University of Padova

Department of Biology

Master's Degree in Marine Biology

Thesis

Understanding common bottlenose dolphin depredation on artisanal fisheries in Mediterranean waters

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Academic Year 2023/2024

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List of abbreviations

PAM	Passive Acoustic Monitoring
CPUE	Catch Per Unit Effort (kg catch biomass per net length per day)
FOD	Fishing Operation Duration (soak time in hours)
ADD	Acoustic Dolphin Detection
RASP	Registratore Acustico Subacqueo Passivo, or Underwater Passive Acoustic Recorder

Abstract

Depredation of fixed net artisanal fisheries by common bottlenose dolphins (*Tursiops truncatus*) is a frequently reported phenomenon in the Mediterranean Basin. Expanding our knowledge on this issue, particularly regarding its impacts and influencing factors, is essential. Understanding which factors affect depredation probability as well as the catch amount of these fisheries is crucial for the development of informed management and mitigation policies. Acoustic dolphin detection (ADD) using passive acoustic monitoring (PAM) devices attached to fishing gear was used as the proxy for dolphin presence (and thus depredation probability). Fishery data was collected through photographing landings, which were then measured in software for body length and converted into biomass via formulas specific to each fishery species. Catch amount was expressed as catch per unit effort (CPUE), which is the total biomass of all caught species standardised in terms of net length and fishing operation duration (FOD). Two statistical models were applied to investigate the influence of different factors on ADD and CPUE. First, the influence of the CPUE, the type of gear used (trammel net or gillnet), the net length, the FOD, and the depth of the fishing site on ADD was tested by Generalised Linear Model (GLM) with a binomial distribution. CPUE, gear type, and FOD showed significant effects on ADD. Higher ADD probability was associated with lower CPUE, and with gillnets as opposed to trammel nets. Increased FOD significantly increased the probability of ADD. Net length and depth at the fishing site showed no significant effects. Second, the influence of ADD and gear type on CPUE was tested by a GLM with a gamma distribution. Gear type and ADD had significant effects on CPUE, with gillnets having higher CPUE than trammel nets, and dolphin presence decreasing CPUE. Understanding how and which factors impact depredation probability and catch quantity is crucial for the continued improvement of coexistence between wildlife and fisheries.

Key words: depredation, *Tursiops truncatus*, fixed net fishery, acoustic monitoring, catch amount

1 Introduction

Depredation of Mediterranean artisanal fisheries by common bottlenose dolphins represents a multifaceted phenomenon with a complex historical, cultural and ecological background. In order to establish a comprehensive context for the involved and affected parties, this thesis will first introduce the focal species, the common bottlenose dolphin, followed by an overview of the artisanal fisheries characteristic of this region. Then, the interactions between these two entities will be examined, with particular emphasis on the depredation phenomenon. Finally, the methodology of passive acoustic monitoring will be introduced, demonstrating its relevance and applicability to both the focal species and the depredation of artisanal fisheries.

1.1 Common bottlenose dolphins of the Mediterranean

The common bottlenose dolphin (*Tursiops truncatus*, Montagu, 1821, Fig. 1) is one of the most recognized and charismatic megafauna species found in the Mediterranean Sea. Though this species has a cosmopolitan distribution, they are most abundant in warm temperate and tropical seas and exhibit some geographical variation between basins (Wells & Scott, 2018). This study focuses on the subpopulation found within the Mediterranean Basin, specifically coastal populations in the Adriatic Sea and in the waters surrounding Sardinia.

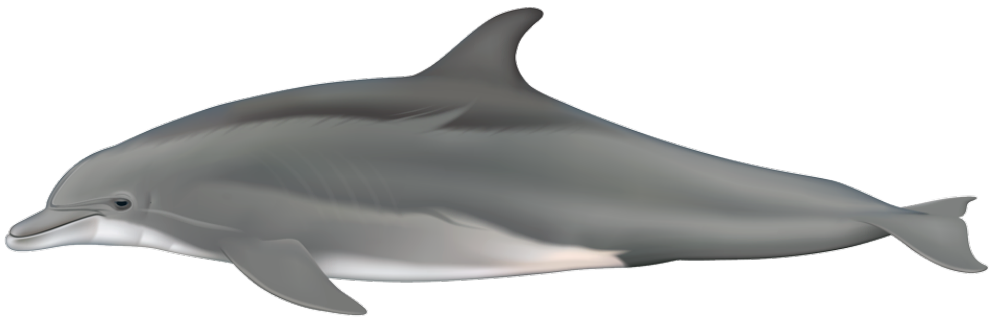

Figure 1: Common bottlenose dolphin (*Tursiops truncatus*) species illustration from NOAA (National Oceanic and Atmospheric Administration), 2022.

Within this region, common bottlenose dolphins (hereafter referred to as bottlenose dolphins) tend to be distributed along the continental shelf (Carpentieri & Gonzalvo, 2022). They occupy a high trophic level within these ecosystems, with only a few shark and cetacean species being documented as their potential predators (Wells & Scott, 2018). Like many other cetaceans, as top predators (Díaz López, 2019), they are vital components of healthy and sustainable ecosystems (Pennino et al., 2015).

In marine ecosystems, food availability is one of the most important factors influencing species distribution (Pennino et al., 2015). Much like any other predator species, the distribution of bottlenose dolphins is influenced by their prey species' availability and distribution patterns (Lauriano et al., 2023), which in turn is influenced by many physical, chemical and biological environmental parameters.

Fluctuations in predator abundance can potentially have propagating effects throughout their inhabited food-webs on all trophic levels (Pace et al., 1999). High trophic level (apex) predators control the populations of their prey species through direct predation pressure. Left unregulated, the populations of their prey species can drastically increase, overconsuming and exhausting lower trophic levels, leading to drastic changes in ecosystem structure and dynamics lower in the food-web. In the case of top-down control, apex predator populations are limited by their resources (bottom-up control, otherwise known as resource limitation), but all other trophic levels are affected by the control they exert on their prey species (Daskalov, 2002), thus regulating the entire community's structure and functioning (Pinnegar et al., 2000). The role of high trophic level predators in the maintenance of their inhabited ecosystems has been observed and studied in marine systems, within the Mediterranean Sea (Pinnegar et al., 2000), even specifically regarding historical dolphin population decline in the Black Sea (Daskalov, 2002).

Most of our knowledge on the diet of this subpopulation comes from stomach content analyses, which is one of the most widely employed methods for cetacean diet evaluation (Blanco et al., 2001; Mioković et al., 1999; Neri et al., 2023). These studies have many limitations however, including small sample sizes, time elapsed since death, secondary predation or ingestion[1] of species, and differences in the digestibility of prey items (Neri et al., 2023). There is evidence of ontogenetic and sexual variation in diet, both in prey species and size (Blanco et al., 2001; La Manna et al., 2020; Neri et al., 2023). Females have been shown to exhibit different feeding behaviours depending on group composition and calving status (Blanco et al., 2001; La Manna et al., 2020). Opportunistic feeding behaviour is supported by the variability of prey items fluctuating with their local availability (Blanco et al., 2001) as well as the presence of fishing gear in the digestive tract (Neri et al., 2023), which is evidence of the opportunistic exploitation of human fishery activities. Their most important prey items are fish species, primarily benthic in nature, found in sandy bottom habitats predominantly at 50-200 m of depth (Blanco et al., 2001). The cephalopod species they prey on are also known to inhabit soft-bottom habitats (Blanco et al., 2001). Many of their prey items are known to be nocturnal (Neri et al., 2023), meaning their predation mainly takes place at night.

Like many odontocete (toothed whale) species, bottlenose dolphins are a highly vocal species and rely heavily on acoustic signals not only for social communication, but also navigation and hunting (McPherson et al., 2004). Due to their aquatic environment, visual communication is often limited, and little is known about their chemoreception and tactile communication (Tyack, 2019). They

[1] Secondary predation entails a predator injesting a prey item along with the contents of its stomach, giving the appearance of the predator preying on both the prey item and its prey.

mainly rely on echolocation for orientation and navigation, but also use it for the detection, localization and differentiation of prey items. (G. Jones, 2005). Although as mammals, they produce sounds through the compression and movement of air, the process of sound production and the structures involved differ from those of terrestrial mammals. Air is forced through phonic lips in their nasal passages under the blowhole and behind the melon (anatomy shown in Fig. 2), which is a fat-filled organ that concentrates the direction of clicks and couples the acoustic signal to the water medium by removing the impedance mismatch between air and water.

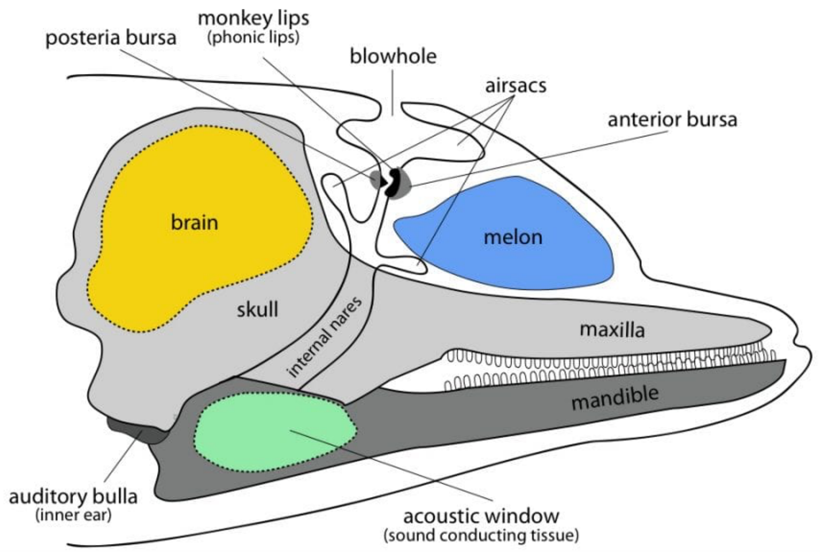

Figure 2: Illustration of head and sound production anatomy from WDC (Whale and Dolphin Conservation, n.d.).

These acoustic signals bounce off objects in the environment, with some echoes returning to the sender (Fig. 3). Dolphins detect these echoes with their mandible, and the signal is transported to their inner ear via bone conduction (G. Jones, 2005). The characteristics of the different categories of vocalizations used for echolocation also allow for inferences regarding their behaviour (La Manna et al., 2023). For example, during prey capture, click rate is known to increase as the distance from the target decreases (B. Jones et al., 2020; La Manna et al., 2023). Their highly vocal nature, broad vocalization repertoire and associated behaviours allows for an acoustic modality of observation and monitoring, which is often more applicable and accurate than direct visual observation (La Manna et al., 2023).

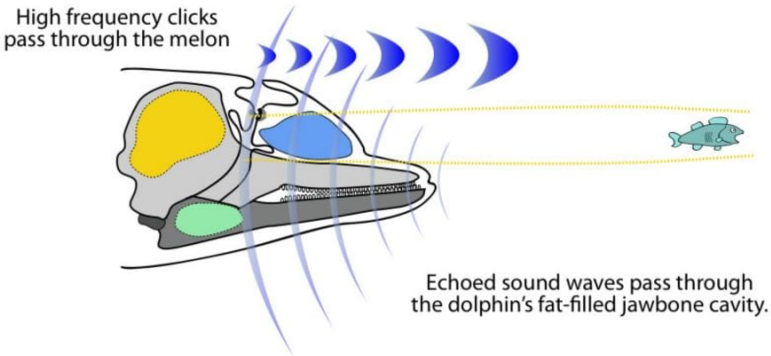

Figure 3: Mechanism of echolocation illustration from WDC (n.d.). Echolocation clicks emitted by the dolphin seen in dark blue, concentrated by the melon between the yellow dotted lines. Returning signals (echoes) shown in light blue.

Following a centuries-long history of government-endorsed intentional killings through culling campaigns, incidental mortality due to bycatch, reduction of prey populations due to overexploitation of fish stocks, and fishery-related habitat degradation and loss (Bearzi, 2002), the Mediterranean subpopulation was declared Vulnerable by the International Union for Conservation of Nature (IUCN) in 2012 (Bearzi et al., 2012). Thanks to the conservation efforts and protective legislature put in place by multiple nations in the 20th century, it has since been updated to Least Concern in 2021 (Natoli et al., 2021). The continued conservation and protection of cetaceans is crucial not only for the species themselves, but also for the health and maintenance of their inhabited ecosystems (Bearzi, 2002).

Anthropogenic impacts currently still threatening this species include prey depletion by overfishing, bycatch and incidental capture in fishery activities, habitat degradation and loss due to pollution and marine traffic, and global climate change (Bearzi et al., 2009; Díaz López, 2019) illustrated in Fig. 4.

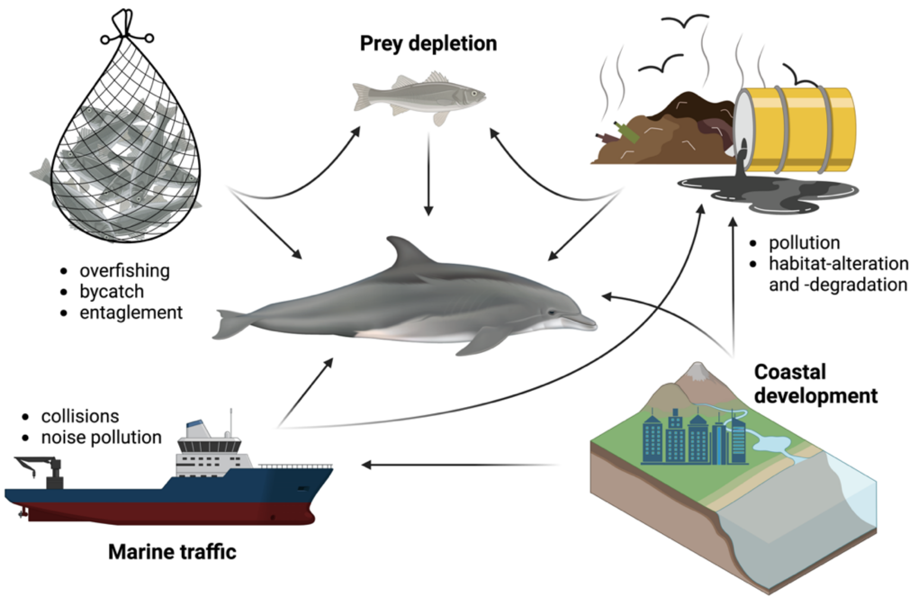

Figure 4: Anthropogenic impacts currently facing bottlenose dolphins in the Mediterranean. Created with BioRender.com.

1.2 Fixed net artisanal fisheries in the Mediterranean

Artisanal fishery (or small-scale fishery) can be defined as small-scale, fisher-owned and -operated fishery that does not require significant capital investments from large companies or corporations (Colloca et al., 2004). Over 80% of fishing vessels in the Mediterranean belong to this category. They are generally family-owned and -operated businesses. Though this type of small-scale fishery has great historical and cultural importance in this region as well as great economic relevance (Colloca et al., 2004), their profits have become marginal in many parts of the Mediterranean (Bearzi, 2002) with worker incomes being close to the poverty line (La Manna et al., 2024). Fishing activity can take place year-round, but may be concentrated between spring and autumn, depending on the target species (La Manna et al., 2024). Fishing sites tend to be coastal, located on the continental shelf, with depths of up to 200 m. These sites can be reached from harbours in a relatively short amount of time by the smaller vessels characteristic of this type of fishery. Employed fishing techniques and gears are highly diversified depending on local customs and traditions, season, target species and habitat characteristics. The most widely used technique is fixed net (otherwise known as static net) fishery using gillnet or trammel net gear (Colloca et al., 2004).

Gillnets (or entangling nets) are rectangular nets usually placed near the bottom of the water column, close to the seabed (illustrated in Fig. 5). They are held upright vertically by a floatline or floats attached to the headrope at the top, and are held in place by a leadrope or weights attached to the footrope (Fig. 6). They are widely used, accounting for 10% of global fish landings. Today, they are mainly made from synthetic materials (most commonly monofilament nylon) because they are less visible to target species, lightweight, and rot-resistant. (FAO, 2024a; He et al., 2021)

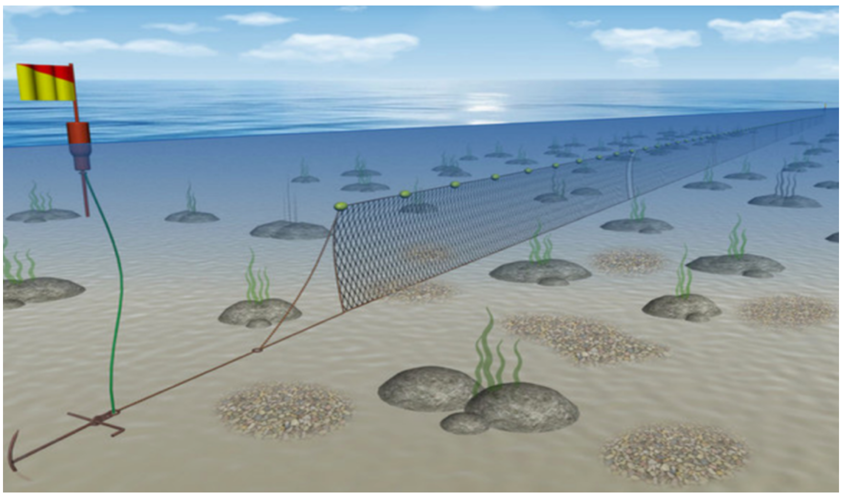

Figure 5: Fleet of bottom set (anchored) gillnets. Ends marked by buoys on the surface. From He et al., 2021.

Set gillnets are the most widely used variety of gillnet. They are a form of passive fishing gear; often left untended for hours or even days. They are comprised of a single layer of netting and are anchored on or very close to the seabed, with their ends marked on the surface by buoys. They capture a wide variety of demersal and benthic fish species (depending on the nets placement in the water column and the depth of the fishing site), mainly through gilling[2] or entanglement. Through their mesh size, gillnets can be highly size-selective. (FAO, 2024b; He et al., 2021)

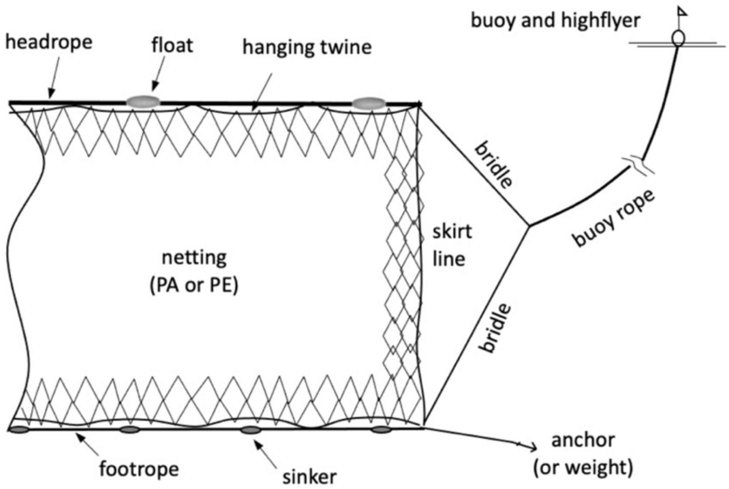

Figure 6: Main components of set gillnets and their arrangement. From He et al., 2021.

Trammel nets are another subtype of entangling net, comprised of three net layers. The two outer layers are characterized by larger mesh size than the internal layer, which is also suspended more loosely. Fish and crustaceans are able to swim through the first outer layer, but not the internal netting, which they pull through the mesh in the outer layer on the opposite side, entrapping them in a small pocket of netting (Fig. 7B). This type of gear is widely employed in small-scale artisanal fishery, usually set on the seabed (Fig. 7A). Thus, it mainly targets demersal and benthic fish, cephalopod and crustacean species. It is also a passive gear, left unattended for long periods. (FAO, 2024c; He et al., 2021)

[2] Gilling is a mechanism of capture in which the mesh size is designed to allow only the head of the fish to pass through, but not the body. As the fish tries to back out, the gills then get caught on the net, entagling it. (NOAA, 2021)

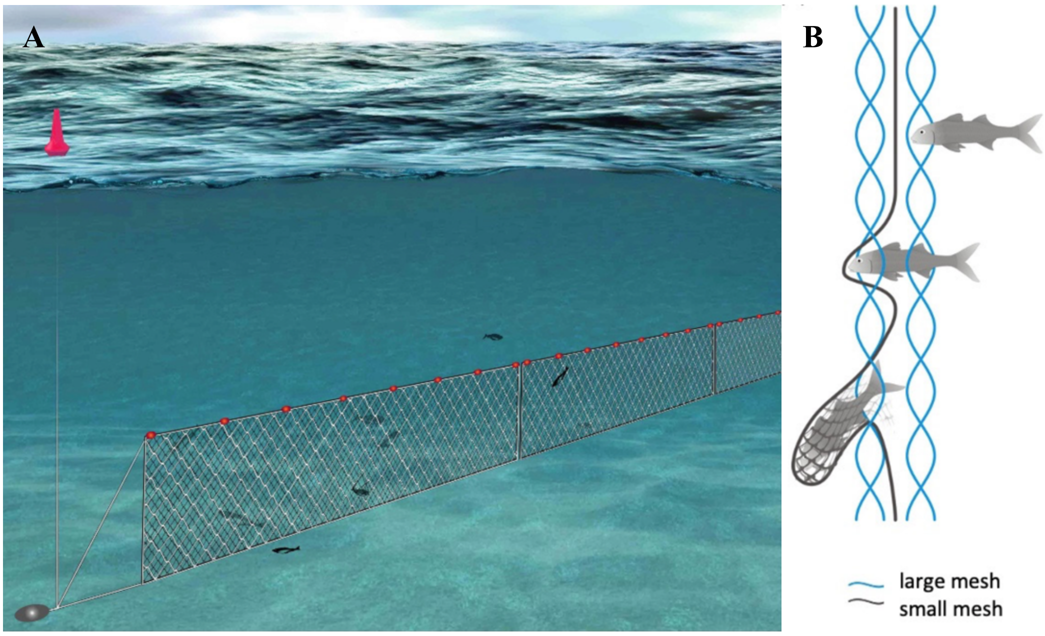

Figure 7: **(A)** Trammel net setup (outer netting layer in white, inner netting layer in black), **(B)** Capture mechanism by entrapment. From He et al., 2021.

1.3 Dolphin-fishery interactions and depredation

The Mediterranean Basin has a long history of human presence and fishery activity. Interactions between fishers and the regions' cetaceans likely span the entirety of this history (Bearzi, 2002), with one of the first written records of dolphin-fishery interaction of the region being from 1895 (Barone, 1895).

Fish are one of the most important resources not just of this region, but the entire world (Pennino et al., 2015). The ever-growing demand for this natural resource (following the growth of the global human population) has facilitated rapid and drastic technical improvements in the efficiency of fisheries, leading to an unprecedented level of exploitation of the majority of fish stocks. The now well-established and supported global trend of overexploited and depleted fish stocks is detrimental to entire marine ecosystems, including higher trophic level predators, such as the bottlenose dolphin (Pennino et al., 2015). The historical and ongoing depletion of the prey species of these high trophic level predators rely on (Carpentieri & Gonzalvo, 2022) has forced their populations to adapt their feeding strategies to survive (Pennino et al., 2015). Their possible responses to shifts in prey availability are to increase time devoted to foraging (which is energetically costly), or to employ a wider range of feeding strategies (Bearzi, 2002). Foraging includes all behaviours involved in the search and detection, and the pursuit and capture of prey (Wells, 2019). As generalist predators with great behavioural plasticity (Díaz López, 2019), bottlenose dolphins have the capacity to exploit feeding opportunities related to human fishery activity. Feeding near fishing gear provides a more efficient foraging method energetically, as prey items are more concentrated. In this way, these predators are able to increase their feeding rate while decreasing their energetic expenditure (Díaz López, 2006) related to different stages of foraging (search, pursuit, capture).

The overlap between bottlenose dolphin distribution and artisanal fishery activity, as well as the overlap between dolphins' prey species and fisheries' target species, all exacerbated by prey depletion and other stressor (illustrated in Fig. 4.), has led to an increased probability of dolphin-fishery interactions (Pennino et al., 2015). Studying and understanding these interactions is crucial, as they can have deleterious effects on both the wild dolphin populations and fishing communities (Bearzi, 2002).

Dolphin-fishery interactions can lead to depredation events, as dolphins are forced to adapt to prey-depleted habitats by supplementing their diets with prey caught by human fishing activities (La Manna et al., 2020, 2023). Depredation is defined as the removal of prey directly from, and foraging activity near fishing gear (Bearzi & Reeves, 2022; La Manna et al., 2024). It has been reported worldwide by various species spanning many taxa including sharks, marine mammals and marine reptiles (Tixier et al., 2021). However, over half of reported toothed whale (odontocete) depredating species belong to the Delphinidae family with bottlenose dolphins being one of the most reported species (Tixier et al., 2021). Depredation behaviour can be transmitted vertically from parent to offspring through social learning and horizontally within and between populations through cultural transmission. Due to their great cognitive abilities and social nature, it has easily become a widespread behaviour in the Mediterranean subpopulation of bottlenose dolphins (Wells, 2019).

Depredation has a clear benefit due to the reduced energetic costs in foraging effort and prey capture (La Manna et al., 2023; Tixier et al., 2021). However, these benefits come with immense risks. Interacting with fishing gear carries the possibility of entanglement, which can lead to chronic injuries or even direct mortality by drowning. Although bycatch of this species is very rarely reported by fishers in the region (Li Veli et al., 2023), there have been some concerning studies stating that even very low annual bycatch rates can seriously impact these populations, especially younger and inexperienced individuals (Díaz López, 2006). Due to the fact that occurrences of bycatch are self-reported by fishers, rates may be drastically underreported and thus, underestimated (Li Veli et al., 2023). Gear can also be ingested accidentally along with the catch, leading to larynx strangulation (Gomerčić et al., 2009) and other obstruction-related complications (Gorzelany, 1998), which result in decreased survival. In addition to these dangers, bottlenose dolphins may also face lethal retaliation by fishers (Carpentieri & Gonzalvo, 2022). Effects of depredation on the ecological role of predators in an ecosystem are still widely unknown (Tixier et al., 2021), with some reported changes in bottlenose dolphin distribution and foraging behaviour being linked to trammel nets in the Southern Mediterranean (Blasi et al., 2015) and gillnets in coastal Sardinian waters (Díaz López, 2006). It is unclear how the changes in these predators' diet and feeding behaviour (Carpentieri & Gonzalvo, 2022) affect the rest of their ecosystems. The long-term ecological effects of provisioning and/or predation pressure displacement, along with a possible increased fishing effort to offset losses from depredation, require further investigation (Tixier et al., 2021).

Consequences of depredation behaviour facing artisanal fisheries are a reduction in catch amount and/or value (due to catch damage), damage to fishing gear, and loss of fishing time (Carpentieri & Gonzalvo, 2022). Catch loss can be direct, meaning the removal or damage of prey already caught in the gear, or indirect, such as due to loss of fishing time or by the predators' scattering schools of fish (La Manna et al., 2024). Unlike large-scale commercial fisheries, artisanal fisheries are more financially vulnerable, with even relatively minor incurred damage or catch loss resulting in substantial economic strain for fishers (La Manna et al., 2023, 2024; Lauriano et al., 2009).

Bottlenose dolphins are not only one of the most reported depredating species globally, but also the most versatile. They are known to depredate a wide variety of fishing gear including static net, long line, hook and line, trawl, siene, and even trap (Tixier et al., 2021). They are the primary species in fishery interactions in various parts of the Mediterranean (La Manna et al., 2024; Lauriano et al., 2009; Pardalou & Tsikliras, 2018) due to their coastal distribution, opportunistic diet and feeding habits, and their adaptability (Blanco et al., 2001; Neri et al., 2023).

Regarding the artisanal fisheries sector, fixed net (or static net) fishery is the most reported fishing technique to experience depredation globally (Tixier et al., 2021). The Mediterranean is no exception, where it also happens to be the most commonly used fishing technique and gear in small-scale fisheries (Carpentieri & Gonzalvo, 2022). The widespread use of these susceptible gears, the overlap between bottlenose dolphin distribution and prey species with fishing activity and target species (La Manna et al., 2020, 2023; Lauriano et al., 2009; Pardalou & Tsikliras, 2018) creates circumstances that enhance the likelihood of depredation.

Though the frequency of depredation appears to have increased in the past decade (Carpentieri & Gonzalvo, 2022; McPherson et al., 2004), there is no clear evidence that depredation rates have increased (Bearzi, 2002), or if this is only the perception due to an increased rate of reporting such events (Tixier et al., 2021). The phenomenon has become more prominent in the eyes of fishers whose livelihoods are affected both by dwindling wild fish stocks (Carpentieri & Gonzalvo, 2022; La Manna et al., 2023) and even relatively small losses to dolphin depredation, which can have a large impact on their income (Bearzi, 2002). Though multiple studies have shown losses suffered because of depredation are not as high as perceived (La Manna et al., 2024; Li Veli et al., 2023), artisanal fisheries are already one of the most economically vulnerable groups in the fishery sector, meaning even smaller losses can have detrimental effects on their livelihoods (Bearzi, 2002).

The importance of developing effective mitigation measures to reduce dolphin-fishery interactions goes beyond socio-economic factors, encompassing ecological and conservation concerns for the species and the affected ecosystems (La Manna et al., 2024).

Historically, some of the first organized government-sanctioned mitigation measures in the Mediterranean were culling campaigns, going as far back as the 16th century, and aimed at the extermination of depredating species. Bottlenose dolphins were seen as pests, competitors for precious fishery resources. It wasn't until the 19th century that non-lethal mitigation measures, such as modified fishing schedules and/or techniques or acoustic deterrents were even conceived. The deliberate killing of these animals became illegal after 1995. (Bearzi et al., 2009)

It is now known that culling high trophic level predators does not improve fishery yields (Bearzi et al., 2009). Studying and understanding phenomena allows for the development and implementation of informed mitigation measures. The more understanding of dolphin-fishery interactions and depredation increases, the closer acceptable trade-offs between the species' conservation and human interests become (Buscaino et al., 2021).

The combination of decreasing fish stocks and decreasing catch rates, along with the recovery of bottlenose dolphin populations following historic intentional killing incentives has led to more pressure being placed on this conflict in the past decades. The increase in reports of depredation can also be attributed in part to an increased research effort in the fisheries sector. Fish stock collapse and other environmental concerns, along with a growing awareness of these issues, have led to an increase in the number of studies being conducted. (Tixier et al., 2021)

1.4 Passive acoustic monitoring

Acoustic observation of depredation events is a relatively new approach. Technological advancements in memory and battery performances have only relatively recently made remote monitoring widely accessible and feasible (Thode et al., 2015).

Passive acoustic monitoring (PAM) methods involve the use of monitoring devices designed to detect and record sound information without emitting acoustic signals themselves (La Manna et al., 2023). PAM devices have been successfully deployed in many situations regarding the study of depredation by various odontocete species (La Manna et al., 2023; Lauriano & Bruno, 2007; Thode et al., 2015). It is an especially effective tool for monitoring cetaceans, as it allows for acoustic observation of the animals in contexts where visual observation is not feasible and does not interfere with their natural behaviours (La Manna et al., 2014). Bottlenose dolphins are especially suited for this method of monitoring due to their highly vocal nature and their use of echolocation for hunting and feeding behaviours, including depredation (B. Jones et al., 2020; La Manna et al., 2023; Tyack, 2019). Because the vocalization characteristics vary between species (and even within species), acoustic data collection can be calibrated for specific species of interest (Todd et al., 2015), such as the common bottlenose dolphin in the case of this study. Along with calibration, knowledge of their distribution, residency in the study area, opportunistic feeding habits, and reports of species sighted by fishers (Li Veli et al., 2023), vocalizations in the acoustic data can be confidently assumed to belong to this specific species.

PAM can be used not only for the detection of this species, but also for making inferences about their behaviours based on their recorded vocalizations. It allows for a more precise measurement of depredation activity than previous methodologies (such as catch analysis and visual observation), and thus, for the testing of the effects of different parameters (environmental or even potential mitigation measures) on depredation activity. The use of PAM has greatly reduced research costs and efforts associated with previous methodologies, which require on-site trained personnel. It is a newer, undisruptive, flexible and convenient tool for monitoring depredation behaviour. (La Manna et al., 2023; Thode et al., 2015)

However, like every method, it also faces some limitations, the greatest one being the masking of acoustic signals by ambient or anthropogenic noise (La Manna et al., 2014). Another limitation involves the directionality of signals. While most hydrophones tend to be omnidirectional (Todd et al., 2015), echolocation vocalizations (clicks) tend to be highly directional (B. Jones et al., 2020), so received signals may highly fluctuate in intensity solely due to the orientation of the animal with respect to the PAM device. The distance between the source of the signal and the receiver is another important limiting factor for signal clarity and intensity (McPherson et al., 2004). There is also a need for the development and improvement of automated analysis tools, as the analysis of such vast amount of sound data is currently still very time and labour intensive (La Manna et al., 2014).

2 Aim

The aim of this study was to discern how different factors affect the probability of depredation and the amount of catch obtained in fishing operations. It is important to investigate effects on both, since current mitigation measures aim to minimize the probability of depredation events taking place, while maintaining catch efficiency for artisanal fisheries.

Obtaining data from regular (commercial) artisanal fishing operations and using undisruptive PAM methodology maintains the environmental and ecological context of the depredation phenomenon and fishery activity being assessed in this study.

3 Materials and Methods

3.1 Experimental design and setup

Data was collected from 119 fishing operations carried out in coastal waters in the Adriatic Sea and surrounding Sardinia. Because these were regular, commercial fishing operations, the primary purpose was fishery and not data-collection. This led to limited control over investigated factors and the management of recording equipment, but very representative data regarding the fishery and depredation activity at the focus of this study. Fishers decided on and ultimately only recorded the GPS coordinates and depth of their selected fishing site, the type of gear used and the length of these nets, and the soak time (or fishing operation duration).

The fishing vessels departed from two Italian ports in the Northern Adriatic and five ports around Sardinia. The Northern Italian ports were Ancona and Pedaso Costa, and the Sardinian ports were Castelsardo, Oristano, Alghero, Tortolì, and Bosa (Fig. 8). The majority of fishing operations originated from Sardinian waters (Table 1). The aim of collecting data from multiple fishing sites was to avoid spatial correlation effects between fishing operations.

Area	Site	Number of fishing operations	
		Per site	Per area
Adriatic Sea	Ancona	9	18
	Pedaso Costa	9	
Northern Sardinian Sea	Castelsardo	41	41
Tyrrhenian Sea	Tortolì	14	14
Western Sardinian Sea	Alghero	22	46
	Bosa	5	
	Oristano	19	

Table 1: Summary of the number of fishing operations from each location.

The following data were recorded from each fishing operation: port of origin, GPS coordinates of the fishing site, depth of fishing site (continuous covariate), type of gear used (categorical variable: gillnet or trammel net), length of net deployed (continuous covariate), fishing operation duration (FOD defined as the time elapsed between the end of net setup and the start of net hauling, also known as soak time, continuous covariate), catch (CPUE: total catch biomass for every 1000 meters of net and every 24 hours of soak time, continuous covariate), and acoustic recordings of the entire FOD.

Although the port of origin and GPS coordinates were not directly used in the context of this analysis, they are included here in order to better illustrate the precise spatial context of the dataset within the Mediterranean Basin (see Fig. 8 and 9).

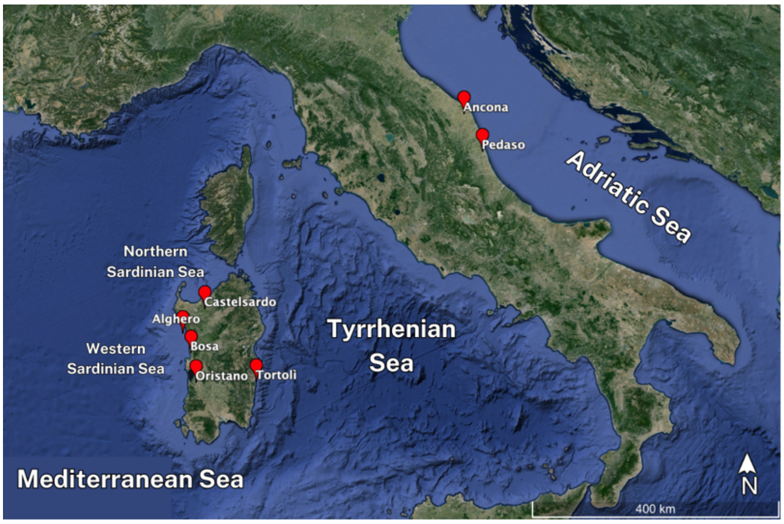

Figure 8: Sites and areas of documented fishing operations. Made in Google Earth, 2024.

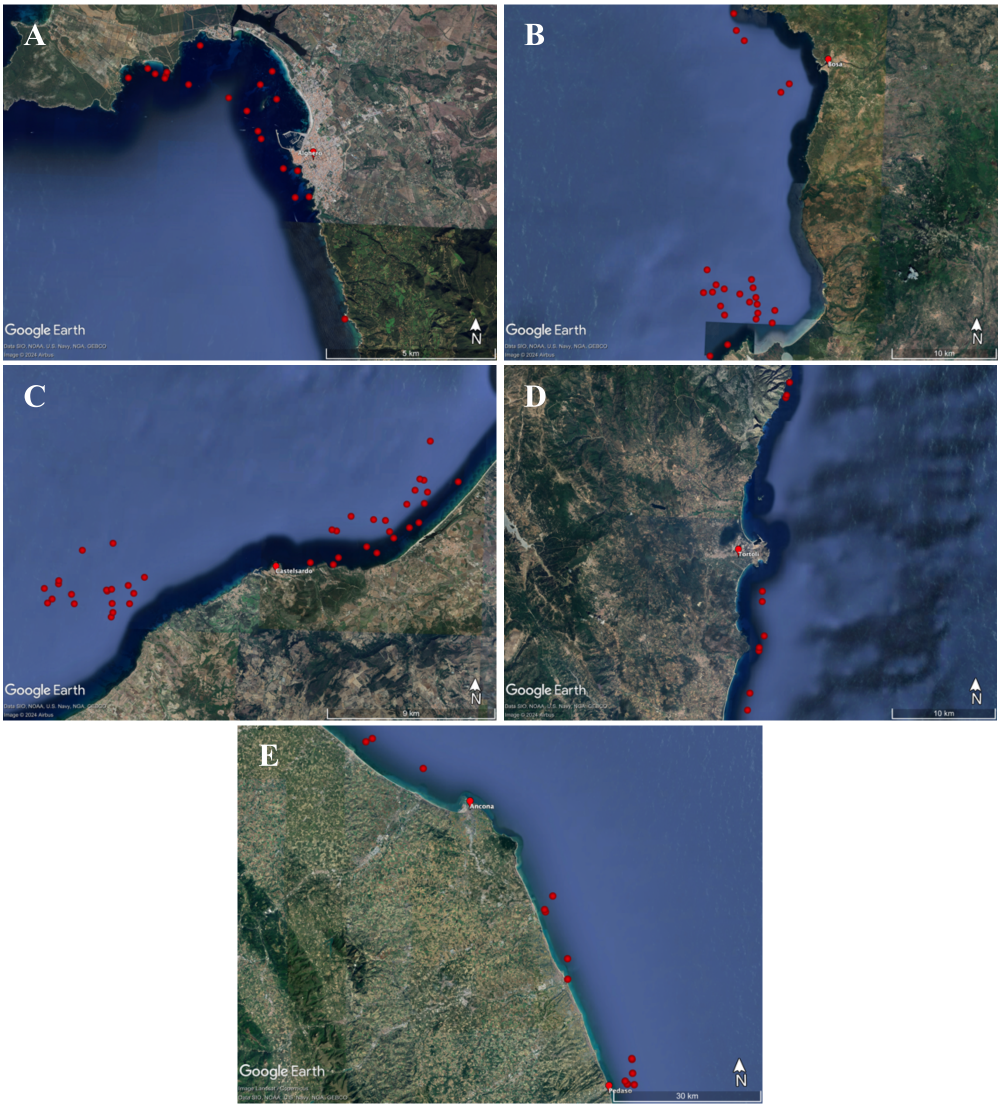

Figure 9: Individual fishing operation coordinates. **(A)** Fishing sites surrounding Alghero, **(B)** Bosa and Oristano**, (C)** Castelsardo, **(D)** Tortolì, **(E)** Ancona and Pedaso. Made in Google Earth, 2024.

3.2 *Acoustic dolphin detection*

Acoustic data collection was conducted using autonomous acoustic recording devices (RASP: Registratore Acustico Subacqueo Passivo, or Underwater Passive Acoustic Recorder). Coordinated data collection was possible thanks to the cooperation of the LifeDelfi Project under the National Research Council (Consiglio Nazionale delle Ricerche, CNR) in the Adriatic and the International System for Agricultural Science and Technology (AGRIS) and the University of Sassari around Sardinia. The setup for these autonomous recorders was the same as those described by La Manna et al., 2023. One RASP-uRec384k-Nauta RCS model (shown in Fig. 10A) was attached to the fishing net (shown in Fig. 10B) deployed in a given fishing operation and was set to record for the duration of the fishing operation (or soak time). Recorders were equipped with a Sensor Technology SQ26-05 pre-amplified hydrophone, a programmable high-frequency acoustic recorder, a battery pack and a 400 Gb microSD memory card.

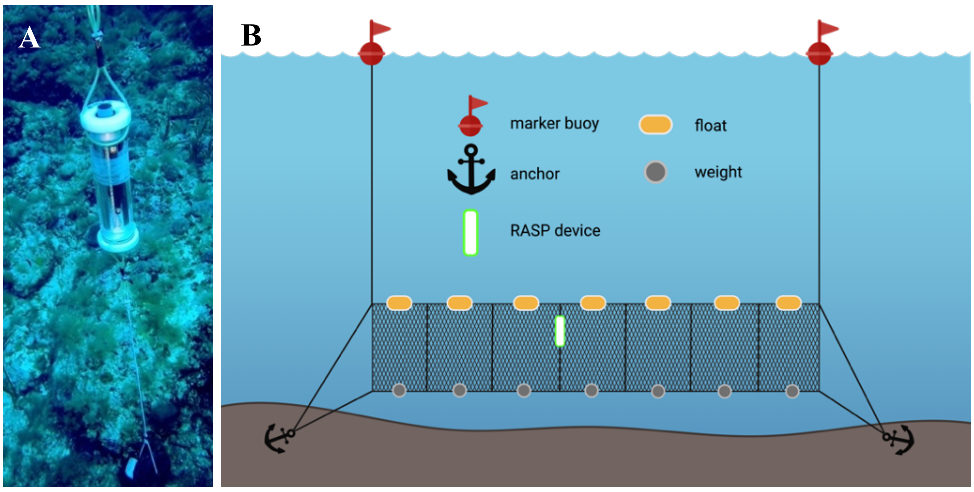

Figure 10: **(A)** Image of RASP-uRec384k-Nauta RCS model provided by Professor Gabriella La Manna, **(B)** RASP device setup on fishing gear created with BioRender.com.

Recordings were then saved as 60 or 30 minute files with a sampling frequency of 192 kHz, 16-bit resolution, in wav file format. A total of just over 1260 hours of recordings were manually analysed via visual and audio inspection using RavenPro 1.5 software (Cornell Laboratory of Ornithology, USA) with Hamming window setting at 512-point FFT with 50% overlap. The various types of vocalizations produced by the common bottlenose dolphin were categorized according to the categories presented by La Manna et al., 2023 (Table 2). For the purposes of this study, the final distinction was between dolphin presence or absence during a given fishing operation. Vocalization types and other characteristics were not taken into account. Fishing operations with a summed vocalization duration (in minutes) over 0.00 were considered to have dolphins present, and those with durations of 0.00 were absent of dolphin presence (meaning no dolphin vocalizations were found in the manual analysis).

Acoustic dolphin detection (ADD) around fishing gear has been found to be a reliable method for the estimation of depredation by La Manna et al., 2023, it was used as the proxy for depredation probability in this study.

General categories	Sound name	General description	Acoustic properties
Whistles	**Variant whistle**	Tonal sound	Narrowband frequency modulated signals
	Signature whistle		Distinctive whistle that broadcasts identity
Multi-burst pulsed sound	**Click train**	Sequence of discernible clicks	Sequence of broadband clicks with a mean inter-click interval over 0.04 s, and generally an overall duration over 2 s
	Creak		Sequence of broadband clicks with a mean inter-click interval between 0.002-0.02 s
	Variable rate click train (VRCT)	Sequence of discernible and non-discernible clicks	Long sequence of clicks including both click trains and creaks (and often but not always, victory squeals)
	Short burst-pulse	Sequence of discernible clicks	Brief burst-pulsed sound, generally under 0.2 s
	Bray series	Rhythmic sequence of short duration pulsed or tonal signals	Series of gulps, grunts, and squeaks
Single burst	**Bang**	Isolated burst pulsed sound	High energy, broadband signals

Table 2: Common bottlenose dolphin vocalization categories and general descriptions used for manual sound file analysis after La Manna et al., 2023 Table 2.

3.3 Catch data

Catch data was collected and analysed under the LifeDelfi Project coordinated by the National Research Council (Consiglio Nazionale delle Ricerche, CNR). Landings were photographed by researchers with the permission and collaboration of fishers.

Figure 11: Images taken of fish landings used for length measurements and biomass estimates with a ruler as reference required for scaling in ImageJ software. (Pictured species from left to right: two specimens of red scorpionfish or *Scorpaena scrofa*, and two specimens of brown meagre or *Sciaena umbra*.)

Landings are defined as the portion of the catch that arrives in the port following a fishing operation (excluding any bycatch and discards which were not brought ashore) (Carpentieri & Gonzalvo, 2022). These photographs (example image shown in Fig. 11) were used for species identification, as well as total body length measurements (Fig. 12) in ImageJ software in the case of all fish species. Measurements and species data were collected in Excel spreadsheets and were entered into species-specific formulas (Weight = a × Length^b, in which parameter *a* is a scaling coefficient, and parameter *b* is a shape coefficient) (Kuriakose, 2017) obtained by regression analyses between the length-weight relationships for the different species. Cephalopod and crustacean catch were directly weighed at the docks using hanging scales.

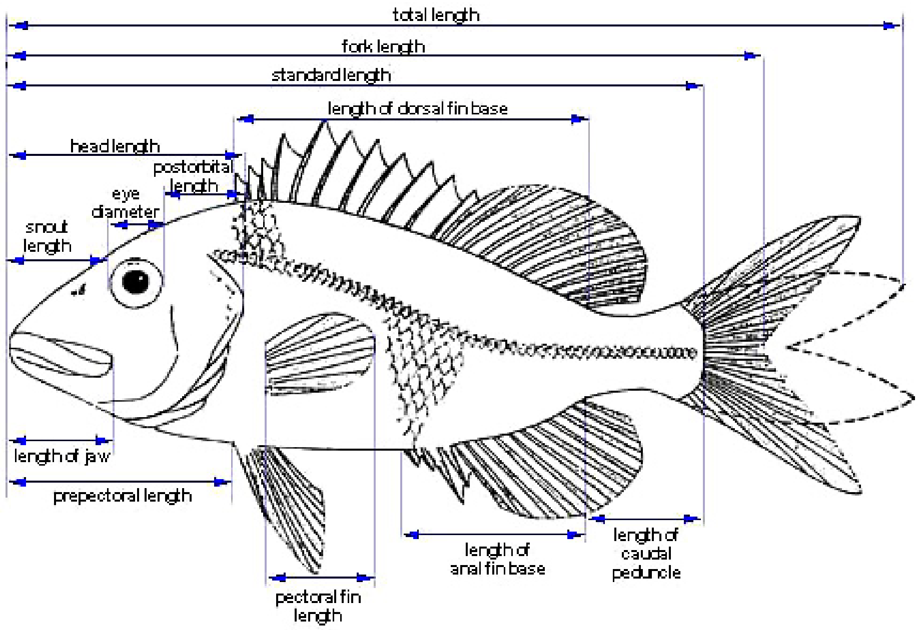

Figure 12: Standard morphometric measurements for fish species. Total length (total body length) used in this study. Image from Florida Museum, 2018.

Generally, catch per unit effort (CPUE) is expressed as the total catch (number or biomass) of a species or pool of species divided by a chosen unit of fishing effort (Carpentieri & Gonzalvo, 2022). In this study, CPUE was defined as the sum of the biomass of all caught species in a given fishing operation standardized for net length (1000 m) and fishing operation duration (soak time of 24 hrs).

3.4 Statistical analysis

A database of 119 fishing operations was compiled, containing the coordinates of the fishing site, depth of fishing site (m), ADD (as analysed from acoustic data), gear type (trammel net or gillnet), the CPUE (kg biomass / 1000 m of net / 24 hrs of soak time), the net length (m), and the FOD (represented by soak time in hours). A final sample size of 118 fishing operations was used after the elimination of any outlier data (1 sample visualized and identified in R via point plot).

As shown by the aim of this study, the two response variables were depredation probability, represented by dolphin presence (ADD), and catch amount, represented by CPUE.

The influence of CPUE, gear type, FOD, net length, and depth at fishing site were investigated on ADD, and the influence of ADD and gear type were investigated on CPUE. Because the sample size did not allow for the investigation of interactions between factors, the effects of factors on response variables were tested separately.

A summary of the dataset showed 73 fishing operations being conducted using trammel nets and 45 operations using gillnets. ADD showed dolphin presence during 62 fishing operations and absence in 56. Due to the unbalanced experimental design and non-normal distribution of some factors and both response variables, Generalised Linear Models (GLM) were used to test correlations between predictors (factors and covariates) and responses (response variables).

The nature of the response variable determined the best-suited GLM. ADD, a binomial categorical variable, followed Bernoulli distribution, so the analysis was done by binomial GLM. CPUE, a continuous variable, exhibited a gamma distribution, thus analysis was performed via gamma GLM.

Statistical analyses were carried out in R Studio. In both cases, models were validated following analysis using Pearson residuals, and their performances were calculated as well. The observational nature of the study, as opposed to an experimental approach, introduces the complexity of the natural system being observed, leading to typically lower acceptable performance levels for models in such contexts.

4 Results

4.1 Depredation probability

Acoustic dolphin detection (ADD) during a fishing operation was used as a proxy for dolphin presence, and thus, depredation probability. The influence of factors listed in Table 3 were investigated independently from one another.

Significant influence on depredation probability were attributed to CPUE, gear type, and FOD (Table 3). Net length (which ranged from 350 to 4200 m, with the average being just over 1 km) and fishing site depth (which ranged from 5 to 55 m, with an average of 25 m) did not significantly influence depredation probability.

Higher depredation probability (ADD) was associated with lower catch amounts (CPUE) (Fig. 13A). Increased soak time (FOD) also significantly influenced the probability of depredation (Fig. 13B). Gillnets showed significantly greater depredation probability as opposed to trammel nets (Fig. 13C).

	Estimate	Standard error	z value	Pr(>|z|)
Intercept	1.4904208	0.8353686	1.784	0.074400
CPUE	−0.2165563	0.0522538	−4.144	**3.41e−05**
Gear (trammel)	−2.0667773	0.6222870	−3.321	**0.000896**
Soak time (hrs)	0.117509	0.0316260	3.716	**0.000203**
Net length	0.0002836	0.0003326	0.853	0.393864
Depth	−0.0049110	0.0176135	−0.279	0.780383

Table 3: Results of binomial GLM testing the influence of CPUE, gear type, FOD (measured in soak time), net length and fishing site depth on acoustic dolphin detection (ADD). Significant values shown in bold.

The binomial GLM used for this analysis showed 34% performance, which was determined to be sufficient in the case of this study.

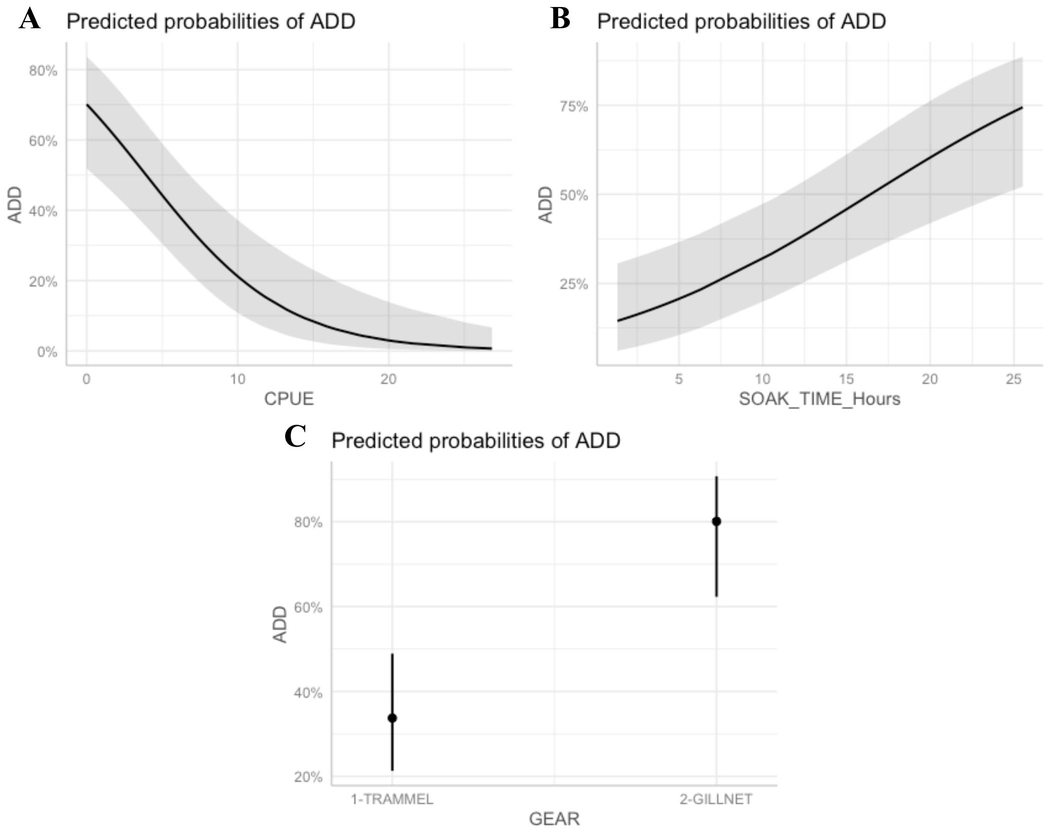

Figure 13: **(A)** Model prediction about the relationship between ADD and CPUE showed greater ADD probabilities associated with lower CPUE values. **(B)** Model prediction about the relationship between ADD and FOD showed greater ADD probability with longer FOD (greater soak time values in hours). **(C)** Model prediction about the relationship between ADD and gear types (trammel net and gillnet) showed greater ADD probability in gillnets as opposed to trammel nets.

4.2 Catch amount

Catch amount, as measured by CPUE, was significantly affected by both dolphin presence (ADD) and gear type (Table 4). Decreased CPUE was related to increased ADD (and thus depredation probability, Fig. 14A), while higher catch amount (CPUE) was related to gillnet rather than trammel net (Fig. 14B). Fishing site depth showed no significant influence on CPUE.

	Estimate	Standard error	t value	Pr(>|t|)
Intercept	2.760166	0.164854	16.743	< 2e–16
ADD (present)	–0.645306	0.123051	–5.244	**7.31e–07**
Gear (trammel)	–0.617163	0.125853	–4.904	**3.15e–06**
Depth	–0.007475	0.004540	–1.647	0.102

Table 4: Results of gamma GLM testing the influence of dolphin presence (ADD), gear type, and fishing site depth on CPUE. Significant values shown in bold.

The performance of the gamma GLM was 28%, determined to be sufficient in the case of this study.

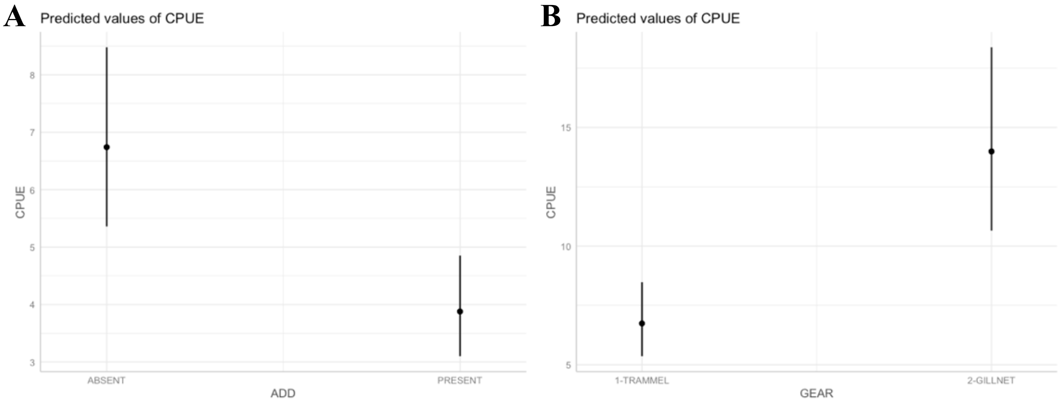

Figure 14: **(A)** Model prediction about the relationship between CPUE and ADD showed higher CPUE values correlated to ADD absence as opposed to presence. **(B)** Model prediction between CPUE and gear types showed higher CPUE values in gillnets as opposed to trammel nets.

5 Discussion

Studying the factors influencing depredation probability as well as catch amount in artisanal fisheries are pivotal for finding optimal mitigation measures that can minimize the occurrence of depredation while protecting fisher's livelihoods.

In this analysis, no significant effect was found on either depredation probability (ADD) or catch amount (CPUE) due to the depth of the fishing site.

Net length did not show a significant effect on the probability of depredation (ADD). Multiple studies have investigated net length as a factor regarding depredation (La Manna et al., 2023; Lauriano et al., 2023), but it has not yet been found to have a significant influence, which is consistent with the findings of this analysis.

The relationship between increased depredation probability and increased FOD was also found by La Manna et al., 2023, and this analysis supports those results. The longer gear stays in the water, the more time bottlenose dolphins have to locate it and forage from or near it. The exact mechanism behind how dolphins manage to find fishing gear requires further research, but current theories include the following of fishing boats from the harbours based on engine noise (La Manna et al., 2023), or recognizing cues of net hauling (Lauriano et al., 2023). There is evidence, that dolphins display strategic and systematic movements between coastal gillnets (Buscaino et al., 2021) suggesting that their discovery and depredation of the nets does not happen accidentally but rather is the result of intentional detection.

While gillnets were found to have a significantly higher chance of depredation, they also had significantly greater CPUE values. The fact they are such an effective fishing gear explains why they are one of the most widespread gear types in artisanal fisheries (He et al., 2021) and why fishers still opt for this method despite the risk of depredation. In their experience, it is worth the gamble of incurring potential catch loss and gear damage because in the cases depredation is avoided, the catch from these nets balances out any losses from other operations, overall surpassing other fishing gears.

CPUE and ADD showed significant impacts on each other, with lower CPUE amounts correlated to higher probabilities of depredation. These results are supported by various studies from Sardinian waters (La Manna et al., 2023; Lauriano et al., 2023; Pennino et al., 2015), but are conflicting with some other findings from Corsica (Rocklin et al., 2009), where the opposite was found. Positive associations between depredation and CPUE could be attributed to the fact that predator presence and abundance is expected to be higher in areas of high prey abundance, or even that dolphins are more likely to find nets and engage in depredation behaviour when nets contain more catch. They may also use the nets as a physical barrier while actively hunting near the gears, chasing fish into the nets (Cox et al., 2004; Rocklin et al., 2009). Negative associations between depredation and CPUE can be explained by effects of depredation on the catch, including direct catch loss due to removal of fish from gear, or the scattering effect on target species by this top predator, all leading to reduced catch amounts (La Manna et al., 2023). Another unlikely reason for negative association proposed by Pennino et al., 2015 was the possibility of a preference in dolphins for areas with lower prey abundance. Another side to that reason is the deeper cause behind prey-depleted areas, like overfishing and habitat degradation, which are recognized to exacerbate dolphin-fishery interactions (Bearzi, 2002). Dolphins are more incentivised to supplement their food intake by depredation in prey-depleted habitats, so lower CPUE and higher depredation may only be a symptom of the stress anthropogenic impacts exert on ecosystems and bottlenose dolphins (Fig. 4).

The nature of the experimental setup being comparable to field observation (from the perspective of experimental design) limits the amount of control researchers have over the factors considered. Fishers are not instructed on fishing site location and depth, net length, FOD, or gear type. This information along with catch and acoustic data is merely recorded. This lack of control over the variables was accounted for when choosing the appropriate statistical analysis methods. The trade-off between ecosystem context and control over variables in this case favours field observations even more, as the primary goal is to find solutions that limit the probability of depredation while maintaining catch efficiency, and not to deepen understanding of the mechanisms underlying the depredation occurrences. While the background and mechanism of why and how certain factors impact depredation probability is an important research area, the need for improved mitigation measures in practice is more urgent. The use of PAM in commercial fishery operations ensures the animal's natural behaviours are not influenced by their observation. This allows for the collection of data that is highly representative of the unaltered depredation phenomenon at the focus of this study.

The data used for analysis in this thesis is a subset of a much larger, continually growing dataset. It is part of a massive undertaking in data collection, very widespread both spatially and temporally. Information on many other factors has been and is being recorded from these fishing operations (some examples shown in Table 5), but in order to carry out analyses on that many factors as well as their potential interactions, a much larger sample size is needed. The complexity of the system observed, the lack of control over many variables and the potential interaction of those variables all contribute to a need for greater sample sizes for proper statistical testing and results. Some similar studies have had similar limitations regarding the opportunistic nature of data collection and sample size (Lauriano & Bruno, 2007), that this long-term, wide-range organization of data collection aims to overcome.

Main considerations	Data collected	Possible derived information
Fishing operation	Area / Site	Spatial patterns
	GPS coordinates	Depth
		Distance from harbour
		Site habitat type
	Gear	Type
		Mesh size
		Net length
Temporal patterns	Start and Stop times	FOD
		Diurnal patterns
	Date	Seasonal patterns
		Annual patterns
Catch	Species composition	Observed changes over time
	Species biomass	CPUE
Dolphin presence and behaviour	Acoustic data	ADD
		Vocalization types (behaviour)
		Depredation occurrence
		Total interaction duration (TID)
	Direct observation	Species
		Behaviour
		Distribution patterns
	Bycatch occurrence	Population impacts

Table 5: Key data points collected within the framework of the LifeDelfi Project currently underway. Recording this type of data is vital for assessing the efficacy of mitigation measures, and their impacts on wildlife and fishery yields.

It is important to keep in mind that dolphin presence near fishing gear does not unequivocally mean depredation has or will occur from that fishing gear. Observed interactions around and with gillnets have included taking catch from the nets (depredation), begging for fish from the fishing vessel or waiting for discards, using the net as a barrier in active foraging/hunting near the gear, and even transiting near gear without directly interacting with it (Cox et al., 2004). Acoustic detection has a demonstrated advantage over direct visual observation, as vocalization behaviour is more directly indicative of depredation behaviour than visual detection of presence (La Manna et al., 2023), however, it is still a proxy for depredation, not a definitive indication of it. Acoustic dolphin detection, even specific categories of vocalizations, are only indicative of feeding related behaviours in proximity to recording devices and should not be taken as definitive evidence of depredation behaviour (Lauriano & Bruno, 2007).

Another key assumption to be pointed out is that the vocalization in the acoustic data all belong to the same species, the common bottlenose dolphin (*Tursiops truncatus*). This is based on the known characteristics of their vocalization repertoire (which has been extensively studied both in captive and wild populations, B. Jones et al., 2020), their distribution patterns and residency in the study area, their opportunistic feeding behaviours and the reported observation of the specific species by fishers (Li Veli et al., 2023). For these reasons, it is well supported assumption that all vocalizations found in the manually analysed acoustic recordings belong to this species.

Depredation is one of the most common, most documented types of adaptation to human activity in odontocete species. It is important to note, that while this behaviour gives the appearance of great resilience to altered seascapes and ecosystems, it may only be the result of a lack of other viable options. Being an opportunistic, coastal, generalist species with high behavioural plasticity, bottlenose dolphins are not only more likely to be exposed to human activities and impacts but are also intrinsically more adaptable to environmental variation. (Bearzi et al., 2019)

As this region has a long history of dolphin-fishery interactions and depredation (Carpentieri & Gonzalvo, 2022), there is also a long and varied history of measures aimed at the reduction of these interactions, mainly at optimizing fishery catch. The intentional (and often systematic) killing of these animals was one such measure. It stemmed from a negative perception built on falsehoods originating from and exacerbated by the continued and intensified overexploitation of natural resources (Mazzoldi et al., 2019). Studies have also shown that the removal of top predators (as was done through deliberate killing of bottlenose dolphins) often has unexpected results in an ecosystem, and there is no scientific evidence that the removal of cetaceans improves fishery yields (Bearzi, 2002).

Current measures aimed at mitigating depredation are mostly non-lethal, thanks to the shift in overall perception of predator species and to the scientific advancements in knowledge on their roles in their ecosystems (Mazzoldi et al., 2019). Depredation mitigation measures include the modification of fishing gears, methods and practices (including both location and schedule) and deterrents or barriers around fishing operations (acoustic, chemical, light). Tixier et al., 2021 examined the global trends and patterns regarding depredation by large marine predators and synthesized the efficacy of some of the most widely employed non-lethal mitigation measures aimed at minimizing wildlife interaction with fishery activities (Fig. 15). Though these measures are designed to be non-lethal, it does not mean they do not pose potential harm to both depredating species and ecosystems in which they are employed.

Non-lethal mitigation approaches	n fisheries	% Effective	% Non-Effective	% unknown
Gear modification				
Catch protection	**17**	59	6	35
Reduced attractiveness (mesh size, net concentration)	**6**	33	0	67
Full change of fishing technique	**6**	67	33	0
Deterrence				
Acoustic Deterrent Devices	**24**	25	67	8
Non-lethal explosives (seal bombs, crackers, fireworks) & gunshots	**19**	5	32	63
Physical harassment	**4**	25	75	0
Chemicals	**4**	0	0	100
Light strobes	**3**	0	100	0
Echolocation disruptor	**2**	0	100	0
Playbacks (predator sounds)	**2**	0	100	0
Electrical repellent	**2**	0	50	50
Electromagnetic disruptor	**1**	0	0	100
Behavioural avoidance				
Peak times/areas avoidance	**21**	57	0	43
Move-on	**15**	53	0	47
Reduced soaking time	**4**	75	0	25
Increased hauling speed	**4**	25	0	75
Decoys	**2**	50	50	0

Figure 15: Table of non-lethal mitigation approaches and their effectiveness from Tixier et al., 2021 (Table 3). The "n fisheries" column depicts the number of fisheries in which the given mitigation approach was applied and tested, and the columns regarding effectiveness ("% Effective", "% Non-Effective" and "% unknown") consider both reduction of depredation occurrence and maintenance of acceptable catch rates.

There are also measures aimed at mitigating retaliation from fishers and the protection of their livelihoods. These include compensation programs, where fishers receive financial relief when incurring catch loss and/or gear damage resulting from depredation. This requires a reasonably accurate and accepted method of economic impact estimation and validation from a regulating authority (such as the Coast Guard) to prevent overreporting and fraudulent abuse of such reimbursement schemes (Pennino et al., 2015). Such financial incentives have been shown to improve tolerance of depredation occurrence. However, experiences in the application of such incentives in terrestrial systems have demonstrated that long-term conservation success strongly relies on lasting cultural and social change resulting in shifts in perception (Bearzi et al., 2019; Mazzoldi et al., 2019).

Because the consequences of dolphin-fishery interactions and depredation affect stakeholders unevenly, fishers (the stakeholders most affected by the burdens of this conflict) need to continue to be included in the development of mitigation measures. Besides being directly faced with the costs of depredation events, they are the ones at the front line of this issue, with the most hands-on experience regarding this phenomenon, and thus have a lot of valuable insights (Bearzi et al., 2019), which can be useful when developing research directions and protocols. Integrating anecdotal information of fishers with an evidence-based scientific approach can accelerate the development and testing of different measures. Anecdotal information, while subject to biases and uncontrolled variables, can be used to shape and "steer" the direction of scientific research which, by nature, is much slower to respond. While unstructured observations do not hold the answers, they are vital when deciding the focus areas and potential factors of consideration for scientific data collection and analysis, and for potentially providing a baseline understanding of the situation in the given area (Pardalou & Tsikliras, 2018).

Many argue that mitigation and management measures should be aimed at the anthropogenic pressures, such as overfishing, habitat-degradation and pollution (Fig. 4), which have led to and exacerbated depredation behaviours (Díaz López, 2019). While reducing these pressures on ecosystems is important, it is a level of management that is not only difficult to implement but is also extremely complicated to develop properly due to the required amount of data and analysis owing to the dynamism and complexity of these natural systems (Bearzi, 2002). This is why studying the apparent consequences of these anthropogenic pressures and developing mitigation measures regarding specific issues, such as depredation, is also vital. While gathering data and progressing the science on these massive overarching issues, progress must also be made on phenomena that stand out in terms of conservation and conflict mitigation. Addressing a particularly relevant part of a much larger issue not only potentially provides more time to understand and act on their underlying problems, but may also introduce new tools for tackling them.

Due to inherent differences between ecosystems, fishing practices, cultures and populations, there is no all-encompassing solution to mitigating depredation. Each scenario is unique and thus requires an adjustable and flexible approach which can be tailored to the specifics of that system (Tixier et al., 2021). One of the most important aspects in developing and improving mitigation measures is gathering information on and improving understanding of the depredation phenomenon. The increasing knowledge on the depredating species and the impact of depredation is responsible for creating a scienced-based, realistic view of wildlife and wildlife-human conflicts. This helps inform the perception of the public and the stakeholders most affected by depredation. Obtaining and spreading supported, relevant, and current information is vital for the implementation, acceptance and enforcement of informed mitigation strategies (Mazzoldi et al., 2019).

6 Conclusion

This analysis adds to our current understanding of and supports previous results regarding factors affecting the depredation of coastal artisanal fisheries by common bottlenose dolphins in the Mediterranean, and factors affecting catch amount.

The data used for this analysis is only a subset of a much greater dataset currently being collected through the cooperation of multiple organizations and stakeholders. The importance of continued collection, organization and analysis of the available data, and the consideration of a multitude of factors will form the basis for the multi- and interdisciplinary approach required to find the optimal trade-off between ecosystem management, species conservation and human interests. The importance of the inclusion of fishers in this massive undertaking cannot be understated, as their cooperation makes the most relevant field data collection possible, and their input will help shape mitigation measures that they can accept and implement. PAM is proving to be an improvement in comparison to past observation and monitoring methods, making more widespread data collection less labour and cost intensive. New and improved recording technologies and automatic sound analysis tools are also becoming more precise and more accessible, further enhancing the applicability of PAM technologies.

Depredation is only a symptom of deeper underlying problems resulting from anthropogenic impacts. A multifaceted approach is required to address not only depredation, but some of its likely causes and exacerbating factors. The historical and continued overexploitation of marine ecosystems, overfishing, habitat-alteration and degradation, urbanization and industrialization of coastal habitats, pollution and marine traffic have all contributed to this conflict between humans and wildlife (Fig. 4). Any measures taken to mitigate this conflict will be ineffective long-term if the underlying causes are not also confronted (Díaz López, 2019). Taking steps to address depredation is vital however, not only due to species conservation and socio-economic factors, but also for the protection of ecosystems from further damage (Bearzi, 2002). Historically, our attitude towards and ignorance regarding this phenomenon has led to the blaming of marine predators and measures aimed at their depletion and eradication. The removal of these top predators are now known to have deleterious cascading effects throughout their ecosystems. The longer we fail to confront our own roles in creating and exacerbating these harmful impacts, the worse the situation becomes. We must learn from these mistakes and avoid making them again by relying on scientific knowledge to inform the best possible mitigation measures. The importance of creating and maintaining a favourable perception of wildlife is highlighted by past negative perceptions, which have had serious consequences for both the species conservation status and the state of their inhabited ecosystems (Mazzoldi et al., 2019).

The point of the continued analysis (even with smaller sample sizes) is to find which factors are relevant as soon as possible, so research efforts can be focused on only the most important and most relevant factors and information. Scientific research effort is a limited resource, restricted by funding, access, trained personnel and time. Continuous examination of the growing dataset allows for fine-tuning data collection protocols and parameters, and is key for maximizing the efficiency of obtaining relevant results from the available research effort.

7 Acknowledgements

Coordinated data collection was made possible thanks to the cooperation of the LifeDelfi Project under the National Research Council (Consiglio Nazionale delle Ricerche, CNR) in the Adriatic and the International System for Agricultural Science and Technology (AGRIS) and the University of Sassari around Sardinia. The cooperation as well as the insight of fishers was an invaluable asset to data collection, and we are very grateful for their contribution to our understanding of depredation.

I would like to thank my supervisors, Professor Gabriella La Manna and Professor Gianfranco Santovito for their guidance and support. I am extremely grateful for the opportunity to work on this topic.

I am deeply thankful for my family and friends, whose support made it possible for me to complete this thesis work.

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