species.

	Balaenoptera acutorostrata	*Balaenoptera physalus*	*Delphinus delphis*	*Globicephala melas*	*Grampus griseus*	*Kogia sima*	*Megaptera novaeangliae*	*Mesoplodon europaeus*	*Physeter macrocephalus*	*Pseudorca crassidens*	*Stenella coeruleoalba*	*Steno bredanensis*	*Tursiops truncatus*	Undetermined	*Ziphius cavirostris*	**Total**
ABRUZZO			2		4				7		37		157	12		**219**
BASILICATA					1				1		14		4	4	3	**27**
CALABRIA		10		5	20				24	1	324		23	92	14	**513**
CAMPANIA	1	8	2		7	1			17		145		35	73	1	**290**
EMILIA-ROMAGNA		2	1		3				1		15		291	38		**351**
ABROAD				1					3		2			7		**13**
FRIULI-VENEZIA GIULIA					3						2		16	5		**26**
LAZIO	1	5	1		11				18		229		73	103	7	**448**
LIGURIA	1	16		21	18				6		330		58	90	12	**552**
LIGURIAN SEA				6					1		11			33	3	**54**
MARCHE		1	3		2						4		181	61		**252**
MOLISE											7		39	21		**67**
APULIA		3	2	2	26				11		396		232	229	11	**912**
SARDINIA	1	19	19	17	32				42	2	321	1	215	102	10	**781**
SICILY	1	6	22	9	29	1	1		78	2	416	7	109	277	21	**979**
TUSCANY	3	29	2	6	20	1		1	15		372		236	77	9	**771**
VENETO			1		1						9		146	21		**178**
TOTAL	**8**	**99**	**55**	**67**	**177**	**3**	**1**	**1**	**224**	**5**	**2634**	**8**	**1815**	**1245**	**91**	**6433**

3.3.2. Cetacean strandings causes of death

Moreover, filtering the database according to the entries of possible causes of death, six entries related to anthropogenic activities, and more directly to fishing activities, have been taken into consideration. These include direct causes such as "bycatch" as well as entries like "signs of fishing gear", "presence of net", "presence of hook" and, additionally, entries such as "firearm injuries" and "collision" were included considering them as indicative of interactions with anthropogenic activities. However, some specimens were recorded with more than only one death cause, reporting different combinations of multiple observable sings or indicating various potential causes of death.

Below is a schema of the various entries in the database, with the possible combinations used to group, for each cetacean species, the most frequent causes of death or observable signs associated with the presence of humans or their fishing activities (see in Methods Table 1).

By selecting these entries, it emerged that out of 6433 stranded animals, 821 animals were categorized in one of these selections: 47.32% for bycatch, 1.95% for sing of fishing gear, 6.21% for presence of nets, 0.12% for presence of hooks, 1.22% for firearm injuries and 5.85% for collision. Then, the combination of these impacts that are most represented is formed by the two categories which are "bycatch" and "presence of net" with the 28.50% of the recorded strandings. It is followed by the two combinations "bycatch and sing of fishing gear" and "bycatch and presence of hook" with respectively 4.75% and 2.19%. The other combinations are less represented with percentage under 1% as it is shown in Figure 97.

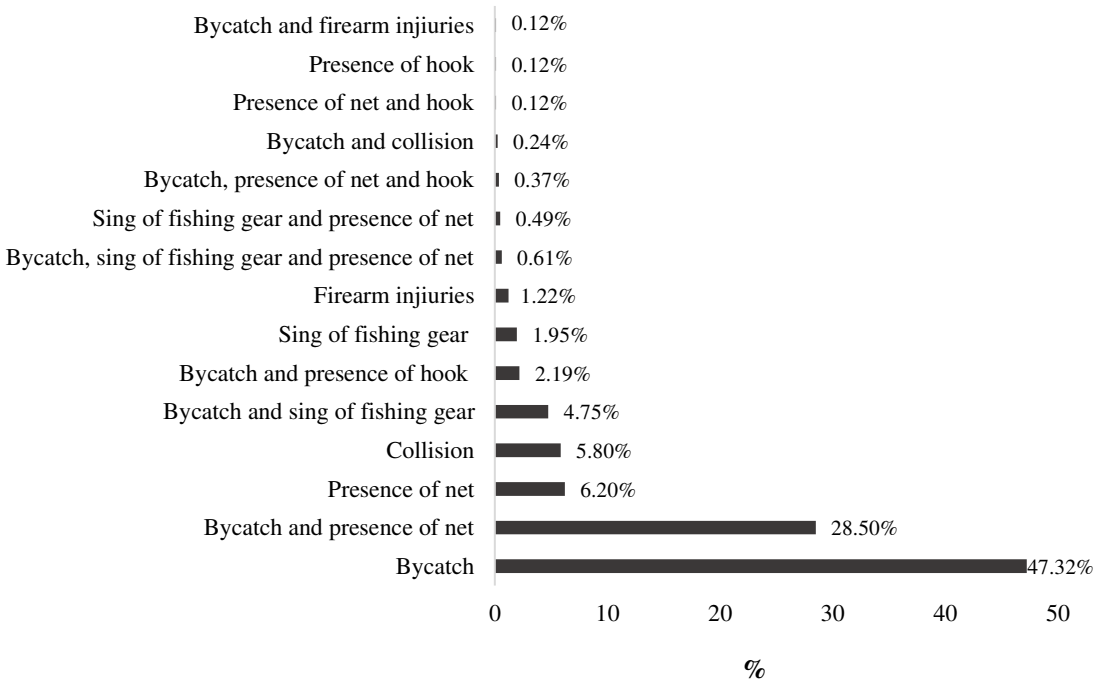

Figure 97 – The percentages of anthropogenic causes of cetacean stranding events occurred in 310 years from January 1st, 1713, to December 31st, 2023.

Considering the area where this type of strandings or deaths occurred, data was elaborated investigating which was the region most involved in these events that has been affected 821 cetacean specimens. As the previous analysis regarding Italian regions, Sicily confirmed to be region with the highest percentage (19.73%) of cetacean dead, also for this elaboration regarding the human pressure such as bycatch or similar causes, but it was followed by Calabria (14.74%), Sardinia (13.28%), Liguria (11.21%), Apulia (9.62%) and Tuscany (6.46%). However, Friuli-Venezia Giulia and Basilicata resulted the two regions less involved in these stranding events, but for example the category "abroad" which includes

French territories, Corsica, and international waters, represented 1.45% of stranding occurred due to human interactions (Figure 98).

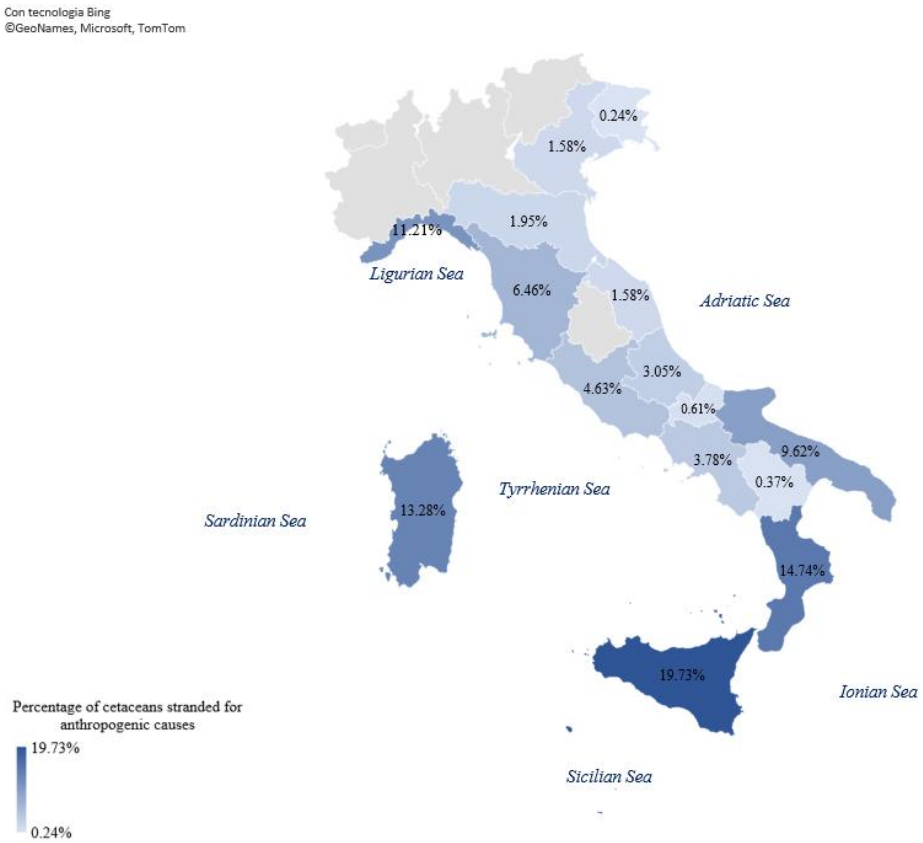

Figure 98 – The map showed the Italian regions where stranding events occurred due to anthropogenic causes from January 1st, 1713, to December 31st, 2023. The other area which was not included in the map is "Ligurian Sean" with 5.72%, instead "abroad" did not occurred stranding events with any of anthropogenic causes.

The Figure 93 represents the eight cetacean regular species that were dead due to human activities interactions. The striped dolphin appears to be the cetacean species most frequently involved in interactions with human activities. Specifically, data on bycatch phenomenon have been collected for 229 individuals of this species. Following the striped dolphin, there was the "undetermined" category, referring to animals for which it was not possible to determine the exact species, with 73 specimens. The common bottlenose dolphin ranks third, with 58 individuals reported deceased due to bycatch. However, the overall total of dead stranded cetaceans, encompassing all reported anthropogenic causes, positions the common bottlenose dolphin in second place after the striped dolphin (n=375), with 171 deceased individuals and the "undetermined" category remains among the most numerous with 114 individuals. In a minority, there were other regular cetacean species such as the sperm whale (n=81), the Risso's dolphin (n=21), the fin whale (n=19), the beaked whale (n=17), the pilot whale (n=15), the common dolphin (n=6). Only two non-regular species, the minke whale

and the humpback whale, reported only one specimen deceased due to collision and bycatch with the presence of nets, respectively.

Among the categories of anthropogenic causes observable and recorded in the BDS forms, bycatch was undoubtedly the one that has involved the most animals, with 388 individuals. Subsequently, there are 234 cases of bycatch with evidence of net presence, followed by 51 instances of net presence alone. In contrast, 48 individuals have been involved in collision incidents with vessels, mostly comprising the striped dolphin species (n=19) and the fin whale (n=15). The results collected and elaborated are reported both in Table 15 and in Figure 99. The important aspect that should be taken into account was the interaction rate. Among the regular cetacean species, the interaction rate was evaluated for each species compared to their total strandings exhibiting different rates: sperm whale (36.2%), pilot whale (22.4%), fin whale (19.2%), Cuvier's beaked whale (18.7%), striped dolphin (14.2%), Risso's dolphin (11.9%), common dolphin (10.9%), and common bottlenose dolphin (9.4%). Therefore, the conservation of cetaceans is still challenged by fishing activities and marine traffic, even though only 12.8% of stranded specimens indicated human interactions.

Table 15 – Categories of death from anthropogenic activities and their observable combinations occurred in the report sheets of BDS from January 1st, 1713, to December 31st, 2023.

	Bycatch	Bycatch and sing of fishing gear	Bycatch, sing of fishing gear and presence of net	Bycatch and presence of net	Bycatch, presence of net and hook	Bycatch and presence of hook	Bycatch and firearm injuries	Bycatch and collision	Sing of fishing gear	Sing of fishing gear and presence of net	Presence of net	Presence of net and hook	Presence of hooks	Firearm injuries	Collision	**Total**
Stenella coeruleoalba	229	28	4	72	1	7			7	1	3		1	3	19	**375**
Tursiops truncatus	58	10	1	36		4	1	2	8	1	38			5	7	**171**
Undetermined	73	1		31	1	2					5	1				**114**
Physeter macrocephalus	10			58	1					2	5				5	**81**
Grampus griseus	7			10		4										**21**
Balaenoptera physalus	2			2											15	**19**
Ziphius cavirostris	1			14		1									1	**17**
Globicephala melas	4			10										1		**15**
Delphinus delphis	4								1					1		**6**
Megaptera novaeangliae				1												**1**
Balaenoptera acutorostrata															1	**1**
Total	**388**	**39**	**5**	**234**	**3**	**18**	**1**	**2**	**16**	**4**	**51**	**1**	**1**	**10**	**48**	**821**

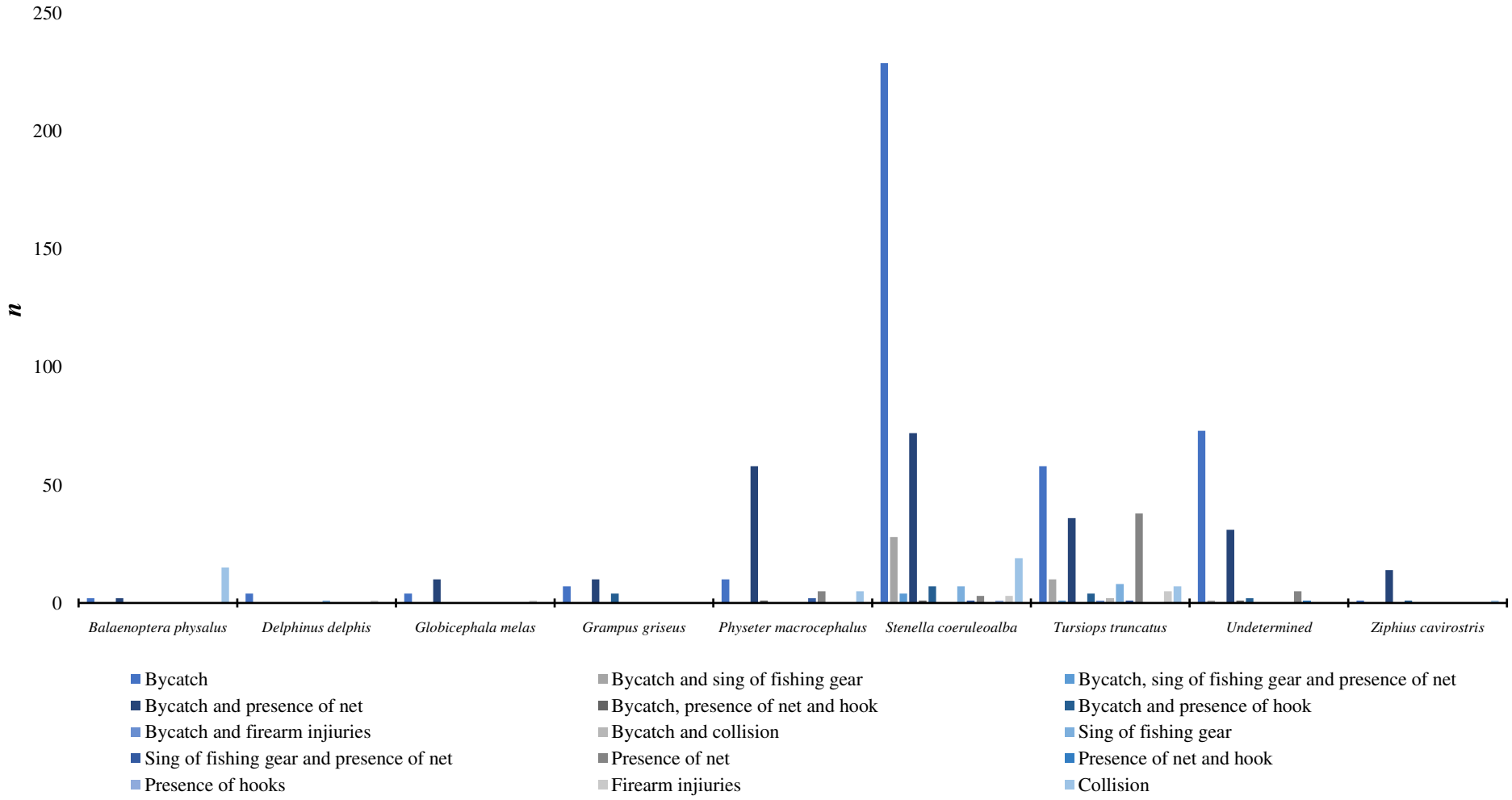

Figure 99 – The chart showed the number of specimens recovered dead or dead at sea for each cetacean species related to one or more anthropogenic activities and all their possible and observable combinations reported in BDS database from January 1st, 1713, to December 31st, 2023.

3.3.3. Common bottlenose dolphin strandings

Regarding the species of interest for this PhD thesis, which focuses on the *Tursiops truncatus*, it was possible to extract data related to this species. From January 1st, 1713, to 31st December 2023, 1,815 common bottlenose dolphin specimens have been recorded in the BDS database, with a mean of stranded animals 45.38 ± 22.77 per year, reaching maximum number of stranded animals in 2019 with 93 specimens and the minimum number in 1902 with only one specimen recorded (Figure 100).

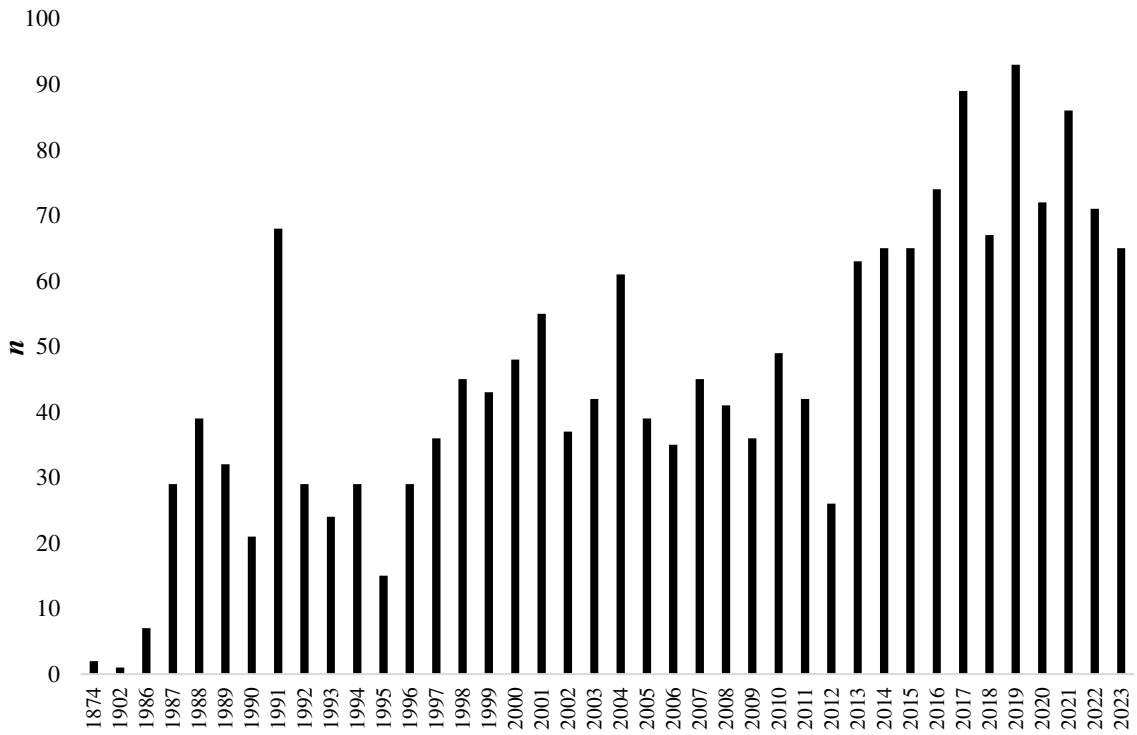

Figure 100 – The temporal trend showed the number of common bottlenose dolphin stranded from January 1st, 1713, to December 31st, 2023. Not all years are represented, likely because some strandings of this species were not recorded.

The stranding of the *Tursiops truncatus* species has affected different regions of Italy in varying degrees, among the 1815 animals the Emilia Romagna emerged as the region with the highest number of stranded common bottlenose dolphin (n=291; 16.03%), followed closely by Tuscany (n=236; 13.00%). Instead, the region with the fewest reports of stranded common bottlenose dolphin was the Basilicata (n=4; 0.22%) (Figure 101).

Figure 101 – The map showed the Italian regions where stranding events occurred due to anthropogenic causes from January 1st, 1713, to December 31st, 2023. "Ligurian Sean" and "abroad" did not occur any stranding event of common bottlenose dolphin.

Taking into account the 1815 common bottlenose dolphin specimens dead from the 1st January 1713 to 31st December 2023, it was possible to directly link the cause of death to anthropogenic activities for only 171 individuals, representing 9.42% of all reported common bottlenose dolphin specimens found dead either stranded or in the open sea in all Italian regions, included "abroad" represented by Corsica, France and international waters and "Ligurian Sea". Furthermore, among these 171 cases, the reported causes varied. The predominant anthropogenic cause was related to fishing activities, encompassing both bycatch and the presence of nets around the animals, along with various combinations of these observable categories. Bycatch was the most frequently reported cause (n=58 animals), followed by the category "presence of net" (n=38), and their combination "bycatch" and "presence of net" (n=36) (Figure 102).

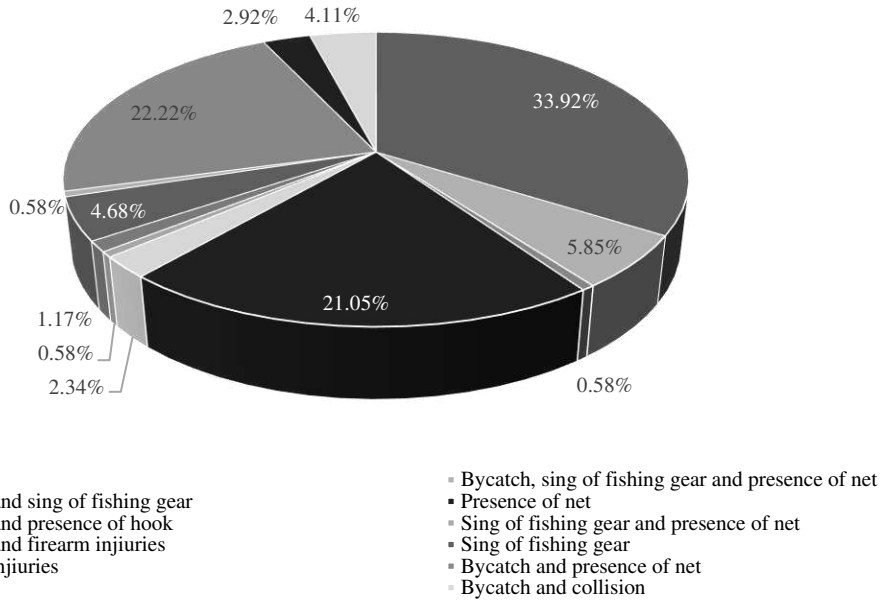

Figure 102 – Pie chart representing the percentages of common bottlenose dolphins dead in Italian regions for each anthropogenic cause identified in the Stranding Database across all reports.

3.4.3.1. Common bottlenose dolphin strandings in Tuscany

Regarding common bottlenose dolphin in Tuscany, data collected in the same database was analysed and first of all, a map from the Strandings Bank of the University of Pavia was extracted to provide a comprehensive overview of common bottlenose dolphin strandings in Tuscany from 1st January 1713 to 31st December 2023 (Figure 103).

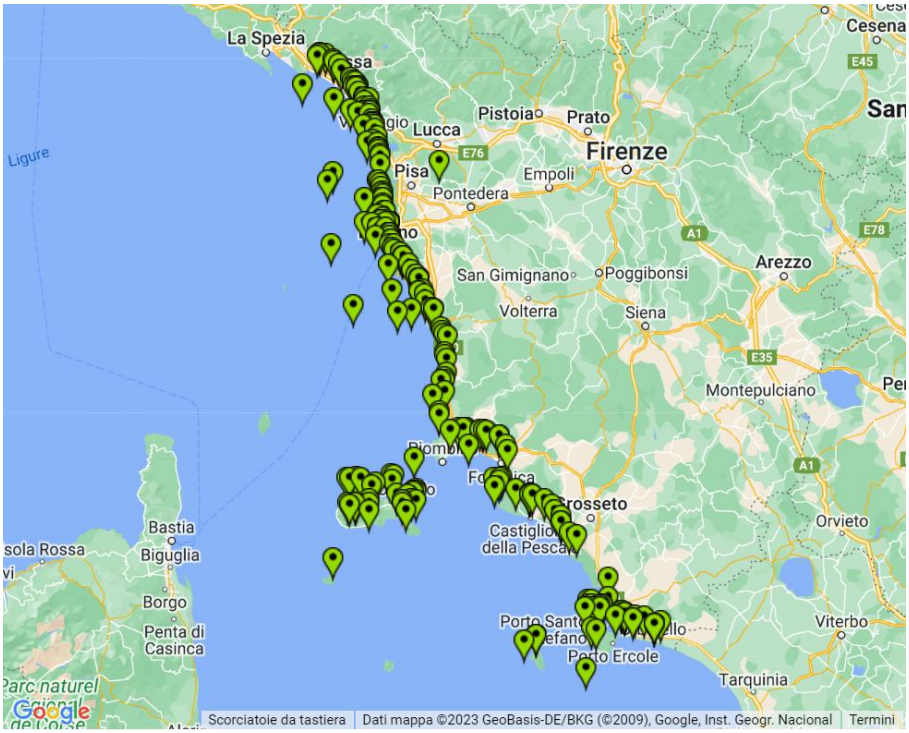

Figure 103 – Maps of common bottlenose dolphin specimen stranded along Tuscany in 310 years from 1st January 1713 to 31st December 2023. Note: the specimen located in land not along coastline or at sea was due to the fact that it was found in the Catalogue of Current Cetaceans of the Natural History Museum and Territory of the University of Pisa, at the Certosa di Calci (BDS ID 11169, Museum Code Pisa: 282 dated 01-01-1874). Partial specimen, missing the cranial skeleton.

Nevertheless, in these 310 years, the common bottlenose dolphin in Tuscany was the second most frequently found species stranded or dead in open sea, with 236 individuals, surpassed only by the striped dolphin, which counts 372 individuals. Other species are significantly less common, with the "undetermined" category ranking third with 77 specimens, followed by the fin whale (n=29), Risso's dolphin (n=20), sperm whale (n=15), beaked whale (n=9), pilot whale (n=6), Northern minke whale (n=3), common dolphin (n=2), dwarf sperm whale and Gervais's beaked whale (n=1 for each) (Figure 104).

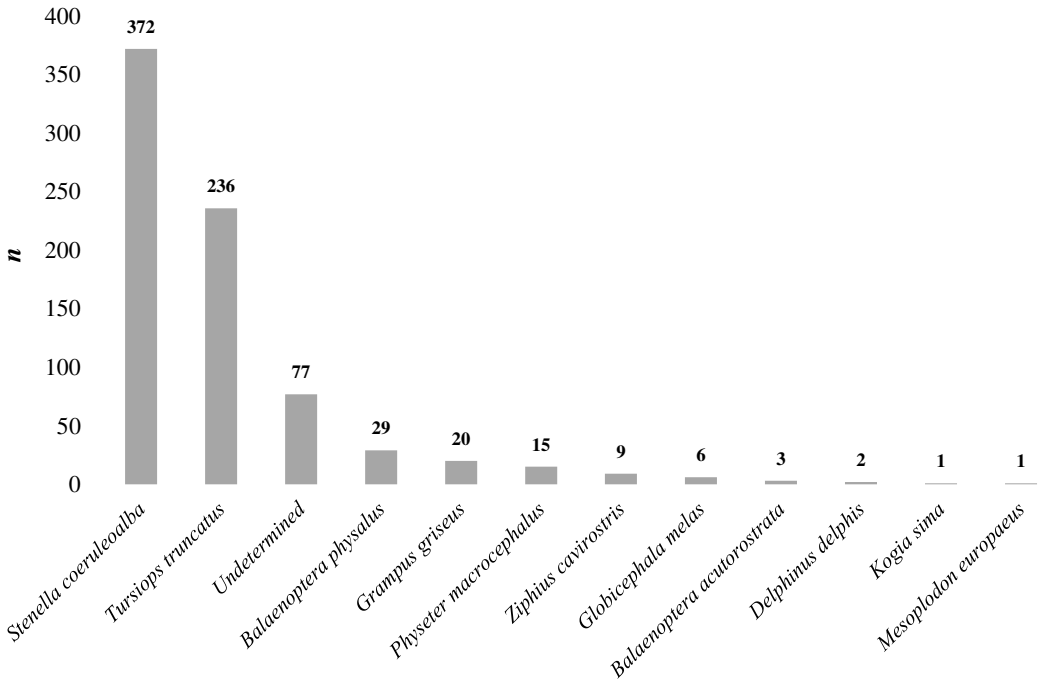

Figure 104 – All species stranded or found dead at sea in Tuscany in 310 years from 1st January 1713 to 31st December 2023. "Undetermined" category referred to all specimens for which it was not possible to identify the exact species.

Among these 236 common bottlenose dolphin dead specimens, only 25, representing the 10.60% of all animals, were founded with connections to anthropogenic causes and in particular with fishing activities. However, among these 25 animals, the predominant cause is bycatch, accounting for 36%, followed by other causes such as "sign of fishing gear" at 24%, and a combination of "bycatch, sign of fishing gear and presence of net" at 20%. Less common causes but still related to fishing activities include "bycatch and presence of net" at 8%, and at 4%, "presence of net", "bycatch and sign of fishing gear" and "bycatch and collision" (Figure 105).

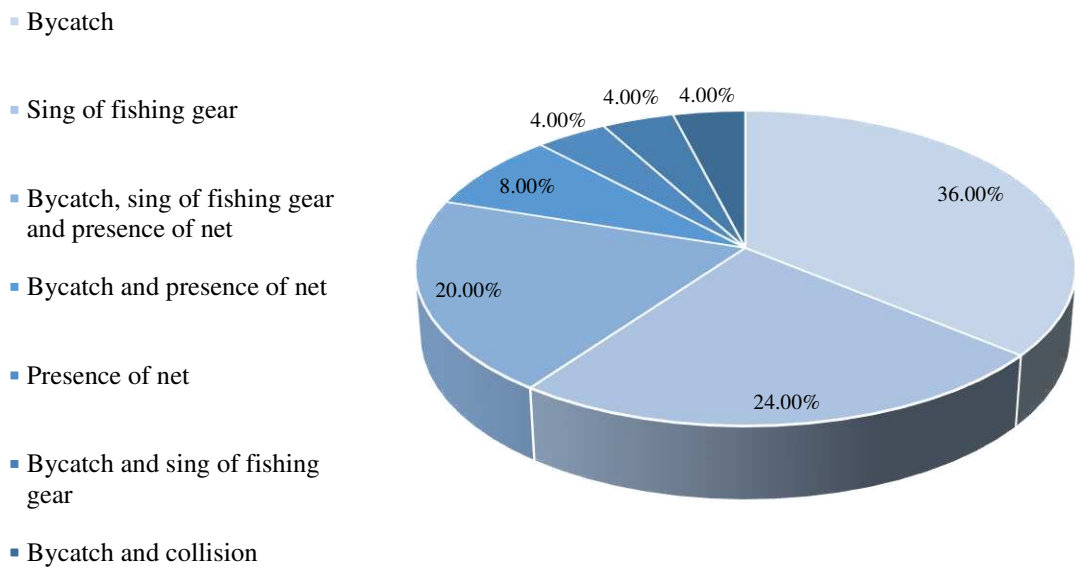

Figure 105 – Pie chart representing the percentages of common bottlenose dolphins dead in Tuscany for each anthropogenic cause identified in the Stranding Database across all reports.

3.4.3.1.1. Bycatch of common bottlenose dolphin in Tuscany during PhD project

During the three years of the project (2021, 2022, and 2023), the activities of the doctoral project concerning the species *Tursiops truncatus* (common bottlenose dolphin) were integrated and further developed, focusing particularly on post-mortem analyses of specimens found stranded along the coast of Tuscany. Specifically, this type of activity was supported and funded by the NAT.NE.T and NAT.NE.T.2 projects, both under the supervision of Professor Letizia Marsili. These projects were approved by Resolution No. 592 of 06/05/2019 and Resolution No. 997 of 29/08/2022 (Regional Law 30/2015).

During the three years 34 common bottlenose dolphins were stranded or dead at sea: 16 in 2021, nine in 2022, and nine in 2023. Among these 34 specimens, only ten were recovered withing NAT.NE.T.2 project, and were studied due to their conservation status that permitted the recovery of samples and/or to carry out post-mortem analyses.

Among these ten animals, only two were recovered with traces of fishing gear around their bodies, specifically signs of gill nets, indicating a possible cause of death due to bycatch. During the three years of the project, no accidental catches of dolphins or other cetaceans were recorded with the fishermen involved in the CTRL and TEST trials. In fact, the two dolphins found stranded with these clear signs of interaction with fishing gear were located north of Tuscany, quite far from the fishing areas where acoustic deterrents were used and tested (Table 16).

Additionally, in line with the research focus of the MAGIAMARE-SIENA group, led by Professor Letizia Marsili, a paper was written examining stranded bottlenose dolphins within the Pelagos Sanctuary (Grattarola et al., 2023) (Figure 106).

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Health Status of Stranded Common Bottlenose Dolphins (*Tursiops truncatus*) and Contamination by Immunotoxic Pollutants: A Threat to the Pelagos Sanctuary—Western Mediterranean Sea

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Abstract: Between 2019 and 2021, 21 bottlenose dolphins were found stranded dead along the Ligurian Pelagos Sanctuary coast (Italy). For 11 animals, out of a total of 14 recovered, the cause of death was classified as natural, anthropic, or not determined based on gross and histological pathology and ancillary testing. Hexachlorobenzene (HCB), dichlorodiphenyltrichloroethanes (DDTs), and polychlorinated biphenyls (PCBs) were examined in their blubber, and results were discussed according to their toxicological properties. All specimens showed the following trend: PCBs > DDTs >> HCB, and the levels of cancerogenic, mutagenic, and teratogenic organochlorine compounds (T-OCs) were >50% of total OCs. Immunosuppressant organochlorine compound (IS-OC) levels in 10 out of 11 animals were above 50% of the total OCs. PCB levels always exceeded the threshold of 17 mg/kg lipid weight for PCB-induced adverse health effects. The results suggest that bottlenose dolphins living in the Pelagos Sanctuary undergo a high level of exposure to pathogens and OCs, betraying the designation of the Cetacean Sanctuary and, consequently, of a region created for their conservation. Immune dysfunction and infectious disease susceptibility appear to be highly connected with high levels of OC xenobiotics. These data are useful to understand health and mortality trends in cetacean populations, as well as for developing policies for cetacean conservation and management in this important protected area of the Mediterranean.

Keywords: common bottlenose dolphin; *Tursiops truncatus*; Italy; Mediterranean Sea; persistent organic pollutants (POPs); PCBs; DDTs; necropsy; pathology; immunosuppression

Figure 106 – Abstract of the paper published regarding the common bottlenose dolphins stranded in the Pelagos Sanctuary. Diversity 2023, 15(4), 569. https://doi.org/10.3390/d15040569.

The study evaluated their causes of death, particularly looking at contamination and immunosuppression. Bycatch was also considered as a potential cause of death, although it is difficult to confirm unless the animal was observed dying during an accidental catch by a fisherman. For stranded animals, confirming bycatch as the direct cause of death is challenging because interaction with fishing gear might have been a risk factor rather than the direct cause of death. Nonetheless, the two stranded dolphins were found with fishing nets completely wrapped around their bodies, making it clear that disentangling them would

have been difficult (Figure 107 and 108). This suggests that bycatch was likely the primary cause of their deaths. However, the fact that such situations still occur suggests that harmful dolphin-fishery interactions remain a crucial concern that needs to be addressed, further studied, and monitored.

Regarding stranding data, it is important to remember that stranded specimens represent only a variable and difficult-to-measure percentage of deceased animals. Not all dead cetaceans are detected: many sink to the seabed, others are preyed upon, and some strand in remote locations or in such poor preservation conditions that determining the cause of death becomes challenging.

Despite these limitations, stranding data provide valuable indirect information, particularly for assessing potential interactions with fisheries and other direct causes of mortality. For instance, some stranded individuals show signs of entanglement in fishing nets along with gunshot wounds, indicating possible interactions with fishing activities.

When analysing the causes of strandings, studies suggest that bycatch accounts for approximately 10–20% of cases, making it the most significant human-related cause of mortality, although diseases remain the predominant factor. In this context, redefining the diagnostic approach is crucial. Findings from the Life DELFI project indicate that around one-third of strandings are linked to human activities, and of these, 90% show clear evidence of interactions with fisheries. These data highlight the importance of more accurate monitoring to better understand the impact of human activities on cetaceans and to develop effective mitigation strategies.

Table 16 – Data regarding the two specimens found stranded with evidence of interactions with fishing activities. The symbol "-" means that data was not available for the length of that specimen.

Date	08/03/2022	13/08/2023
Location of recovery	Camaiore (LU)	Lecciona, Viareggio (LU)
Identification code (Tuscany Region)	RT189Tt	RT198Tt
Identification code (BDS)	13568	13822
Sex	F	ND
Length (m)	2.08	-
Weight (kg)	108.8	83.5

Figure 107 – A specimen of common bottlenose dolphin stranded on March 8th 2022 in Bagno Tucano, Lido di Camaiore, Camaiore (LU) with evidence of interactions with fishing activities with a setnets enveloped the entire body.

Figure 108 – A specimen of common bottlenose dolphin stranded on August 13th in Lecciona, Viareggio (LU) with evidence of interactions with fishing activities with a setnets enveloped the entire body.

Chapter 4 DISCUSSION

Discussions were presented in the same order as methods and results, with their respective subsections.

4.1. E*x ante* and *ex post* monitoring

The results obtained from the *ex ante* and *ex post* monitoring activities within the Life DELFI project provided valuable insights into the extent of interactions between dolphins and fisheries along the Tuscan coast, focusing specifically on setnets and the mitigation measures adopted by fishers. In this discussion, the findings from this research were compared with similar studies conducted in other Mediterranean areas and worldwide, in particular regarding:

1. **Fisher's perception and interactions with dolphins**: in this study conducted within the GSA9, 61.11% of fishers reported frequent dolphin sightings during their fishing activities, with 83.33% noting an increase in dolphin presence over the years. This finding was a bit higher to the results of Terribile and Laspina (2022), who reported a 76% increase in perceived encounters with dolphins in the GSA1, GSA15, GSA19, and GSA10 and higher compared to the study conducted in GSA20 where approximately 70.4% of fishers interviewed reported dolphin depredation (Bonizzoni et al., 2016). Instead, this result was slightly lower compared to Revuelta et al. (2018), a study conducted in GSA6, in which 97.7% fishers reported that frequently encountered common bottlenose dolphins. Additionally, Aguilera et al. (2020) found that fishers interviewed in the GSA1 confirmed a growing presence of common bottlenose dolphins interacting with fishing activities. Nonetheless in this study only 7.9% of respondents perceived a decrease in dolphin sightings, which was higher than the 3% reported by Terribile and Laspina (2022), who noted a decline in common bottlenose dolphin presence around fishing operations. In a study conducted in GSA1 the 82% of fishers reported to see dolphins mostly during fishing manoeuvres (Aguilera et al., 2020) and this fisher's perception was very similar to fishers from GSA9 of this study accounting 83.33%.
2. **Damages to the catch and gears**: in this study, 61.11% of fishers reported never having caught a dolphin, while 33.33% acknowledged experiencing bycatch incidents, which resulted in damage to both gear and catch. This result aligned with the findings of Revuelta et al. (2018), where 87% of fishers reported negative interactions with dolphins, primarily due to gear damage and reduced catch and also with the study conducted in GSA19 of Bearzi et al. (2011), where the 97% of fishers interviewed experienced gear damage with 67%

claiming an economic cost. Also, in Bearzi et al. (2011) 52% of fishers reported that dolphins stole fish from the nets, the 18% reported that dolphins damaged entangled fish and the 18% answered that dolphins scared fish away from the nets, similar with this study where these answers accounted respectively: 100%, 33.33% and 14.29%.

The cited studies confirm that interactions between dolphins and fisheries have negative economic impacts. In the study of Li Veli et al., (2023), the wide range of economic losses per year suffered by the interviewed artisanal fishers, i.e., from €0 to 20,000, was in accordance with the estimates of other studies in other Mediterranean areas (e.g., €500–€20,000 per vessel in Italy and Greece, and €1,000–2,000 in Spain, Italy and France (Snape et al., 2018). However, the estimated economic loss reported by fishers interviewed in the GSA9 was €4,800 ± 3,392.80, slightly higher than the annual average loss of €2,907 reported by Revuelta et al. (2018) but its was very similar to what reported Bearzi et al. (2011) accounting and economic cost exceeding €1,000 per year, and an average reported cost of €2,561. These reports were bit lower than what fishers reported in Gulf of Ambracia (GSA20) with losses between up to €5,000 annually. Furthermore, the results obtained in this thesis were lower than the economic losses estimated by fishers in the GSA16 and GSA19, where lost an average of €10,000 annually, with one estimate reaching €13,000, and almost four times lower to the fishers in the Inner Ionian Sea Archipelago (GSA20) reported losses of up to €20,000 (Gonzalvo et al., 2015; Monaco et al., 2019). This variation underscores how differently the issue can manifest depending on several factors, such as the type of materials used in fishing nets or the commercial target species.

Another issue pointed out from many fishers was that not all catch of net damage were due to dolphin predation. In fact, dolphins were not seen as the sole cause of economic losses: conger, sharks, cephalopods were often blamed (Gonzalvo et al., 2015).

3. **Use of deterrent devices:** in the GSA9, most of the respondents (61.11%) had never used an acoustic deterrent device in their careers, but the 77.78% of fishers were willing to test acoustic deterrent devices, such as the DiD01®, and in the end of the project most (72.22%) observed a significant reduction in dolphin interactions when using these devices. Among the fishers interviewed in GSA19 the 46% of fishers had heard of acoustic deterrent devices (pingers), and 6% had tested them. Other studies, such as Goetz et al. (2014), also report that deterrent devices were effective in reducing interactions with dolphins. However, in the GSA9 fishers noted dolphin habituation to the deterrents, suggesting a need for improvements in the devices or their usage.

4. **Underreporting of bycatch:** in my research, 33.33% of fishermen reported accidental dolphin bycatch, with 50% of those incidents involving dolphins that were still alive. This was comparable to the Goetz et al. (2014) study, where 23.5% of fishermen considered bycatch a significant issue, though it was not seen as the primary problem. Both studies suggest that bycatch rates may be underreported, and further research could provide a more accurate picture of the impact on dolphin populations.
5. **Participation in sustainability projects:** in this study, the majority of fishermen showed a positive attitude toward participating in sustainability projects, such as dolphin-watching activities and fishery tourism. This finding was the same to other Mediterranean regions, such as Sardinia and the Balearic Islands, where fishers expressed interest in collaborating on conservation initiatives and co-management of marine resources (Brotons et al., 2008; Gonzalvo et al., 2015).

So, in conclusion, the similarities across studies were all regions reported: (i) significant economic losses due to dolphin interactions with fishing gear, (ii) the primary type of gear affected was consistently passive gear like setnets, gillnets, and trammel nets, and (iii) the perception among fishers was that dolphin populations have increased in recent years, leading to more frequent interactions and damage to fishing gear.

4.2. Acoustic deterrent devices

4.2.1. Species compositions

Comparing the various papers available in the literature that conducted similar studies and investigations, it was possible to evaluate the different or similar target species of the fisheries practiced. Most of the selected studies employed setnets, whether they were bottom set nets, gillnets, or trammel nets, all of which were part of small-scale artisanal fisheries. Many of these species were similar to those caught in the PhD study area. To make a more interesting comparison, each study area from the selected research was identified, when possible, with its corresponding GSA to provide a geographical reference, also considering the perspective of fisheries policy. Each GSA had specific target species that were commercially important. However, the variation in these species reflected local fishing practices, market demands, habitat availability, type of gear, gear features, and many other factors such as seasonality, cultural culinary differences, etc (Figure 109).

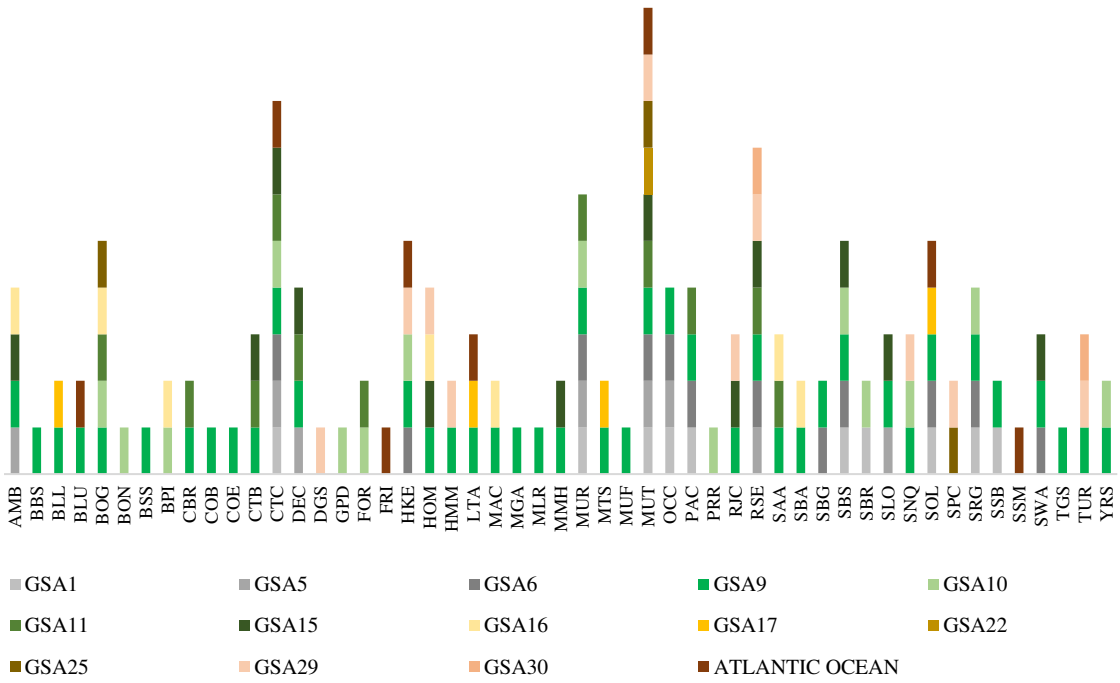

Figure 109 – Major target species (indicated with FAO code) caught across the areas reported in the studied selected for the comparison of the PhD discussions, when possible, indicating with their corresponding Geographical Sub Areas (GSA). The following fishing area corresponded to their respective paper: GSA1 (Aguilera et al., 2020), GSA5 (Gazo et al., 2008; Brotons et al., 2008), GSA6 (García-Rodríguez et al., 2006; Feliu-Tena et al., 2023), GSA9 (Fossa et al., 2011; Ceciarini et al., 2023; PhD thesis, 2024), GSA10 (Bonanno Ferrero et al., 2018; Bruno et al., 2021, Life DELFI, 2023), GSA11 (Lauriano et al., 2004, Pennino et al., 2015, Life DELFI, 2023; La Manna et al., 2024), GSA15 (Terribile and Laspina, 2023), GSA16 (Buscaino et al., 2009; Maccarone et al., 2014), GSA17 (Life DELFI, 2023), GSA22 (Garagouni et al., 2022), GSA25 (Snape et al., 2018), GSA29 (Gönener and Bilgin, 2009; Gönener and Özdemir et al., 2012; Bilgin and Kose 2018; Namhturk and Bahk, 2021), GSA30 (Popov et al., 2020) and Atlantic Ocean (Bruke et al., 2005; Marçalo et al., 2021).

From the comparative analysis of various studies, it emerged that the red mullet has been the species caught in most of the areas considered, followed by the cuttlefish, surmullet, and thornback ray. The bogue, hake, common sole, and saddled seabream were also species caught in several of the areas examined. Also, scorpionfishes (*Scorpaena* spp.), and other members of the Sparidae family (e.g., seabreams) were captured in several areas mostly because these species were often targeted in small-scale fisheries due to their high commercial value and prevalence in coastal habitats. The overlap between artisanal fisheries and these species highlighted their importance in local economies and their availability in fishing grounds (García-Rodríguez et al., 2006; Brotons et al., 2008; Finezzo and Ipuche, 2011; Fossa et al., 2011; Gazo et al., 2008; Gönener and Özdemir, 2012; Pennino et al., 2015; Bruno et al., 2021; Aguilera et al., 2020, Feliu-Tena et al., 2023; La Manna et al., 2024). Some of the main captured species across the various studies confirmed what FAO reported that in the last decades a number of the main demersal species have followed an

overall increasing trend in landings: cuttlefish (from 830 tonnes in 1970 to 14,033 tonnes in 2021), red mullet (from 2,800 tonnes in 1970 to 13,570 tonnes in 2021), and surmullet (from 3,934 tonnes in 1970 to 8,243 tonnes in 2021) (FAO, 2023).

However, some relevant species were observed in other studies where dolphin interactions occurred but were not captured in the study area for example: the picked dogfish (DGS), dusky grouper (GPD), forkbeard (FOR), frigate mackerel (FRI), Mediterranean parrotfish (PRR), Blackspot seabream (SBR), picarel (SPC), and Atlantic Spanish mackerel (SSM), which were caught in ecologically very different areas such as the Atlantic Ocean or the Black Sea, or through slightly different fishing practices compared to those used in the area, as in the case of GSA10, where studies were conducted using specific *métiers* and targeting those species. Moreover, in a study conducted in the Black Sea (GSA29), where turbot fishery was carried out, in which dolphins interacted many times, also resulted in catches species like spiny dogfish (*Squalus acanthias*) and gurnard (*Trigla spp.*) (Bilgin and Köse, 2018). Moreover, in the Atlantic Ocean off the coast of North Carolina, USA, studies documented by Burke (2005) focused on species such as Spanish mackerel (*Scomberomorus maculatus*) and frigate mackerel (*Auxis thazard*), which are specific to that geographical region. Another example of different target species could be observed in the study by Lolipakam et al. (2022), conducted in India, where they captured species like *Crossocheilus latius*, *Gagata cenia*, *Botia dario*, and *Johnius coitor*. These species are not typical in the Mediterranean but reflect the diversity of target species in different global fisheries and still a food resource for common bottlenose dolphin.

Overall, most of the studies conducted in the Mediterranean showed a high similarity in commercial target species for this type of fishing and gear. While the quantities of the catch might vary due to several factors, the overall pattern of species remained consistent. This was significant because many of these species were also part of the diet of the common bottlenose dolphin, suggesting a competitive overlap for the same resources between dolphins and fishers as also confirmed in the PhD thesis of Neri (2024) where was observed the opportunistic interactions with fishing activities due to the common bottlenose dolphin ability and plasticity to search, hunt and feed food.

4.2.1.1. Fishing effort in CTRL and TEST nets

As shown in the results section, the CPUE (Catch Per Unit Effort) increased when pingers were used. Although this was not statistically demonstrated, the total catch in kilograms for certain species, such as cuttlefish and red mullet, was higher in the test nets equipped with pingers compared to the control nets. Additionally, many studies have reported similar

findings; in some cases, the increase in captures was confirmed by statistical analysis, while in others the results were not statistically significant but still observed a noticeable increase when using pingers (Maccarone et al., 2014; Marçalo et al., 2021). In GSA29, some studies demonstrated that CPUE was slightly higher in nets with pingers compared to control nets though the difference was not statistically significant for Namlıtürk and Blik (2021) was 2.01 kg/km²/hour vs. 1.97 kg/km²/hour. And also, Gönener and Bilgin (2009) recorded a CPUE higher in nets with pingers than in control nets, but no significant difference in the size and weight of the target and non-target fish species between nets with and without pingers.

In many studies catches were not affected by dolphin interactions permitting fishers to keep captured fish resources (Waples et al., 2013; Bonanno Ferraro et al., 2018; Cruz et al., 2014; Namlıtürk and Blik et al., 2021; Ceciarini et al., 2023), and in some other studies CPUE resulted also significantly higher using nets employed with pingers (Marçalo et al., 2021), as obtained in this study for the year 2023.

Therefore some study observed that pingers had no significant impact on fishing efficiency or the behaviour of the fish (Gazo et al., 2008) and in fact, pingers did not either affect the catch rates of the target species turbot (*Psetta maxima*) or non-target species such as thornback ray (*Raja clavata*), spiny dogfish (*Squalus acanthias*), and gurnard (*Trigla lucerna*), and also there was no statistical difference in CPUE between nets with and without pingers for either fish species or cetaceans (Bilgin and Köse, 2018).

4.2.2. Effects of acoustic deterrent devices on dolphin interactions

For the bibliographic comparison, studies that conducted similar research under comparable conditions, such as the use of acoustic deterrents to reduce interactions between small-scale artisanal fishing gear and common bottlenose dolphins were selected. The type of deterrent used in the PhD thesis was the same as employed by Marçalo et al. (2021) and by Terribile and La Spina (2022). Alos, in some other project areas the DiD01 were tested. A common aspect that emerged from various studies was the high site-specific variability in the behaviour of common bottlenose dolphins in response to the use of different deterrents or even the same ones. For instance, within the Life DELFI project, the responses obtained in some areas differed from those observed in this study, sometimes highlighting a habituation of dolphins to the sound emitted by pingers. This prompted some project partners to develop a promising new device, currently in the prototype phase, equipped with advanced technology based on convolutional neural network (CNN) to address the limitations identified in the DiD01 pinger. This innovative approach to passive acoustic monitoring

(PAM) was to enhance the detection of dolphin whistles, even in environments with a high density of vocalizations and ambient noise. The CNN was trained on labelled spectrograms, correctly identifying approximately 98 out of 100 whistles and accurately classifying around 95% of the instances where no whistles were present. This approach minimizes the risk of false positives and false negatives, thereby increasing the effectiveness of deterrent devices (Scaradozzi et al., 2024). Furthermore, considering that some studies using different types of pingers suggest that certain species may acclimate to the sounds, reducing their deterrent effect, future devices should incorporate greater variability in the emitted clicks. This measure would help minimize the risk of habituation in dolphins, ensuring long-term effectiveness. To be explored how in the future could be applied to a device.

Other studies, however, used different types of deterrents which, unlike the one in this study, were not interactive: the most commonly used pingers emitted a continuous sound as soon as they were activated. The new generation of acoustic deterrents, like the one used here (described in Methods paragraph 2.2.2.), have the distinct feature of remaining silent in the water and only activating in response to the natural sounds emitted by common bottlenose dolphins when hunting or communicating with each other.

In Table 17, all type of pingers commercialized used in various studies were listed, indicating different locations where trials were conducted, periods when studies took place, fishing gears employed to their respective target fishes, and main response of the study using different ADDs. First of all, one aspect that clearly emerged from the table was that, whilst, in some studies, the number of control and test trials corresponded, (Buscaino et al., 2009; Gönener and Bilgin, 2009; Gönener and Özdemir et al., 2012; Maccarone et al., 2014; Bilgin and Köse, 2018; Snape et al., 2018; Namlıtürk and Blik, 2021; Terribile and Laspina, 2022), in many others, as well as in this study, the number of control trials was different from the number of test trials (Brotons et al., 2008: Gazo et al., 2008; Cruz et al., 2014; Ceciarini et al., 2023). This could be explained by various factors, one of which was certainly the fishers' scepticism to employ a net without pinger. Having seen the effectiveness of the pingers, they were reluctant to deploy the nets without them and this phenomenon was particularly evident in Portugal during the iNOVPESCA project by Marçalo and collaborators (personal communication).

Despite some slight differences in the target species across the studies, especially those conducted in the Black Sea that practiced exclusively turbot fishery (Gönener and Bilgin, 2009; Bilgin and Köse, 2018; Popov et al., 2020), the majority of them had as target fishes' demersal species, discussed deeper in next paragraph (4.2.1.), which were part of the

common bottlenose dolphin's diet, thereby explaining the high frequency of interactions (Gazo et al., 2008; Gönener and Özdemir et al., 2012; Maccarone et al., 2014; Bonanno Ferrero et al., 2018; Snape et al., 2018; Bruno et al., 2021; Marçalo et al., 2021; Ceciarini et al., 2023; Terribile and Laspina, 2022; Neri, 2024).

Another point that was highlighted by the Table 17 was that the use of these devices has had a history spanning decades, in fact, although the earliest studies date back to the 1990s, one of the most notable being that of Stone et al. (1997), the systematic and widespread use of these devices began to gain traction from 2000. So, even in the past, the use of acoustic deterrent devices was considered one of the most effective methods for reducing interactions between dolphins and fishing activities, still nowadays, beyond the latest innovations of the bycatch reduction devices (BRDs) used in the Black Sea, such as acrylic glass spheres to enhance acoustic visibility (Kratzer et al., 2021), used acoustic deterrents like pingers to reduce interactions with marine mammals were widely and commonly recognized. These devices have been explored as a potential solution to mitigate such interactions. Although pingers have been extensively tested in various fisheries worldwide, and across the Mediterranean and Black Seas (FAO, 2021), their uptake by fishers remained limited despite citizen science campaigns (Li Veli et al., 2024). Their effectiveness was debated, with positive results reported in some regions both in Mediterranean Sea (Brotons et al., 2008; Gazo et al., 2008; Gönener and Bilgin, 2009; Maccarone et al., 2014; Monaco et al., 2019; Popov et al., 2020; Bruno et al., 2021; Namlıtürk and Blik, 2021; Terribile and Laspina, 2022; Ceciarini et al., 2023) or in other area (e.g., Crosby et al., 2013; Mangel et al., 2022), but less success observed in others (Cox et al., 2004; Dawson et al., 2013; Snape et al., 2018; Buscaino et al., 2021). In fact, in some cases, pingers could sometimes act as a "dinner bell" attracting dolphins to set nets caused a sort of habituation (Trippel et al., 1999; Dawson et al. 1998; Cox et al., 2001; 2003; Reeves et al., 2001) as a leading cause of failure in the use of acoustic repellents. However, long-term deployment of acoustic alarms in several commercial fisheries has not resulted in an increase in cetacean bycatch rates in properly equipped nets with functioning pingers (Palka et al., 2008; Carretta and Barlow 2011; Dawson et al., 2013; Snape et al., 2018).

Several studies have examined the behaviour of common bottlenose dolphins around nets equipped with pingers, suggesting that while pingers did not completely eliminate interactions, they could help reduce their negative effects. Dolphin interactions were observed to occur more frequently when pingers were not in use. Fishers who used pingers

reported a significant reduction in dolphin interactions compared to those using nets without deterrents and reported that catches were not affected by the use of pingers.

A reduction in rates of dolphin/net interactions using pingers was recorded in GSA9, GSA15, (Terribile and Laspina, 2022; Ceciarini et al., 2023) and these reductions resulted significant statistically in FAO31, GSA1 and GSA5 (Sagarminaga et al., 2006; Brotons et al., 2008; Waples et al., 2013).

Northridge et al., (2003) recorded significantly fewer holes (69%) attributed to being caused by dolphin depredation in trammel nets in Greece equipped with Saver pingers; identical results were obtained in in GSA5 dolphin interactions were reduced also significantly while using pingers showing a 70% reduction in net interactions (Brotons et al., 2008) two times higher than the reduction in this study which was -28% of harmful interactions using pingers, but this rate was closer to a study conducted in GSA 29 where demonstrated that acoustic deterrent devices reduced dolphin interactions with bottom gillnets by 36.3% (Namlıtürk and Blik, 2021). Overall, differences in interaction rates depending on the devices used. Also, in Maccarone et al. (2014) the results suggested that pingers were effective in reducing dolphin interactions and economic losses, also improving fishing efficiency in the Egadi Islands. In another study this reduction of interactions was not equal to all fishing gear employed considering that while pingers were effective in reducing depredation in gillnets and lampara nets, they had less impact on squid jigging lines and trammel nets, where dolphin interactions remained significant (Bruno et al., 2021), while in this study using both gillnet, trammel nets or combined net were not affected in different ways.

Some studies suggested that pingers might not be effective in reducing bycatches for all cetacean and pinniped species (Dawson et al., 2013). Moreover, particularly for common bottlenose dolphins (*Tursiops truncatus*), pingers have been shown to reduce depredation only in the short term, with little to no effect, or even the opposite effect, over time (Buscaino et al., 2021).

Key factors influencing dolphin depredation in coastal fisheries appear to be the target species, mesh size, and fishing area, as discovered by Pardalou and Tsikliras (2020) in the northern Aegean Sea. In their study, dolphins exhibited the highest interactions with nets targeting mullets (surmullet and red mullet), in alignment with other research (Balearic Islands: Gazo et al., 2008; northwest Sardinia: Lauriano et al., 2004). However, trammel nets designed for common sole, an important secondary prey for common bottlenose and common dolphins, also showed a high likelihood of depredation (Blasi et al., 2015). Furthermore, the frequency of depredation on gillnets and trammel nets was negatively

correlated with mesh size, likely due to the gear's increased selectivity as mesh size grows. Variations in prey species availability and distribution may contribute to differences in dolphin species occurrence, distribution, and movement, both daily and seasonally.

From a conservation perspective, depredation poses multiple threats to cetaceans. It exposes dolphins to the risk of entanglement, resulting in death or severe injuries. Moreover, the accidental ingestion of net fragments along with prey can lead to larynx strangulation or ulceration/obstruction of the digestive tract. Economically, depredation results in significant losses, including damage to gear and the removal or mutilation of fish caught in the net. Fishers often complain that dolphins disperse and scatter fish, making them less available for capture.

As reported in other studies in the bibliography, when discussing dolphin-fishery interactions, they referred to both direct interactions with dolphins, such as sightings, and indirect interactions, most of the times which were harmful, such as damage to the catch or fishing gear (evidenced by holes in the net), caused by dolphins or other species (paragraph 4.2.2.1 and 4.2.2.2).

Another aspect to consider is that the use of pingers, while effective in reducing interactions between dolphins and fishing activities, may have unintended consequences on non-target species and broader ecosystem dynamics. Several studies have highlighted that ADDs can influence the behaviour of other marine animals, raising concerns about potential cascading effects within the ecosystem. For instance, research has shown that pingers can alter the behaviour of non-target marine mammals, such as seals, which may be attracted rather than repelled by the emitted sounds (Carlström et al., 2009; Götz & Janik, 2013). Similarly, there is evidence that pingers may disturb non-target cetaceans, such as certain whale species, interfering with their communication and navigation (Findlay et al., 2023). At the ecosystem level, the widespread use of artificial acoustic signals could contribute to significant underwater noise pollution, with detrimental effects on sound-sensitive marine fauna. For example, fish and marine invertebrates, which rely on sound for navigation, foraging, and reproduction, may experience disruptions in their natural behaviours (Codarin et al., 2009). Such disruptions could lead to imbalances in trophic chains and changes in species distribution within marine habitats.

Table 17 - Studies using different types of pingers to reduce common bottlenose dolphin or other cetacean species depredation, indicating: technical features of the ADDs where source levels of pingers were referenced to 1 µPa at 1 m, location where the study took place included, between brackets, the GSA when studies were conducted in Mediterranean or Black Sea and the FAO area when studies were conducted in other part of the world. Moreover, period when the study was carried out, number of control and test trials, target commercial species and main response of the study included the reference were reported. "N.A." means that data were "Not Available", and "PSD" was "power spectral density (Buscaino et al., 2021).

PINGER	TECHNICAL FEATURES	LOCATION	PERIOD	CTRL TRIALS	TEST TRIALS	TARGET COMMERCIAL SPECIES	MAIN RESPONSE	REFERENCES
Aquatech AQUAmark® 100	20-160 kHz at 145 dB	Alboran Sea (GSA1)	Jun-Aug 2005	144	743	N.A.	Significant reduction in rates of dolphin/net interactions in pinger nets; no significant changes in net damage rates and CPUE	Sagarminaga et al., 2006
Aquatech AQUAmark® 100	20-160 kHz at 145 dB	Balearic Islands (GSA5)	Sep-Oct 2001	28	27	Red mullet	Damages caused by dolphin reduced of 87.00% with pingers; 50.00% depredation reduction	Gazo et al., 2008
Aquatech AQUAmark® 100	20-160 kHz at 145 dB	Black Sea (GSA29)	Mar-Jun 2012	23	23	Turbot	No reduction of harbor porpoises' bycatch	Bilgin and Köse, 2018
Aquatech AQUAmark® 210	5-160 kHz at 155 dB	Balearic Islands (GSA5)	Jul-Dic 2005	118	260	N.A.	Statistically significant reductions in dolphin interactions (-49%); no significant economic benefit	Brotons et al., 2008
Aquatech AQUAmark® 210	20-160 kHz at 145 dB	Black Sea (GSA29)	Mar-Jun 2012	23	23	Turbot	No reduction of harbor porpoises' bycatch	Bilgin and Kose, 2018
Aquatech AQUAmark® 210	5-16 k Hz at 145 dB	Northern Cyprus (GSA25)	2011-2014	43	43	Red mullet, bogue, Mediterranean parrotfish, and picarel	Pingers did not significantly reduce dolphin depredation or net damage	Snape et al., 2018
Aquatech AQUAmark® 300	2-10 kHz at 132 dB	Atlantic Ocean (FAO27)	May 2010-Sep 2011	59	86	squid	Depredation rate was similar with or without pingers; Pingers presence had no effect on fishing success; CPUE had no significant changes in captures	Cruz et al., 2020
Dukane NetMark® 1000	up to 10 kHz at 132 dB	Western Central Atlantic (FAO31)	Apr-May 2001	N.A	N.A	N.A	The use of acoustic alarms did not significantly affect the catch of fish	Cox et al., 2004
Dukane NetMark® 1000	up to 10 kHz at 130 dB	Balearic Islands (GSA6)	Jul-Dic 2005	74	272	N.A.	Dolphin interaction rates decreased by 49.00% with pingers; no significant economic benefit	Brotons et al., 2008
Dukane NetMark® 1000	10-12 kHz at 132 dB	Black Sea (GSA29)	Mar-Apr 2006	20	20	Turbot	CPUE of turbot was higher in pinger nets	Gönener and Bilgin, 2009

Dukane NetMark® 1000	10-12 kHz at 120-146 dB	Pacific Ocean (FAO87)	Apr 2009-Aug 2011	195	156	Smooth hammerhead, blue shark, short fin mako, thresher, and eagle rays *Myliobatis* spp.	37% reduction in the bycatch of small cetaceans with pinger nets; pingers did not impact the catch rates of the target species	Bowles et al., 2012
DDD-02® (STM Products S.r.l.)	0.1-200 kHz at 160 dB	Egadi Archipelago (GSA16)	Mar-May 2006	29	29	Bogue, round sardinella, Atlantic horse mackerel, *Pagellus* spp., blotched picarel	PPUE was 28% higher in the pinger nets; 31% fewer holes.	Maccarone et al., 2016
DDD-03® (STM Products S.r.l.)	5-500 kHz at 160 dB	Maltese islands (GSA15)	Mar 2021-May 2022	17	17	Cuttlefish, saddled bream, red mullet, bogue, spiny lobster, octopus, scorpion fish	Depredation decreased by 26.90% with pingers	Terribile and Laspina, 2023
DiD01® (STM Products S.r.l.)	5-500 kHz at 168 dB	Tuscan Archipelago (GSA9)	Mar-Oct 2021	42	97	Cuttlefish, common sole, red mullet and spottail mantis squillid	Pingers reduced dolphin interactions with fishing nets; species richness was also higher in pinger nets	Ceciarini et al., 2023
DiD01® (STM Products S.r.l.)	5-500 kHz at 168 dB	Tuscan Archipelago (GSA9)	Mar 2021-Nov 2023	295	573	Cuttlefish, red mullet, surmullet, greater amberjack, scorpion fish, sadded seabream, blotched picarel	Damages to fishing gear decreased by 29.52% with pingers; damages to catch decreased by 25.73% with pingers and harmful interaction rate decreased by 28.00%	PhD thesis
DiD01® (STM Products S.r.l.)	5-500 kHz at 168 dB	Maltese Islands (GSA15)	Mar 2021-May 2022	30	30	Cuttlefish, saddled bream, red mullet, bogue, spiny lobster, octopus, scorpion fish	Depredation decreased by 38.10% with pingers	Terribile and Laspina, 2023
DiD01® (STM Products S.r.l.)	5-500 kHz at 168 dB	Algarve coast (FAO27)	Jun 2019-Jun 2021	N.A	N.A	Red mullet, hake, cuttlefish, common sole	Depredation reduction 60.00-70.00% with pingers; CPUE increased with pingers	Marçalo et al., 2021
Fishtek Banana Pingers ®	50-120 kHz at 145 dB	Aeolian Archipelago	Apr-Sep 2017	N.A	N.A	Surmullet, blotched picarel, forkbeard	No depredation recorded; catch reduction in control net; nets with pingers caught significantly more fish than control nets	Bonanno Ferrero et al., 2018
Fishtek Banana Pingers ®	50-120 kHz at 145 dB	Aeolian Archipelago	Apr-Sep 2017	N.A	N.A	Surmullet, blotched picarel, forkbeard, bogue, cuttlefish	Substantial economic benefits with pinger-equipped nets	Bruno et al., 2021
Future Oceans	10-70 kHz at 145 dB	Black Sea (GSA30)	Mar-Jul 2019	N.A	N.A	Turbot	Pingers did not significantly reduce bycatch	Popov et al., 2020
Future Oceans	10-70 kHz at 145 dB	Black Sea (GSA29)	May 2015-Feb 2017	65	65	Whiting	CPUE was slightly higher in nets with pingers	Namlıtürk and Blik, 2021

Interactive pinger	40-60 kHz PSD (dB re 1 μPa2 Hz−1)	Pelagie Islands (GSA15)	Oct -Nov 2015	29	29	N.A.	Interactive pingers could be an effective tool in deterring depredation by common bottlenose dolphin on small-scale artisanal fisheries but when used discontinuously and in the short term (2-3 weeks)	Buscaino et al., 2009
Interactive pinger	40-60 kHz PSD (dB re 1 μPa2 Hz−1)	Atlantic Ocean (FAO31)	May 2010-Sep 2011	59	86	squid	Depredation rate was similar with or without pingers; Pingers presence had no effect on fishing success; CPUE had no significant changes in captures	Cruz et al., 2020
Fumunda Marine®	0-10 kHz at 132 dB	Atlantic Ocean (FAO27)	N.A.	N.A.	N.A.	Atlantic Spanish mackerel	Risk of interactions decreased from 81% to 50%	Read and Waples, 2010
Fumunda Marine®	70 kHz at 145 dB	Atlantic Ocean (FAO27)	N.A.	N.A.	N.A.	N.A.	No difference with control nets	Read and Waples, 2010
Fumunda Marine®	N.A.	Atlantic Ocean (FAO27)	May 2010-Sep 2011	59	86	squid	Depredation rate was similar with or without pingers; Pingers presence had no effect on fishing success; CPUE had no significant changes in captures	Cruz et al., 2020
NetMark®	N.A.	Alboran Sea (GSA1)	Jun-Aug 2005	144	743	N.A.	Significant reduction in rates of dolphin/net interactions in pinger nets; no significant changes in net damage rates and CPUE	Sagarminaga et al., 2006
Save Wave® Dolphinsaver	30-60 kHz at 155 dB	Aegean Sea (GSA22)	N.A.	N.A.	N.A.	N.A.	Significant reduction in depredation: fewer number of holes in the nets; 1 dolphin bycaught	Northridge et al., 2013
Save Wave® Dolphinsaver	5-160 kHz at 155 dB	Balearic Islands (GSA5)	Jul-Dic 2005	114	211	N.A.	Dolphin interaction rates decreased by 49.00% with pingers; no significant economic benefit	Brotons et al., 2008
Save Wave® White & Black	5-90 and 30-160 kHz at 155 dB	Black Sea (GSA29)	Apr 2007-Feb 2008	33	33	Red mullet	70.00% fewer holes with pingers; 34.00% more fish catch with pingers	Gönener and Özdemir et al., 2012
Save Wave® Dolphinsaver	N.A.	Alboran Sea (GSA1)	Jun-Aug 2005	144	743	N.A.	Significant reduction in rates of dolphin/net interactions in pinger nets; no significant changes in net damage rates and CPUE	Sagarminaga et al., 2006
Save Wave® White & Black	5-90 and 30-160 kHz at 155 dB	Western Central Atlantic (FAO31)	May 2003-Jun 2005	68	83	Spanish mackerel	Significantly fewer interactions; pingers did not significantly reduce the target fish catch; a notable reduction in the number of dolphins caught as bycatch in nets equipped with	Waples et al., 2013

4.2.2.1. Damages to the fishing gear and/or to the catch

Many papers reported damages to the catch and to the gear occurred by dolphins' presence around fishing grounds. For example, Aguilera et al., (2020) reported damage to fishing gear as broken nets and scattered catches occurred in 46% of fishing operations in those nets without pingers, bit more but very similar to this study where the 32.88% of CTRL trials reported at least a damage occurred by dolphins.

The study of Gazo et al. (2008) showed that pingers reduced net damage caused by bottlenose dolphins by 87%. Although pingers did not prevent dolphins from approaching the nets, they significantly minimized the number of holes in the nets, same result found by Namlıtürk and Blik (2021) where they observed fewer and smaller holes in nets equipped with pingers compared to control nets. Also, in Snape et al., (2018) net damages caused by dolphins was six times greater when dolphins were present, indicating a strong correlation between dolphin presence and increased gear damage. In Bruno et al. (2021) study gillnets equipped with pingers experienced no depredation, while the control nets suffered severe catch and gear damage. Therefore, Terribile and Laspina (2022) reported that fishers observed fewer dolphin encounters, which contributed to less gear damage and improved fishing productivity.

The holes recorded in nets were often attributed to dolphin activity, especially during their feeding attempts on the fish caught in the nets both if trammel nets or gillnets; also, some studies highlighted that monofilament nets were particularly susceptible to damage not only by dolphins but also by operational factors, such as disentangling fish or contact with the seafloor (Buscaino et al., 2009; 2021).

The economic loss caused by the net damages was higher than the estimated economic loss given by the catch damaged. The estimate of the damage was highly subjective and could vary depending on the type of equipment, the size of the holes, the type of thread used, and whether the nets were repaired by the individual fisherman or purchased pre-made. All these factors could indeed lead to significant discrepancies in the estimates of economic loss.

It is known that damage to fish catches was caused not only by dolphins but also by other species, as emerged during the years in which this PhD thesis was conducted. Indeed, the literature included several studies reporting that fish catches have been damaged not only by dolphins but also by other marine species. The work of Lauriano et al. (2004) was particularly useful and relevant, as it also described how to identify the different types of damage inflicted on the catch, allowing for the damage to be attributed to the responsible species based on factors such as bite type or the part of the body consumed. For example,

Ceciarini et al. (2023) and Aguilera et al. (2020) highlighted that the European conger was among the species that cause the most damage to catches. Furthermore, a study conducted in Portugal found that swordfish, bluefin tuna, and cormorants are also species that damage catches, likely due to the different fishing techniques used compared to the main study area. Bruke et al. (2005) also reported that sharks were responsible for 37% of depredated fish. This data was also suggested by Goetz et al. (2014) where interviewed fishers reported damage to catch and gear caused by cetaceans (52.3% of damage events), but also by other animals (47.7%), such as bony fish (e.g., conger), elasmobranchs (e.g., blue shark and shortfin mako).

The cost of the damages varied from fishers to fishers and depended on the type of damage incurred. If a fish weighing several kilograms was damaged, the economic loss was clearly greater compared to that of a smaller fish, and similarly, the type of fish species, whether more or less market valuable, also played a role. A cost analysis should be further explored, considering that results can vary from study to study. This is because fish prices also depend on the auction market, which can be highly variable.

4.2.2.2. Common bottlenose dolphin sightings

In several studies, dolphin sightings have been considered an important indicator not only for evaluating interactions but also for estimating the probability of depredation or behavioural changes, such as “feeding around fishing grounds”. Brotons et al., (2008) monitored dolphin sightings during hauls and found that they were a strong predictor of depredation. The probability of depredation when dolphins were sighted was much higher, while the probability of depredation in the absence of sightings was much lower. During this study, the only species observed interacting with set nets was the common bottlenose dolphin. This result is similar to those observations off the coast of southern Italy where frequent interactions between bottlenose dolphins and bottom-set gill nets, resulting in both net damage and fish removal were observed (Buscaino et al., 2009). In this study, dolphins were sighted during 2.77% of the 868 hauls conducted over three years. This sighting rate was much lower takin into account only year 2021 where in the North Tyrrhenian Sea (GSA9) the sighing rate was 23.7% as reported by the Life DELFI report (2022). This result was mor similar to the sighting rate recorded in the Aeolian Archipelago (6.8%) still during Life DELFI project. Moreover, this result is very similar to those observations occurred from GSA10 (Punta Campanella MPA) where dolphin sightings were recorded in 4 out of 9 events, with indirect signs of interaction in the remaining 5 events.

Despite these sightings, no significant economic damage to the catch or fishing gear was reported. Bruno et al. (2021) demonstrated that dolphin sightings can have varying effects depending on the type of fishing gear. For example, in trials using trammel nets, no dolphin damage was detected in either the test or control nets, despite sightings of different common bottlenose dolphin groups. However, when using the “lampara"” net, five dolphins sighted near the vessel during test only plundered the control net, drastically reducing the catch weight by 91.6% and leading to a revenue loss of €250. Also in this study, trammel nets were the fishing gear more affected by dolphin interaction both with holes in the net or with catch damaged, while combined nets recorded less damages, instead gillnet did not record any type of dolphin interaction either holes or damages to the catch.

In the 24 hauls recorded dolphin sightings, in 13 of those trials, damages were observed. More damage occurred in the control trials than in those using pingers. This aligned with Broton and Rendell’s observation that sightings were often followed by depredation, though this study reported a lower percentage of interactions resulting in damage (54%) compared to their 67%. Additionally, these findings were consistent with Terribile and La Spina (2022), who observed dolphin sightings in 5 onboard operations using pingers and recorded depredation in 18.2% of cases. Therefore, Buscaino et al. (2009) similarly reported that during their study, 11 groups of *T. truncatus* were observed interacting with both control and test nets (in 11 out of 29 hauls, or 38%).

Feliu-Tena et al. (2023) noted that 10 out of 11 dolphin sightings involved were common bottlenose dolphins, with groups ranging in size from one to eight individuals. Most of the sightings occurred at depths greater than 20 meters very similar to this study where the majority of specimens observed was at 17.61 m with a minimum of 3 demonstrating how close to the cost common bottlenose dolphin could arrive and the maximum 31.5 m.

Gazo et al. (2008) also observed that dolphin sightings could lead to a reduction in fish catch. For example, they found that the mean weight of the red mullet catch was significantly lower when dolphins were present near the nets, as dolphins may either scare the fish away or consume them before they can be harvested by fishers. This was reported also by a fisher who reported that in a trial when he observed six dolphins during hauling, he did not catch any fishes, only caramote prawn which is not a target species for the bottlenose dolphin diet.

Finally, as in many other studies no common bottlenose dolphin by-catch were recorded (Brotons et al., 2008; Buscaino et al., 2009; Popov et al., 2020; Ceciarini et al., 2023; Terribile and Laspina, 2022).

4.3.3. How policies and regulations could improve dolphin-fishery interactions

The *ex-ante* and *ex-post* questionnaire activities have highlighted that the interaction between cetaceans and fisheries has become an increasing issue in recent years. On the other hand, the study on cetacean strandings has provided the opportunity to develop a detailed protocol, carried out within the Life DELFI project and proposed to all partners, including ACCOBAMS. In this context, the political relevance of this research as a tool for policy improvement is evident, as it has contributed to monitoring interactions between cetaceans and fisheries and defining a standardized protocol for diagnosing stranded cetaceans and their causes.

Mid-frequency cetaceans, such as the common bottlenose dolphin — the subject of this PhD thesis — have a sound pressure level of 110-120 dB re: 1 μPa Lp RMS, which represents the threshold for various types of noise (single impulses, multiple impulses, and non-impulsive sounds) responsible for the first significant behavioural responses, such as escape, aversion, or "avoidance", according to ISPRA Guidelines. These guidelines formalize the obligations for acoustic environmental compatibility, as outlined in Descriptor No. 11 of the European Marine Strategy Framework. Therefore, all policies should focus on species protection and the reduction and minimization of acoustic pollution, which is already regulated by ISPRA guidelines that specifically protect the common bottlenose dolphin and other cetaceans.

Moreover, the study by La Manna et al. (2024) has been crucial in understanding the direction the scientific community is taking in resolving harmful interactions between dolphins and fisheries. Finding viable strategies for coexistence between dolphins and fisheries is one of the most urgent challenges in environmental management, requiring contributions from scientists, conservationists, policymakers, and stakeholders worldwide. This has led to the development of a framework for assessing and mitigating conflicts proposing management strategies categorized into *adaptation*, *mitigation*, *compensation*, and *alternative solutions*. Some of these strategies, such as compensation, have sometimes proven contradictory. In fact, they have not been entirely satisfactory for fishers, and while they have been objectively evaluated in certain regions, they remain difficult to implement.

A virtuous example in this regard is the Sardinia Region, which, as a special-status and therefore autonomous region, has been able to implement specific regulations to address damages caused by wildlife. In particular, it has introduced measures to compensate both artisanal fishers for damages caused by cetaceans and marine mammals in general, the first Decree n. 19824/DecA/712 of December 13th, 2018, the public notice related to Measure

1.40 “Protection and restoration of biodiversity and marine ecosystems and compensation schemes within the framework of sustainable fishing activities” (Article 40, paragraph 1, letter h) of Regulation (EU) No. 508/2014) was approved, concerning compensation for damages caused by protected mammals (cetaceans). As well as aquaculture businesses for losses due to cormorants through the Decree n. 14/85 of May 22nd, 2024. Although compensation is among the most preferred strategies by fishers, as it provides an objective and reassuring form of reimbursement, it remains an impractical solution. Currently, mitigation strategies to reduce the frequency of interactions between cetaceans and fisheries represent one of the most feasible solutions.

Chapter 5 CONCLUSION

What emerged over the years of this PhD research, when comparing the results with other studies in the literature, was that the issue of interactions between the fishing industry and cetaceans (or other protected marine species) was always highly specific and could vary from one region to another, from one type of gear to another, and from species to species of cetacean. This meant that mitigation measures effective in some parts of the world and with certain species were not necessarily applicable elsewhere, making mitigation an ongoing challenge. For example, in a 2019 ACCOBAMS report concerning various mitigation measures for different types of fishing gear (e.g., setnets, longlines, trawls, purse seines, trap nets, and pots) for protected species such as sharks, seabirds, sea turtles and cetaceans, technical experts suggested that acoustic deterrent devices alone were insufficient. They recommended combining them with: modifications to fishing gear, improvements in net acoustic reflectivity, and the use of passive acoustic devices, as well as chemosensory or visual mitigation methods.

However, in this PhD thesis, a new generation of interactive acoustic deterrents were primarily investigated, as they were among the most commonly used methods against cetaceans, even though they were not the only option. Manufacturers have proposed various solutions to reduce depredation, such as using pingers that were louder than standard bycatch pingers, randomization (e.g., Fishtek, Future Oceans, etc.), and signals with constant frequency, amplitude modulation, frequency modulation, and impulse signals. In this thesis a new pinger was selected that was tested only in two other studies (Marçalo et al., 2021; Terribile and Laspina, 2022). By the way, according to Dawson et al. (2013), a risk to incur was that common bottlenose dolphins involved in depredation could easily use pingers to locate nets and prey, thanks to their cognitive ability to adapt their foraging behaviour and their likely tolerance to higher acoustic pressures compared to other dolphins. Also, Gazo et al. (2008) suggested that habituation risk may develop quickly if the acoustic disturbance was moderate, particularly for common bottlenose dolphins, which were considered more adaptable to human impact than many other cetaceans (Whitehead et al., 2000). This was one of the main reasons why acoustic deterrents were seen as a short-term solution rather than a long-term one (Buscaino et al., 2021; Marçalo et al, 2021; Terribile and Laspina, 2022).

In this PhD thesis a side-effect of long-term use of pinger were not assessed, but actually the use of pingers produced positive outcomes. By using DiD01, the number of trials with catch damage was reduced by 25.73%, while the number of trials with net damage (holes) was

reduced by 29.52%. Moreover, the frequency of harmful interactions with dolphins decreased by 28.00% with the use of pingers, all these providing economic benefits to fishers, who saved an average of average €1,924.33 ± €679.07 annually. However, economic losses should be further investigated with a detailed assessment specifically focused on the extent of these losses. Nevertheless, this was the reason why the fishers were very satisfied with using this device. Additionally, another positive aspect was that the devices were not purchased directly by fishers, but it was lent by the University of Siena. Despite these successes, some fishers experienced technical difficulties, particularly with the battery. As there was no visual indicator for battery status, they had to check as they were trained to do it or with a voltmeter, which latter involved additional costs. Even when charging the pingers at home, they could not tell if they were fully charged even they were trained to understand and to control it (personal communication). So technical improvements were strongly suggested. Clearly, beyond the technical aspects related to the acoustic device, which could be enhanced by the use of artificial intelligence and more advanced technologies to make it a more promising tool another fundamental aspect to consider in this PhD study was the methodology of data sampling. In particular, the selection of fishers for the trials was primarily based on the availability and cooperation of professional fishers. While this approach was useful, it could introduce bias, as the fishers involved in the project may not represent the entire fishing community. In fact, it was possible that the cooperative fishermen might overstate or understate the extent of interactions with dolphins or the damage they suffer, influenced by personal interests, memory lapses, or expectations regarding the study's outcomes. Consequently, the results obtained may not fully reflect reality, making further investigation and a more representative sampling necessary to provide a more accurate understanding of the phenomenon.

In this regard, it was useful to refer to an Italian study conducted specifically to address this issue (La Manna et al., 2022). The study compared direct observations (DDO) with those obtained through passive acoustic monitoring to monitor dolphin depredation. For example, in recent years, numerous studies have highlighted the challenges regarding the perception of the conflict between dolphins and fishing activities, particularly emphasizing the tendency of fishers to overestimate depredation, documenting this phenomenon in various cases, as fishers might hope to obtain financial compensation by exaggerating (consciously or unconsciously) the extent of the problem (Bearzi et al., 2011; Rechimont et al., 2018; Revuelta et al., 2018). However, in the study by La Manna et al. (2022), conducted in Sardinia, it was found that depredation measured via acoustic detection of dolphin was

higher than that measured through direct observation. This result might indicate that the phenomenon was previously underestimated, but also that acoustic monitoring could offer better performance than other detection methods. While each study has a specific context, characterized by the local peculiarities of fishing activities and dolphin populations' behavior, the data suggest that depredation in coastal static nets may have increased over the past two decades. A possible factor behind this increase could be the rising human pressure on marine resources, coupled with the general decline in fish stocks (Tixier et al., 2021).

As a matter of fact, by now, there is no simple solution for mitigating detrimental between fisheries and cetaceans. An inclusive and participatory process involving all stakeholders (scientists, fishers, government entities, NGOs) is needed to discuss the best strategies. From the perspective of a balancing harmony between ecology, economy, and ethics, it is essential to develop mitigation solutions that protect both dolphins and fishers. First of all, from one hand mitigation measures must safeguard dolphins without altering their natural behaviour and hunting methods. Additionally, it is important to keep in mind that some type of solutions such as the use of pingers must avoid acoustic pollution in the marine environment, which could harm also other species such as sea turtles, sharks, bony fishes, or other marine invertebrates. At the same time, from the other hand, these solutions should benefit fishers by improving and increasing the efficiency of fishing gear. For example, institutions and government entities should introduce stricter regulations for the management of certain protected areas where common bottlenose dolphins habitually live, along with more rigorous regulation of fishing activities, in order to reduce these interactions. In fact, it is worth keeping in mind that the common bottlenose dolphin is classified as an "ecologically relevant" species in the European Marine Strategy Framework Directive (MSFD, 2008/56/EC), it is considered a Species of Community Interest listed in Annex II of the Habitat Directive (Council Directive 92/43/EEC) and it is one of the most affected cetacean species by anthropogenic activities, because of its synanthropic behaviour. For this reason, in 2020 in the waters of the Northern Tyrrhenian and Ligurian Seas, the largest Mediterranean Site of Community Importance (SIC) (about 3740 km2) was established (Natura 2000 code IT516002−Regional Council Decision No. 2, of January 14th, 2020), specifically devoted to the conservation of this species. Simultaneously, the government entities, thanks to the economic losses for fishers both to gears and catches evaluated by the scientist through projects or monitoring campaigns, should apply and foresee financial compensation measures as it has already been established in Sardinia Region (Italy) with a regional law (Reg.L. No. 19824/DecA/712 of 12/13/2018).

Meanwhile, scientists should certainly find mitigation solutions above mentioned, but at the same time continue investigations into the health status of common bottlenose dolphins through indirect monitoring of stranded individuals. During these three years, no bycatch of common bottlenose dolphin was recorded, by among the recovered stranded specimens, two of these were found with high evidence of fishery-interactions due to their fishing gears sings around their bodies. The stranding monitoring provide valuable information, gathered indirectly, but crucial for better understanding the trends in these fishery interactions. Nevertheless, it also remains a priority to apply strict protocols to determine direct causes of death, whether linked to fishing interactions (such as pieces of net in the tail, body, or mouth) or not, with the exception of bycatch, which is a direct event.

Finally, regarding fishers, as a priority it is also important to raise awareness that dolphins are valuable resources for the marine ecosystem, and the interspecific competition between common bottlenose dolphins and artisanal fishers should be transformed into peaceful coexistence. Even in some countries, there is a positive cooperation between dolphins and fishers (Simões-Lopes et al., 1998; Zappes et al., 2011; D'Lima et al., 2014; Barnhill et al., 2022). To achieve this, alternative fishing gear, such as pods that were efficient for fishers and safe for dolphins (Ganias et al., 2021; Virgili et al., 2024) and alternative economic activities, such as dolphin watching (Life DELFI, 2022-2023), were proposed. In particular in this way dolphins can turn into assets for fishers, rather than being seen as obstacles to their economic activities. Moreover, involving tourists can help spread greater public awareness of marine ecosystem conservation and environmental protection.

Finding solutions for sustainable coexistence between wildlife and humans is one of the most challenging environmental management issues faced by scientists, conservationists, managers, and stakeholders worldwide. As with all ecological issues, it is crucial to adopt a holistic approach and view things in their complexity. Only in this way can we effectively address environmental challenges, promoting sustainable solutions that account for interactions between nature, the economy, and society.

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CONFLICT OF INTEREST

I declare that there are no personal, financial, or professional conflicts of interest that could have influenced the work reported in this thesis.

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SUPPLEMENTARY MATERIALS

The chapter dedicated to Supplementary Materials provides additional information that enhances the main part of the project, offering a more detailed view of the activities carried out during sampling and field trials. These materials served as a critical complement, essential for gaining a deeper understanding of data collection processes and the monitoring of fishing activities. The information includes a variety of documents and tools, such as questionnaires, logbooks, and technical data sheets, in the following order:

- EX ANTE QUESTIONNAIRE
- EX POST QUESTIONNAIRE
- OBSERVER LOGBOOK DATA SHEET
- FISHER LOGBOOK DATA SHEET
- FEATURES OF SETNETS EMPLOYED BY FISHERS INVOLVED IN THE PROJECT
- DATA IN TERMS OF N, KG, AND DAMAGES (N AND KG) FOR EACH TRAIL IN ALL FIVE AREAS
- DATA SHEET FROM ITALIAN STRANDINGS BANK

EX ANTE QUESTIONNAIRE

LIFE DELFI

Dolphin Experience: Lowering Fishing Interactions

LIFE18 NAT/IT/000942

QUESTIONNAIRE SURVEY FOR PROFESSIONAL FISHERMEN

Action A3 Data gathering and scientific protocols

Action D3 Socio-economic impact

Dear Fisherman,

We would like to involve you in an important project aiming to lower the interaction between dolphins and the commercial fishery activities. The objective of this questionnaire survey is to gather useful information to understand the interaction of dolphins with the different commercial fishery gears used in the Mediterranean Sea.

For this reason, we kindly ask your availability to answer to some questions. The participation is voluntary and the data are used anonymously. The survey lasts 10 minutes.

The questionnaire is divided in 3 sections in order to gather preliminary information to plan the following phases of the project.

Area	Port
Interviewer	Date

Name of the boat (optional) _____

LOA (meter) _____

GT _____

Power (KW) _____

Age of the fisherman_____

Years of work in the fishery _____

Fishing frequency (n. per year) _____

Main fishing gear _____

Secondary fishing gear _____

SECTION 1 – DOLPHINS' PRESENCE AND FISHING INTERCATION

This section is useful to get a general scenario about the geographical and seasonal presence of dolphins as well as the fishing interaction. It is also useful to understand the possible issues/damages caused by the dolphins and how to reduce them.

1. **How frequent do you observe dolphins while fishing?**

□ Always
□ Often
□ Occasionally
□ Never

1a. How many animals do you observe per day? _____

1b. How do they interact?

□ No interaction
□ They take fish from the net
□ They damage the fish
□ They damage the net
□ They scare the fish
□ Other _____

1c. If there are damages, how much do you estimate the economic loss per year?

The damage is meant as the fish loss and the damage to the gears

€_____per year

2. **Which is the season where do you spot more dolphins, even from distance, without any interaction with your fishing activity? Score the seasons from 1 to 4 (1= season with less sightings and 4 = season with more sightings).**

Spring	
Summenr	
Autumn	
Winter	

3. **Using the map, report the coordinates of YOUR USUAL FISHING AREA, if possible taking into account the seasons (you could also report the local names of the areas)**

_____

_____

_____

_____

4. **Using the map, report the coordinates of the AREAS WHERE YOU USE TO OBSERVE THE DOLPHINS even without any interaction, if possible taking into account the seasons (you could also report the local names of the areas)**

_____

_____

_____

_____

5. **How you feel the presence of dolphins has changed during the years?**

□ it is increased
□ it is decreased
□ it is the same
□ I don't know

5a. If it is increased, how much do you think?

□ double
□ triple
□ I don't know
□ Other (e.g. report the temporal period: 1980-2000 or 2000-today)

_____

6. **Did you ever accidentally catch a dolphin?**

□ Yes □ No

6a. If yes, which gear was by?

_____

6b. How many time has t happened? (number of bycatch/years of activity)
_____

6c. How many animals were dead and how many alive? _____

6d. Did the presence of dolphin in the nets create an obstacle to your fishing activity?
□ Yes □ No

6e. Which was the issue?
□ Obstacle to travel and fishing time reduction
□ Gear damage
□ Catch damage
□ Other (specify) _____

6f. How did you manage such situation?
_____
_____
_____

7. **Which is the season where the dolphin interactions are more frequent? Score the seasons from 1 to 4 (1= season with less sightings and 4 = season with more sightings).**

Spring	
Summer	
Autumn	
Winter	

8. **In a scale from 1 (not important) to 5 (very important), report your opinion on how problematic do you think is the presence of dolphins in the fishing areas.**

1 □ 2□ 3□ 4□ 5□

Justify your answer

_____
_____
_____
_____

9. Do you believe that the dolphins represent an important resource of the marine ecosystem?

□ Yes □ No

Justify your answer

_____

_____

_____

SECTION 2 – RESPONSIBLE FISHERY

In this section, we would like to know your opinion about some aspects related to the responsible fishery.

10. Do you have experience with bycatch mitigation devices? *(Only 1 answer)*

□ I use them regurarly
□ I use them occasionally
□ I've never used them
□ Other _____

10a. If you use them which type do you have?

_____

10b. If you use them, are you satisfied?

_____

10c. If you DON'T use them, why?

□ I don't know them
□ I know the, but I'm not interested to test them
□ I have tested them but I was not satisfied with them
□ Other _____

11. Do you use any other strategy to keep the dolphins away?

□ Yes □ No

11a. If yes, which ones?

_____-

12. Do you think it is necessary to reduce such interactions?

□ Yes □ No

Justify your answer:

_____
_____

_____
_____

12a. If yes, how do you think this result could be achieved?

□ Using pingers or other mitigation device
□ With an economical reimbursement for the damages
□ I don't know
□ Other _____

SECTION 3 – PARTICIPATION AND COOPERATION

This section is useful to know your availability to take part to the Life DELFI project. To lower the interaction between dolphins and fishing activities, Life DELFI project will develop the following sustainable fishing methods:

- Modern pinger for gillnets e trawl
- Visual deterrent for gillnets and trawl
- Alternative fishing gears

13. Are you awared that the future operative fishery programme (2021-2027), with the aim to apply the new FEAMP, currently under review, will fund the replacement of your gears with new ones more selective and sustainable?
□ Yes □ No

14. Would you like to receive information about national and European opportunity of mitigation measurements and use of low impact fishing gears?

□ Yes □ No

15a. If yes, why?
_____
_____
_____
_____

15. Would you be available to test mitigation devices proposed by Life DELFI for your boat?
□ Yes □ No

16. Would you be available to take part of Dolphin Watching activities with your boat?
□ Yes □ No

17. Would you be available to get involved in fishing-tourism with your boat?
□ Yes □ No

18. Would you be available to get involved in ichthyic-tourism?
□ Sì □ No

19. Would you be available to join a quality certification for better selling your products?
□ Yes □ No

20. Would you like to share with us your contacts if you are interested in the aformentioned activities?

_____

INTERVIEWER NOTES

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

EX POST QUESTIONNAIRE

Life DELFI

Dolphin Experience: Lowering Fishing Interactions
LIFE18 NAT/IT/000942

QUESTIONNAIRE FOR PROFESSIONAL FISHERS

Action A3: Data gathering and scientific protocols
Action D3: Socioeconomic survey

SECTION 1
INFORMATION ABOUT THE FISHERS INVOLVED AND THE TRIAL

Area	Port
Interviewer	Date

Name of the fishing vessel (*optional*) _____

Length Overall (Mt) _____
Gross tonnage (GT) _____
Engine power (kW) _____
Age of the fisher _____
Years of work in the fishing industry _____

1. As part of the Life DELFI project in which activity did you participate? *(In case of involvement in more than one activity, fill out one questionnaire each)*
□ Acoustic deterrents testing
□ Visual deterrents testing
□ Fishing trap testing
□ Dolphin watching

2. How often did you collaborate with the project *(number of sea trips per year)*
_____

3. Type of gear used for activities with deterrents or alternative gears *(one answer per row)*

	Primary	Secondary
Bottom trawling	□	□
Midwater trawling	□	□
Longline	□	□
Gillnet	□	□
Purse seine	□	□
Pots and traps	□	□
Other (Specify):	□	□

SECTION 2
EVALUATION OF THE SOCIO-ECONOMIC IMPACT OF THE TRIAL

1. What was your experience with acoustic/visual deterrents or alternative fishing gears (pots and traps) before you were involved in the project? *(one answer only)*

- □ I regularly used deterrents or alternative gears
- □ I occasionally used deterrents or alternative gears
- □ I occasionally used other kinds of deterrents or alternative gears
- □ I had never used any dolphin mitigation device
- □ I would have liked to use deterrents, but they were too expensive
- □ Other (Specify): _____

2. On a scale of 1 (low) to 5 (high) answer the following questions:

	Using deterrents or alternative gears					**NOT using deterrents or alternative gears**				
How often have you observed dolphins interacting with your fishing gear?	1 □	2 □	3 □	4 □	5 □	1 □	2 □	3 □	4 □	5 □
How much damage was done to your fishing gear?	1 □	2 □	3 □	4 □	5 □	1 □	2 □	3 □	4 □	5 □
How much damage was done to your catches?	1 □	2 □	3 □	4 □	5 □	1 □	2 □	3 □	4 □	5 □

3. On a scale of "Very much" to "I do not know" answer the following questions:

	VERY MUCH	**SUFFICIENTLY**	**LITTLE**	**NOT AT ALL**	**I DO NOT KNOW**
Have you had an economic benefit in using deterrents or alternative gears?	□	□	□	□	□
The use of deterrents or alternative gears has improved the value of the catches?	□	□	□	□	□
Deterrents or alternative gears were easy to use?	□	□	□	□	□
How much your fishing methods have changed?	□	□	□	□	□
How much has the use of deterrents or alternative gears reduced interaction with the dolphins?	□	□	□	□	□
How much has the use of traps and pots reduced the amount of discards?	□	□	□	□	□

Were you satisfied by the use of deterrents or alternative gears?	□	□	□	□	□

4. Did you encounter difficulties while using the deterrents?
□ Yes □ No

4a. If yes, which ones? (*multiple answers are possible)*
□ Adapting to a different way of fishing
□ Modifying the gear I usually used
□ Getting the crew to accept the new gear
□ The time it takes to set the fishing gear has increased
□ Other (Specify): _____

5. Have you ever accidentally caught a dolphin during the project? (*multiple answers are possible)*
□ Yes, while using deterrents
□ Yes, without using deterrents
□ No, never

5a. How many times has this happened? *(specify the number of catches/years of activity)*
_____

5b. How many were alive and how many were deceased?
N. alive _____
N. deceased _____

5c. How did you handle the situation? (*multiple answers are possible)*
□ We cut the fishing gear and released the dolphin
□ We released the dolphin without any damage to the fishing gear
□ We called the Coast Guard
□ Other (Specify): _____

6. On a scale of 1 (Not important) to 5 (very important) how problematic do you think the presence of dolphins in your fishing areas is?

1□ 2□ 3□ 4□ 5□

Explain your answer
_____
_____
_____

7. Do you think dolphins represent an important resource of the marine ecosystem?
□ Yes □ No

Explain your answer
_____
_____

8. Would you like to keep using deterrents or alternative gears tested during the project? *(one answer)*
□ Yes, I would buy the same type of deterrents or alternative gears already tested
□ Yes, I would buy another type of deterrents or alternative gears
□ No, because I was not satisfied
□ Other (Specify): _____

9. Would you improve the deterrents used during the project?
□ Yes □ No

9a. If yes, what would you improve? (*multiple answers are possible)*
□ The way of lowering the nets
□ The way of reloading the nets
□ The cost
□ The weight
□ Other (Specify): _____

10. Do you think the use of the new gears brings benefits to the marine environment?
□ Yes □ No

10a. If yes, why? (*multiple answers are possible)*
□ Because fewer protected species are accidentally caught
□ Because accidentally caught species can be more easily released
□ Because it increases gear selectivity

11. What would motivate you to use the new gears regularly? *On a scale of 1 (low) to 5 (high) give a priority to each sentence*

	1	2	3	4	5
A quality label that could help to better sell the catches	□	□	□	□	□
An allowance for the purchase of new fishing gear	□	□	□	□	□
A tax cut or economic relief	□	□	□	□	□
More information on gear efficiency	□	□	□	□	□
Continue the test for a longer period of time	□	□	□	□	□
The entry into force of a regulation	□	□	□	□	□
The recovery of points on your license					

12. How was the information regarding the use of deterrents or alternative gears that you received during the project?
□ Exhaustive
□ Barely sufficient
□ Scarce
□ Don't know

13. Would you be interested in repeating the trial?
□ Yes □ No

SECTION 3
PARTICIPATION AND COLLABORATION

This section is useful to be aware of the fishers' willingness to participate in other projects, related to sustainable and responsible fishing and to reduce the interaction between professional fishing activities and dolphins.

14. Are you aware that the Operational Program for Fisheries (2021-2027), which will be responsible for implementing the new European Maritime Affairs and Fisheries Fund (EMFF) in Italy, would fund the replacement of your fishing gear with new, more selective and sustainable gear?
□ Yes □ No

15. Would you find it useful to have information about the opportunities implemented at national and European level on mitigation measures and about the use of low-impact fishing gear?
□ Yes □ No

15a. If yes, why?
_____
_____

16. Would you collaborate on other projects related to sustainable fisheries?
□ Yes □ No

17. Did you participate in the dolphin watching training courses organized during the DELFI project?
□ Yes □ No

18. Would you be willing to carry out dolphin watching activities on your boat?
□ Yes □ No □ Already in progress *(answer to question 18.a)*

18.a On a scale of 1 (low) to 5 (high) how do you evaluate the experience of dolphin watching?

1□ 2□ 3□ 4□ 5□

19. Would you be willing to carry out fish tourism activities?
□ Yes □ No □ Already in progress *(answer to question 19.a)*

19.a On a scale of 1 (low) to 5 (high) how do you evaluate the experience of fish tourism?

1□ 2□ 3□ 4□ 5□

20. Would you use a quality label to better sell your catch?
□ Yes □ No

NOTES _____
_____

OBSERVER LOGBOOK DATA SHEET

Action C1, D1

SET NETS

OBSERVER LOGBOOK

www.lifedelfi.eu

NET WITH PINGER ☐ NET WITHOUT PINGER ☐ HAUL N:_____

DEPTH (m):_____ VESSEL NAME:_____

FISHING AREA(Lat./Long.):_____ NET TYPE (e.g. trammel):_____

NET LENGTH (m)_____ NET HEIGHT (n° meshes):_____ MESH LENGTH (mm):_____

DATE AND SETTING TIME:_____ DATE AND HAULING TIME:_____

NUMBER OF PINGERS:_____ PINGERS SPACING (m):_____

Fill the table with the commercial species caught and details on non-marketable catch attributable to dolphin depredation. If an accurate measurement cannot be done, estimate the data.

COMMERCIAL SPECIES	Total number of individuals	Total weight (Kg)	N° non-marketable individuals	Total non-marketable catch weight (g)
Example: Common sole	*30*	*2.5*	*2*	*80 gr*

Number of dolphins sighted				
Distance between dolphins and nets				
Number of new damages (e.g. holes, tears)				
Diameter new holes (estimate in cm)				
Economic loss (estimate in €):	Catch damages	€_____	Gear damages	€_____

Notes (e.g. dolphins' behaviour):_____

Action C1, D1

DISTRIBUTION SHEET

OBSERVER LOGBOOK

www.lifedelfi.eu

NET WITH PINGER ☐ NET WITHOUT PINGER ☐ HAUL N: _____

DATE: _____ / _____ / _____ SPECIES: _____

TOTAL WEIGHT: _____ SUBSAMPLE WEIGHT: _____

LENGTH (cm)	NUMBER	LENGTH	NUMBER	LENGTH	NUMBER
1.5		18.5		35.5	
2		19		36	
2.5		19.5		36.5	
3		20		37	
3.5		20.5		37.5	
4		21		38	
4.5		21.5		38.5	
5		22		39	
5.5		22.5		39.5	
6		23		40	
6.5		23.5		40.5	
7		24		41	
7.5		24.5		41.5	
8		25		42	
8.5		25.5		42.5	
9		26		43	
9.5		26.5		43.5	
10		27		44	
10.5		27.5		44.5	
11		28		45	
11.5		28.5			
12		29			
12.5		29.5			
13		30			
13.5		30.5			
14		31			
14.5		31.5			
15		32			
15.5		32.5			
16		33			
16.5		33.5			
17		34			
17.5		34.5			
18		35			

Note:_____

CETACEAN BYCATCH SHEET

OBSERVER LOGBOOK

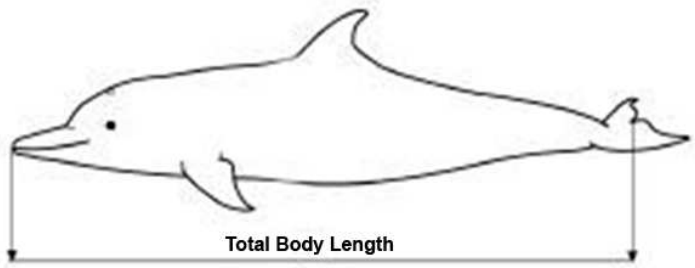
NET WITH PINGER ☐ NET WITHOUT PINGER ☐

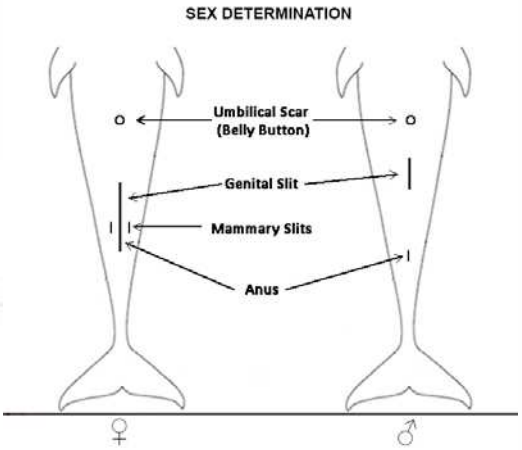
DATE: _____ / _____ / _____ SPECIES: _____

INDIVIDUAL WEIGHT (Kg): _____(measured/estimated)

TOTAL LENGTH (TBL): _____(measured/estimated)

Catch conditions	Good	Bad	Inactive	Dead
Release conditions	Good	Bad	Inactive	Dead
Sex	M	F	IND.	
ID image				





PRESENCE OF WOUNDS:_____

ADDITIONAL NOTES: _____

Other vulnerable species caught				
	Species 1	**Species 2**	**Species 3**	**Notes**
GROUP OF VULNERABLE SPECIES (Sea turtles, seabirds, sharks, rays and benthic species)				
SPECIES				
ID IMAGE				
NUMBER OF INDIVIDUALS				
TOTAL WEIGHT				
CATCH CONDITIONS				
RELEASE CONDITIONS				

FISHER LOGBOOK DATA SHEET

Action C1, D1

SET NETS

FISHER LOGBOOK

www.lifedelfi.eu

NET WITH PINGER ☐ NET WITHOUT PINGER ☐ HAUL N:_____

DEPTH (m):_____ VESSEL NAME:_____

FISHING AREA:_____ NET TYPE (e.g. trammel):_____

NET LENGTH (m)_____ NET HEIGHT (n° meshes):_____ MESH LENGTH (mm):_____

DATE AND SETTING TIME:_____ DATE AND HAULING TIME:_____

NUMBER OF PINGERS:_____ PINGERS SPACING (m):_____

Fill the table with the commercial species caught and details on non-marketable catch attributable to dolphin depredation. If an accurate measurement cannot be done, estimate the data.

COMMERCIAL SPECIES	Total number of individuals	Total weight (Kg)	N° non-marketable individuals	Total non-marketable catch weight (g)
Example: Common sole	*30*	*2.5*	*2*	*80 gr*

Number of dolphins sighted				
Distance between dolphins and nets				
Number of new damages (e.g. holes, tears)				
Diameter new holes (estimate in cm)				
Economic loss (estimate in €):	Catch damages	€_____	Gear damages	€_____

Notes (e.g. dolphins' behaviour):_____

Beneficiario coordinatore | Beneficiari associati

CETACEAN BYCATCH SHEET

FISHER LOGBOOK

www.lifedelfi.eu

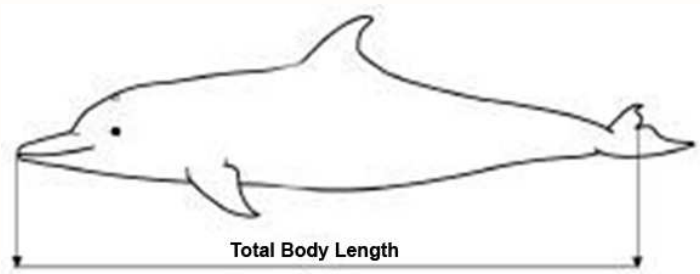
NET WITH PINGER ☐ NET WITHOUT PINGER ☐

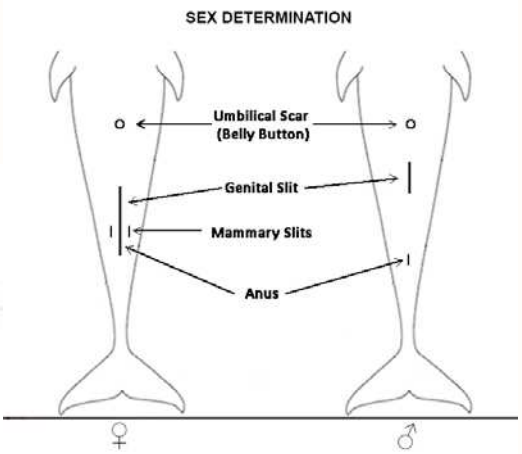
DATE: _____ / _____ / _____ SPECIES: _____

INDIVIDUAL WEIGHT (Kg): _____(measured/estimated)

TOTAL LENGTH (TBL): _____(measured/estimated)

Catch conditions	Good	Bad	Inactive	Dead
Release conditions	Good	Bad	Inactive	Dead
Sex	M	F	IND.	
ID image				





PRESENCE OF WOUNDS:_____

ADDITIONAL NOTES: _____

Other vulnerable species caught				
	Species 1	**Species 2**	**Species 3**	**Notes**
GROUP OF VULNERABLE SPECIES (Sea turtles, seabirds, sharks, rays and benthic species)				
SPECIES				
ID IMAGE				
NUMBER OF INDIVIDUALS				
TOTAL WEIGHT				
CATCH CONDITIONS				
RELEASE CONDITIONS				

FEATURES OF SETNETS EMPLOYED BY FISHERS INVOLVED IN THE PROJECT

Table S1 – Technical features such as mesh size (mm) and net height (m) of all three types of setnets (GTR, GNS and GTN) employed during all trials in all areas for each vessel. Mesh size is measured from opposite knot to knot for each individual mesh. The symbol "-" indicated that data the type of setnet was not used. *The two numbers indicate, for the combined nets that the first one is referred to the mesh size of the gillnet (upper section) and the second number is referred to the mesh size of the trammel (lower section).

AREA	VESSEL	Type of set net		
		GTR	GNS	GTN
AREA 1	8LI104	Mesh size (mm) 36.00 Net height (m) 1.20	Mesh size (mm) 42.00 Net height (m) 1.60	Mesh size (mm) 40.00-42.00* Net height (m) 9.60
	8LI114	Mesh size (mm) 36.00 Net height (m) 1.70 Mesh size (mm) 45.00 Net height (m) 2.00 Mesh size (mm) 22.00 Net height (m) 0.80	Mesh size (mm) 42.00 Net height (m) 1.50 Mesh size (mm) 50.00 Net height (m) 3.00	-
AREA 2	2LI2801	Mesh size (mm) 40.00 Net height (m) 1.80	Mesh size (mm) 42.00 Net height (m) 1.50	Mesh size (mm) 38.00-42.00* Net height (m) 8.00
	8LI102	Mesh size (mm) 33.00 Net height (m) 1.50	-	Mesh size (mm) 42.00-50.00* Net height (m) 3.50
	14LI37	Mesh size (mm) 23.00 Net height (m) 1.30 Mesh size (mm) 36.00 Net height (m) 1.40	-	Mesh size (mm) 40.00-45.00* Net height (m) 12.00
	2LI2637	Mesh size (mm) 22.00 Net height (m) 1.50	Mesh size (mm) 40.00 Net height (m) 18.00	Mesh size (mm) 36.00-40.00* Net height (m) 5.00 Mesh size (mm) 40.00-40.00* Net height (m) 9.00
	2LI2739	Mesh size (mm) 33.00 Net height (m) 1.50 Mesh size (mm) 22.00 Net height (m) 1.50	-	Mesh size (mm) 38.00-40.00* Net height (m) 18.00
	2LI2850	Mesh size (mm) 28.00 Net height (m) 1.20 Mesh size (mm) 35.00 Net height (m) 1.80	Mesh size (mm) 50.00 Net height (m) 1.50	Mesh size (mm) 38.00-40.00* Net height (m) 12.00
	2LI2772	Mesh size (mm) 50.00 Net height (m) 2.00 Mesh size (mm) 70.00 Net height (m) 2.00	-	-

AREA 3	**14LI36 14LI50 14LI46**	Mesh size (mm) 40.00 Net height (m) 1.50	-	Mesh size (mm) 35.00-40.00* Net height (m) 5.00
	8LI95	Mesh size (mm) 35.00 Net height (m) 1.70	-	-
	14LI49	Mesh size (mm) 32.00 Net height (m) 1.50 Mesh size (mm) 50.00 Net height (m) 3.00	-	-
AREA 4	**13LI125 13LI120**	Mesh size (mm) 60 Net height (m) 2.00 Mesh size (mm) 21.00 Net height (m) 1.50	Mesh size (mm) 60.00 Net height (m) 2.00	Mesh size (mm) 60.00-60.00* Net height (m) 2.00
	13LI121 13LI119	Mesh size (mm) 38.00 Net height (m) 0.50 Mesh size (mm) 33.00 Net height (m) 1.20	Mesh size (mm) 40.00 Net height (m) 4.00 Mesh size (mm) 50.00 Net height (m) 4.00	-
	13LI127	Mesh size (mm) 35.00 Net height (m) 2.50 Mesh size (mm) 25.00 Net height (m) 2.00	Mesh size (mm) 40.00 Net height (m) 1.40	-
AREA 5	**1LI1321**	Mesh size (mm) 44.00 Net height (m) 1.70	-	-

MASTER'S OFFICE LOGBOOK

ANNEX VI

MODEL OF COMBINED EUROPEAN UNION FISHING LOGBOOK, LANDING DECLARATION AND TRANSHIPMENT DECLARATION

No .....

EUROPEAN UNION LOG-BOOK

Day Month Hour Year , 20– ,

Name of vessel(s) (1) _____ External identification (2) _____

International Radio call sign (s) (1)

Name of master(s) (3) _____ 1

Address(es)
1 _____ 1

Departure (4) 1 ---------1 1 ---------1 1 ---------1 from 1 ---------1

Return (5) 1 ----------1 1 ----------1 1 ----------1 to 1 ----------1

Landing (6) 1 ----------1 1 ----------1 1 ----------1 at 1 ----------1

Gear (8) 1 ----------1 Mesh size (9) 1 ----------1 Dimension (10) 1 ----------1

In case of transhipment (7) Day 1 --------1
Month 1 ---------1 1 ---------1

Name and radio call sign (if any) _____
External identification _____
Nationality of recipient fishing vessel _____

Date (11)	Number of fishing operations (12)	Fishing time (13)	Position (14)			Catch by species kept on board in kilograms live weight or number of units (15)[2]												
			Statistical rectangle	ICES/ NAFO/ CECAF/ CFGM-zone	Non-Member States' fishing zone												Give weight of unit in live weigh, of species concerned	Initials
																		Estimated total discards (16)

	ICES/ NAFO/ CECAF/ CFGM-zone (22)	Non-Member States' fishing zone (22)	Landing/transhipment (*) declaration / (18) in kilograms or unit utilized: equals ..... Kilograms
Presentation of fish (17) Quantities (19) Presentation of fish (17) Quantities (19) Presentation of fish (17) Quantities (19) Presentation of fish (17) Quantities (19)			Signature Master/Agent Π (20) Agent's name and address (where applicable) (21) Agent's name and address (where applicable) (21)

(*) Delete whichever does not apply. Comments:_

DATA IN TERMS OF N, KG, AND DAMAGES (N AND KG) FOR EACH TRAIL IN ALL FIVE AREAS

Table S2 – All species listed with FAO CODE captured in AREA 1 (Porto Ercole) during all trials of the year 2022. For each species are shown: number of individuals, kilograms, number of individuals damaged and kilograms of catch damaged for both CTRL and TEST nets.

Species caught / FAO code	**n**		**kg**		**DAMAGES (n)**		**DAMAGES (kg)**	
	CTRL	**TEST**	**CTRL**	**TEST**	**CTRL**	**TEST**	**CTRL**	**TEST**
MON	0.00	2.00	0.00	6.20	0.00	0.00	0.00	0.00
DEC	2.00	12.00	1.40	7.50	0.00	0.00	0.00	0.00
AMB	17.00	119.00	19.50	139.00	0.00	0.00	0.00	0.00
BLL	6.00	21.00	7.20	26.20	0.00	0.00	0.00	0.00
BON	1.00	3.00	1.50	4.00	0.00	0.00	0.00	0.00
CBM	0.00	2.00	0.00	3.00	0.00	0.00	0.00	0.00
CBR	80.00	220.00	7.00	15.00	0.00	0.00	0.00	0.00
CTC	180.00	756.00	31.10	151.70	0.00	2.00	0.00	0.00
GUU	0.00	15.00	0.00	11.80	0.00	0.00	0.00	0.00
HKE	2.00	0.00	2.60	0.00	0.00	0.00	0.00	0.00
LTA	17.00	36.00	23.20	55.60	0.00	0.00	0.00	0.00
MGA	10.00	7.00	6.00	5.00	0.00	0.00	0.00	0.00
MLR	50.00	40.00	40.00	30.00	0.00	0.00	0.00	0.00
MMH	0.00	24.00	0.00	14.90	0.00	0.00	0.00	3.40
MUF	0.00	3.00	0.00	2.00	0.00	0.00	0.00	0.00
MUR	372.00	1021.00	34.00	120.00	0.00	0.00	0.00	0.00
MUT	432.00	3223.00	39.60	299.60	0.00	0.00	0.00	3.80
OCC	0.00	3.00	0.00	4.20	0.00	0.00	0.00	0.00
PAC	3.00	4.00	1.00	2.00	0.00	0.00	0.00	0.00
RJC	63.00	139.00	53.00	116.80	0.00	0.00	0.00	0.00
RSE	35.00	395.00	4.00	43.60	0.00	0.00	0.00	3.60
SBG	24.00	49.00	32.30	47.60	0.00	0.00	0.00	0.00
SLO	1.00	0.00	0.90	0.00	0.00	0.00	0.00	0.00
SMD	4.00	48.00	11.00	91.00	0.00	0.00	0.00	0.00
SNQ	50.00	60.00	6.00	7.00	0.00	0.00	0.00	0.00
SOL	58.00	276.00	15.80	62.20	0.00	0.00	0.00	0.00
SOS	0.00	60.00	0.00	2.00	0.00	0.00	0.00	0.00
SSB	0.00	224.00	0.00	14.00	0.00	0.00	0.00	0.00
SWA	10.00	25.00	5.00	14.50	0.00	0.00	0.00	0.00
TGS	855.00	4880.00	29.60	214.80	0.00	0.00	0.00	0.00
UUC	21.00	117.00	6.90	70.00	0.00	0.00	0.00	0.00
YFC	0.00	6.00	0.00	3.50	0.00	0.00	0.00	0.00
Total	**2293.00**	**11790.00**	**378.60**	**1584.70**	**0.00**	**2.00**	**0.00**	**10.80**

Table S3- All species listed with FAO CODE captured in AREA 1 (Porto Ercole) during all trials of the year 2023. For each species are shown: number of individuals, kilograms, number of individuals damaged and kilograms of catch damaged for both CTRL and TEST nets.

Species caught / FAO code	**n**		**kg**		**DAMAGES (n)**		**DAMAGES (kg)**	
	CTRL	**TEST**	**CTRL**	**TEST**	**CTRL**	**TEST**	**CTRL**	**TEST**
MON	1.00	12.00	2.00	24.00	0.00	0.00	0.00	0.00
DEC	43.00	3.00	19.85	1.75	0.00	0.00	0.00	0.00
AMB	18.00	0.00	11.50	0.00	0.00	0.00	0.00	0.00
BLL	13.00	30.00	11.20	38.80	0.00	0.00	0.00	0.00
BLU	95.00	126.00	114.50	114.00	0.00	0.00	0.00	0.00
BON	2.00	6.00	4.00	9.00	0.00	0.00	0.00	0.00
BSS	2.00	0.00	3.50	0.00	0.00	0.00	0.00	0.00
CBM	14.00	7.00	6.23	2.50	0.00	0.00	0.00	0.00
CBR	40.00	200.00	6.30	22.19	0.00	0.00	0.00	0.00
COB	76.00	66.00	69.50	101.00	0.00	0.00	0.00	0.00
CTB	5.00	4.00	1.62	1.00	0.00	0.00	0.00	0.00

CTC	328.00	465.00	75.92	117.01	0.00	0.00	0.00	0.00
GFB	12.00	4.00	2.50	0.60	0.00	0.00	0.00	0.00
GUU	0.00	4.00	0.00	1.30	0.00	0.00	0.00	0.00
LEE	17.00	35.00	35.50	73.50	0.00	0.00	0.00	0.00
LTA	1.00	5.00	2.50	6.00	0.00	0.00	0.00	0.00
MAC	1.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00
MGA	73.00	124.00	61.14	98.00	0.00	0.00	0.00	0.00
MLR	49.00	0.00	65.00	0.00	0.00	0.00	0.00	0.00
MTS	0.00	12.00	0.00	1.00	0.00	0.00	0.00	0.00
MUF	77.00	120.00	78.70	113.00	0.00	0.00	0.00	0.00
MUR	555.00	652.00	107.95	105.17	3.00	0.00	0.41	0.00
MUT	400.00	1947.00	58.78	201.17	2.00	0.00	0.16	0.00
MZZ	6.00	2.00	8.30	5.80	0.00	0.00	0.00	0.00
OCC	28.00	6.00	15.91	8.70	0.00	0.00	0.00	0.00
PAC	23.00	1.00	3.36	0.30	0.00	0.00	0.00	0.00
POP	10.00	7.00	5.00	3.00	0.00	0.00	0.00	0.00
RJC	16.00	28.00	18.50	27.50	0.00	0.00	0.00	0.00
RPG	11.00	0.00	1.74	0.00	0.00	0.00	0.00	0.00
RSE	347.00	218.00	50.66	30.17	0.00	0.00	0.00	0.00
SBA	89.00	43.00	14.22	13.18	0.00	0.00	0.00	0.00
SBG	136.00	210.00	131.20	165.30	0.00	0.00	0.00	0.00
SBS	2.00	2.00	0.59	0.59	0.00	0.00	0.00	0.00
SHR	3.00	0.00	0.96	0.00	0.00	0.00	0.00	0.00
SKA	52.00	90.00	65.00	95.80	0.00	0.00	0.00	0.00
SLM	17.00	5.00	5.54	1.23	0.00	0.00	0.00	0.00
SLO	0.00	1.00	0.00	0.80	0.00	0.00	0.00	0.00
SNQ	0.00	20.00	0.00	3.00	0.00	0.00	0.00	0.00
SOL	78.00	500.00	22.80	126.90	0.00	0.00	0.00	0.00
SOS	20.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00
SQC	1.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00
SQF	0.00	1.00	0.00	0.03	0.00	0.00	0.00	0.00
SQR	0.00	1.00	0.00	0.25	0.00	0.00	0.00	0.00
SRG	0.00	5.00	0.00	0.75	0.00	0.00	0.00	0.00
SRK	185.00	80.00	26.70	11.50	2.00	0.00	0.00	0.00
SSB	42.00	75.00	16.00	25.00	0.00	0.00	0.00	0.00
SWA	11.00	0.00	4.75	0.00	0.00	0.00	0.00	0.00
SYC	0.00	15.00	0.00	5.00	0.00	0.00	0.00	0.00
TGS	780.00	4610.00	23.10	130.00	0.00	0.00	0.00	0.00
TTV	0.00	10.00	0.00	15.00	0.00	0.00	0.00	0.00
UUC	66.00	73.00	21.70	26.05	0.00	0.00	0.00	0.00
WEG	2.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00
YFC	79.00	8.00	16.60	2.34	0.00	0.00	0.00	0.00
YRS	6.00	11.00	2.01	4.40	0.00	0.00	0.00	0.00
Total	**3832.00**	**9844.00**	**1196.52**	**1733.58**	**7.00**	**0.00**	**0.57**	**0.00**

AREA 2 (Porto Santo Stefano)

Table S4 - All species listed with FAO CODE captured in AREA 2 (Porto Santo Stefano) during all trials of the year 2021. For each species are shown: number of individuals, kilograms, number of individuals damaged and kilograms of catch damaged for both CTRL and TEST nets.

Species caught / FAO code	n		kg		DAMAGES (n)		DAMAGES (kg)	
	CTRL	TEST	CTRL	TEST	CTRL	TEST	CTRL	TEST
DEC	0.00	3.00	0.00	1.10	0.00	0.00	0.00	0.00
AMB	0.00	2.00	0.00	10.70	0.00	0.00	0.00	0.00
ANN	0.00	1.00	0.00	0.15	0.00	0.00	0.00	0.00
BLL	0.00	4.00	0.00	1.30	0.00	0.00	0.00	0.00
BON	1.00	0.00	1.00	8.00	0.00	0.00	0.00	0.00
BRF	0.00	33.00	0.00	8.45	0.00	0.00	0.00	0.00
CEO	0.00	0.00	0.00	0.00	6.00	0.00	2.00	0.00
COB	0.00	7.00	0.00	2.50	0.00	0.00	0.00	0.00
CTB	0.00	0.00	0.00	3.00	0.00	0.00	0.00	0.00
CTC	10.00	78.00	4.00	23.95	0.00	1.00	0.00	0.20
DPS	0.00	15.00	0.00	1.65	0.00	0.00	0.00	0.00
GFB	0.00	1.00	0.00	0.30	0.00	0.00	0.00	0.00
GUU	0.00	6.00	0.00	1.30	0.00	0.00	0.00	0.00
HMM	0.00	1.00	0.00	0.10	0.00	0.00	0.00	0.00
JRS	0.00	1.00	0.00	0.30	0.00	0.00	0.00	0.00
LTA	0.00	0.00	0.00	31.00	0.00	0.00	0.00	0.00
MLR	0.00	1.00	0.00	115.20	0.00	4.00	0.00	0.00
MSF	0.00	130.00	0.00	7.00	0.00	4.00	0.00	0.20
MTS	19.00	193.00	1.00	13.50	0.00	0.00	0.00	0.00
MUF	1.00	4.00	1.00	66.00	0.00	0.00	0.00	0.00
MUR	0.00	0.00	0.00	3.00	0.00	0.00	0.00	0.00
MUT	13.00	275.00	5.10	80.35	0.00	28.00	0.00	2.10
OCC	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00
PAC	0.00	42.00	0.00	10.95	0.00	0.00	0.00	0.00
RJC	0.00	1.00	0.00	0.80	0.00	0.00	0.00	0.00
SAA	4.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00
SBG	0.00	11.00	0.00	4.20	0.00	0.00	0.00	0.00
SLM	0.00	2.00	0.00	0.40	0.00	0.00	0.00	0.00
SLO	0.00	2.00	0.00	0.95	0.00	0.00	0.00	0.00
SOL	13.00	94.00	11.00	46.40	0.00	1.00	0.00	0.20
SSB	0.00	3.00	0.00	0.70	0.00	0.00	0.00	0.00
TGS	0.00	134.00	0.00	21.00	0.00	0.00	0.00	0.00
TUR	0.00	1.00	0.00	0.55	0.00	0.00	0.00	0.00
UUC	0.00	3.00	0.00	0.35	0.00	0.00	0.00	0.00
Total	**61.00**	**1048.00**	**24.60**	**467.15**	**6.00**	**38.00**	**2.00**	**2.70**

Table S5 - All species listed with FAO CODE captured in AREA 2 (Porto Santo Stefano) during all trials of the year 2022. For each species are shown: number of individuals, kilograms, number of individuals damaged and kilograms of catch damaged for both CTRL and TEST nets.

Species caught / FAO code	n		kg		DAMAGES (n)		DAMAGES (kg)	
	CTRL	TEST	CTRL	TEST	CTRL	TEST	CTRL	TEST
AMB	0.00	201.00	0.00	163.00	0.00	0.00	0.00	0.00
BLL	0.00	0.00	0.00	2.30	0.00	0.00	0.00	0.00
BLU	0.00	9.00	0.00	4.30	0.00	0.00	0.00	0.00
BON	0.00	13.00	0.00	8.00	0.00	0.00	0.00	0.00
CTC	0.00	177.00	10.00	85.50	0.00	0.00	0.00	0.00
DEC	0.00	8.00	0.00	1.50	0.00	0.00	0.00	0.00
DPS	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00
EZS	0.00	89.00	0.00	12.50	0.00	0.00	0.00	0.00
HKE	0.00	152.00	0.00	58.15	8.00	0.00	2.00	0.00
LTA	0.00	11.00	0.00	0.00	0.00	0.00	0.00	0.00
MSF	0.00	125.00	0.00	18.60	0.00	0.00	0.00	0.00
MTS	0.00	410.00	0.00	31.90	0.00	2.00	0.00	0.00
MUR	0.00	35.00	0.00	6.00	0.00	0.00	0.00	0.00
MUT	0.00	261.00	0.00	58.00	0.00	1.00	0.00	0.10
MZZ	0.00	60.00	0.00	13.00	0.00	0.00	0.00	0.00
OCC	0.00	14.00	0.00	26.70	0.00	0.00	0.00	0.00
PAC	0.00	72.00	0.00	34.50	0.00	0.00	0.00	0.00
RJC	0.00	7.00	0.00	5.30	0.00	0.00	0.00	0.00
SAA	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00
SBG	0.00	4.00	0.00	0.25	0.00	0.00	0.00	0.00
SNQ	0.00	50.00	0.00	7.00	0.00	0.00	0.00	0.00
SOL	0.00	121.00	0.00	59.87	4.00	0.00	1.00	0.30
SSB	0.00	12.00	0.00	3.40	0.00	0.00	0.00	0.00
SWA	0.00	4.00	0.00	9.75	0.00	0.00	0.00	0.00
TGS	0.00	169.00	0.00	17.90	0.00	3.00	0.00	0.10
TTV	0.00	1.00	0.00	1.50	0.00	0.00	0.00	0.00
UUC	0.00	10.00	0.00	3.70	0.00	0.00	0.00	0.00
Total	**0.00**	**2016.00**	**10.00**	**635.12**	**12.00**	**6.00**	**3.00**	**0.50**

Table S6 - All species listed with FAO CODE captured in AREA 2 (Porto Santo Stefano) during all trials of the year 2023. For each species are shown: number of individuals, kilograms, number of individuals damaged and kilograms of catch damaged for both CTRL and TEST nets.

Species caught / FAO code	n		kg		DAMAGES (n)		DAMAGES (kg)	
	CTRL	TEST	CTRL	TEST	CTRL	TEST	CTRL	TEST
DEC	1.00	26.00	4.40	32.80	0.00	0.00	0.00	0.00
AMB	10.00	47.00	131.50	204.00	0.00	5.00	0.00	2.00
ANK	0.00	3.00	0.00	6.20	0.00	0.00	0.00	0.00
ANN	67.00	891.00	6.00	55.60	12.00	15.00	1.20	1.60
BLL	3.00	18.00	1.30	12.90	0.00	0.00	0.00	0.00
BLU	20.00	20.00	7.50	7.30	0.00	0.00	0.00	0.00
BOG	10.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00
BON	23.00	52.00	20.30	75.00	4.00	2.00	1.00	0.50
BSS	3.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00

CBM	0.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00
CBR	0.00	135.00	0.00	11.50	0.00	0.00	0.00	0.00
COB	4.00	12.00	1.00	8.90	0.00	0.00	0.00	0.00
CRA	0.00	22.00	0.00	3.00	0.00	0.00	0.00	0.00
CTB	0.00	45.00	0.00	19.40	0.00	0.00	0.00	0.00
CTC	262.00	952.00	57.80	214.10	0.00	6.00	0.00	0.00
GFB	0.00	1.00	0.00	1.90	0.00	0.00	0.00	0.00
GPW	0.00	1.00	0.00	2.00	0.00	0.00	0.00	0.00
GUU	7.00	19.00	2.00	6.00	0.00	0.00	0.00	0.00
HKE	78.00	251.00	24.50	52.30	9.00	3.00	4.00	0.00
HOM	6.00	117.00	1.50	23.30	0.00	2.00	0.00	0.50
LEE	0.00	0.00	0.00	3.00	0.00	0.00	0.00	0.00
LTA	0.00	20.00	0.00	30.20	0.00	0.00	0.00	0.00
MAC	0.00	11.00	0.00	1.50	0.00	0.00	0.00	0.00
MMH	0.00	9.00	0.00	12.60	0.00	0.00	0.00	0.00
MSF	30.00	368.00	1.55	26.90	8.00	51.00	0.60	4.80
MSP	0.00	3.00	0.00	3.80	0.00	0.00	0.00	0.00
MTS	380.00	2086.00	22.40	120.60	0.00	1.00	0.00	0.02
MUF	111.00	166.00	35.00	104.20	0.00	0.00	0.00	0.00
MUR	123.00	480.00	9.50	57.50	12.00	3.00	1.90	0.70
MUT	677.00	6224.00	60.70	652.40	2.00	93.00	0.20	10.70
MZZ	0.00	4.00	0.00	0.80	0.00	0.00	0.00	0.00
OCC	4.00	26.00	11.30	42.10	0.00	0.00	0.00	0.00
PAC	82.00	809.00	14.45	144.20	5.00	7.00	0.70	2.10
RJC	3.00	26.00	2.50	25.80	0.00	0.00	0.00	0.00
RSE	100.00	728.00	6.00	55.50	0.00	0.00	0.00	0.00
SBG	16.00	74.00	17.40	80.20	0.00	0.00	0.00	0.600
SBS	0.00	15.00	0.00	4.80	0.00	0.00	0.00	0.00
SLM	20.00	147.00	14.00	77.80	0.00	0.00	0.00	0.00
SNQ	10.00	41.00	1.30	4.30	0.00	0.00	0.00	0.00
SOL	44.00	469.00	12.70	105.12	3.00	15.00	0.30	1.40
SOS	7.00	10.00	0.80	1.50	0.00	0.00	0.00	1.50
SQF	0.00	2.00	0.00	0.60	0.00	0.00	0.00	0.00
SSB	26.00	84.00	7.20	30.70	5.00	0.00	1.40	0.70
SWA	0.00	22.00	5.00	21.40	0.00	1.00	0.00	0.40
SYC	0.00	5.00	0.00	1.00	0.00	0.00	0.00	0.00
TGS	45.00	204.00	1.90	13.60	0.00	0.00	0.00	0.00
UUC	9.00	41.00	1.60	8.00	0.00	0.00	0.00	0.00
Total	**2181.00**	**14686.00**	**488.60**	**2366.32**	**60**	**204.00**	**11.30**	**27.52**

AREA 3 (Talamone)

Table S7 - All species listed with FAO CODE captured in AREA 3 (Talamone) during all trials of the year 2021. For each species are shown: number of individuals, kilograms, number of individuals damaged and kilograms of catch damaged for both CTRL and TEST nets.

Species caught / FAO code	n		kg		DAMAGES (n)		DAMAGES (kg)	
	CTRL	TEST	CTRL	TEST	CTRL	TEST	CTRL	TEST
DEC	2.00	8.00	1.80	4.30	0.00	1.00	0.00	0.20
AMB	0.00	15.00	0.00	7.70	0.00	0.00	0.00	0.00
ANK	0.00	7.00	0.00	37.85	0.00	0.00	0.00	0.00
BLL	6.00	96.00	2.80	43.34	0.00	2.00	0.00	0.80
BLU	0.00	1.00	0.00	0.50	0.00	0.00	0.00	0.00
BON	0.00	16.00	0.00	20.30	0.00	0.00	0.00	0.00
BSS	1.00	3.00	0.55	3.80	0.00	0.00	0.00	0.00
CBM	12.00	0.00	9.10	0.00	3.00	0.00	1.50	0.00
COB	5.00	10.00	2.40	6.50	0.00	0.00	0.00	0.00
COE	1.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00
CTB	0.00	2.00	0.00	0.40	0.00	0.00	0.00	0.00
CTC	704.00	2602.00	217.50	660.50	8.00	22.00	1.20	4.50
EZS	6.00	0.00	1.80	0.00	0.00	0.00	0.00	0.00
GFB	1.00	2.00	0.52	0.70	0.00	0.00	0.00	0.00
GPW	2.00	3.00	1.00	4.39	0.00	0.00	0.00	0.00
GUU	2.00	7.00	1.10	1.14	0.00	0.00	0.00	0.00
HKE	4.00	57.00	1.90	17.75	0.00	5.00	0.00	1.20
HMM	0.00	1.00	0.00	0.20	0.00	0.00	0.00	0.00
LBE	0.00	2.00	0.00	3.00	0.00	0.00	0.00	0.00
MLR	8.00	1.00	5.90	0.30	0.00	0.00	0.00	0.00
MMH	2.00	0.00	4.20	0.00	0.00	0.00	0.00	0.00
MSF	3.00	87.00	0.30	10.04	0.00	0.00	0.00	0.00
MTS	0.00	15.00	0.00	0.90	0.00	0.00	0.00	0.00
MUF	14.00	7.00	6.60	3.60	0.00	0.00	0.00	0.00
MUR	11.00	1.00	1.48	0.40	0.00	0.00	0.00	0.00
MUT	9.00	93.00	1.00	13.44	0.00	2.00	0.00	0.35
MZZ	20.00	6.00	16.00	5.70	0.00	0.00	0.00	0.00
OCC	1.00	33.00	2.00	34.90	0.00	0.00	0.00	0.00
PAC	2.00	64.00	1.10	14.44	0.00	2.00	0.00	0.65
SAA	1.00	2.00	0.60	1.37	0.00	0.00	0.00	0.00
SBG	6.00	6.00	4.00	5.50	0.00	0.00	0.00	0.00
SBS	6.00	0.00	1.20	0.00	0.00	0.00	0.00	0.00
SLM	7.00	10.00	2.20	2.40	0.00	0.00	0.00	0.00
SLO	5.00	10.00	2.50	6.80	0.00	2.00	0.00	1.80
SOL	19.00	552.00	5.50	115.82	0.00	4.00	0.00	1.10
SOS	25.00	20.00	3.00	2.80	1.00	0.00	0.25	0.00
SSB	6.00	0.00	1.80	0.00	0.00	0.00	0.00	0.00
SWA	19.00	28.00	5.20	10.30	0.00	0.00	0.00	0.00
TGS	0.00	10.00	0.00	0.80	0.00	0.00	0.00	0.00
Total	**910.00**	**3777.00**	**306.55**	**1041.88**	**12.00**	**40.00**	**2.95**	**10.60**

Table S8 - All species listed with FAO CODE captured in AREA 3 (Talamone) during all trials of the year 2022. For each species are shown: number of individuals, kilograms, number of individuals damaged and kilograms of catch damaged for both CTRL and TEST nets.

Species caught / FAO code	**n**		**kg**		**DAMAGES (n)**		**DAMAGES (kg)**	
	CTRL	**TEST**	**CTRL**	**TEST**	**CTRL**	**TEST**	**CTRL**	**TEST**
DEC	0.00	45.00	5.00	34.30	0.00	0.00	0.00	0.00
AMB	0.00	88.00	0.00	61.70	0.00	0.00	0.00	0.00
ANE	0.00	0.00	0.00	0.00	4.00	0.00	0.50	0.00
ANN	15.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00
BLL	0.00	3.00	3.00	4.00	0.00	0.00	0.00	0.00
BLU	0.00	5.00	18.50	51.20	0.00	0.00	0.00	0.00
BON	0.00	14.00	0.00	34.10	0.00	0.00	0.00	0.00
BSS	0.00	3.00	0.00	1.80	0.00	0.00	0.00	0.00
CBM	0.00	2.00	0.00	0.90	0.00	0.00	0.00	0.00
COB	0.00	30.00	12.50	48.60	0.00	0.00	0.00	0.00
CTC	0.00	28.00	22.60	42.90	0.00	0.00	0.00	0.00
DOL	0.00	2.00	3.00	3.80	0.00	0.00	0.00	0.00
HKE	1.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00
HOM	0.00	2.00	0.00	0.80	0.00	0.00	0.00	0.00
LBE	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00
LEE	0.00	16.00	31.00	12.50	0.00	0.00	0.00	0.00
MGA	0.00	0.00	0.00	10.40	0.00	0.00	0.00	0.00
MSF	0.00	8.00	0.00	1.80	0.00	0.00	0.00	0.00
MTS	0.00	4.00	0.00	0.50	0.00	0.00	0.00	0.00
MUF	3.00	48.00	9.00	36.80	0.00	0.00	0.00	0.00
MUT	0.00	25.00	0.00	3.00	0.00	11.00	0.00	0.90
MZZ	0.00	0.00	4.00	16.50	0.00	0.00	0.00	0.00
OCC	0.00	2.00	0.00	2.70	0.00	0.00	0.00	0.00
PAC	0.00	9.00	0.00	2.60	0.00	3.00	0.00	2.00
POP	0.00	10.00	0.00	3.00	0.00	0.00	0.00	0.00
RJC	0.00	13.00	0.00	5.50	0.00	2.00	0.00	0.00
RSE	1.00	0.00	0.20	1.50	0.00	0.00	0.00	0.00
SBA	0.00	32.00	0.00	17.30	0.00	0.00	0.00	0.00
SBG	1.00	39.00	13.50	50.20	0.00	0.00	0.00	0.00
SHR	0.00	0.00	0.00	5.60	0.00	0.00	0.00	0.00
SLM	1.00	11.00	0.30	6.60	0.00	0.00	0.00	0.00
SLO	4.00	2.00	1.00	0.80	0.00	0.00	0.00	0.00
SOL	0.00	8.00	0.00	2.30	0.00	0.00	0.00	0.00
SSB	0.00	2.00	0.00	1.50	0.00	0.00	0.00	0.00
SWA	0.00	14.00	13.00	6.70	0.00	0.00	0.00	0.00
TTV	3.00	0.00	0.80	17.00	2.00	5.00	0.00	3.00
TUR	0.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00
UUC	0.00	8.00	0.00	2.00	0.00	0.00	0.00	0.00
Total	**29.00**	**474.00**	**142.80**	**491.90**	**6.00**	**21.00**	**0.50**	**5.90**

Table S9 - All species listed with FAO CODE captured in AREA 3 (Talamone) during all trials of the year 2023. For each species are shown: number of individuals, kilograms, number of individuals damaged and kilograms of catch damaged for both CTRL and TEST nets.

Species caught / FAO code	n		kg		DAMAGES (n)		DAMAGES (kg)	
	CTRL	TEST	CTRL	TEST	CTRL	TEST	CTRL	TEST
DEC	35.00	48.00	17.00	27.00	0.00	0.00	0.00	0.00
AMB	118.00	145.00	55.50	69.80	2.00	0.00	0.00	0.00
BLU	8.00	6.00	9.70	3.90	0.00	0.00	0.00	0.00
BON	9.00	17.00	9.00	17.40	0.00	0.00	0.00	0.00
BSS	0.00	2.00	0.00	5.50	0.00	0.00	0.00	0.00
CBM	27.00	24.00	15.70	14.80	0.00	0.00	0.00	0.00
COB	113.00	85.00	59.60	49.90	0.00	0.00	0.00	0.00
CRU	3.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
CTB	8.00	0.00	2.40	0.00	0.00	0.00	0.00	0.00
CTC	31.00	237.00	9.00	65.40	0.00	0.00	0.00	0.00
GPW	1.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00
HKE	2.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
HOM	10.00	7.00	4.10	2.70	0.00	0.00	0.00	0.00
LTA	6.00	11.00	5.20	8.90	0.00	0.00	0.00	0.00
MGA	0.00	27.00	0.00	23.50	0.00	0.00	0.00	0.00
MLR	33.00	47.00	25.60	32.50	0.00	0.00	0.00	0.00
MSP	2.00	3.00	3.00	3.00	0.00	0.00	0.00	0.00
MTS	31.00	33.00	2.20	3.50	0.00	0.00	0.00	0.00
MUF	87.00	57.00	53.90	57.50	0.00	0.00	0.00	0.00
MUT	0.00	23.00	0.00	6.10	0.00	0.00	0.00	0.00
MZZ	7.00	2.00	11.00	6.00	0.00	0.00	0.00	0.00
OCC	1.00	7.00	1.20	10.70	0.00	0.00	0.00	0.00
PAC	5.00	26.00	2.20	9.90	0.00	0.00	0.00	0.00
POP	13.00	86.00	6.30	35.10	0.00	0.00	0.00	0.00
RSE	6.00	9.00	2.00	1.70	0.00	0.00	0.00	0.00
SBG	420.00	221.00	163.80	90.20	0.00	0.00	0.00	0.00
SHR	1.00	1.00	0.60	0.45	0.00	0.00	0.00	0.00
SLM	87.00	71.00	31.40	30.70	3.00	0.00	0.00	0.00
SLO	0.00	1.00	0.00	1.10	0.00	0.00	0.00	0.00
SOL	3.00	3.00	2.90	0.90	0.00	0.00	0.00	0.00
SOS	0.00	10.00	0.00	2.00	0.00	0.00	0.00	0.00
SSB	34.00	19.00	9.30	6.60	0.00	0.00	0.00	0.00
SWA	26.00	37.00	9.20	15.90	0.00	0.00	0.00	0.00
Total	**1127.00**	**1265.00**	**513.50**	**602.65**	**5.00**	**0.00**	**1.00**	**0.00**

AREA 4 (Marina di Grosseto)

Table S10 - All species listed with FAO CODE captured in AREA 4 (Marina di Grosseto) during all trials of the year 2021. For each species are shown: number of individuals, kilograms, number of individuals damaged and kilograms of catch damaged for both CTRL and TEST nets.

Species caught / FAO code	n		kg		DAMAGES (n)		DAMAGES (kg)	
	CTRL	TEST	CTRL	TEST	CTRL	TEST	CTRL	TEST
ANN	0.00	0.00	0.00	2.70	0.00	0.00	0.00	0.00
BLL	11.00	73.00	4.69	32.50	0.00	0.00	0.00	0.00
BLU	0.00	2.00	0.00	0.70	0.00	0.00	0.00	0.00
BRF	2.00	2.00	0.50	0.30	0.00	0.00	0.00	0.00
BSS	0.00	8.00	0.00	2.20	0.00	0.00	0.00	0.00
COB	5.00	42.00	1.30	7.50	0.00	0.00	0.00	0.00
CTC	7.00	28.00	2.80	7.40	0.00	0.00	0.00	0.00
EZS	0.00	22.00	0.00	1.50	0.00	0.00	0.00	0.00
GFB	0.00	5.00	0.00	1.65	0.00	0.00	0.00	0.00
GUU	1.00	2.00	0.60	0.14	0.00	0.00	0.00	0.00
LDB	3.00	11.00	2.00	7.10	0.00	0.00	0.00	0.00
MSF	120.00	110.00	8.00	6.70	0.00	0.00	0.00	0.00
MTS	1033.00	2060.00	22.40	48.90	0.00	0.00	0.00	0.00
MUF	0.00	95.00	0.00	45.40	0.00	0.00	0.00	0.00
MUR	1.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00
MUT	756.00	1331.00	36.20	81.90	20.00	4.00	2.00	0.20
MZZ	10.00	5.00	2.10	1.30	0.00	0.00	0.00	0.00
OCC	4.00	8.00	3.40	6.78	0.00	0.00	0.00	0.00
PAC	32.00	14.00	8.15	5.05	0.00	0.00	0.00	0.00
RJC	1.00	2.00	0.40	1.80	0.00	0.00	0.00	0.00
RJO	9.00	7.00	6.00	2.70	0.00	0.00	0.00	0.00
SBG	0.00	5.00	0.00	0.70	0.00	0.00	0.00	0.00
SLM	12.00	12.00	4.40	1.60	0.00	0.00	0.00	0.00
SLO	0.00	1.00	0.00	0.40	0.00	0.00	0.00	0.00
SOL	166.00	492.00	16.80	48.23	0.00	0.00	0.00	0.00
SQF	0.00	10.00	0.00	1.00	0.00	0.00	0.00	0.00
SSB	5.00	40.00	1.30	7.45	0.00	0.00	0.00	0.00
TGS	680.00	2300.00	41.75	154.80	0.00	0.00	0.00	0.00
TTV	8.00	3.00	5.50	2.70	0.00	0.00	0.00	0.00
UUC	3.00	18.00	0.80	6.65	0.00	0.00	0.00	0.00
WEG	0.00	2.00	0.00	0.15	0.00	0.00	0.00	0.00
YRS	9.00	24.00	1.66	4.79	0.00	0.00	0.00	0.00
Total	**2878.00**	**6734.00**	**170.83**	**492.69**	**20.00**	**4.00**	**2.00**	**0.20**

Table S11 - All species listed with FAO CODE captured in AREA 4 (Marina di Grosseto) during all trials of the year 2022. For each species are shown: number of individuals, kilograms, number of individuals damaged and kilograms of catch damaged for both CTRL and TEST nets.

Species caught / FAO code	n		kg		DAMAGES (n)		DAMAGES (kg)	
	CTRL	TEST	CTRL	TEST	CTRL	TEST	CTRL	TEST
ANN	0.00	50.00	0.00	18.00	0.00	0.00	0.00	0.00
BLL	0.00	4.00	0.00	1.30	0.00	0.00	0.00	0.00
COB	0.00	2.00	0.00	0.60	0.00	0.00	0.00	0.00
CTC	0.00	10.00	0.00	2.35	0.00	0.00	0.00	0.00
EZS	0.00	1.00	0.00	0.75	0.00	0.00	0.00	0.00
HKE	0.00	1.00	0.00	0.40	0.00	0.00	0.00	0.00
MSF	0.00	20.00	0.00	1.50	0.00	0.00	0.00	0.00
MSP	0.00	1.00	0.00	1.60	0.00	0.00	0.00	0.00
MTS	0.00	915.00	0.00	29.00	0.00	0.00	0.00	0.00
MUT	0.00	1438.00	0.00	86.00	0.00	0.00	0.00	0.00
OCC	0.00	1.00	0.00	1.20	0.00	2.00	0.00	1.60
SLO	0.00	1.00	0.00	0.45	0.00	0.00	0.00	0.00
SOL	0.00	7.00	0.00	1.35	0.00	0.00	0.00	0.00
TGS	0.00	980.00	0.00	38.60	0.00	0.00	0.00	0.00
TUR	0.00	3.00	0.00	1.55	0.00	0.00	0.00	0.00
UUC	0.00	1.00	0.00	0.13	0.00	0.00	0.00	0.00
YRS	0.00	3.00	0.00	0.50	0.00	0.00	0.00	0.00
Total	**0.00**	**3438.00**	**0.00**	**185.28**	**0.00**	**2.00**	**0.00**	**1.60**

Table S12 - All species listed with FAO CODE captured in AREA 4 (Marina di Grosseto) during all trials of the year 2023. For each species are shown: number of individuals, kilograms, number of individuals damaged and kilograms of catch damaged for both CTRL and TEST nets.

Species caught / FAO code	n		kg		DAMAGES (n)		DAMAGES (kg)	
	CTRL	TEST	CTRL	TEST	CTRL	TEST	CTRL	TEST
ANN	0.00	0.00	0.00	18.00	0.00	0.00	0.00	0.00
BLL	0.00	14.00	0.00	11.60	0.00	0.00	0.00	0.00
BLU	0.00	1.00	0.00	0.60	0.00	0.00	0.00	0.00
BSS	0.00	1.00	0.00	2.40	0.00	0.00	0.00	0.00
COB	1.00	9.00	0.60	29.20	0.00	0.00	0.00	0.00
CTC	0.00	2.00	0.00	0.30	0.00	0.00	0.00	0.00
MSP	0.00	1.00	0.00	2.10	0.00	0.00	0.00	0.00
MTS	0.00	130.00	2.00	74.90	0.00	0.00	0.00	0.00
MUF	0.00	12.00	0.00	42.20	0.00	0.00	0.00	0.00
MUT	0.00	640.00	2.00	317.50	0.00	0.00	0.00	0.00
MZZ	3.00	0.00	0.90	0.00	0.00	0.00	0.00	0.00
PAC	0.00	0.00	0.00	8.50	0.00	0.00	0.00	0.00
SBG	1.00	8.00	0.40	6.15	0.00	0.00	0.00	0.00
SKA	0.00	0.00	0.00	6.20	0.00	0.00	0.00	0.00
SLM	0.00	0.00	0.00	18.30	0.00	0.00	0.00	0.00
SOL	0.00	71.00	0.00	41.05	0.00	0.00	0.00	0.00
SOS	2.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00
SSB	0.00	8.00	0.00	9.30	0.00	0.00	0.00	0.00
TGS	0.00	218.00	0.50	160.60	0.00	0.00	0.00	0.00
TTR	0.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00
UUC	1.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00
WEG	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00
Total	**8.00**	**1121.00**	**6.80**	**749.30**	**0.00**	**0.00**	**0.00**	**0.00**

AREA 5 (Piombino)

Table S13 - All species listed with FAO CODE captured in AREA 5 (Piombino) during all trials of the year 2021. For each species are shown: number of individuals, kilograms, number of individuals damaged and kilograms of catch damaged for both CTRL and TEST nets.

Species caught / FAO code	n		kg		DAMAGES (n)		DAMAGES (kg)	
	CTRL	TEST	CTRL	TEST	CTRL	TEST	CTRL	TEST
DEC	0.00	0.00	0.57	5.42	0.00	0.00	0.00	0.00
BBS	0.00	0.00	2.64	48.26	0.00	0.00	0.00	0.00
BRF	0.00	0.00	0.00	3.20	0.00	0.00	0.00	0.00
BSS	0.00	0.00	1.58	14.22	0.00	0.00	0.00	0.00
CBM	0.00	0.00	0.50	6.20	0.00	0.00	0.00	0.00
CBR	0.00	0.00	4.15	24.15	2.00	0.00	0.10	0.00
COE	0.00	0.00	0.67	18.73	0.00	0.00	0.00	0.00
CTC	0.00	0.00	10.57	88.73	0.00	0.00	0.00	0.00
EZS	0.00	0.00	0.21	1.89	0.00	0.00	0.00	0.00
LBE	0.00	0.00	0.00	1.20	0.00	0.00	0.00	0.00
MGA	0.00	0.00	0.00	5.50	0.00	0.00	0.00	0.00
MMH	0.00	0.00	4.55	27.63	0.00	0.00	0.00	0.00
MUR	0.00	0.00	10.55	58.17	19.00	0.00	2.90	0.00
MUT	0.00	0.00	0.29	20.39	0.00	0.00	0.00	0.00
OCC	0.00	0.00	1.67	14.63	0.00	0.00	0.00	0.00
SBG	0.00	0.00	0.80	0.80	0.00	0.00	0.00	0.00
SDS	0.00	0.00	0.00	3.60	0.00	0.00	0.00	0.00
SNQ	0.00	0.00	11.49	141.01	0.00	0.00	0.00	0.00
Total	**0.00**	**0.00**	**50.24**	**483.73**	**21.00**	**0.00**	**3.00**	**0.00**

Table S14 - All species listed with FAO CODE captured in AREA 5 (Piombino) during all trials of the year 2022. For each species are shown: number of individuals, kilograms, number of individuals damaged and kilograms of catch damaged for both CTRL and TEST nets.

Species caught / FAO code	n		kg		DAMAGES (n)		DAMAGES (kg)	
	CTRL	TEST	CTRL	TEST	CTRL	TEST	CTRL	TEST
DEC	0.00	10.00	0.00	15.70	0.00	0.00	0.00	0.00
AMB	0.00	2.00	0.00	1.20	0.00	0.00	0.00	0.00
BBS	0.00	0.00	30.30	76.20	0.00	0.00	0.00	0.00
BON	0.00	2.00	0.00	1.90	0.00	0.00	0.00	0.00
CBM	11.00	29.00	9.00	19.10	15.00	0.00	2.80	0.00
CBR	1.00	2.00	24.20	69.80	23.00	0.00	2.40	0.00
COE	9.00	24.00	11.10	36.70	20.00	0.00	1.80	0.00
CTC	0.00	0.00	106.00	507.00	4.00	0.00	0.50	0.00
DOL	0.00	1.00	0.00	1.30	0.00	0.00	0.00	0.00
EZS	2.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00
HOM	0.00	0.00	0.00	3.20	0.00	0.00	0.00	0.00
JOD	0.00	1.00	0.00	1.70	0.00	0.00	0.00	0.00
LBE	1.00	0.00	1.20	0.00	6.00	0.00	0.40	0.00
MGA	2.00	6.00	1.20	4.00	4.00	0.00	0.70	0.00
MMH	15.00	34.00	16.40	63.20	29.00	0.00	3.16	0.00
MUR	0.00	3.00	35.30	171.50	15.00	0.00	2.00	0.00
OCC	14.00	33.00	17.50	38.20	5.00	0.00	0.70	0.00
PAC	0.00	3.00	0.00	2.30	0.00	0.00	0.00	0.00
RSE	6.00	7.00	3.60	10.60	0.00	0.00	0.00	0.00
SBG	1.00	3.00	0.60	3.50	0.00	0.00	0.00	0.00
SBS	0.00	0.00	1.20	3.00	0.00	0.00	0.00	0.00

SLO	0.00	1.00	0.00	0.90	0.00	0.00	0.00	0.00
SMD	0.00	2.00	0.00	1.60	0.00	0.00	0.00	0.00
SNQ	0.00	0.00	63.40	219.00	4.00	0.00	0.80	0.00
SWA	0.00	5.00	0.00	2.20	0.00	0.00	0.00	0.00
Total	**62.00**	**168.00**	**322.40**	**1253.80**	**125.00**	**0.00**	**15.26**	**0.00**

Table S15 - All species listed with FAO CODE captured in AREA 5 (Piombino) during all trials of the year 2023. For each species are shown: number of individuals, kilograms, number of individuals damaged and kilograms of catch damaged for both CTRL and TEST nets.

Species caught / FAO code	**n**		**kg**		**DAMAGES (n)**		**DAMAGES (kg)**	
	CTRL	**TEST**	**CTRL**	**TEST**	**CTRL**	**TEST**	**CTRL**	**TEST**
DEC	6.00	25.00	5.60	24.80	0.00	0.00	0.00	0.00
BBS	0.00	2.00	33.50	68.80	0.00	0.00	0.00	0.00
BLU	0.00	1.00	0.00	1.40	0.00	0.00	0.00	0.00
BSS	2.00	4.00	1.00	3.20	0.00	0.00	0.00	0.00
CBM	1.00	18.00	0.70	14.70	5.00	0.00	1.00	0.00
CBR	0.00	0.00	35.60	79.40	8.00	0.00	0.50	0.00
COE	10.00	14.00	15.30	22.00	0.00	0.00	0.00	0.00
CTC	0.00	0.00	61.40	331.90	5.00	0.00	0.70	0.00
LBE	0.00	2.00	0.00	2.40	0.00	0.00	0.00	0.00
MGA	20.00	19.00	13.00	39.00	0.00	0.00	0.00	0.00
MMH	22.00	28.00	29.40	42.20	5.00	0.00	0.80	0.00
MUR	0.00	0.00	36.30	155.30	110.00	0.00	14.75	0.00
OCC	14.00	25.00	11.00	28.50	0.00	0.00	0.00	0.00
RSE	4.00	14.00	4.90	11.50	0.00	0.00	0.00	0.00
SBG	7.00	3.00	4.00	3.10	0.00	0.00	0.00	0.00
SLM	0.00	0.00	1.60	2.00	2.00	0.00	0.50	0.00
SLO	0.00	1.00	0.00	0.70	0.00	0.00	0.00	0.00
SMD	0.00	1.00	0.00	2.40	0.00	0.00	0.00	0.00
SNQ	0.00	0.00	68.90	226.60	0.00	0.00	0.00	0.00
SQF	0.00	6.00	0.00	1.00	0.00	0.00	0.00	0.00
SWA	0.00	0.00	0.00	2.10	0.00	0.00	0.00	0.00
YFC	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00
YRS	0.00	3.00	0.00	1.40	0.00	0.00	0.00	0.00
Total	**86.00**	**166.00**	**322.20**	**1068.40**	**135.00**	**0.00**	**18.25**	**0.00**

DATA SHEET FROM ITALIAN STRANDINGS BANK

Bagno la Perla ci ha dato una mano

BANCA DATI SPIAGGIAMENTI

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Università degli Studi di Pavia
Via Taramelli 24 - 27100 PAVIA

DATA (primo rinvenimento) 08/03/22 RT189TT 13568

LOCALITÀ LIDO CAMAIORE COMUNE CAMAIORE PROVINCIA LU

COORD. GEOG. _____

SPECIE T. truncatus

Sesso M ( ) F (X) Lunghezza totale (metri) 2,08 misurata (X) presunta ( ) Peso 108.8

Esemplare deceduto (X) Esemplare vivo ( ) (allegare relazione dettagliata)

Condizioni conservazione carcassa: 1 (X) 2 ( ) 3 ( ) 4 ( ) 5 ( )

Segni particolari rilevabili sulla carcassa:

Collisione con natante [ ] Segni di attrezzi da pesca [ ] Presenza reti [X] Ferite da arma da fuoco [ ]

Segnalato da _____

Partecipanti alla ricognizione scientifica (data e luogo se diversi dal rinvenimento)

09/03/22 G. GONSALES, L. MINDIA, G. TERRACCIANO, M. GNOCCHI

Ente di appartenenza UNISI IZSLT

Esemplare recuperato per studio (X) Abbandonato sul posto ( ) Distrutto ( )

Necroscopia effettuata da G. TERRACCIANO

(allegare referto)

Ente IZSLT

Causa decesso _____

Parti conservate _____

c/o Museo o Istituto _____

Fotografie c/o _____

Usare fogli aggiuntivi per eventuali descrizioni dettagliate dell'evento

NOME DEL COMPILATORE G. GONSALES FIRMA _____

Ministero dell'Ambiente e della Tutela del Territorio e del Mare

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Centro Interdisciplinare di Bioacustica
Università degli Studi di Pavia
Via Taramelli 24 - 27100 PAVIA

DATA (primo rinvenimento) 13 agosto 2023 (RT198Tt)

LOCALITÀ Lecciona (palo 12) COMUNE Viareggio PROVINCIA LU

COORD. GEOG. 43,835597 N 10,248962 E

SPECIE Tursiops truncatus

Sesso M ☐ F ☐ Lunghezza totale (metri) _____ misurata ☑ presunta ☐ Peso _____

Esemplare deceduto ☑ Esemplare vivo ☐ (allegare relazione dettagliata)

Condizioni conservazione carcassa: **1** ☐ **2** ☑ **3** ☐ **4** ☐ **5** ☐

Segni particolari rilevabili sulla carcassa:

Collisione con natante ☐ Segni di attrezzi da pesca ☐ Presenza reti ☐ Ferite da arma da fuoco ☐

Segnalato da Privato cittadino

Partecipanti alla ricognizione scientifica (data e luogo se diversi dal rinvenimento)

_____

Ente di appartenenza _____

Esemplare recuperato per studio ☑ Abbandonato sul posto ☐ Distrutto ☐

Necroscopia effettuata da G.Terracciano

(allegare referto)

Ente IZSLT Pisa

Causa decesso _____

Parti conservate Nessuna

c/o Museo o Istituto _____

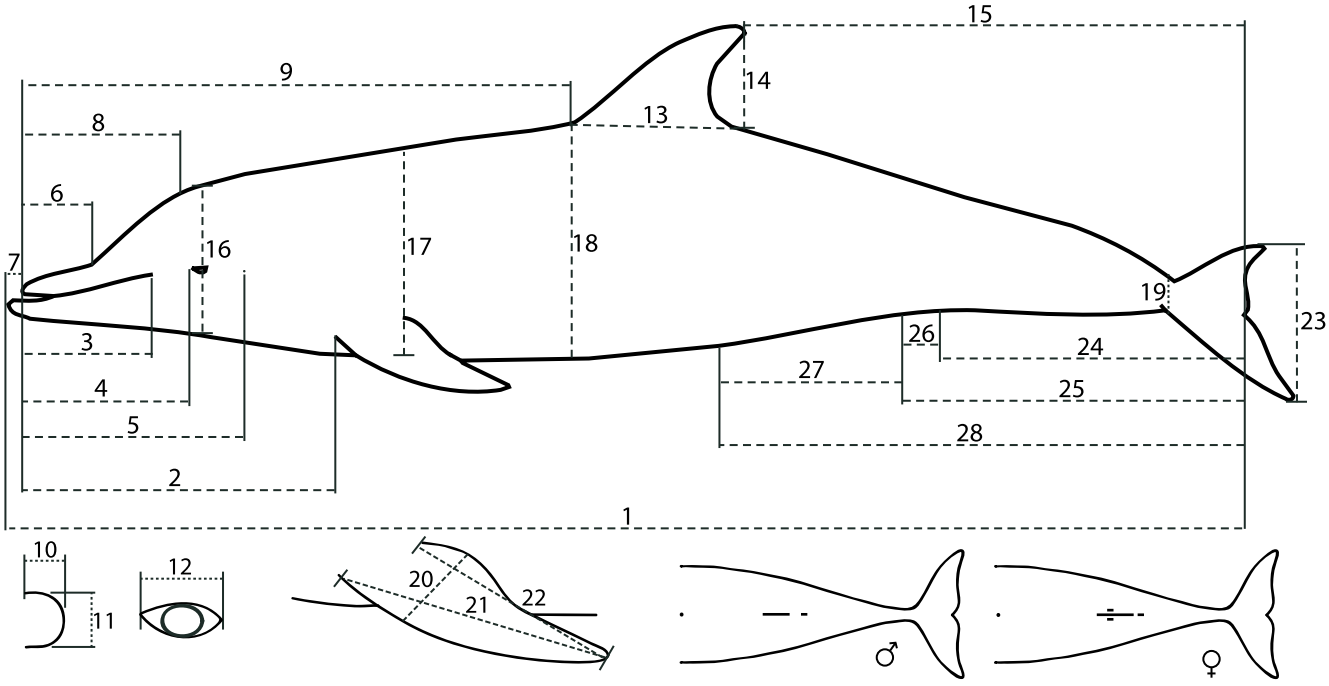
Fotografie c/o ARPAT, Settore Mare Livorno

Usare fogli aggiuntivi per eventuali descrizioni dettagliate dell'evento

NOME DEL COMPILATORE Cecilia Mancusi FIRMA _____

Ministero dell'Ambiente e della Tutela del Territorio e del Mare

SPECIE T.truncatus (RT 198Tt) DATA 16/08/2023



1 - Lunghezza totale: estremità anteriore del capo - parte mediana dell'incavo caudale (seno interlobare): cm 83,5

2 - Estremità anteriore del rostro - inserzione anteriore della pinna pettorale: 23

3 - Estremità anteriore del rostro - estremità posteriore della bocca: 14,5

4 - Estremità anteriore del rostro - margine anteriore dell'occhio: 16

5 - Estremità anteriore del rostro - orifizio auricolare: 20

6 - Lunghezza del rostro: 5,8

7 - Estremità anteriore del rostro - estremità anteriore della mandibola: _____

8 - Estremità anteriore del rostro - estremità anteriore dello sfiatatoio: 15

9 - Estremità anteriore del rostro - inserzione anteriore della pinna dorsale: 41

10 - Lunghezza massima dello sfiatatoio: 1,8

11 - Larghezza massima dello sfiatatoio: _____

12 - Diametro orizzontale dell'occhio: 1,8

13 - Lunghezza della pinna dorsale alla base: 12,5

14 - Altezza della pinna dorsale: 6

15 - Estremità posteriore della pinna dorsale - seno interlobare della coda: 32

16 - Altezza del corpo al margine anteriore dell'occhio: 11

17 - Altezza del corpo all'inserzione posteriore della pinna pettorale: _____

18 - Altezza del corpo all'inserzione anteriore della pinna dorsale: _____

19 - Circonferenza del peduncolo caudale: 4,5

20 - Larghezza massima della pinna pettorale: 5

21 - Lunghezza della pinna pettorale dall'inserzione anteriore: 14,5

22 - Lunghezza della pinna pettorale dall'inserzione posteriore: _____

23 - Larghezza della pinna caudale: 14,5

24 - Orifizio anale - seno interlobare della coda: 25

25 - Parte mediana dell'apertura genitale - seno interlobare della coda: 27

26 - Distanza tra la parte mediana dell'apertura genitale e l'ano: 2

27 - Distanza fra ombelico e parte mediana dell'apertura genitale: 16

28 - Distanza fra ombelico - seno interlobare della coda: 41,5