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Exploring the spatial distribution, composition, and depth-related patterns of marine litter in the Mediterranean Sea: insights from the MEDITS survey data

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1 Abstract

Marine litter is one of the most serious anthropogenic challenges to the global marine ecosystem. Public awareness is often limited to the visible litter that washes up on beaches or floats on the ocean surface. Less attention is paid to marine litter that is deposited and accumulates on the seafloor. The Mediterranean Bottom Trawl Survey (MEDITS) aims to provide insight into the state of seabed litter by collecting marine litter from the seabed. This study analyses the MEDITS 2020/2021 marine litter dataset in terms of spatial, temporal and depth distribution in the Geographical Subarea (GSA) 15, i.e. off the coast of Malta. The composition of the litter and potential major sources were determined. For these analyses, the two-sided independent *t*-test was applied using SPSS. Visualisation was done by creating maps and bar charts using MATLAB and QGIS. Results reveal tourism and household items as primary contributors to marine litter, with plastics comprising the majority. Surprisingly, the COVID-19 pandemic appears correlated with a significant reduction in seafloor litter accumulation. Spatial distribution dynamics suggest that subsurface currents influence the transport of light litter like plastic, while heavy litter, such as metals, tends to remain localised. Compared to other Mediterranean regions, the seabed off Malta demonstrates a relatively clean status. This study not only contributes valuable insights into the local marine environment but also underscores the need for global strategies to address marine litter. The findings prompt considerations for future environmental management practices and highlight potential areas for further research in the broader context of marine ecology and pollution.

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5 List of Acronyms

MEDITS: Mediterranean International Bottom Trawl Survey

ALDFG: Abandoned, lost, or discarded fishing gear

IAS: Invasive Alien Species

GSA: Geographical Sub-Area

GFCM: General Fisheries Commission for the Mediterranean

MPA: Marine Protected Ara

MSFD: Marine Strategy Framework Directive

SPA RAC: Regional Activity Centre for Specially Protected Areas

EOs: Ecological Objectives

EcAp: Ecosystem Approach

AMAre project: Actions for Marine Protected Areas project

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1 Introduction

1.1 Contextualising marine litter accumulation

The United Nations is currently speaking about marine litter as a planetary crisis affecting all ocean regions from the poles to the deep ocean trenches (United Nations Climate Change, 2022). The term ´marine litter` is defined as ´any persistent, manufactured or processed solid material that has been discarded, disposed of or abandoned in the marine environment` (United Nations Environment Programme, 2005, p.1). This includes the generation of marine litter through various transport pathways, whether on land through rivers or coastal landfills, or at sea through the loss of fishing nets (Canals et al., 2021). The size of the litter varies from nanoparticles to objects several meters in size (Canals et al., 2021). In particular, litter larger than 25 mm is referred to as macro-litter (Canals et al., 2021). The methodology for recording this litter can be carried out using bottom trawls followed by visual counting (Canals et al., 2021), as was done in the MEDITS survey in the central Mediterranean. The Mediterranean Sea and the Maltese Islands are considered one of the most threatened environmental regions in the world due to marine litter pollution (Boucher & Billard, 2020). However, despite numerous scientific publications on the subject, it is still unclear exactly how much litter enters the sea and in which marine regions it accumulates, be it on the sea surface or on the seabed (Boucher & Billard, 2020). Most of the available data in scientific papers relate to litter that accumulates on the sea surface. While litter found on beaches or on the sea surface raises public awareness of the extent of pollution, the seafloor remains out of sight for most people (Canals et al., 2021). Although the seafloor covers approximately 70% of the Earth's surface, the litter that accumulates there is the least studied fraction (Canals et al., 2021).

The increasing amount and extent of marine litter poses a significant threat to the health of oceans and seas (United Nations Environment Programme, 2021). The presence of litter serves as a distinct marker of the Anthropocene, the current geological epoch, and is increasingly becoming an essential component of Earth’s fossil record (United Nations Environment Programme, 2021). The ocean is also called the ´plastisphere` because of this condition, as plastics have found a new habitat there (United Nations Environment Programme, 2021).

The urgency of taking action to minimize marine litter has been recognised, but this requires standardised monitoring of the effectiveness of these actions, as well as quantitative assessment of the litter and its impact on the ecosystem (Canals et al., 2021). To date, there are few studies using standardised methods (Canals et al., 2021). The present study aims to contribute to filling this gap by applying a harmonized monitoring approach of the MEDITS survey at spatial, temporal and depth scales to study seafloor litter.

1.2 Research objectives and questions

The overall objective of this study is to analyse the spatial and temporal variations of marine litter on the seafloor in the Mediterranean Sea, specifically focusing on the years 2020 and 2021. The analysis will be conducted using the data collected through the MEDITS survey for the Geographical Sub-Area 15 (GSA 15), in which the Maltese Islands are found. This data set has not been analysed previously. The study further aims to explore the relationship between depth and litter accumulation and investigates possible correlations with anthropogenic activities and subsurface currents. These objectives will be guided by the following research questions:

1. What are the spatial configurations and temporal fluctuations characterising the marine litter collected?
2. How does the amount of marine litter collected vary with depth?
3. What are the most potential sources of marine litter in the area?
4. What is the composition of the marine litter found?

1.3 The MEDITS survey: Data source and purpose

Due to increasing anthropogenic pressures on the marine environment and conflicts between users from different sectors competing for resources, timely environmental policies increasingly rely on a comprehensive approach to managing marine biological resources (Terribile et al., 2016). However, many regions, especially in the Mediterranean, struggle with fragmented information on marine biotic communities making basic habitat maps the exception rather than the rule (Terribile et al., 2016).

The absence of basic knowledge about seafloor habitats and species communities and biology, poses a significant hurdle to the advancement of spatial and strategic planning, especially in contexts with competing demands such as fisheries, tourism, and conservation (Bianchi et al., 2012). In addition, the findings are important for evaluating the effective implementation of legislations aimed at achieving good environmental status through sustainable use and conservation of marine biodiversity (Terribile et al., 2016). Significant legislative frameworks, such as the Habitats Directive or the Marine Strategy Framework Directive, all rely on biocoenotic data for their meaningful implementation (Terribile et al., 2016). In the central Mediterranean, particularly within the General Fisheries Commission (GFCM) Geographic Subarea (GSA) 15, the understanding of biotic communities at greater depths remains limited (Terribile et al., 2016). This is also true for the Maltese Islands, which are strategically located to monitor changes in Mediterranean biodiversity patterns (Terribile et al., 2016). Nevertheless, the benthic habitats of the surrounding circalittoral and deeper waters are among the least studied areas (Terribile et al., 2016).

A particularly alarming concern relates to increasing marine litter pollution, which is having a particularly detrimental impact on the seafloor (García-Rivera et al., 2018). Accurate assessment of these impacts requires a comprehensive understanding of the distribution of litter (Galgani, 2014). Trawling has been advocated as an effective method for monitoring marine litter (Galgani, Hanke, Werner, L, et al., 2013), but considerable variation in methods has been noted among Mediterranean regions and research teams (Galgani, 2014). Standardisation of these approaches, as advocated by Galgani (2014), promises to provide more robust and comparable data.

The Mediterranean International Bottom Trawl Survey (MEDITS) program provides hope in this context. It was launched in 1994 through the collaboration of research institutes from four Mediterranean European Union member states (France, Greece, Italy, Spain) (MEDITS, 2017). The goal was to conduct a standardised trawl survey with uniform equipment, sampling protocols and methods (MEDITS, 2017). Over time, other partners from Slovenia, Croatia, Albania, Montenegro, Cyprus and also Malta have joined the project, promoting a unified approach to data collection (MEDITS, 2017). Of particular note is the integration of marine litter coverage into the survey, making it an ideal tool to gain standardised insights into the composition and distribution of marine litter across the Mediterranean (Kavadas et al., 2013; MEDITS, 2017). This is in line with the requirements of the Marine Strategy Framework Directive and is reinforced by a joint protocol that was agreed upon during the 2013 MEDITS Coordination Meeting (MEDITS, 2013). By monitoring all of the above, this endeavor is expected to contribute not only to the sustainable management and conservation of marine resources in the Mediterranean Sea, but also to finding solutions to the growing problem of marine pollution. The collected data will be the basis for the analysis in this master thesis.

1.4 Relevance and significance

This study on the spatial, temporal and depth-related distribution of marine litter in the Mediterranean makes a significant contribution to promoting environmental awareness in the context of environmental protection. A comprehensive analysis of litter distribution opens up significant perspectives for targeted environmental conservation measures. In particular, several key aspects of the study are highlighted.

(1) The study enables the precise identification of litter hotspots where the concentration of marine litter on the seabed is particularly high. These findings open the possibility of developing and implementing targeted cleaning and prevention strategies at the relevant locations.

(2) The correlation-based analysis in conjunction with anthropogenic pressures and subsurface currents contributes to a better understanding of the main sources of marine litter. By investigating the distribution of litter along ocean currents, a more comprehensive view of spatial dynamics is made possible.

(3) The study will lead to an improved assessment of the environmental impact of marine litter. A more precise assessment of these impacts will provide a sound scientific basis for policymakers, environmentalists, and other stakeholders for informed decision-making.

Overall, this research acts as an important source of information and enables the development of effective strategies to tackle the global problem of marine litter. A solid scientific basis enables measures that are effective not only locally but also globally, thus making a sustainable contribution to environmental preservation.

1.5 Thesis structure

After presenting the research context, research questions and relevance of the study in the introduction, the state of knowledge on marine litter in Maltese waters globally, regionally, and nationally will be explored in the form of a literature review. This will form the basis for understanding the research gap discussed in Section 2.2.

The methodology Section that follows will briefly discuss the data collection processes. However, the process of data analysis and interpretation will be the focus of this Section.

Next, the results of the data analysis will be presented and visualised in the context of the research questions. This will be followed by a discussion that will compare and interpret the findings with the literature. In doing so, the implications and significance of the findings and how they relate to the broader research context will be addressed.

The final written Section of this master’s thesis will close with a conclusion that will briefly summarise the findings and suggest possible guidelines and recommendations for future research.

Supplementary materials will be provided in the appendix.

2 Literature review

The following literature review provides the foundation of the master thesis, which will address the issue of marine litter in the Mediterranean Sea, around the coast of Malta. The urgency of this issue is highlighted by its far-reaching effects on the ecosystem, economy, and society, as already touched upon in the introduction.

The objective of this literature review is to look into the underlying causes, current impacts and potential solutions in context to marine litter. The systematic analysis of scientific papers, reports and studies is intended to highlight the current state of knowledge and to identify areas where further research is needed.

To establish a coherent framework, the DPSIR (Driving forces, Pressures, State, Impact, Response) Framework will serve as a guiding structure, facilitating a thorough literature review. The following Section delves deeper into the DPSIR framework, providing a detailed overview and elucidating its application as an analytical tool within this thesis.

2.1 Conceptual Framework: DPSIR analysis

DPSIR (Driving forces, Pressure, State, Impact, Response) is an analytical method developed to systematically understand and structure complex environmental problems (Federigi et al., 2022; Lewison et al., 2016). It provides a comprehensive approach to capturing the different aspects of a problem and organising them into a logical framework (Figure 1) (Lewison et al., 2016; Troian et al., 2021). For this reason, the framework is particularly useful when dealing with large and multi-faceted challenges (Federigi et al., 2022; Lewison et al., 2016; Troian et al., 2021), such as the problem of marine litter in the oceans and in this case the Mediterranean Sea. This thesis uses the DPSIR framework as a guide to structure the literature review and to comprehensively analyse the different dimensions of the research topic. The components of the DPSIR framework are briefly introduced below before being applied in context to the specific topic of this thesis.

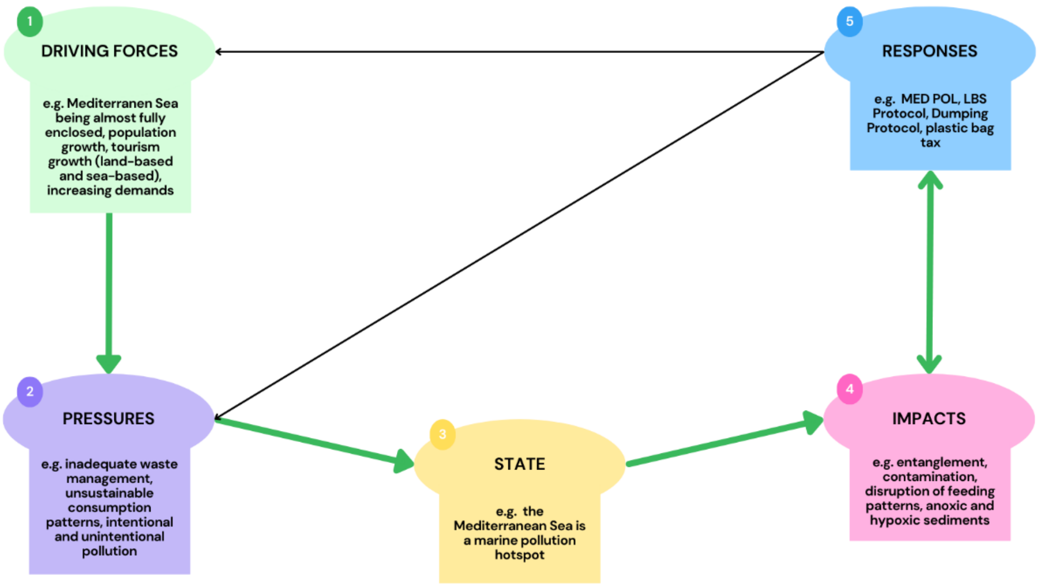

Figure 1: The DPSIR framework applied to marine litter in the Mediterranean Sea. Source: own figure.

2.1.1 Driving forces and pressures

In the Mediterranean, there are several key drivers and consequently pressures that are responsible for the generation and accumulation of marine litter in the sea. Although the traditional definition of the DPSIR framework derives the drivers and pressures only from anthropogenic factors, marine research studies divide them into anthropogenic and natural (Federigi et al., 2022). This will be considered in the following review.

2.1.1.1 Natural factors

2.1.1.1.1 The structure of the Mediterranean Sea

The closed structure of the Mediterranean Sea, the long coastline (46000 km), the presence of numerous islands and the specific features of the sub-basin mesoscale surface circulation favor the trapping of garbage and the interaction between floating and shore litter (Prevenios et al., 2018; Robinson et al., 2001). It also has a high number of submarine canyons and submarine channels. These can serve as transport pathways for particles from the coast (e.g. marine litter) to bathyal and abyssal areas (Ramirez-Llodra et al., 2013).

2.1.1.1.2 The degradation of marine litter to microplastics

Macroplastic fragmentation is an important process that contributes to the exacerbation of global plastic pollution. It is driven by a combination of factors. Mechanical forces such as waves, currents and tides play an important role (Andrady, 2015). These forces act on plastic objects, causing them to break and disintegrate into smaller pieces called microplastics (< 5mm) (Andrady, 2015). Microplastics, like macroplastics, can accumulate and disperse in the marine environment. They are difficult, if not impossible, to remove (Lusher et al., 2015). The impact of microplastics on aquatic life is of concern because these small particles can easily enter the food chain, leading to contamination of marine life and serving as an entry point for microplastics into the human body (Gola et al., 2021).

2.1.1.2 Anthropogenic factors

2.1.1.2.1 Land-based factors

The global population growth can also be clearly observed on the Mediterranean coasts (Figure 2). According to Civili, (2010), the resident population in the coastal states has locally doubled, bringing the population of the Mediterranean states to 512 million people in 2018. This figure represents 6.7% of the world's population (Civili, 2010). There are estimates that by the end of the 21st century there will be 700 million people in the region (Civili, 2010).

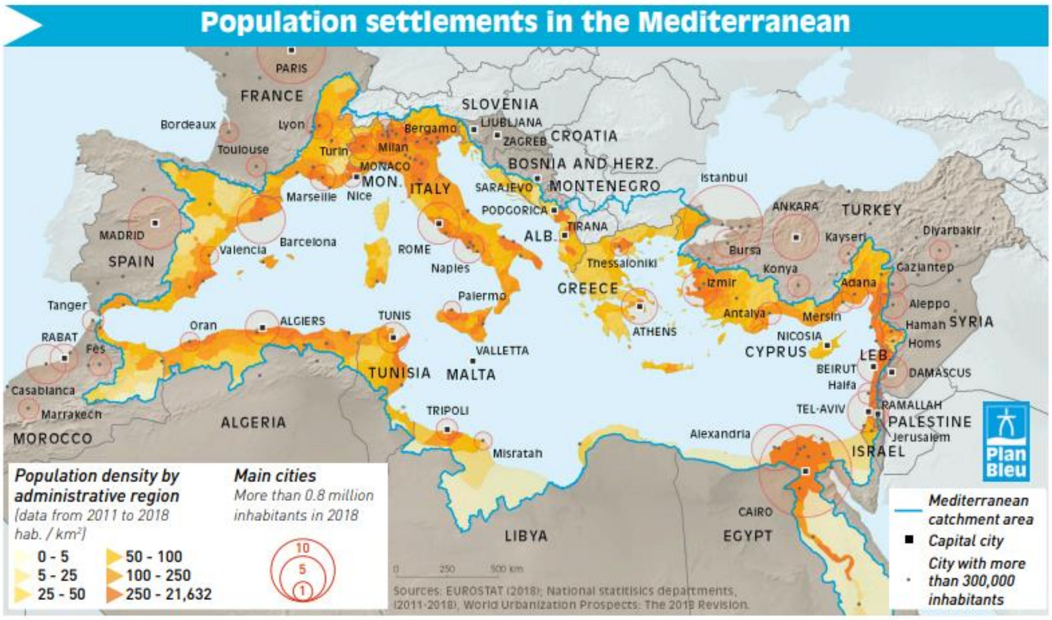

Figure 2: Population settlements in the Mediterranean Sea from 2011 to 2018. Source: (Plan Bleu, 2020).

In addition to the resident population, the tourism industry is highly developed in the Mediterranean (Plan Bleu, 2020). Every year, 360 million tourists visit Mediterranean destinations (Plan Bleu, 2020). 50% of the tourists who spend their holidays in the Mediterranean do so on the coast, close to the sea (Civili, 2010). Tourism is expected to grow at a high rate in the coming years. And especially in Malta, tourism takes precedence, with a recorded influx of 2,771,888 tourists in 2019 (Malta Tourism Authority, 2019).

With an increasing population growth, the behavioural patterns and consumption of people are magnified. Increasing plastic production due to growing demand, unsustainable consumption patterns and inadequate litter management systems represent only a small number of the consequences yet represent the main driving forces for marine litter in the Mediterranean (Plan Bleu, 2020). According to Tekman et al. (2022), an analysis estimates that 307-925 million pieces of litter enter the sea each year in Europe alone, and that 82% of the litter is plastic. Between 2003 and 2016, as much plastic was produced as in all previous years (Tekman et al., 2022). That the problem is only going to get worse is reflected in the plans of the plastics industry, which has invested $180 billion in new factories since 2010 (Tekman et al., 2022). According to an estimate by the Alfred-Wegener-Institute, this will lead to a 40% increase in plastic production over the next decade (Tekman et al., 2022). By 2040, plastic marine litter will have tripled (Tekman et al., 2022).

2.1.1.2.2 Ocean-based factors

Marine-based factors that contribute to marine litter pollution are fishing, aquaculture, ship-based tourism and shipping, as well as offshore operations (FAO, 2020; United Nations Environment Programme, 2021). Marine litter contributing to marine pollution from fishing and aquaculture includes ropes and lines, buoys, nets, packaging, and fishing gear such as fish aggregating devices (FAD) (FAO, 2020; United Nations Environment Programme, 2021). Shipping and ship-based tourism include items such as packaging and personal belongings (FAO, 2020; United Nations Environment Programme, 2021).

The FADs are artificial floating devices made from palm leaves or plastic sheets (Consoli, Sinopoli, et al., 2020; Dagorn et al., 2013; Dempster & Taquet, 2004). Styrofoam or plastic bottles are used in the construction as floats, and nylon ropes and large stones are used as anchors (Consoli, Sinopoli, et al., 2020) (see Figure 3). This construction is used to attract juvenile and adult pelagic fish species (Dagorn et al., 2013). In addition to the Lampuki FADs (or Kannizzati), other fishing gears used in the Maltese fisheries sector are the lampara fishery (a type of pelagic fishery), the bottom trawl fishery (which operates all year round in Malta), and the longline fishery, which targets heavy fish and bluefin tuna (Environment & Resources Authority, 2019; Mifsud et al., 2013; Sinopoli et al., 2020).

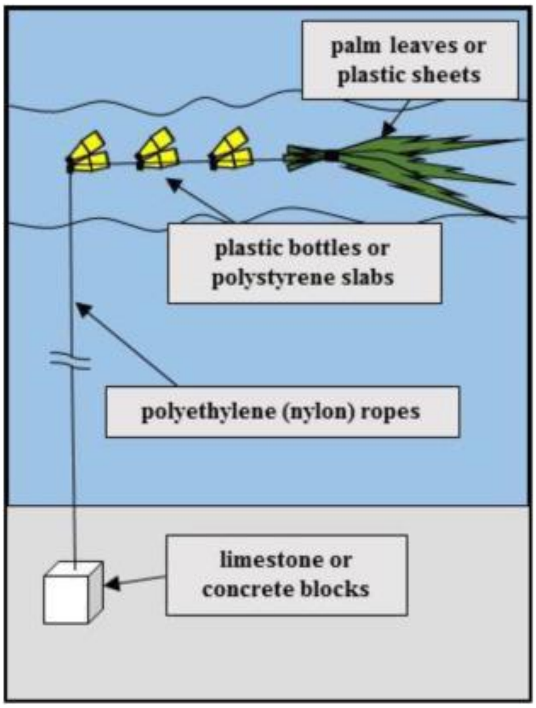

Figure 3: The setup of Fish Aggregation Devices for the Dolphin Fish (Coryphaena hippurus). Source: (Consoli, Sinopoli, et al., 2020)

With regard to ship-based tourism, a study analysed the type and date of manufacture of all the bottles found in the sea, which showed that ships are responsible for the majority of the bottles found in the central South Atlantic (United Nations Environment Programme, 2021). In addition, an internal study by a fleet operator found that the crew of 75 vessels discarded 50,000 plastic bottles per year after a single use (IMarEST, 2019). It can be seen that not only fishing, but also coastal and marine tourism is a major source of marine litter, as the intentional or unintentional pollution from this sector leads to the above statistics (European Union, 2014). The reasons for this are litter mismanagement, i.e. the dumping of litter at sea, due to excessive costs of litter disposal in port, inadequate facilities to deal with litter generated by maritime activities, and a lack of incentives to reuse or recycle equipment (United Nations Environment Programme, 2021). A review of the EU's Port Reception Facilities Directive showed that up to 30% of the litter that should be delivered by all types of ships does not arrive and is instead dumped at sea (source in (United Nations Environment Programme, 2021)).

All of these driving forces and associated pressures result in a variety of impacts that are not limited to marine organisms (see Section 2.1.3). The situation will become even more serious in the coming years, given the global increase in fish consumption by humans. In view of the projected growth in the world's population, coupled with rising standards of living, economic recession, and global food crises, the estimated increase in production will be met by an increase in demand for fish products (Röcklinsberg, 2015). Global fish production from aquaculture and capture fisheries is expected to increase from 176 million tons to 200 million tons by 2029 (OECD & Food and Agriculture Organisation of the United Nations, 2020). This trend will be reflected in marine litter, making the current global, regional, and national status of marine litter, described below, look small.

2.1.2 State

This Section looks at the current state of marine litter pollution globally, regionally in the Mediterranean Sea, and locally, around the Maltese Islands. Data and information are gathered on how much the ecosystem is already being impacted to this date.

2.1.2.1 Global

It is estimated that 15 million tons of plastic enter the oceans each year (Forrest et al., 2019). In terms of the geographic distribution of marine litter, Haarr's research (Haarr et al., 2022) shows that the highest density of seafloor litter is found in the North Atlantic. In contrast, the highest densities of pelagic litter were found in the North Pacific, while the highest densities of beached litter were found in various parts of Asia (Haarr et al., 2022).

The increase in marine litter pollution in various categories is alarming. By 2040, plastic litter in aquatic ecosystems is projected to nearly triple if no effective action is taken (United Nations Environment Programme, 2021). The current state of marine litter is estimated at 75-199 million tons of plastic (United Nations Environment Programme, 2021). The extent of this number can be seen in Figure 4.

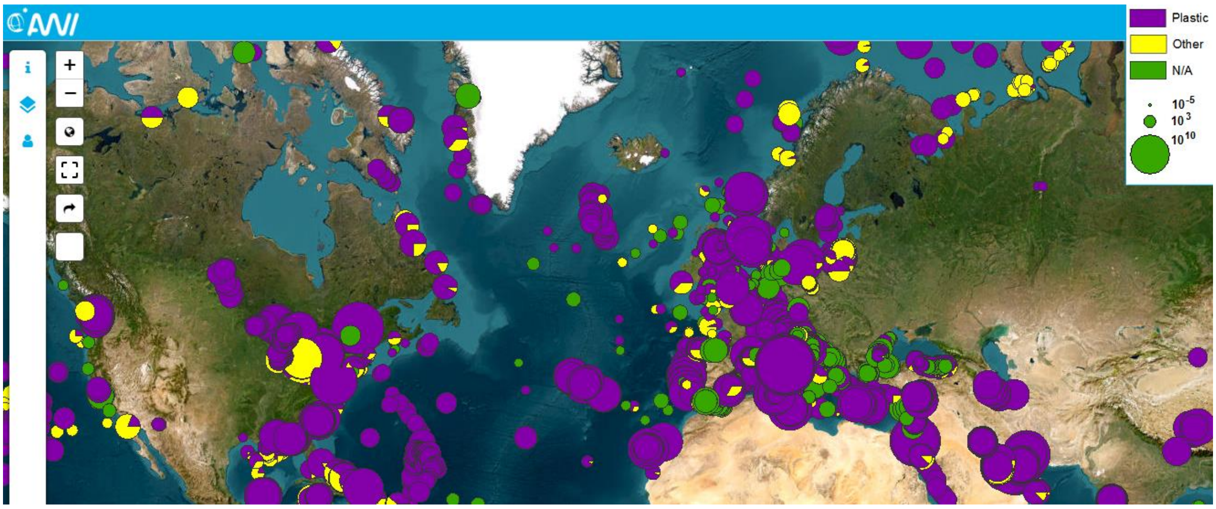

Figure 4: Marine litter found globally as displayed by the online port for marine litter by the Alfred-Wegener Institute. Source: (AWI-Litterbase, 2023).

The main sources of plastic litter are the packaging, consumer goods, institutional products and textiles sectors (United Nations Environment Programme, 2021). This litter is largely made of polyethylene and polypropylene, with most items older than 15 years, indicating that the majority of microplastic pollution is due to objects from the 1990s (Lebreton et al., 2019).

Ongoing pollution has led to the emergence of hotspots that pose significant risks to ecosystems and human health (United Nations Environment Programme, 2021). The Mediterranean Sea is one such hotspot, which will be discussed in more detail in a later Section (United Nations Environment Programme, 2021). To make matters worse, recycling rates are still very low, with less than 10% of plastics ever produced being recycled (Dauvergne, 2018; Geyer, 2020; Zheng & Suh, 2019).

The exact disposition of 99% of the plastic litter that ends up in the oceans remains unknown. A significant proportion is thought to be deposited on the seafloor, where it continues to increase (Canals et al., 2021; Gerigny et al., 2019; Tekman et al., 2017). In terms of environmental protection efforts and regulations, there is currently no unified, standardised regulation (United Nations Environment Programme, 2021). There is limited policy coordination among states, and national and subnational policies suffer from gaps, irregular implementation, and inconsistent standards (Dauvergne, 2018; Forrest et al., 2019) (see more in Section 2.1.4).

2.1.2.2 Regional – Mediterranean Sea

In addition to being a hotspot for marine litter, the Mediterranean is also the world's fourth largest producer of plastic products (United Nations Environment Programme, 2021). Approximately 0.57 million tons of plastic enter the Mediterranean each year, which is equivalent to 33,800 plastic bottles per minute (Boucher & Billard, 2020; Dalberg Advisors, WWF Mediterranean Marine & Initiative, 2019). This scale of the Mediterranean hotspot can be compared to the amount of litter found in the five major ocean gyres (North Atlantic, South Atlantic, North Pacific, South Pacific and Indian Ocean) (United Nations Environment Programme, 2021). Global models support this assessment by identifying the Mediterranean as the sixth largest accumulation zone of marine litter in the world (Baini et al., 2018; Fossi et al., 2018; Panti et al., 2015; Sebille et al., 2015). The considerable amount of litter in the Mediterranean is illustrated in Figure 5, where the occurrence of plastic and other litter is graphically depicted by the Alfred Wegener Institute (AWI-Litterbase, 2023). This is due to several factors, which are discussed in detail in Sections 2.1.1.1 and 2.1.1.2. Anthropogenic impacts are not the only factor contributing to this situation.

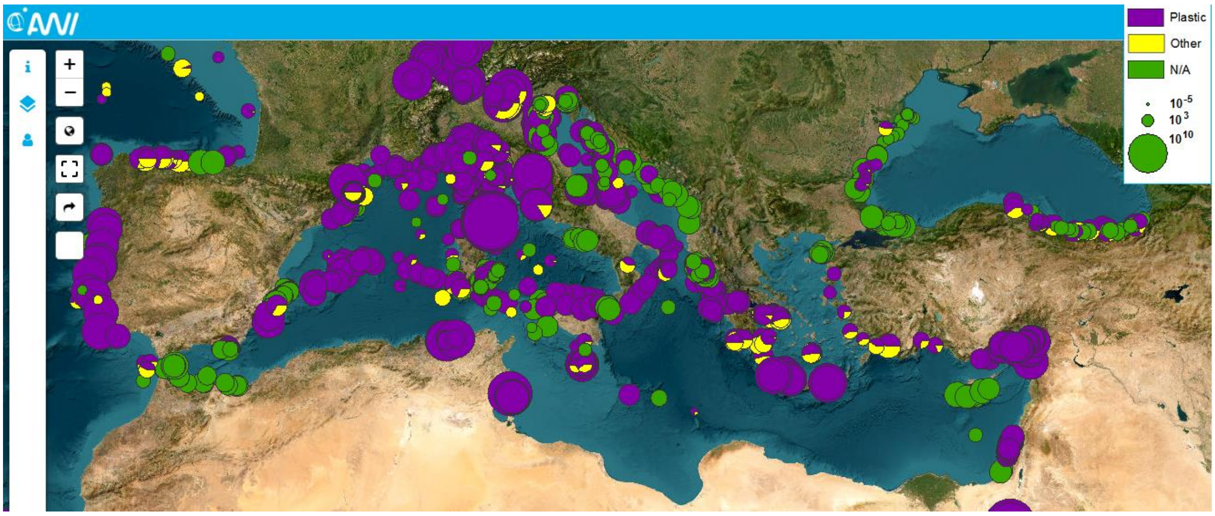

Figure 5: Marine litter found regionally in the Mediterranean Sea as displayed by the online port for marine litter by the Alfred-Wegener Institute. Source: (AWI-Litterbase, 2023).

With regard to benthic accumulation areas, it is hypothesized that the seafloor also represents a sink for litter in the Mediterranean Sea (Canals et al., 2021). Tubau et al. 2015 estimated that there are approximately 8,000 pieces of litter per km^2 in the Mediterranean Sea (Figure 6).

Figure 6: Seafloor litter in the Messina Strait, Central Mediterranean at (a) 415, (b + c) 550 and (d) 575 water depth. All scale bars are 20 m. All pictures were taken using POLLUX III ROV by M Pierdomenico and D Casalbore from the CNR, as well as F Chiocci from the University of Rome La Sapienza, Italy. Source: (Canals et al., 2021).

2.1.2.3 Local – Maltese Islands

Marine litter is also found on the seabed of the central Mediterranean Sea, close to the coast of Malta (Consoli, Sinopoli, et al., 2020). A study by Consoli et al. (2020) confirmed that the seabed at this location has an average litter density of 4.63 pieces of litter per 100m^2 and interacts with benthic organisms. The litter consisted mainly of abandoned, lost or otherwise discarded fishing gear (ALDFG) (97% of the total), which can be attributed to local fisheries (Consoli, Sinopoli, et al., 2020). 83% of the ALDFG found were items from the FAD fishery, which is used by local fishermen to catch dolphinfish (*Coryphaena hippurus*) in Maltese waters between 15 August and 31 December (Consoli, Sinopoli, et al., 2020; Deidun et al., 2015). Some of these items can be seen in Figure 7.

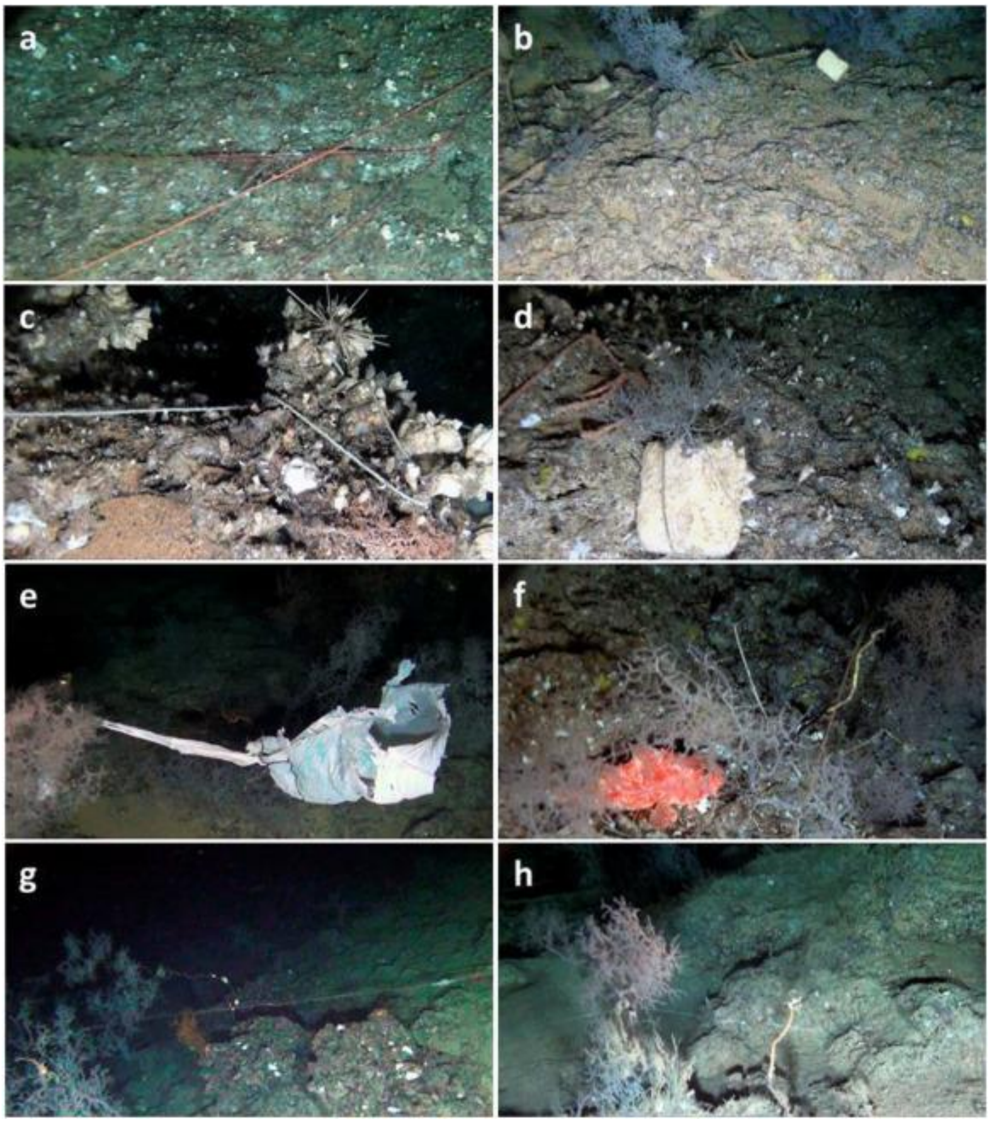

Figure 7: ROV images showcasing the interaction of marine litter with benthic deep sea organisms around the Maltese Islands. Source: (Consoli, Sinopoli, et al., 2020)

2.1.3 Impact

The presence of marine litter is not only an aesthetic problem, but also poses significant challenges to the marine ecosystem and the organisms that live in it. An in-depth analysis of the impacts and their overarching implications for other sectors is elaborated in the following Section.

2.1.3.1 Impact on marine organisms

The impact on marine organisms can be divided into four areas. Their interaction with marine litter can lead to entanglement, prevent them from feeding, contaminate them with chemicals, and result in them being covered with litter, causing further problems (Plan Bleu, 2020; Tekman et al., 2022).

Entanglement of marine organisms in marine litter is primarily caused by discarded or abandoned fishing gear (Tekman et al., 2022). This can include nets, ropes or lines (Tekman et al., 2022). However, entanglement with these items occurs not only at sea, but also on land as a result of birds using marine litter for nesting (Schrey & Vauk, 1987; Tekman et al., 2022). Entanglement can result in restricted movement, injuries and, in the worst cases, strangulation and death (Derraik, 2002; Tekman et al., 2022). A study by Karris et al. (2023) investigated the effects of the COVID-19 pandemic on seabirds. They focused on the improper disposal of masks and plastic gloves used for human protection (Karris et al., 2023). During the early breeding season, a Yelkouan shearwater, endemic to the Mediterranean and Black Seas and common in Malta, was observed entangled in a mask (Karris et al., 2023) (Figure 8). There was clear evidence that the entanglement had an impact on the bird's flight and foraging behaviour (Karris et al., 2023). Another study conducted in Oahu, Hawaii found that 65% of the coral colonies there were entangled in fishing lines (Yoshikawa & Asoh, 2004). As a result, 80% of these colonies were partially or completely destroyed (Tekman et al., 2022; Yoshikawa & Asoh, 2004). These situations are not limited to populated areas but have been found in all oceans and depths. This is confirmed by a study from the Arctic deep sea, where up to 20% of sponge colonies were entangled in plastic (Parga Martínez et al., 2020).

Figure 8: A Yelkouan shearwater entangled in a face mask. Source: (Karris et al., 2023)

Besides marine litter entanglement, plastic ingestion is a serious problem affecting marine organisms throughout the food chain, from plankton to megafauna (Tekman et al., 2022). It is species-specific, meaning that different organisms are exposed or more vulnerable towards different sizes of plastic fragments (Egbeocha et al., 2018; Karbalaei et al., 2019; Kühn et al., 2015; Woods et al., 2021; Zhu et al., 2019). Deposit feeders, detritivores, and filter feeders, for example, more commonly ingest microplastics (Thompson et al., 2004). The ingestion of plastic or other litter gives animals a false sense of satiety (Tekman et al., 2022). As a result, they stop eating and eventually starve to death (Tekman et al., 2022). In addition, ingestion of marine litter can result in internal injuries or digestive system disorders (Tekman et al., 2022). The increased ingestion of marine litter by animals has been confirmed by numerous studies and, again, is not limited to marine organisms (Derraik, 2002). According to an estimate by Wilcox et al. (2015), 90% of all seabirds ingest plastic. Also, 52% of all sea turtles examined showed plastic ingestion (Schuyler et al., 2015). In one extreme case in Thailand, a single straw was found to cause damage to the digestive tract of a whale shark, ultimately killing the animal (Haetrakul et al., 2009). Overall, several studies show that ingestion of marine plastics and marine litter in general can lead to impaired growth, immune response, behaviour, and fertility. The severity of the effects depends on the amount of marine litter the animals are exposed to and the ingredients used to in their manufacturing process (Tekman et al., 2022).

According to Mattsson et al. (2017) and Prüst et al. (2020), pollutants can penetrate body cells and in some cases even reach the brain of marine animals. These pollutants include endocrine disruptors, which, as described above, can alter the hormonal balance, and thus affect the development, behaviour, and reproduction of marine animals (Porte et al., 2006). Other pollutants include persistent organic pollutants (POPs) (D'Agostino et al., 2020). Polychlorinated biphenyls (PCBs), for example, are POPs (Geyer et al., 2017). POPs are generally characterised in that they are difficult or impossible to degrade and can be transported over long distances - by wind or water (D'Agostino et al., 2020; United States Environmental Protection Agency, 2014). They enter the marine environment through anthropogenic activities such as industrial processes or oil spills but can also be introduced from natural sources (D'Agostino et al., 2020). They are hydrophobic and therefore adhere to marine litter in their vicinity (Tang et al., 2020). Marine litter thus becomes a kind of Trojan horse (Figure 9), as the synergistic effect of the litter and the contaminants in and on it can cause tremendous harm to marine organisms (Ivar do Sul & Costa, 2014). There is also a lot of new knowledge about the interaction between human health and POPs, which will be discussed in more detail in Section 2.1.3.3.

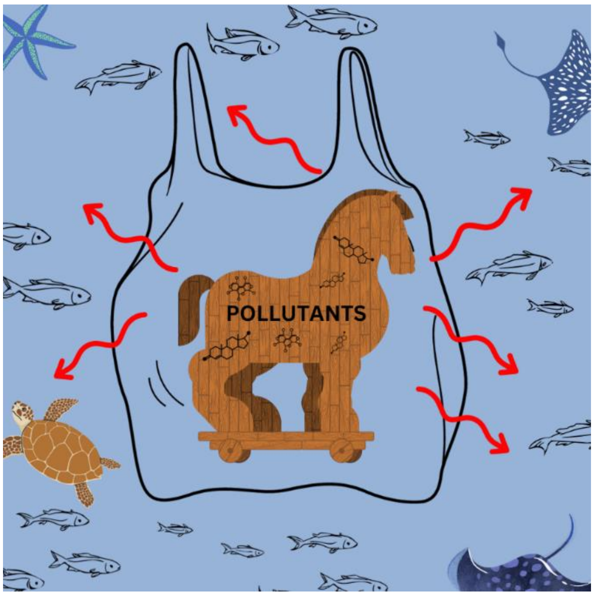

Figure 9: Marine litter acting as a Trojan horse, containing POPs. Source: own figure.

Marine litter also results in the coverage of marine organisms or the seabed and its biota (Gregory, 2009). This is usually caused by larger and softer pieces of marine litter such as sheets or foils (Gregory, 2009). For sponges, such coverage can lead to a reduction in particle uptake, which in turn limits growth and reproduction (Bergmann & Klages, 2012). Covering the seafloor with marine litter can affect gas exchange and local biogeochemistry, ultimately leading to anoxic and hypoxic sediments (Goldberg, 1994, 1995; Gregory, 2009; Mordecai et al., 2011) (see Figure 10). As a result, benthic communities are severely affected (Bergmann & Klages, 2012). Deep-sea organisms are particularly susceptible. This is because they have longer life spans and are exposed to contamination for longer durations, and because the deep sea is characterised by calm, non-turbulent waters where marine litter remains in place for a prolonged period of time (Bergmann & Klages, 2012; Woods et al., 2021).

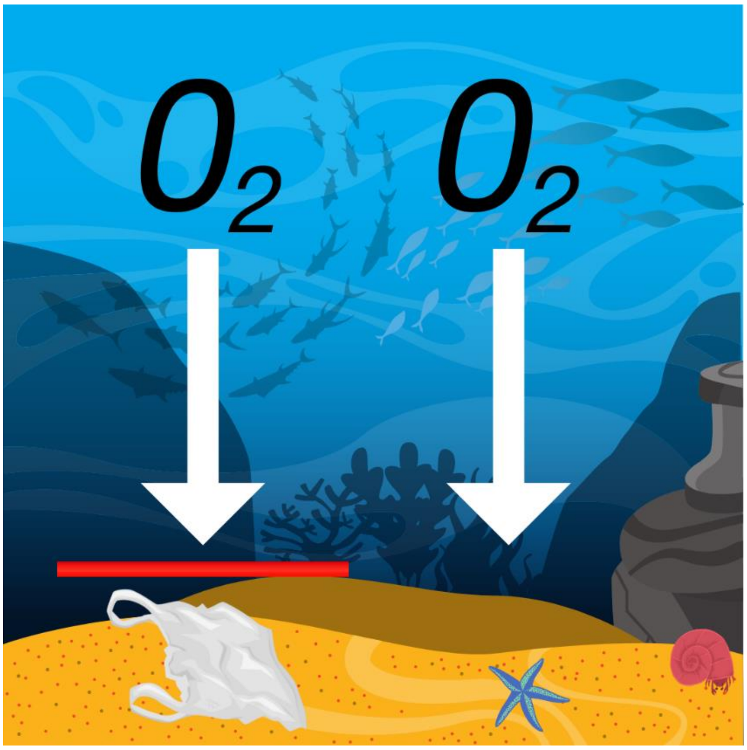

Figure 10: Coverage of seafloor sediment (left) leading to hypoxic and/or anoxic conditions. Source: own figure.

According to Gall & Thompson (2015), 700 marine species have been found to interact with marine litter around the world, of which 17% are listed on the IUCN Red List. While some of these interactions are beneficial for marine organisms by providing them shelter, the majority imposes harmful effects on them (de Carvalho-Souza et al., 2018). A summary of these interactions is visualised in Figure 11, showcasing pictures taken by de Carvalho-Souza et al. (2018).

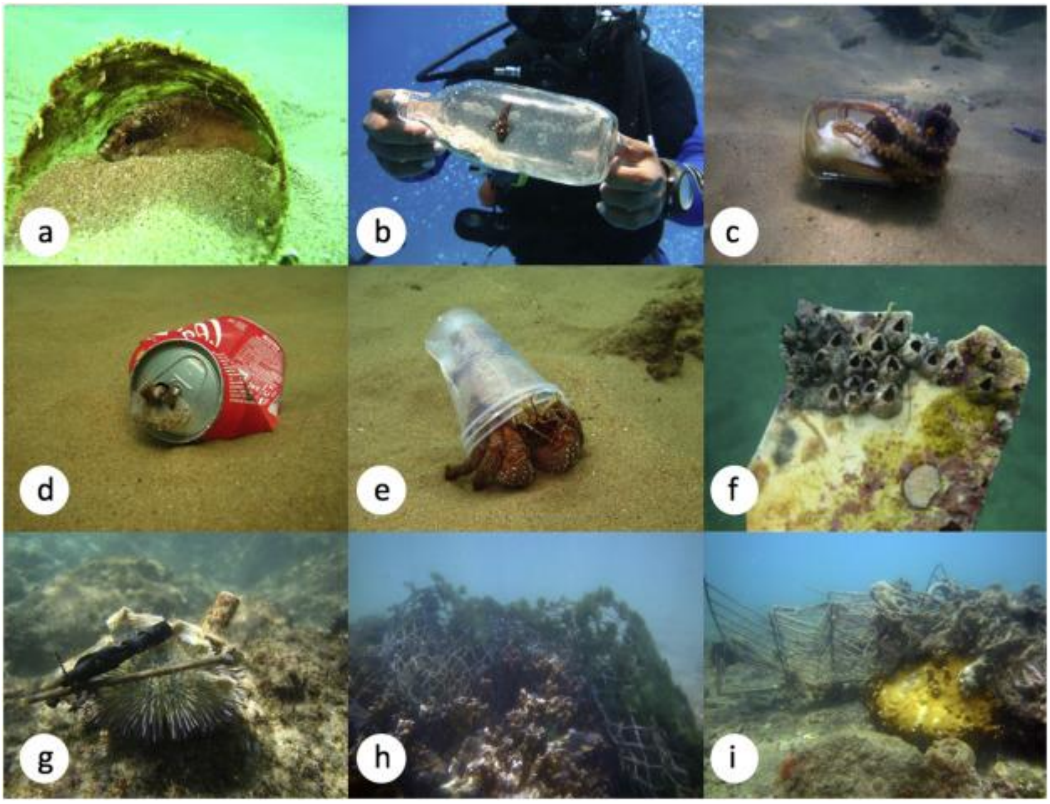

Figure 11: Interactions between marine life and marine litter. (a+b): reef fish using marine litter as shelter, (c+d) octopus using marine litter as shelter, (e) a hermit crab using plastic cups as its shell, (f) barnacles overgrowing a plastic item, (g) sea urchin using plastic litter to cover itself, (h) fishing nets entangling and covering coral colonies. Source: (de Carvalho-Souza et al., 2018)

2.1.3.2 Invasive alien species (IAS)

The introduction and transport of marine invasive species to new habitats poses a significant threat to biodiversity and ecosystem services and can have economic impacts (Rech et al., 2016). There are several pathways and mechanisms by which alien species are transported and dispersed in the marine environment, including shipping, waterways, and aquaculture (Mghili et al., 2023). Within waterways, the presence of floating litter in the ocean can offer a dispersal substrate for marine organisms and increase the potential for alien species transport (Mghili et al., 2023). According Mghili et al. (2023), the most common groups of non-native animals found on marine litter are arthropods (29%), mollusks (23%), bryozoans (19%), annelids (7%), and cnidarians (5%). The increasing amount of floating marine litter creates a large number of substrates for colonisation by various organisms, and many studies have documented this transport (Battaglia et al., 2019; J. Carlton & Fowler, 2018; J. T. Carlton et al., 2017; Lacerda et al., 2022; Mghili et al., 2023). Marine litter is dispersed by ocean currents and winds over short and long distances in the ocean, facilitating the spread of invasive species (Battaglia et al., 2019; J. T. Carlton et al., 2017; Katsanevakis & Crocetta, 2014; Kiessling et al., 2015; Mghili et al., 2023; Shabani et al., 2019). It can double or even triple the distribution of marine species, especially if the litter has large free surfaces (Barnes, 2002; Kiessling et al., 2015). Plastic appears to be the most efficient in spreading invasive species due to its buoyancy and persistence in all marine environments (Barnes, 2002; Kiessling et al., 2015).

In addition, the COVID-19 pandemic has led to a dramatic increase in the use of plastic-based personal protective equipment (PPE) worldwide, which has introduced large amounts of this litter into the marine environment and aquatic ecosystems (Gunasekaran et al., 2022; Mghili et al., 2023). This PPE litter provide additional substrates for marine organisms and could also act as vectors for non-native species, increasing the introduction of invasive organisms (De-la-Torre & Aragaw, 2021). For instance, a study by Zhou et al. (2022) showed that facemasks support and enhance microbial communities.

Invasive species can have serious impacts on marine ecosystems by affecting and altering ecosystem structure and function through competition with native species (Gallardo et al., 2019). This process can also lead to the introduction of new pathogens (Gallardo et al., 2019). In the Mediterranean, the following invasive species have been associated with marine litter: *Balanus trigonus* (Triangle barnacle), *Perforatus perforates* (Perforated barnacle), *Amphibalanus reticulatus* (Reticulated barnacle), *Cellana rota* (Rayed limpet), *Eriphia verrucosa* (Yellow crab), *Sphaerozius nitidus* (Luster round crab) (Mghili et al., 2023).

The buoy as a vector species mentioned in Section 2.1.1.2.2 originates from aquaculture and, together with ropes, is one of the primary dispersal vectors of marine invasive species (Mghili et al., 2023). The materials can become detached from aquaculture facilities, providing good rafting conditions for the species (Astudillo et al., 2009; Rech et al., 2016). Litter can also act as an excellent refuse for nekton too, as show in Figure 12, illustrating a *Stephanolepis diaspros* (Reticulated leatherjack) juvenile individual sheltering in a fragment of floating plastic at an offshore location off the southern coast of Malta.

Figure 12: A Reticulated Leatherjack juvenile taking shelter in a plastic fragment off the coast of Malta. Source: Environment & Resource Authority Malta provided by Prof. Alan Deidun.

2.1.3.3 Human health

Humans ingest between 39,000 and 52,000 pieces of plastic each year, and some of these fragments enter our food chain through the marine environment (Cox et al., 2019; Woods et al., 2021). This is because marine animals can ingest plastic, either directly from seawater or through the consumption of organisms that have already ingested plastic (Woods et al., 2021). Human exposure to plastic can then occur through the consumption of plastic-contaminated seafood (Woods et al., 2021).

In terms of human health effects, research indicates that even mere exposure to the persistent organic pollutants introduced above can pose a health risk to humans, regardless of ingestion, as has been shown in animals (Conlon, 2022). Studies of POP exposure report an association between occupational exposure, which may be comparable to that experienced by a person who regularly picks up marine litter as part of their research or as a local environmental activist, and health problems related to cardiovascular and endocrine disorders (Lind & Lind, 2012). Another report linked

POPs to diseases including cancer, impaired neurobehavioural and immune function, as well as diabetes (Damstra et al., 2002).

2.1.3.4 Socio-economic impact

In recent years, the focus has been on quantifying the ecological impact of marine litter in our oceans. Less attention has been paid to the potential economic and socio-economic impacts, although there is ample evidence that a large number of economic sectors are suffering as a result of marine litter. Examples of such sectors include tourism, shipping, and fisheries.

2.1.3.4.1 Tourism

The cleanliness of holiday beaches is a factor that tourists consider when choosing a holiday destination (Williams, 2009). Marine litter can therefore represent a financial loss to local economies, in addition to its negative impact on the environment (Grelaud & Ziveri, 2020; UN Environment, 2017). Particularly for countries in the Mediterranean region, the likelihood of visitors returning to a beach is highly dependent on marine litter (Zielinski et al., 2019). To ensure that beaches are kept clean, beach clean-ups are organised by coastal communities (Bergmann et al., 2015). However, there are direct costs associated with these cleanups (Bergmann et al., 2015). These costs include collection, transportation, disposal, and administrative costs (Bergmann et al., 2015). A 1998 cross-country study found that coastal cleanups in the EU resulted in direct costs of $2.9 million per year (Hall, 2000). In view of the fact that there has been an increase in both tourism and marine litter pollution only in recent years, an estimate can be made of how high these costs are today.

2.1.3.4.2 Shipping industry

The shipping and yachting industries are also affected by the economic impact of marine litter pollution (Mouat et al., 2010). As a result, ports incur significant costs to remove marine litter from their facilities (Mouat et al., 2010). This is necessary to maintain safety and attractiveness to users (Mouat et al., 2010). In addition, ships unfortunately suffer from damage to their propellers, anchors, rudders, and clogged intake pipes and valves due to marine litter (Mouat et al., 2010). In some cases, these obstructions even pose a navigational hazard to vessels, requiring rescue services to be called in, resulting in significant cost increases (Bergmann et al., 2015). The 2010 study by Mouat et al. (2010). estimated that marine litter removal in UK ports costs an average of €2.4 million per year. These costs naturally vary with the size and activity of the port (Mouat et al., 2010).

2.1.3.4.3 Fisheries

The fishing industry faces its own economic challenges with marine litter, although it is more commonly viewed as a source of it (Bergmann et al., 2015). Direct economic impacts result from the need to repair or replace equipment damaged or lost due to marine litter (Bergmann et al., 2015). This includes repairing vessels whose propellers, anchors, rudders, or intake pipes have been damaged by plastic litter (Mouat et al., 2010). In addition, the time spent removing marine litter from fishing nets results in loss of income, as this time is deducted from actual fishing activities (Newman et al., 2015). Mouat et al. (2010) estimated that marine litter costs Scottish fishing vessels an average of €17,000-19,000 per year for the latter reason.

Furthermore, DFGs can continue to catch marine organisms after they are lost (Newman et al., 2015). This process is known as ghost fishing (Newman et al., 2015). The use of durable materials in fishing gear means that it can continue to act as marine litter long after it is lost, posing unique challenges for litter management (Newman et al., 2015). A study in Puget Sound, Washington, estimated that over 175,000 Pacific blue crabs were killed each year by derelict pots, representing 4.5% of the average annual harvest (Antonelis et al., 2011).

Fisheries are thereby faced with costs to replace lost fishing gear and costs as a consequence of a reduction in harvestable and sustainable catches (Arthur et al., 2014; Bilkovic et al., 2014; Butler et al., 2013). These significant costs strain an industry already under pressure from climate change, human population growth, and increased demand for seafood (Newman et al., 2015).

2.1.4 Response

Measures have been taken to address and solve marine pollution problems, including initiatives, financial support, international cooperation, and education and training programs. In the Mediterranean, guidelines have been in place for many years to address the issue of marine pollution.

2.1.4.1 The G7 Ocean Plastics Charter

The G7 Oceans Plastics Charter was signed in 2018 by leading economies including Germany, Italy and France, and is a central part of global efforts to curb marine pollution (Plastic Action Centre, 2023). The Charter sets out concrete actions to tackle plastic pollution and was developed in response to the urgent need to address the challenges associated with marine pollution (Plastic Action Centre, 2023). The key commitments of the Charter are as follows

(1) ´Sustainable design, production and after-use markets;
(2) Collection, management and other systems and infrastructure;
(3) Sustainable lifestyle and education;
(4) Research, innovation and new technologies, and;
(5) Coastal and shoreline action.` (Plastic Action Centre, 2023, p. 2-4)

By consistently implementing the G7 Oceans Plastics Charter, Member States and the European Union can make a significant contribution to raising awareness of the challenges associated with marine pollution, promoting innovative solutions and making a collective effort to achieve the targets of SDG 14. The far-reaching commitments of the Charter provide a structured framework for the development and implementation of effective measures to reduce plastic pollution on a global scale (Plastic Action Centre, 2023).

2.1.4.2 Sustainable Development Goal (SDG) 14

The G7 Ocean Plastics Charter aligns with SDG 14 Life Below Water. SDG target 14.1 relates to marine pollution and aims to ´by 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution` (The Global Goals, n.d., p. 1).

2.1.4.3 MED POL and Barcelona Convention

The ´Program for the Assessment and Control of Marine Pollution in the Mediterranean` (MED POL) was established to assist Mediterranean countries in implementing the three main protocols of the Barcelona Convention (UNEP/MAP, 2023b). These Protocols are the ´Protocol for the Protection of the Mediterranean Sea against Pollution from Land-based Sources`, the ´Protocol for the Prevention of

Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft` and the ´Protocol of Pollution of the Mediterranean Sea by Transboundary Movements of Hazardous Wastes and their Disposal` (UNEP/MAP, 2023b).

2.1.4.3.1 Dumping Protocol

In particular, the ´Protocol for the Prevention of Pollution in the Mediterranean Sea by Dumping from Ships and Aircrafts - the Dumping Protocol` aims to ensure that the Parties take all necessary measures to prevent pollution of the Mediterranean Sea by litter and other substances (UNEP/MAP, 2023a).

2.1.4.3.2 LBS Protocol

Similarly, the ´Protocol for the Protection of the Mediterranean Sea against Pollution from Land-based Sources - LBS Protocol` aims to reduce or ideally eliminate land-based sources and activities of marine pollution in order to prevent toxic substances from entering the sea (UNEP/MAP, 2023a).

2.1.4.4 Marine Strategy Framework Directive (MSFD)

The Marine Strategy Framework Directive (MSFD) was introduced to achieve Good Environmental Status (GES) in EU seas (Danovaro et al., 2020). It defines indicators and criteria to assess whether good environmental status is being achieved (Environment & Resources Authority, n.d.a). Descriptor 10 of the MSFD addresses the issue of marine litter and examines trends in the composition of litter and the amount ingested by marine animals (Environment & Resources Authority, n.d.a), as its aim is that ´Properties and quantities of marine litter do not cause harm to the coastal and marine environment` (Galgani, Hanke, Werner, & De Vrees, 2013, p. 1056). The MSFDs objectives and associated indicators for descriptor 10 are defined as follows

(1) 10.1 - Characteristics of litter in the marine and coastal environment: This objective requires accurate monitoring of the quantity, composition and spatial distribution of litter in coastal areas, both in the water column and on the seabed (10.1.1, 10.1.2) (European Union, 2015). The indicators also call for a detailed study of microplastics to gain a full understanding of the presence and impact of these microparticles (10.1.3) (European Union, 2015).

(2) 10.2 - Impacts of litter on marine life: The indicator for this target focuses on the study of marine litter found in the stomachs of marine animals (10.2.1) (European Union, 2015).

The precise definition of these targets and indicators illustrates the MSFD's ambition to carry out a differentiated and comprehensive assessment of marine litter. Particular attention is paid to the quantity, composition, and ecological impact of litter in the coastal and marine environment to ensure a comprehensive understanding of this complex issue (Galgani, Hanke, Werner, & De Vrees, 2013).

2.1.4.5 Ecological Objectives (Eos)

At the regional level, particularly in the Mediterranean region, the SPA Regional Activity Center (SPA RAC) is responsible for implementing the Ecosystem Approach (EcAp) (SPA/RAC, n.d.). As part of this approach, an objective is formulated that is represented by one of the Ecological Objectives (EOs) (SPA/RAC, n.d.) contained therein. This EO substantiates the claim that ´marine and coastal litter does not adversely affect the coastal and marine environment` (SPA/RAC, n.d., ´EO10: Marine Litter`). The definition of these Ecological Objectives was the result of an intensive consultation process led by the UNEP/MAP Secretariat, with the full participation of the Parties and the involvement of the members and technical experts of the Mediterranean Action Plan (SPA/RAC, n.d.).

2.1.4.6 Local scope: Malta

At the national level, particularly in Malta, several pieces of legislation have been implemented, including MAR POL, the London Convention, the Barcelona Convention and its Protocols, as well as EU Directives such as ´Directive 2000/59/EC on port reception facilities for ship-generated litter and cargo residues` and ´Directive on packaging and packaging waste (Directive 2004/12/EC)` (Environment & Resources Authority, n.d.b). Malta is also committed to reducing the consumption of single-use plastics and promoting the sustainable management of plastic litter (Environment & Resources Authority, 2021). As part of this effort, several initiatives are being pursued:

(1) Single-Use Plastic Strategy for Malta 2021-2030 - Rethink Plastic:

This strategy aims to reduce the consumption of certain single-use plastic products, including items such as straws and stirrers (Environment & Resources Authority, 2021). It is important to emphasise the dynamic nature of this strategy as a ´living document` that will be continuously updated (Environment & Resources Authority, 2021). This adaptability allows for a timely response to innovative technologies and societal attitudes to ensure that the strategy remains relevant and effective (Environment & Resources Authority, 2021).

(2) Public awareness campaigns:

The Maltese government emphasises public awareness initiatives (Environment & Resources Authority, 2021). These include the ´Dont Waste Waste` campaign, which has been running since April 2016 and highlights the importance of proper waste management (Environment & Resources Authority, 2021). Another key initiative is ´Saving our Blue`, a campaign that has been running since June 2019 in collaboration with NGOs and private sector to raise awareness about marine pollution (Environment & Resources Authority, 2021).

(3) Beverage Container Refund System:

A national beverage container refund system was implemented by the Maltese government in 2021 (Environment & Resources Authority, 2021). This system enables consumers and producers to take greater responsibility in dealing with packaging waste, while increasing the collection rate of empty beverage containers (Environment & Resources Authority, 2021).

(4) Legislative Measures - Legizlazzjoni Malta:

In an ongoing effort, legislation is being enacted that specifically addresses marine pollution (Leġiżlazzjoni Malta, 2020). An example of this is the Legizlazzjoni Malta of December 30, 2020, which prohibits the placing on the market of certain single-use plastic products as of July 3, 2024, as detailed in Part C of the Annex (Leġiżlazzjoni Malta, 2020). Part C refers to, among others, waste groups such as glass or metal beverage containers with plastic caps and lids (Leġiżlazzjoni Malta, 2020).

(5) The Blue Flag Program:

This program sets high standards for local authorities and beach operators in the categories of safety, environmental education, water quality and environmental management (Environment & Resources Authority, n.d.b).

(6) The plastic bag tax:

This tax was introduced in 2009 to discourage citizens and tourists from using plastic bags (Environment & Resources Authority, n.d.b).

These comprehensive measures and international frameworks help to address the challenges of marine pollution in the Mediterranean and promote environmental protection.

2.2 Research gaps and opportunities

For Malta, there is no comprehensive analysis of the litter data collected during the MEDITS survey, which was, amongst other aspects, designed to investigate the seabed in relation to litter. Existing research on this topic is limited to one well-known study by Consoli et al. (2020) that analysed the seafloor around Malta for litter. However, there is a lack of detailed research on the spatial, temporal and depth patterns of marine litter around Malta, despite the fact that the Mediterranean, including Malta, faces significant marine pollution problems. The annual MEDITS survey usually provides basic information on benthic and demersal species that are important to fisheries (Relini et al., 2008; Terribile et al., 2016). However, marine litter is collected in abundance during these surveys and the opportunity was taken to collect, identify and quantify the litter (Mifsud et al., 2013).

A promising opportunity of this study lies in the implementation of a standardised research methodology that can be successfully applied not only in Malta but also in other countries. Given the urgency of the pollution problem, as evidenced by this literature review, it is crucial to analyse what is happening on the seafloor and to visualise the amount of litter found. The unseen nature of marine litter on the seafloor compared to its visible presence on beaches underscores the need for this analysis, as belief and awareness are often influenced by visibility.

3 Methodology

3.1 Study area

This study was carried out in geographical subregion (GSA) 15 of the FAO's General Fisheries Commission for the Mediterranean (GFCM) and covered the seabed around the Maltese Islands. The specific locations of the hauls collected over a two-year period as part of the MEDITS survey are shown in Figure 13 and Figure 14. The dots represent the start and end coordinates of the individual hauls, while the connecting lines indicate the distance covered. The MEDITS survey, providing results for this study, was conducted in September 2020 and in August and September 2021, with a significant difference in the number of samples collected between the two years. In 2020, 18 hauls were conducted, while in 2021 this number increased to 35. The map illustrates the significant differences in the depths at which the hauls were conducted over the 2 years. The maximum depth in 2020 and 2021 were 702.2m and 678.4m, respectively. The shallowest depth was 76.2m in 2020 and 82.8m in 2021.

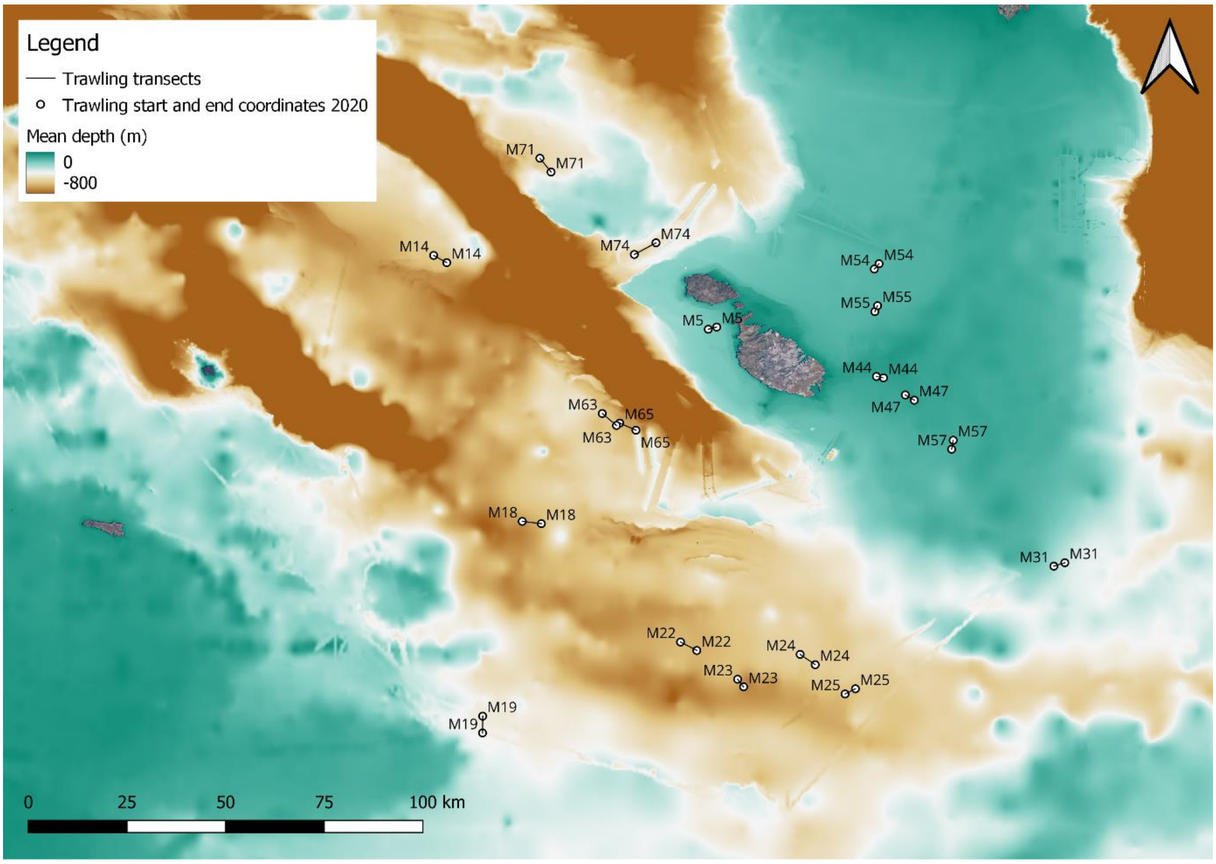

Figure 13: Trawling transects in 2020. The dots visualise the start and end coordinates. The connecting lines indicate the distance covered.

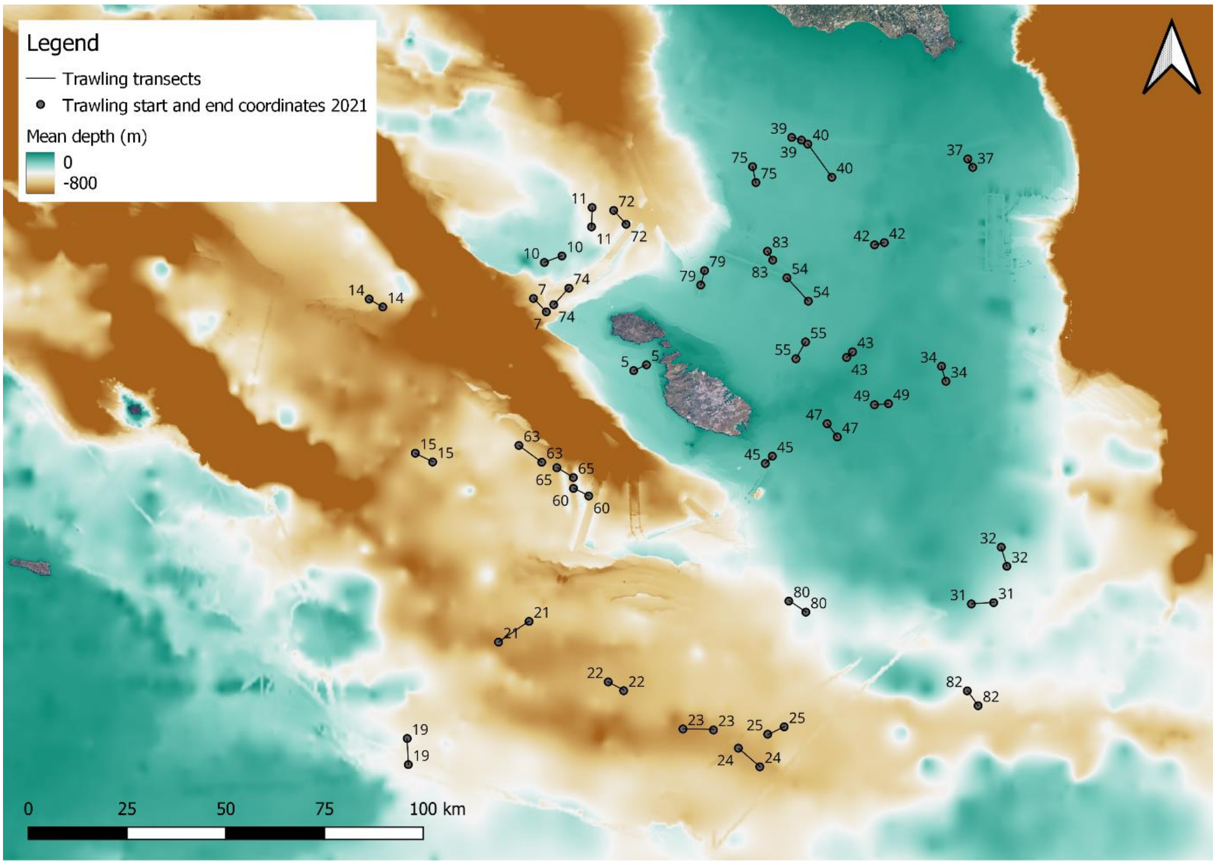

Figure 14: Trawling transects in 2021. The dots visualise the start and end coordinates. The connecting lines indicate the distance covered.

3.2 Data pre-processing

Data pre-processing began with a thorough review of the 2020 and 2021 data sets to identify future potential statistical analyses and suitable data visualisations. For example, to improve comparability with existing literature, the weight of detected litter was converted from grams to kilograms. In addition, unavailable (N/A) values were removed from the dataset. The associated geographic coordinates of the haul locations were converted from the degrees and minutes coordinate format to the decimal degrees format using an online coordinate conversion tool (https://coordinatesconverter.com/en/decimal/51.000000,10.000000?karte=OpenStreetMap&zoom=8). This step made the data compatible with geographic information systems (GIS) such as QGIS.

These pre-processing steps were taken to ensure data integrity and to prepare the data for subsequent statistical analysis and visualisation.

3.3 Qualitative analysis

For the qualitative analysis, the litter categories and their respective items were examined in detail. The objects identified in each category were systematically recorded in a table to ensure a comprehensive overview. Subsequently, these objects were classified into three anthropogenic activity groups which are (1) fishing-related, (2) tourism and household-related and (3) shipping-related. Finally, descriptive statistics were used to determine the frequency of each category of litter, which are depicted in Table 1. The table also shows a comprehensive list of all identified items found, each with its associated litter category.

Table 1: Litter categories as appointed by the MEDITS survey as well as a detailed description of the litter items found within the respective category.

Litter code	Litter type	Detailed description of litter found within category
L1	Plastic litter	Plastic bottles (white, green, transparent, yellow), orange nylon line/ mainline (FAD), pasta plastic wrapper, white plastic float, plastic bags (transparent, white, black, yellow, blue, brown, yellow), white plastic container (Vasketta-2k, cooking oil), disposable white plastic cup, piece of net, nylon fishing line (longline), orange squid lure (longline), small piece of net (codend), plastic sheet (white,

		black, transparent, grey, blue), blue plastic packaging (Kristal Water 2L), green wine bottle crate (empty), plastic light cover, piece of blue plastic (nylon trawling net), food wrappers, rope (Calament tal-fangu), small pieces of transparent plastic, orange plastic disposable razor blade, light blue 20L bucket (empty) with metal handle, yellow sunblock bottle (empty), disposable white plastic plates, orange fuel funnel, transparent egg cartons, large mesh netting (piece/trawling), packets of sweets (wrapper), disposable latex glove (violet), blue bucket
L2	Rubber litter	
L3	Metal litter	Aluminium can, empty paint can, paint can filled with cement, large unidentified metal object, unidentified metal object, large

		brass pipe (Katusa), metal drain pipe, bottom of large tin (1kg)
L4	Glass and ceramics litter	Beer bottle (brown, green), wine bottle (green, transparent, brown), transparent glass bottle (with and without lid), transparent glass jar, white coke bottle, terracotta brick, white whiskey bottle
L5	Cloth and neutral fibres litter	Baseball cap (blue/white), piece of cloth (cotton, wool, unknown material), brown tshirt, yellow cotton cloth, safety shoe
L6	Processed wood litter	Fruit crate (apples)
L7	Paper and cardboard litter	Piece of cardboard
L8	Other litter	Capaciter, sponge, stone slab (limestone, not from FADs), plastic jumbo bag with capacity of ~ 2T
L9	Unspecified litter	-

This qualitative analysis promises to provide a deeper insight into the composition of the marine litter found, which in turn will allow a more precise estimation of the origin of the litter.

3.4 Statistical analysis

To analyse the spatial, temporal, and depth-related distribution of marine litter collected during the MEDITS survey in 2020 and 2021, the two-sided independent samples *t*-test was applied using SPSS software. The two-sided independent samples *t*-test was applied as it is well suited for comparing means in the context of continuous variables, assuming normal distribution and independence of observations.

The two-sided independent samples *t*-test was used to compare the average amount of marine litter between each of two independent scenarios (1) East vs. West (2) Deep vs. Shallow (3) 2020 vs. 2021). The null hypothesis (H0) states that the average amount of marine litter will vary marginally between the above scenarios and is accepted if the *p*-value exceeds the 0.05 significance level. The alternative hypothesis (H1) states that the average amount of marine litter varies significantly between the above scenarios and is accepted if the *p*-value is less than the 0.05 criterion.

Before applying the two-sided independent *t*-test, Levene's test was used to determine the equality of the standard deviations of the two groups. The null hypothesis states that the standard deviations of the two groups are comparable and is accepted if the *p*-value exceeds the 0.05 significance level (*p*-value for equal variances assumed was chosen). The alternative hypothesis states that the standard deviations of the two groups are significantly different and is accepted if the *p*-value is less than the 0.05 criterion (*p*-value for equal variances not assumed was chosen).

The analysis was conducted for the total amount of marine litter as well as for the respective litter categories ´L1, L3, L4, L5, L6, L7` and ´L8`. In this study, the term ´total litter` is utilised interchangeably with ´all litter` to denote the comprehensive classification of marine litter considered in the context of this thesis. Detailed information on data organisation and analysis is provided below:

(1) Spatial distribution:

For the spatial distribution analysis, the hauls around the Maltese Islands were divided arbitrarily into East and West ones. This classification was determined independently and is shown in Figure 15 for the years 2020 and 2021. In the analysis, the value ´1` was used for the East and ´2` for the West. A corresponding column with these classifications and the associated amount of marine litter per haul was prepared for analysis in SPSS.

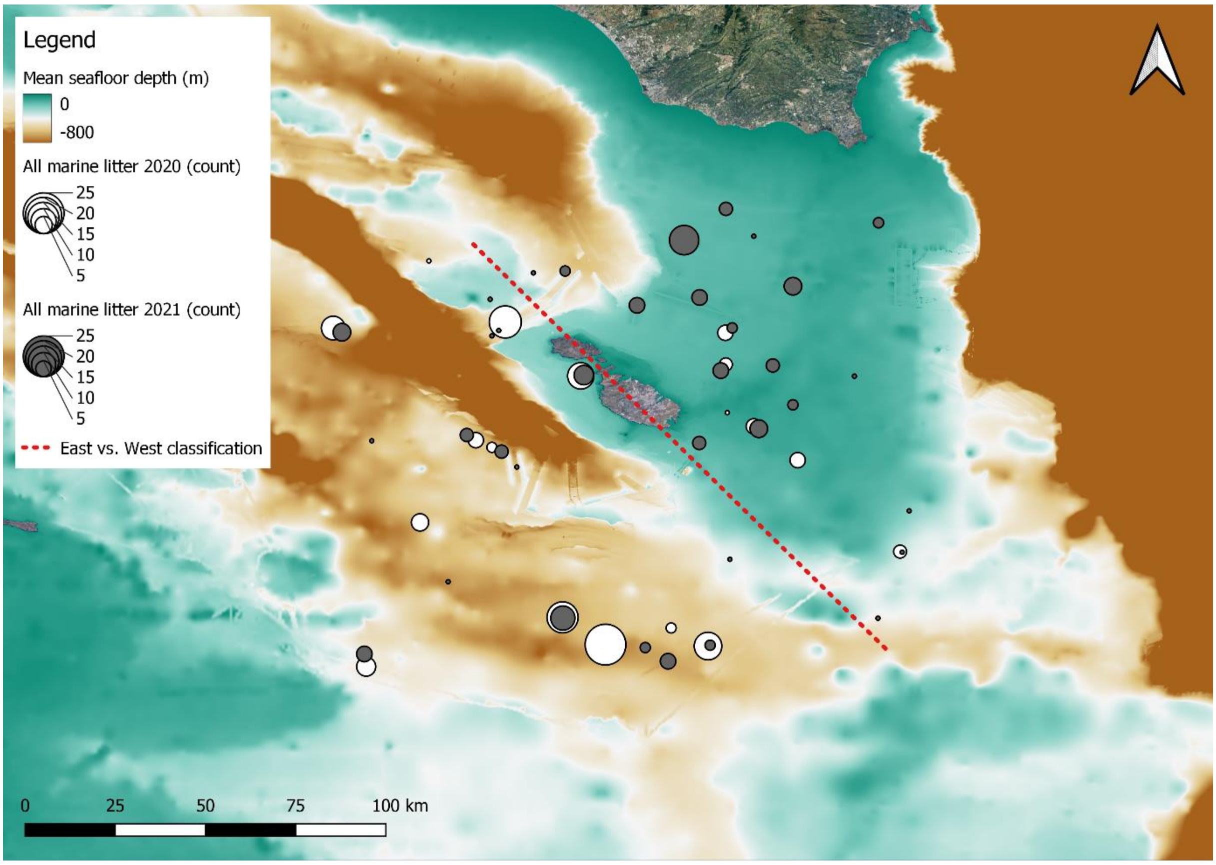

Figure 15: East vs. West classification for all hauls of 2020 and 2021 determined independently.

(2) Temporal distribution:

To analyse the temporal distribution of marine litter, the amounts of marine litter found were assigned to the years in which they were found. This information was recorded in two columns and was prepared for analysis using the two-sided independent samples *t*-test in SPSS.

(3) Depth-based distribution:

Similar to the spatial distribution, depth measurements were divided into two categories: ´shallow` (0-399 m) and ´deep` (400-800 m). The ´shallow` category was assigned a value of ´1` and the ´deep` category was assigned a value of ´2`. Again, this classification was determined independently and was not based on any particular study or empirical data. The data were prepared for analysis in SPSS according to this classification.

3.4.1 Visualisation of statistical results

The results of the independent samples *t*-test applied above were visualised for the analysis of the spatial, temporal and depth distribution of marine litter using MATLAB software. The following code was used in the editor:

```
means = [0.795800000000000, 0.850892857142857]; % Assigns a vector of mean values
stds = [1.159083402233564, 1.382725471247268]; % Assigns a vector of standard
deviations
p = 0.875305614150226; % Assigns a p-value

figure; % Opens a new figure window
b = bar(means); % Creates a bar chart with the mean values
b.FaceColor = 'flat'; % Allows individual coloring of the bars
b.CData(1,:) = [0.3 0.3 0.3]; % Sets color for the first bar to dark grey
b.CData(2,:) = [1 1 1]; % Sets color for the second bar to white
hold on; % Holds the current plot for further additions

% Adds error bars to the bar chart
x = 1:length(means); % Generates x-coordinates for the error bars
errorbar(x, means, stds, 'k.', 'LineWidth', 1.5); % Adds error bars with specified
color and line width

xticks(x); % Sets x-axis tick positions
xticklabels({'East', 'West'}); % Lavels x-axis ticks with corresponding categories
title('Mean marine plastic litter by location 2020/2021'); % Adds a title to the
plot
ylabel('Mean weight of marine plastic litter (kg)'); % Labels the y-axis

% Adds significance indicator for both bars
for i = 1:length(means) % Iterates through each bar
    if p < 0.05 % Checks if p-value is less than 0.05
        text(i, means(i) + stds(i) + 0.2, '*', 'HorizontalAlignment', 'center',
'FontSize', 12); % Adds '*' for significance
    else
        text(i, means(i) + stds(i) + 0.2, 'ns', 'HorizontalAlignment', 'center',
'FontSize', 12); % Adds 'ns' for non-significance
    end
end
```

3.5 Data processing and analysis of sub-surface currents

The data set used was obtained from the Copernicus Marine Service database and is referred to as the ´Mediterranean Sea Physics Reanalysis`. In the context of this study, ´reanalysis` means that the data have been further refined by additional measurements. The time period of the data extends from 01/06/2020 to 30/09/2021 and thus includes a total of 13 time stamps, one for each month.

Eight different depth levels were selected for the 13 months to study the subsurface currents. These are listed in Table 2. The area of interest in question from which the data were extracted had the following coordinates: (N) 37°, (S) 34.841°, (W) 12.306°, and (E) 15.505° (Figure 16). The broad scope of the designated area of interest in Figure 16 is based on the recognition that subsurface currents, even at greater distances from Malta, can have consequential effects on the accumulation of marine litter found on the seafloor adjacent to Malta and should therefore be included in the analysis.

Table 2: Depth levels of sub-surface currents data, extracted from Copernicus Marine Service. The left column showcases the desired depth level while the right column displays the elevation that was obtained from the dataset available.

Desired depth level (m)	Elevation (m) obtained from Copernicus
1	1.02
10	10.54
20	19.4
50	51.38
100	97.93
200	203.17
500	492.67
1000	1005.14

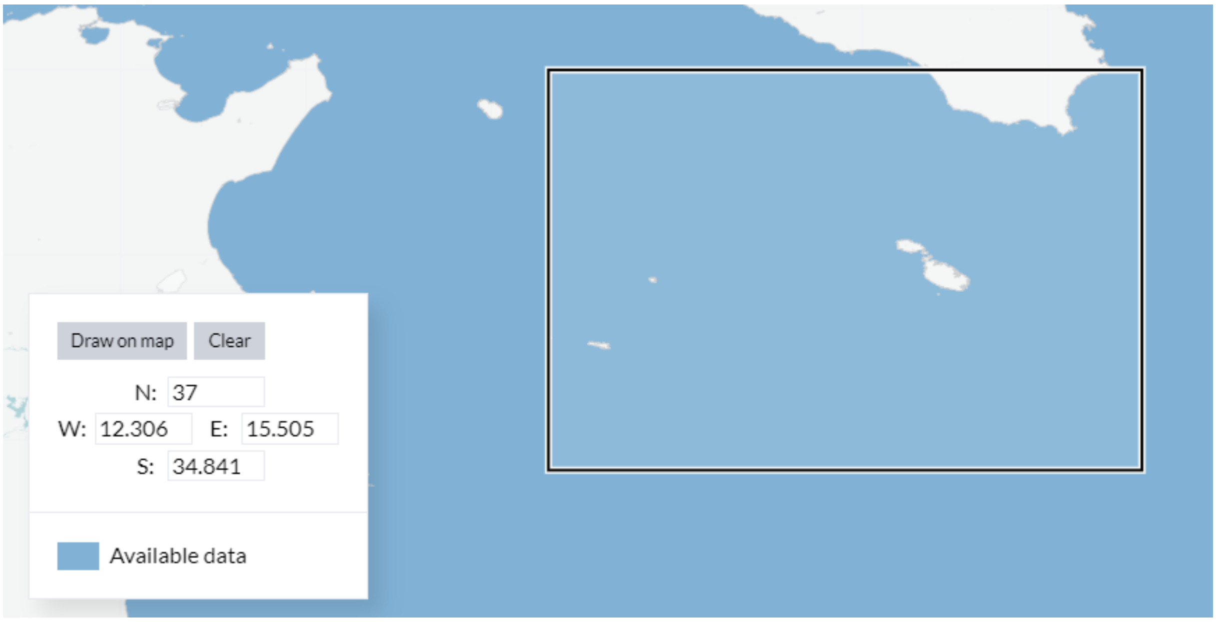

Figure 16: The area of interest out of which the sub-surface currents data was extracted from.

After downloading the data, it was processed using CDO (Climate Data Operators) software. The 13 time stamps were converted into time-averaged NetCDF files. This process was performed using the following code: `cdo timavg 1000.nc 1000_avg.nc`. The result was a raster layer that could be loaded into QGIS.

In QGIS, the *uo* and *vo* components of the raster layer were modified using the Warp (Reproject) tool. In this process, *uo* and *vo* were used as input data and the source and target coordinate reference systems (CRS) were set to the project's CRS, which is EPSG:4326-WGS84 (Figure 17). The Warp (Reproject) tool in QGIS is used to change the coordinate reference system of a dataset. This ensures that all layers in a project are properly aligned.

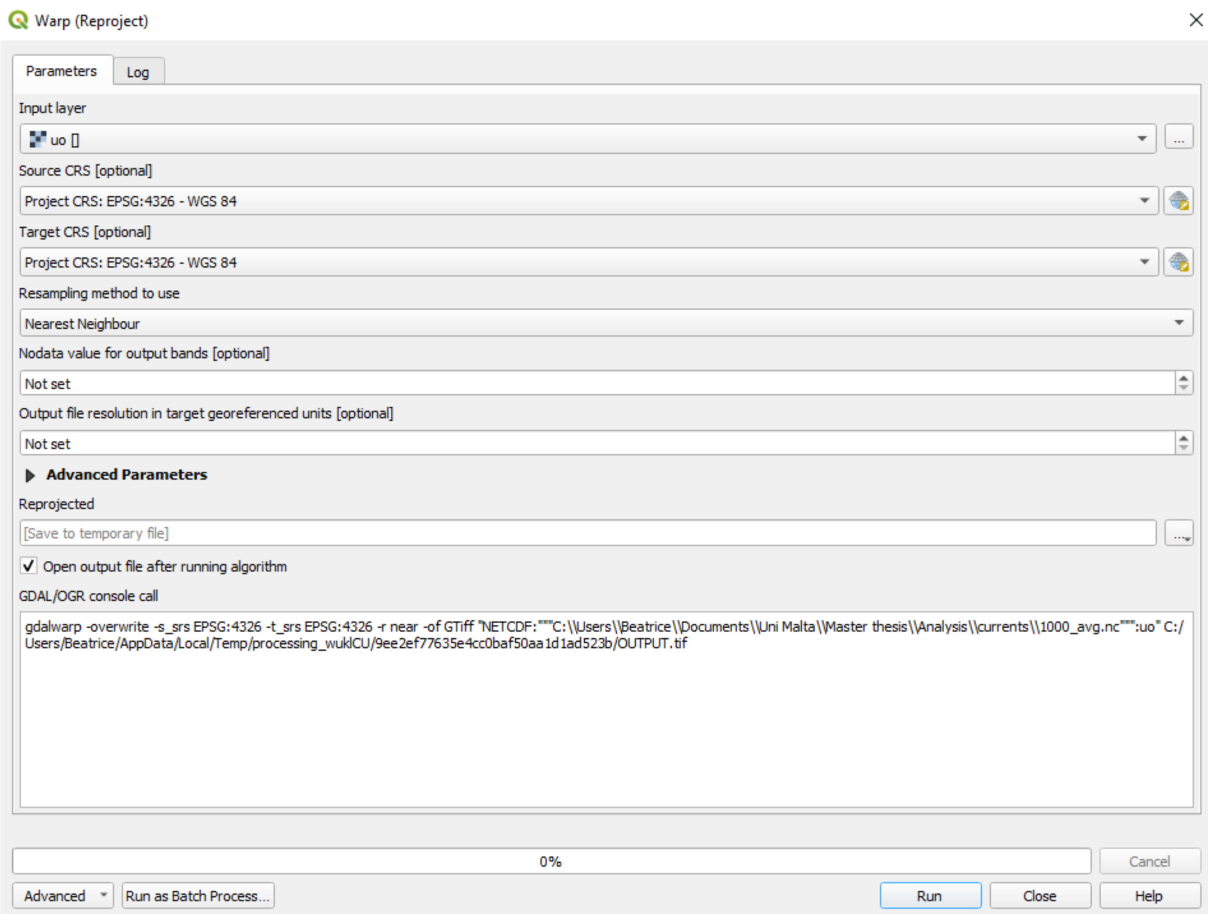

Figure 17: Warp (reproject) tool in QGIS applied to the uo component of the imported raster layer.

Once this step was completed, the SAGA Gradient Vectors from Directional Components tool was used to analyse the spatial distribution and direction of underwater currents. It takes into account the directional components of the currents (e.g., north-south and east-west flow velocity and direction) and calculates the gradient vectors to provide information about the rate and direction of change of the currents in the specified area. Longer arrows indicate higher flow velocities (i.e. stronger currents), while shorter arrows indicate slower (i.e. weaker) currents. The direction of the arrow indicates the direction of flow. To use this tool, the ´reprojected *uo*` created by the ´Warp (Reproject)` tool is used for the X-component and the ´reprojected *vo*` is used for the Y-component (see Figure 18). The mean value was chosen as the Aggregation value and arrows were chosen as the style (see Figure 18). This process was repeated for all depth layers. All gradient vectors indicating the intensity and direction of the currents were then overlaid with the amount of marine litter found. This was done to see if there were any correlations or patterns, e.g. with convergence zones of the currents.

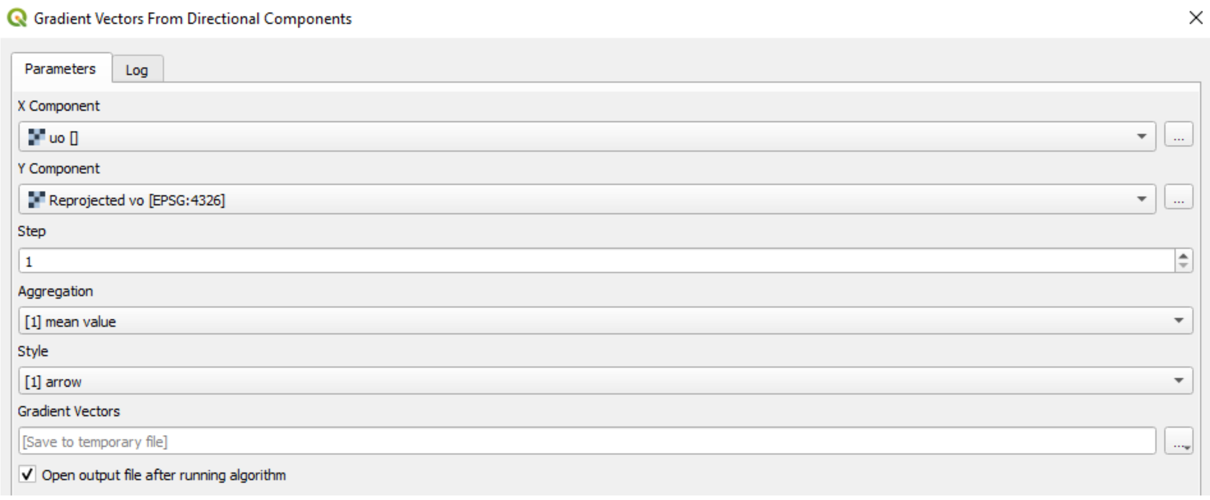

Figure 18: QGIS Gradient Vectors From Directional Components tool applied to provide information about the strength and direction of flow of the currents.

3.5.1 Overlay of marine litter amounts

Once the subsurface currents were successfully visualised using QGIS, the quantities of marine litter determined for the statistical analyses were overlaid. This approach was chosen to identify potential visual relationships or correlations between the subsurface currents and geographic locations and the quantities of marine litter collected during the 2020 and 2021 MEDITS surveys. The overlay process was applied to the total amount of marine litter and not additionally to the individual litter categories, as no specific interactions with the different litter categories were expected at this stage.

3.6 Plotting of anthropogenic activities

In order to investigate possible correlations between human activities around the Maltese Islands and the marine litter identified in the 2020/2021 MEDITS survey, the following human activities were selected. These include trawling, bunkering zones, Natura 2000 areas, swimming areas, fishing activities, vessel traffic (route density) and aquaculture farms. These anthropogenic activities have been selected on the basis of their negative impacts on the marine environment that have previously been scientifically confirmed. The aim is the investigation of their potential correlation with marine litter around the Maltese islands.

All these anthropogenic activities were added to the marine litter map using QGIS. They were visualised by adding them as vector layers and then overlaying them with the different litter category amounts. To document the origin of the data, the sources of the different anthropogenic activity datasets are listed in Table 3.

Table 3: Sources of the anthropogenic activity datasets that will be plotted in QGIS.

Anthropogenic activity	Source
Trawling	AMARE Project (University of Malta)
Bunkering zones	AMARE Project (University of Malta)
Natura 2000 sites	AMARE Project (University of Malta)
Swimming zones	AMARE Project (University of Malta)
Dive sites	https://maltadives.com/map
Fishing activity (route density)	EMODnet
Ship traffic (route density)	EMODnet
Aquaculture farms	AMARE Project (University of Malta)

For the anthropogenic activities (1) fishing activity and (2) ship traffic, the vessel route densities of the survey years 2020 and 2021 were added to QGIS as a raster layer, where they were subsequently averaged using the Raster Calculator (*(density_2020 + density_2021) / 2)*). On the generated maps, these two activities therefore display an average amount of the route density for (1) fishing vessels and (2) all vessels in routes per km^2 per year over the period of two years (2020 and 2021).

3.6.1 Overlay of marine litter amounts

After successfully visualising anthropogenic activities using QGIS, the quantities of marine litter, as determined for statistical analyses (Section 3.4), were superimposed. This was performed so as to look at potential visual associations or correlations between the anthropogenic activities and the quantities of marine litter collected during the 2020 and 2021 MEDITS surveys. The overlay process was specifically applied to the overall amount of marine litter as well as to the individual litter categories.

3.7 Generation of QGIS maps

3.7.1 Background map sources and processing

The background maps for the QGIS maps were provided as two different map types: (1) a geographic map of Malta and (2) a bathymetry map. The geographic map of Malta was generated in QGIS via the XYZ Tiles feature using the following link: *https://www.google.cn/maps/vt?lyrs=s@189&gl=cn&x={x}&y={y}&z={z}.* The data for the bathymetry map has been downloaded from EMODnet from the dataset ´Mean depth in multi colour (no land)`. This dataset is a multi-layer bathymetric product covering depths from 0 to about 800 meters in the case of Malta.

The use of these two maps thus provides the background for further geographic representations, as shown in Figure 19.

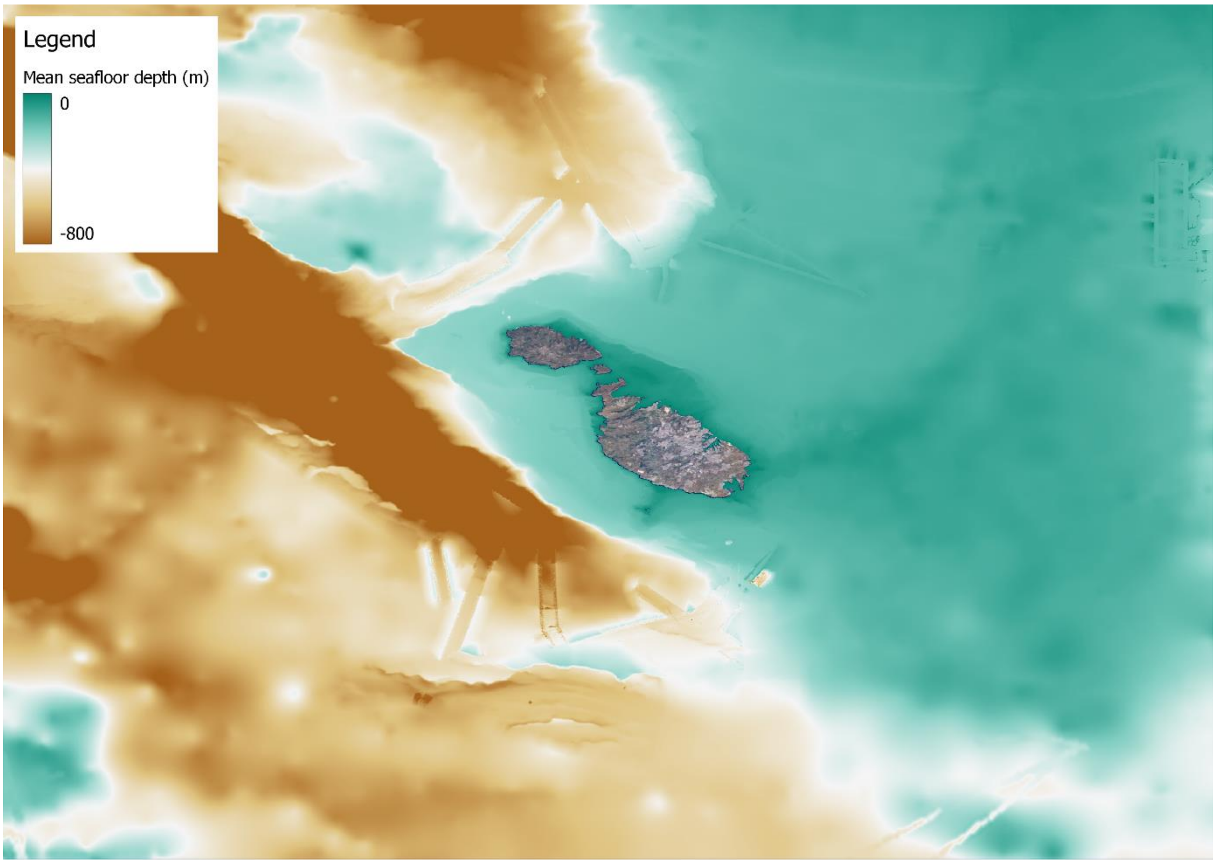

Figure 19: Bathymetry map showing the mean seafloor depth in m.

3.7.2 Addition of the litter quantities found

QGIS software was used to visualise the number of marine litter items found on the seafloor. The coordinate-based data was adjusted using an online tool according to the procedure described in Section 3.2. Four columns were then created in an Excel file containing (1) the start latitude (2) the start longitude (3) the haul number (4) the amount of marine litter found (count). This file was then converted from `.xlsx` to `.csv` for integration and further processing in QGIS.

In QGIS, the CSV file was added as a ´Delimited Text Layer`, which initially made only the coordinates visible on the map. Each type of marine litter was given a specific colour and a corresponding symbol, as shown in Table 4. The values for 2020 were displayed with a transparency of 100%, while those for 2021 were displayed with a transparency of 50% to distinguish between the years.

Table 4: Colours, symbols and scale chosen to visualise the amounts of different marine litter types found around the Maltese Islands.

Litter type	Assigned colour	Assigned symbol	Range (items found in count)
Total litter 2020	White	Circle (black frame)	0-25
Total litter 2021	Dark grey	Circle (black frame)	0-25
L1 2020	Yellow	Circle (black frame)	0-21
L1 2021	Yellow (50% opacity)	Circle (red frame)	0-21
L3 2020	Pink	Circle (black frame)	0-5
L3 2021	Pink (50% opacity)	Circle (red frame)	0-5
L4 2020	Light blue	Circle (black frame)	0-3
L4 2021	Light blue (50% opacity)	Circle (red frame)	0-3
L5 2020	Red	Circle (black frame)	0-3

L5 2021	Red (50% opacity)	Circle (red frame)	0-3
L8 2020	Dark blue	Circle (black frame)	0-5
L8 2021	Dark blue (50% opacity)	Circle (red frame)	0-5

To generate a proportional, realistic map, the Symbol Size Assistant was used, which considered values of numbers and from the Flannery Scale method. This ensured that the size of the symbols on the map depended on the number of items found. The scales used for this purpose were determined individually for each type of marine litter. For example, the values for litter type L1 (plastic) ranged from 0 to 21 plastic items found. An overview of all other scales can be found in Table 4.

A data-dependent size legend was then created, in this case as a collapsed legend. In the QGIS print layout, the previously-created legend, a north arrow, and a scale bar were added to the map.

The creation of these maps allowed for a better visual analysis of the spatial and depth distribution of the marine litter found, taking into account a variety of factors such as currents and anthropogenic activities.

4 Results

4.1 Qualitative analysis of litter composition

As explained in Section 1.3, the MEDITS survey includes nine different litter categories to which specific items are assigned. A comprehensive list of all identified items, each with its associated litter category, is presented in Table 1. To illustrate the nature and origin of the litter, the identified items, as categorized by the MEDITS survey, were further divided into thematic categories. Three thematic categories were selected: ´fishing-related`, ´tourism and household-related` and ´shipping-related` litter. These additional categories are presented below, and the trawl collections for each litter item within these three categories are visualised.

4.1.1 Fishing gear

Some of the items listed in Table 5 have been identified as belonging to typical Maltese fishing equipment. These include various fishing lines, nets, and stone slabs (Table 5). Although stone slabs are not immediately associated with fishing, they are an integral part of the Lampuki fishery in Malta, as illustrated in Figure 3 and confirmed in the literature (R. et al., 2007). In Figure 3, plastic bottles are used as kannizzata (i.e. floats), but this is not common in local Maltese waters where cork is more frequently used. Therefore, plastic bottles were not identified as fishing gear in this qualitative analysis.

Table 5: Items found in 2020 and 2021 that were characterised as fishing gear.

Litter type	Items characterised as fishing gear
L1 - Plastic	Orange nylon line/ attachment (FAD)
L1 - Plastic	Orange nylon line/ Mainline (FAD)
L1 - Plastic	Large mesh Netting (Piece/Trawling)
L1 - Plastic	Piece of Net
L1 - Plastic	Nylon Fishing Line (Longline)
L8 - Other (Specific)	Stone Slabs (Limestone)
L1 - Plastic	White Plastic Float
L1 - Plastic	Orange Squid Lure (Longline)
L1 - Plastic	Piece of Blue Plastic/Nylon Trawling Net
L1 - Plastic	Rope/Calament tal-fangu

The sites where fishing gear was found within the MEDITS survey in 2020 and 2021 are indicated by yellow markings in Figure 20. In the year 2020, approximately 18.11% of the total identified litter items conformed with the characterisation of fishing gear, as delineated in Table 5. In the subsequent year, 2021, this proportion increased to approximately 21.54%.

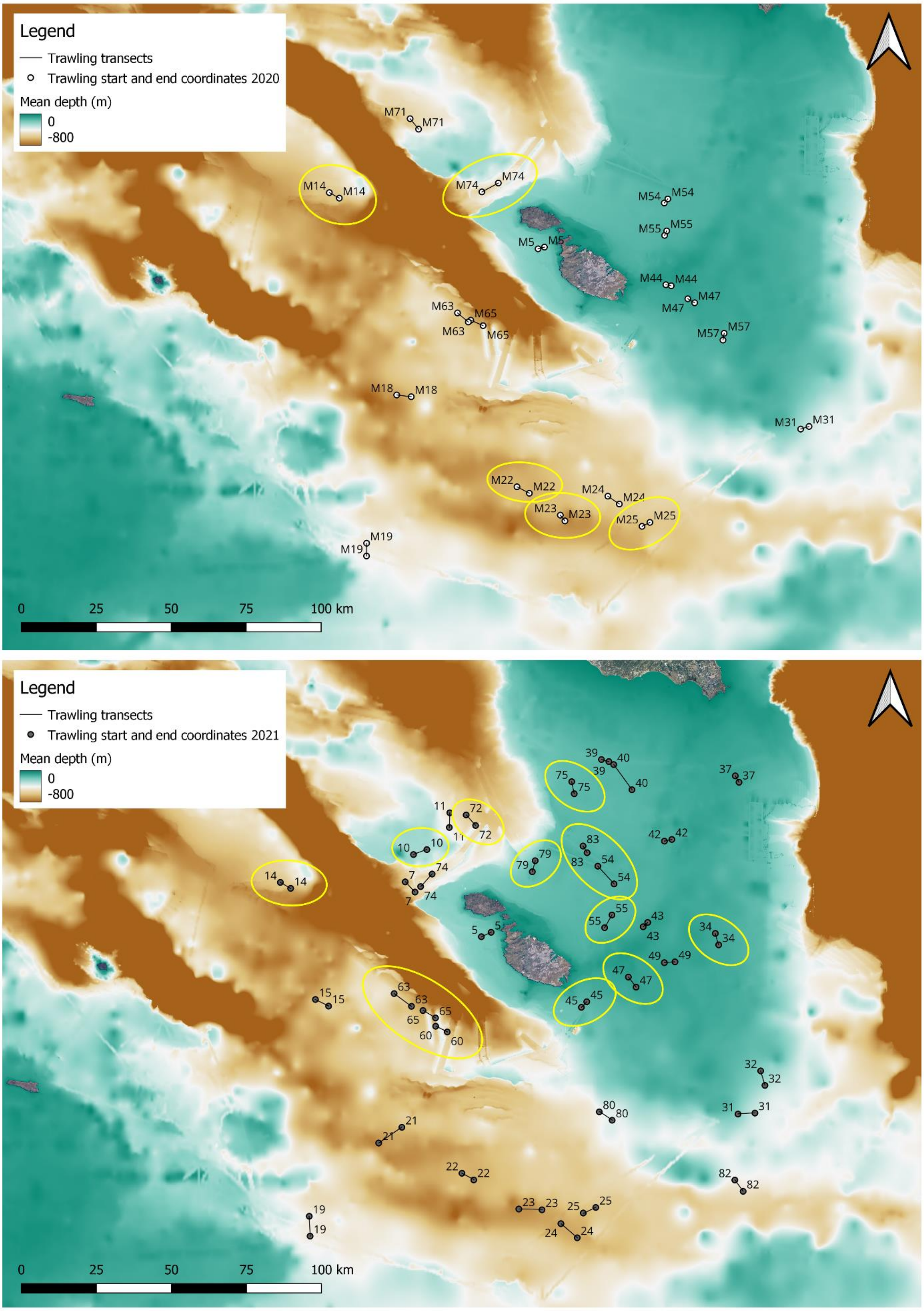

Figure 20: Hauls in 2020 and 2021 in which fishing gear was found, as indicated by yellow markings.

4.1.2 Tourist items

Taking into account all the sampled objects, those that could be classified as characteristic tourist objects were also identified. These specific objects are listed in Table 6 and occurred in different hauls whose geographical localisation is shown in Figure 21. An analysis of this figure shows a homogeneous distribution of these objects around Malta, as at least one object of touristic relevance was found in almost all hauls.

Table 6: Items found in 2020 and 2021 that were characterised as tourist items.

Litter type	Items characterised as tourist items
L1 - Plastic	Plastic bottles
L1 - Plastic	Sunblock bottles
L4 – Glass/Ceramic	Wine bottles
L4 – Glass/Ceramic	Beer bottles
L4 – Glass/Ceramic	Whiskey bottles
L4 – Glass/Ceramic	Glass jars
L1 - Plastic	Disposable white plastic plates
L1 - Plastic	Transparent egg cartons
L1 - Plastic	Disposable white plastic cups
L1 - Plastic	Plastic bags
L1 - Plastic	Pasta plastic wrapper
L3 - Metal	Drinking cans
L5 – Cloth/Neutral Fibres	Tshirts
L1 - Plastic	Plastic wrappers
L6 – Wood Processed	Fruit crate (apples)

This observation is valid for both of the years under consideration, 2020 and 2021. In 2020, 55.12% of all collected litter was classified as tourism-related. In the following year, 2021, this proportion decreased to 46.92%.

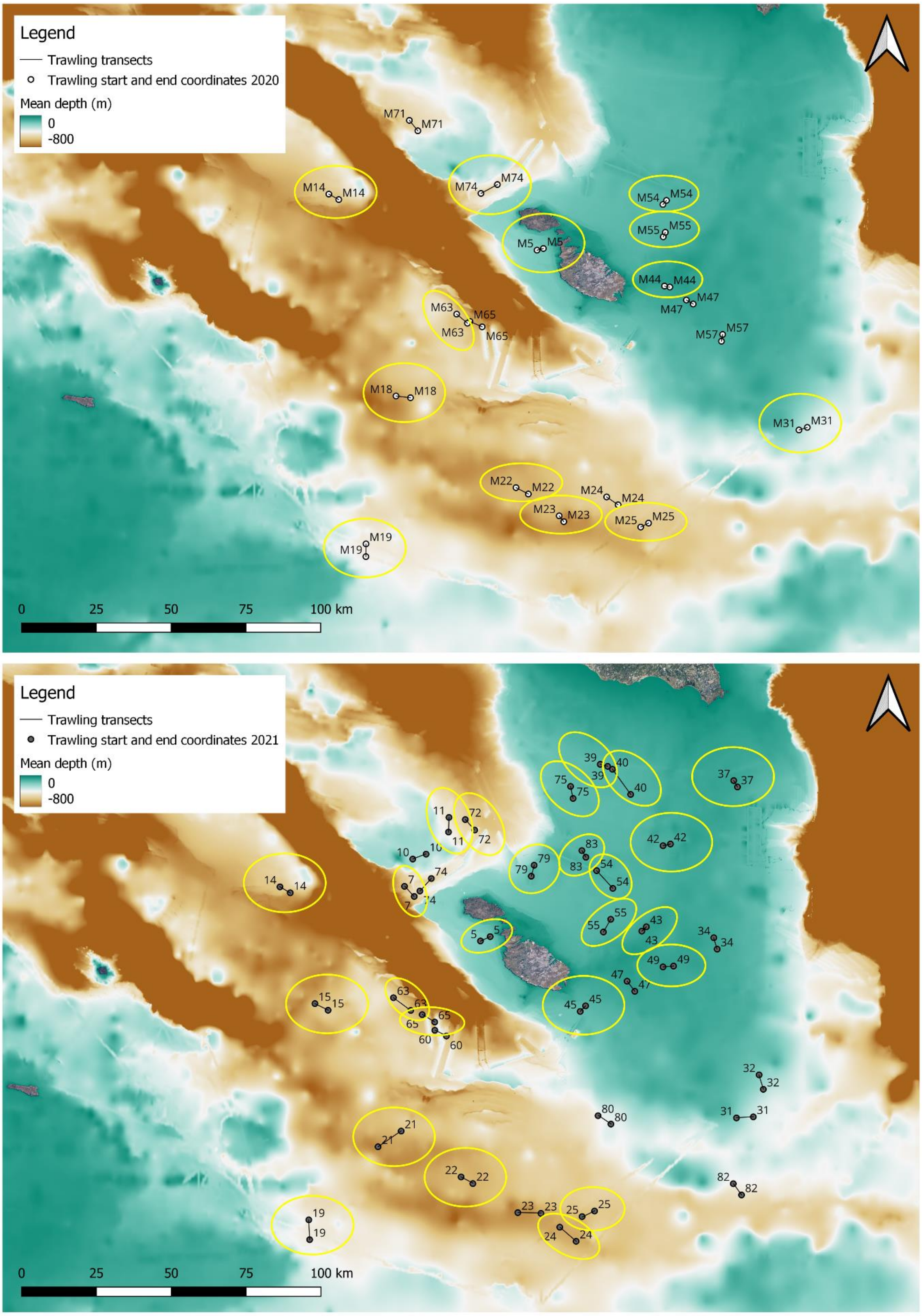

Figure 21: Hauls in 2020 and 2021 in which tourist items were found, as indicated by yellow markings.

4.1.3 Typical ship litter

Among the identified marine litter were items that could potentially be attributed to the shipping industry. Items classified as such are listed in Table 7 and include paint buckets and large, unidentified metal objects, amongst others. The significant variance in the occurrence of these items between 2020 and 2021 is noteworthy (Figure 22).

Table 7: Items found in 2020 and 2021 that were characterised as typical ship litter.

Litter type	Items characterised as tourist items
L3 - Metal	Aluminium cans
L3 - Metal	Paint buckets
L3 - Metal	Fuel funnels
L3 - Metal	Large unidentified metal objects
L3 - Metal	Large tins
L5 - Cloth/Neutral Fibres	Safety shoes
L3 - Metal	Metal drain pipe

In 2020, items classified as typical marine litter were mainly found west of Malta. In 2021, however, they were mainly found to the east in the Malta-Sicily Channel. Typical shipping litter represented only 6.3% of total marine litter in 2020, increasing to 10.77% in 2021.

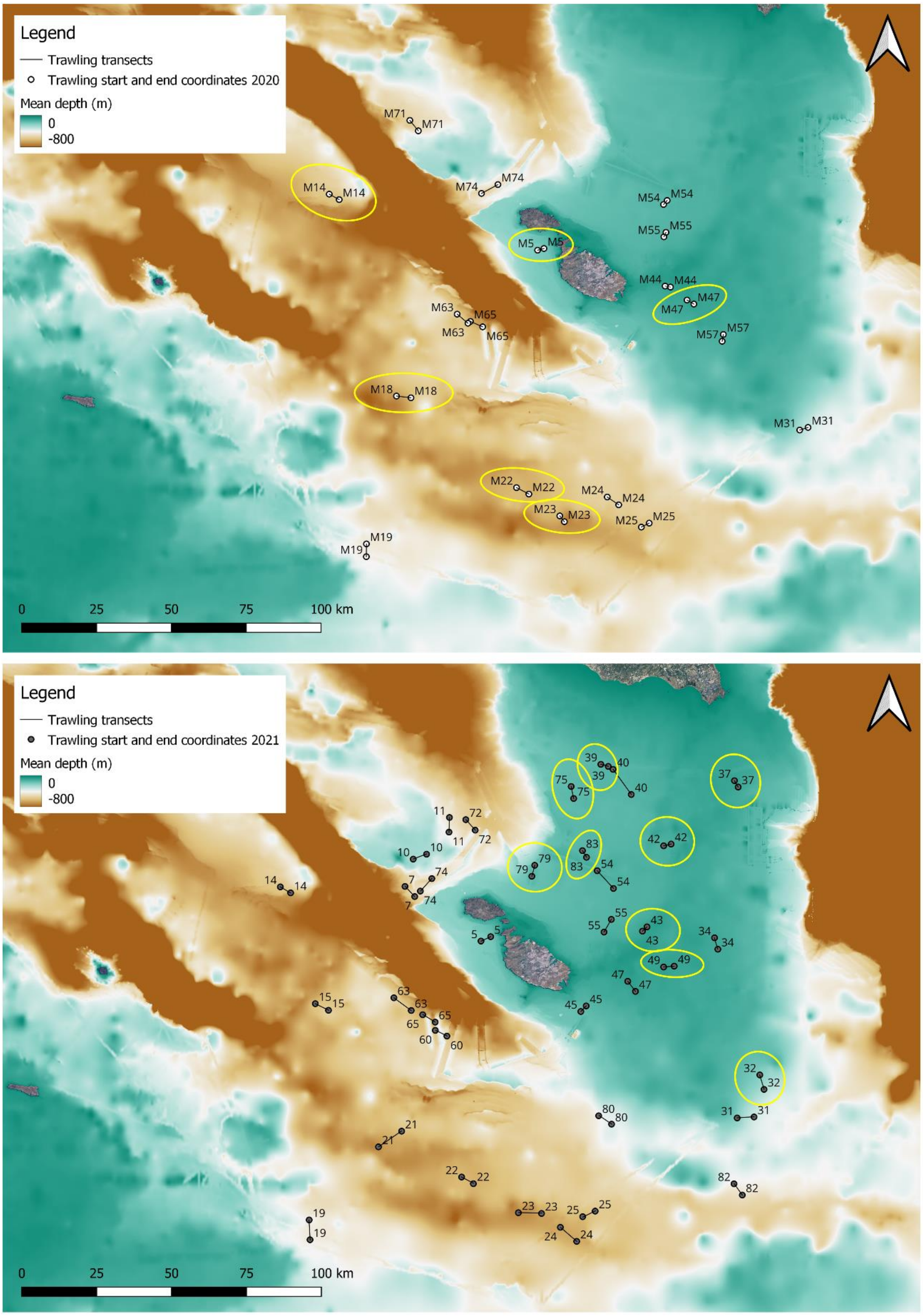

Figure 22: Hauls in 2020 and 2021 in which typical ship litter was found, as indicated by the yellow markings.

4.2 Qualitative assessment of litter categories

The percentage distribution of the litter categories ´L1-L9` is shown in Figure 23 and Figure 24. In both years it is clear that plastic litter makes up the largest proportion of the total. In 2020, plastic litter, metal litter, other litter, glass and ceramics litter, cloth and neutral fibres litter, and finally processed wood were identified most frequently in descending order.

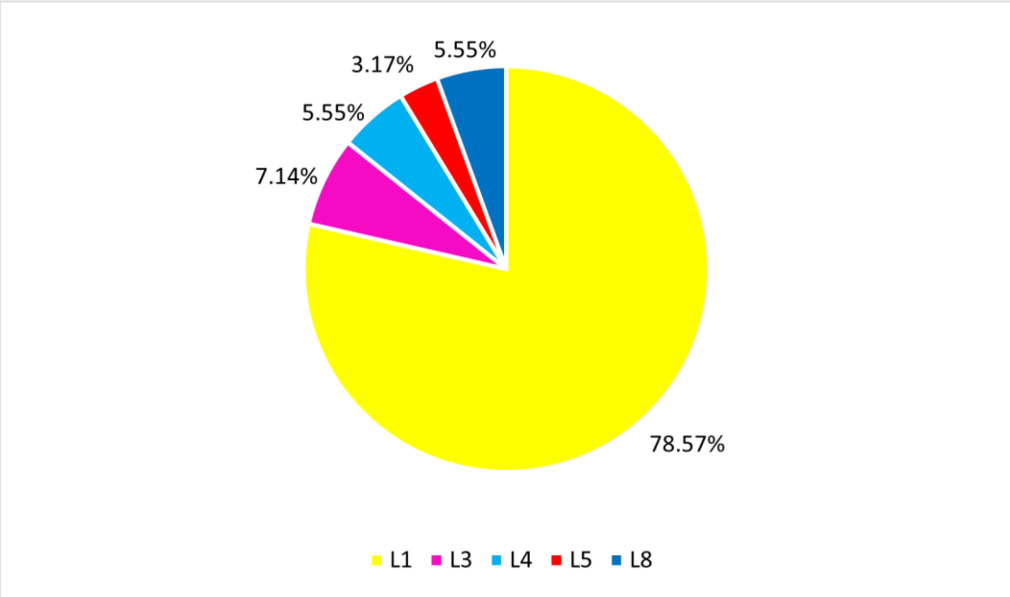

Figure 23: Percentile amount of litter categories in regard to the total amount found in 2020. The litter categories are as follows: ´L1: plastic litter`, ´L3: metal litter`, ´L4: glass and ceramics litter`, ´L5: cloth and neutral fibres litter`, ´L8: other litter`.

The composition is similar in 2021, with the exception that this year more cloth and neutral fibres litter was found than glass and ceramics litter, and no processed wood was detected (Figure 24). A detailed discussion of the extent to which this distribution corresponds to the litter characteristics described in scientific literature, and the extent to which external influences may have influenced these differences is provided in subsequent chapters.

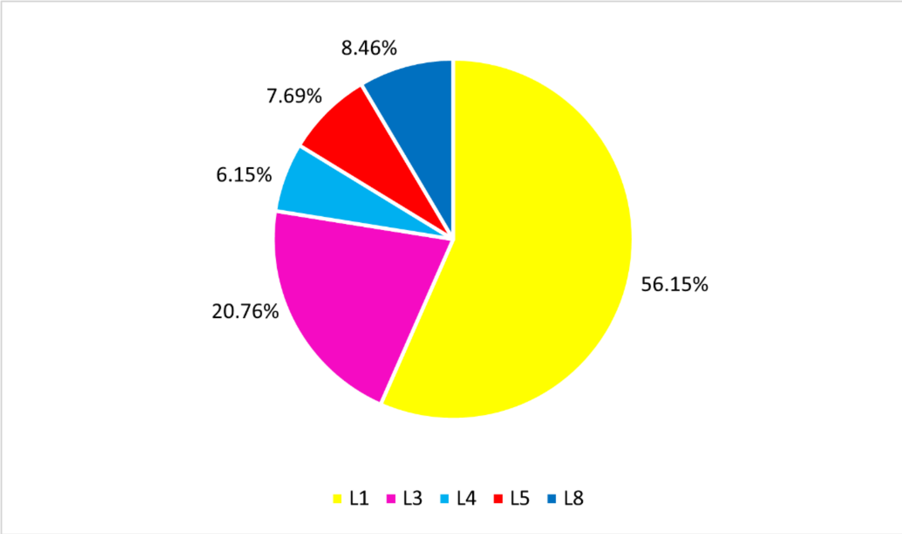

Figure 24: Percentile amount of litter categories in regard to the total amount found in 2021. The litter categories are as follows: ´L1: plastic litter`, ´L3: metal litter`, ´L4: glass and ceramics litter`, ´L5: cloth and neutral fibres litter`, ´L8: other litter`.

4.3 Quantitative analysis of spatial, temporal, and depth-related patterns

4.3.1 Quantity per km^2

The calculated number of litter items per km^2 shows a significantly higher level in 2020 compared to 2021 (see Figure 25). In 2020, a number of 2.2892 items per km^2 was recorded, while this number was reduced to 0.9317 items per km^2 in 2021.

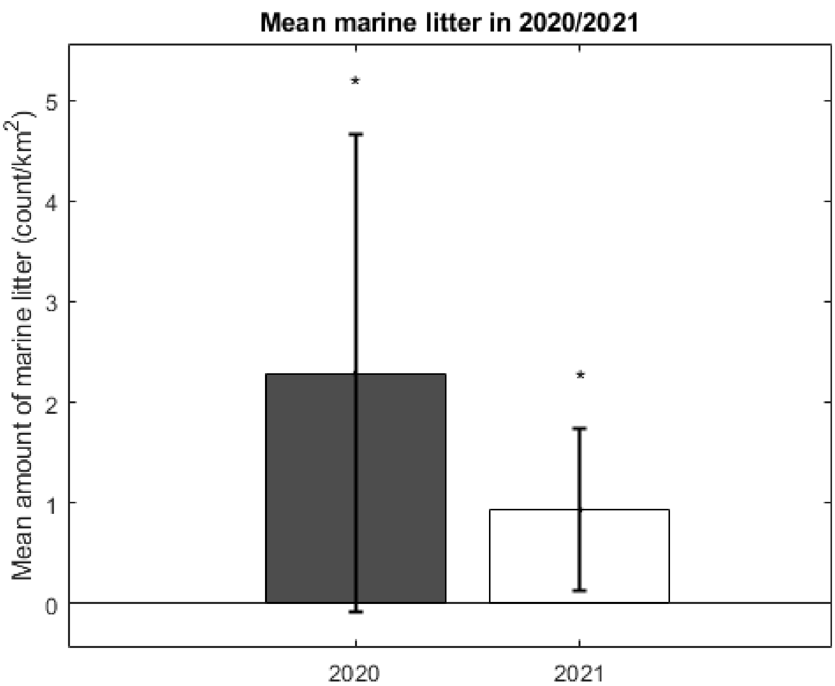

Figure 25: Mean amount of marine litter in count/km² in 2020 and 2021. The symbol ´` shows a statistical significance between amounts found in 2020 and 2021 after doing the two-sided independent* t-test.

4.3.2 Spatial distribution

The following study deals with the spatial analysis of the marine litter generation west and east of the Maltese Islands in the period from 2020 to 2021. The results were obtained by applying the two-sided independent *t*-test as well as through a geographical representation of the litter amounts and these were displayed using a bar chart.

4.3.2.1 All marine litter

The two-sided independent *t*-test was first performed on the entire marine litter survey dataset before being reapplied specifically to the individual litter categories. This test yielded a Levene's *p*-value of 0.004 (see Table 8). This result indicates that the standard deviations of the two populations are significantly different. Therefore, the alternative hypothesis (H1) is accepted.

Table 8: Results of Levene's Test to check for equal variances in all marine litter data.

Levene's Test

	F	*P*-value
Amount of litter	9.004	.004

The average amount (in counts) of marine litter off the eastern side of Malta (3.72) and off the western side of Malta (5.86) was not significantly different according to a *p*-value of 0.082 (Figure 26 and Table 9).

Table 9: Statistical data of the two-sided independent t-test performed on total litter.

Independent Samples T-Test

	Location	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	East	25	3.72	2.606	.521
	West	28	5.86	5.694	1.076

t(38.758) = 1.787, p = 0.082

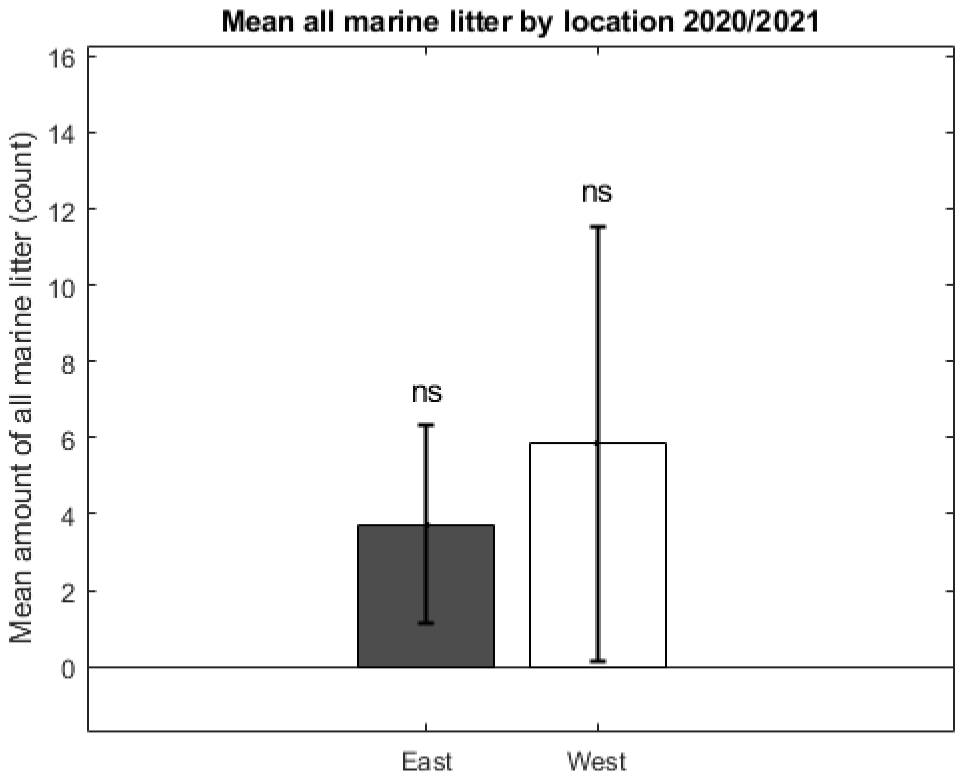

Figure 26: Mean of all marine litter by location (east and west of the Maltese Islands) 2020/2021. The analysis visualised in the figure shows no significant difference (´ns`) in the amount of total litter found on the east and west side.

These results are also reflected geographically, as shown in Figure 27. In summary, there is no significant difference in the distribution of total marine litter between the eastern and western sides of Malta. A detailed analysis of the individual litter categories is presented in the following chapters.

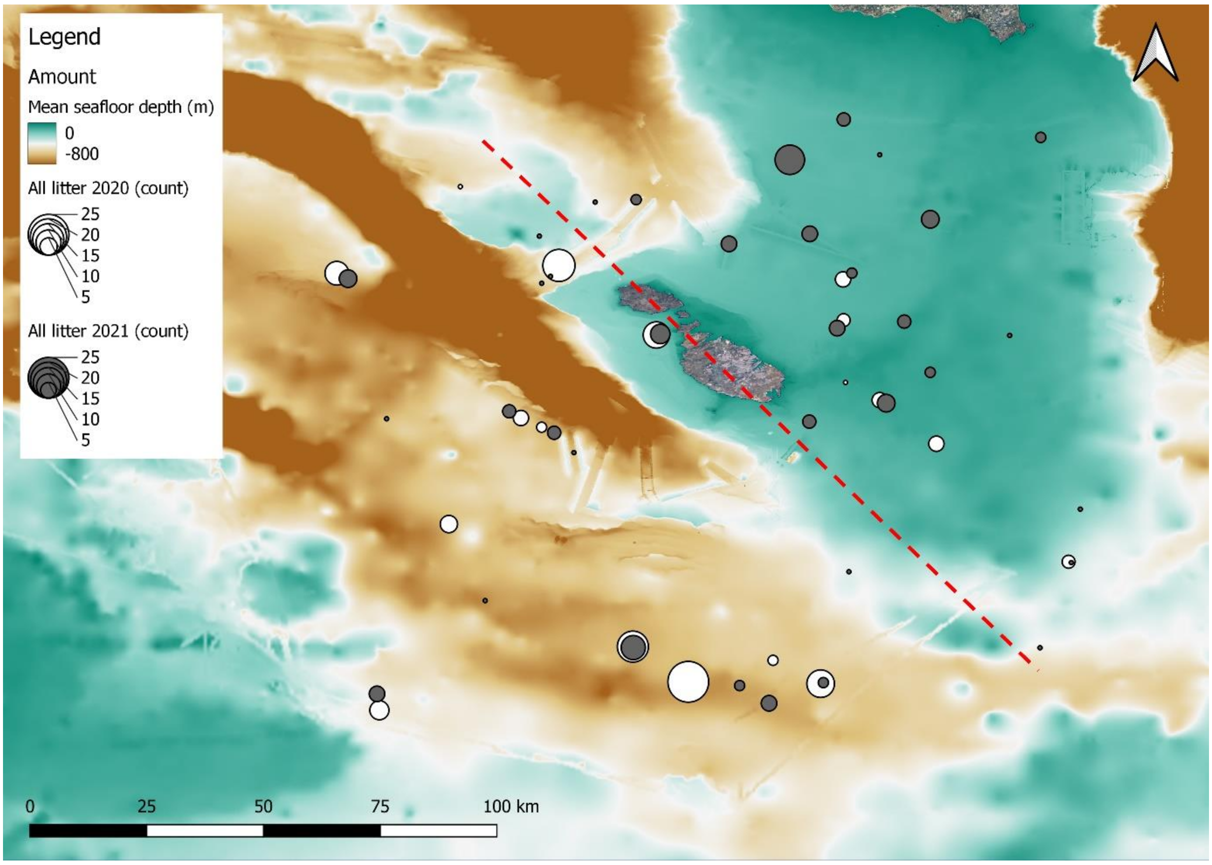

Figure 27: Proportional symbol map indicating all marine litter collected during trawls in 2020 and 2021. The map additionally shows the seafloor bathymetry in m and the characterisation of east and west trawls.

4.3.2.2 Plastic litter

For plastic litter items, the Levene's *p*-value (0.003) is smaller than the 0.05 level of significance, indicating that the two population standard deviations differ significantly (Table 10). Therefore, equal variances are not assumed. The average amount of plastic litter items on the eastern side was ~ 1.84, while an average amount of ~ 4.50 was recorded on the western side. With a *p*-value of 0.009, this difference is significant (Figure 28). The exact data, including standard deviations, is shown in Table 11.

Table 10: Results of Levene's Test to check for equal variances in plastic litter data.

Levene's Test

	F	*P*-value
Amount of litter	9.770	.003

Table 11: Statistical data of the two-sided independent t-test performed on plastic litter.

Independent Samples T-Test

	Location	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	East	25	1.84	1.546	.309
	West	28	4.50	4.842	.915

$t(33.033) = 2.754$, $p = 0.009$

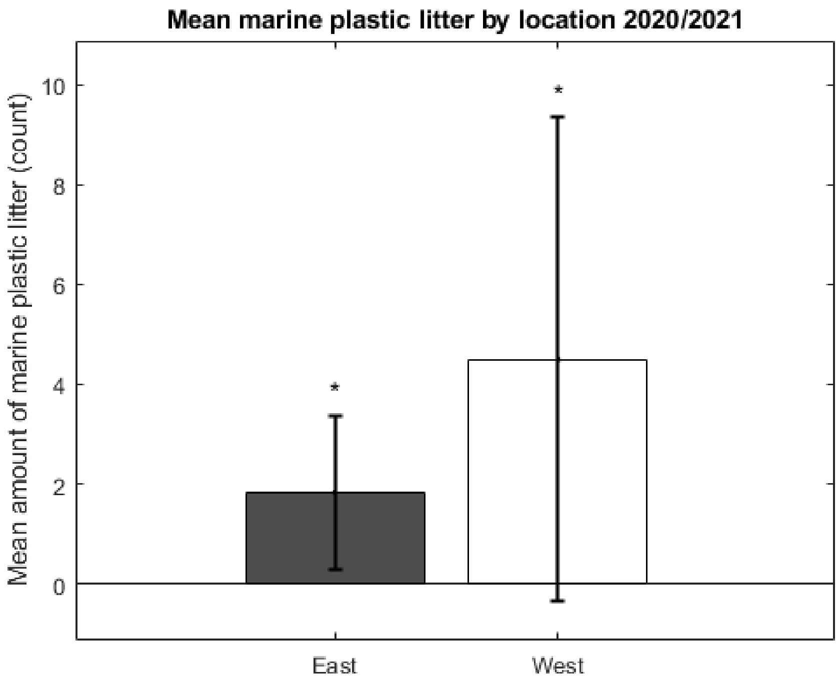

Figure 28: Mean marine plastic litter items by location (east and west of the Maltese Islands) 2020/2021. The analysis visualised in the figure shows a significant difference (´`) in the amount of plastic litter items found on the east and west side at a confidence level of 95%.*

The geographical representation of the plastic litter quantities recorded (Figure 29) clearly illustrates the distribution of plastic litter items in the region. An uneven distribution of the amount of litter along the coastal areas to the west and east of the Maltese Islands can be observed.

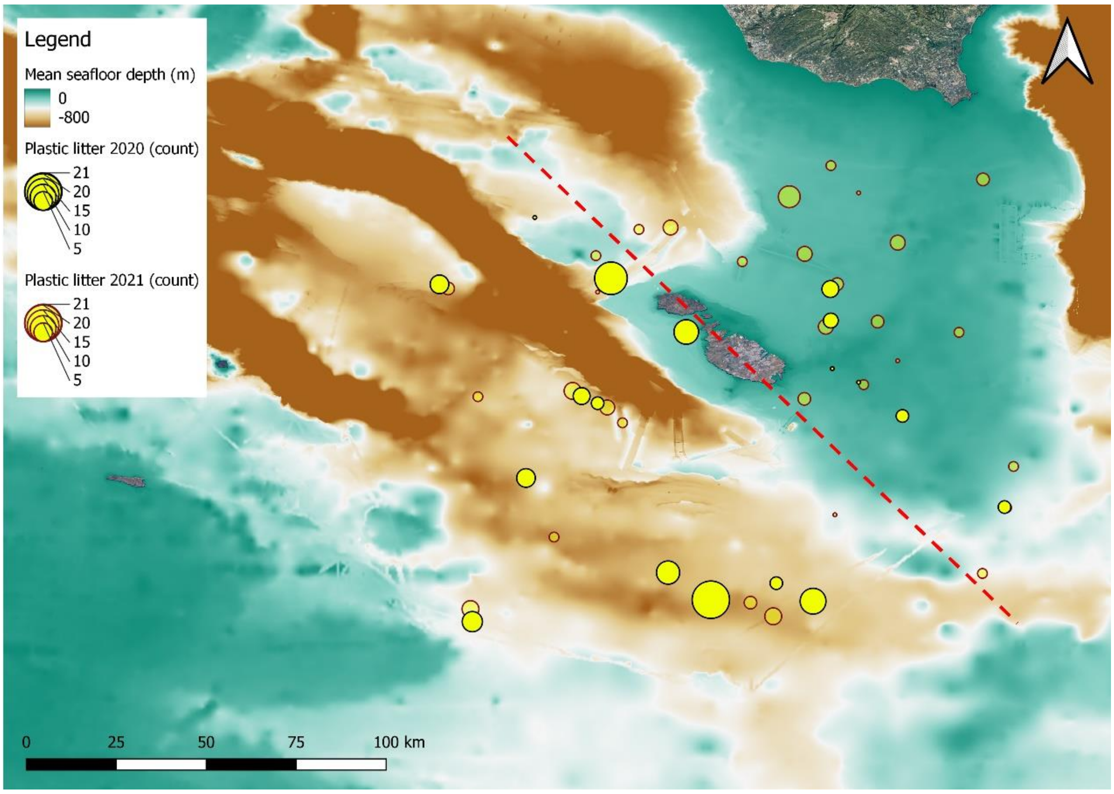

Figure 29: Proportional symbol map indicating marine plastic litter items collected during trawls in 2020 and 2021. The map additionally shows the seafloor bathymetry in m and the characterisation of east and west trawls.

4.3.2.3 Metal litter

The mean value for metal litter items east of Malta is ~ 1 and west of Malta is ~ 0.39 (Table 13). The Levene's test performed in SPSS gives a *p*-value of 0.085, indicating that the null hypothesis (H0) is accepted (Table 12). The *p*-value for assuming equal variances shows a value of 0.059. As shown in Figure 30, this indicates that the difference in the amount (count) of metal litter items found west and east of Malta is not significantly different at a 95% significance level (Table 13).

Table 12: Results of Levene's Test to check for equal variances in metal litter data.

Levene's Test

	F	*P*-value
Amount of litter	3.094	.085

Table 13: Statistical data of the two-sided independent t-test performed on metal litter.

Independent Samples T-Test

	Location	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	East	25	1.00	1.323	.265
	West	28	.39	.875	.165

t(51) = 1.990, p = 0.052

Geographically, significance in location would be suspected for this category of litter (see Figure 31) and can be attributed to the fact that the *p*-value is just above significance at 0.052. However, the difference between the two sides is not statistically significant.

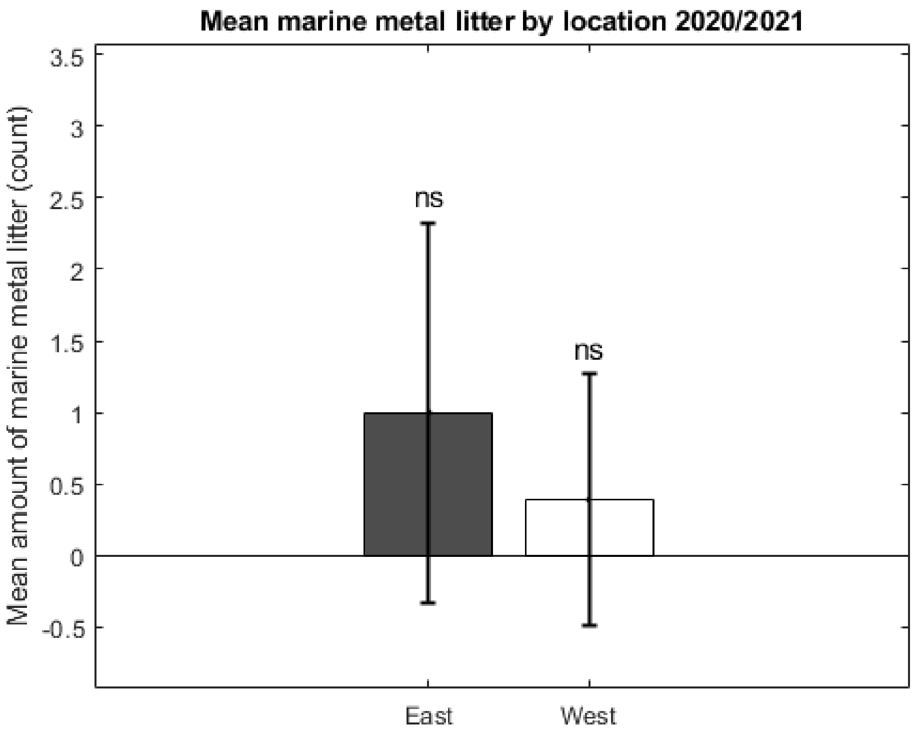

Figure 30: Mean marine metal litter items by location (east and west of the Maltese Islands) 2020/2021. The analysis visualised in the figure shows no significant difference (´ns`) in the amount of plastic litter items found on the east and west side.

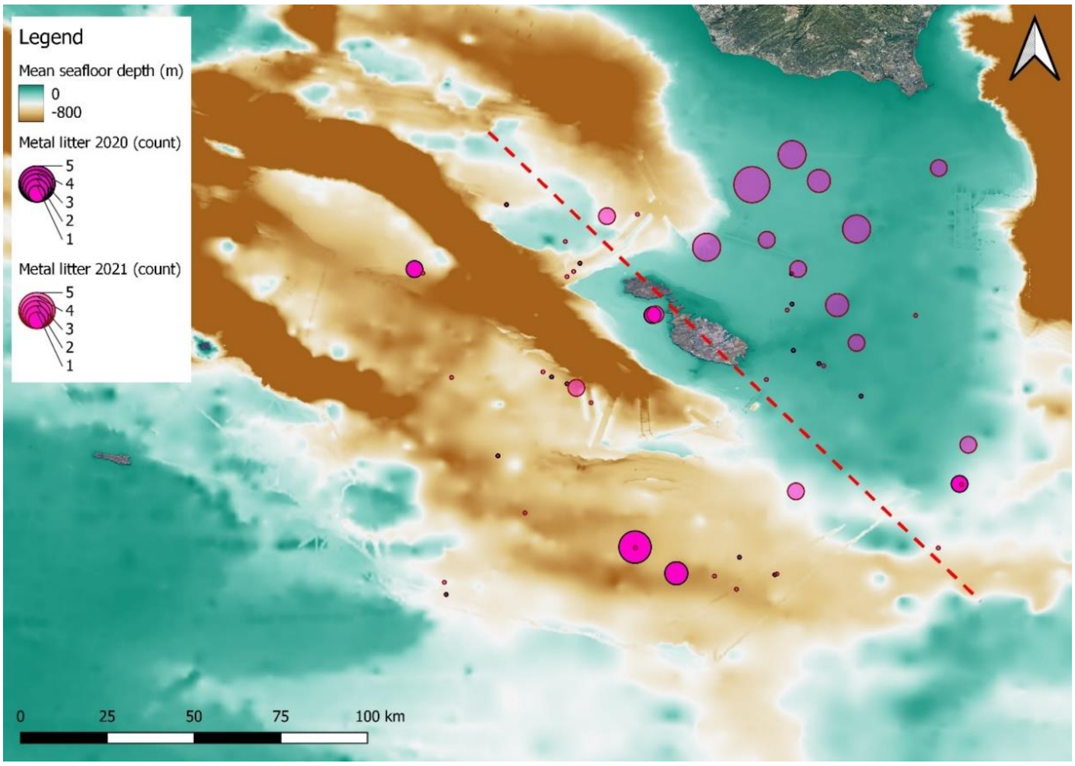

Figure 31: Spatial distribution of metal marine litter collected during trawls in 2020 and 2021. The map additionally shows the seafloor bathymetry in m and the characterisation of east and west trawls.

4.3.2.4 Glass and ceramics

An analysis of the ´glass and ceramic litter` category was performed using the two-sided independent *t*-test in SPSS statistical software as with the previous litter categories. The resulting means were ~ 0.12 for the eastern part and ~ 0.43 for the western part (Table 15). The Levene's *p*-value (0.003 < 0.05) (Table 14) led to the acceptance of the alternative hypothesis (H1).

Table 14: Results of Levene's Test to check for equal variances in glass and ceramics litter data.

Levene's Test

	F	Sig.
Amount of litter	9.443	.003

Table 15: Statistical data of the two-sided independent t-test performed on glass and ceramics litter.

Independent Samples T-Test

	Location	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	East	25	.12	.440	.088
	West	28	.43	.879	.166

t(40.664) = 1.642, p = 0.108

This *p*-value is 0.108, indicating statistical insignificance. This is noted in Figure 32 with the label ´ns`. A look at the map (Figure 33) confirms the statistical analysis and shows an even distribution of glass and ceramic litter items on both sides of Malta.

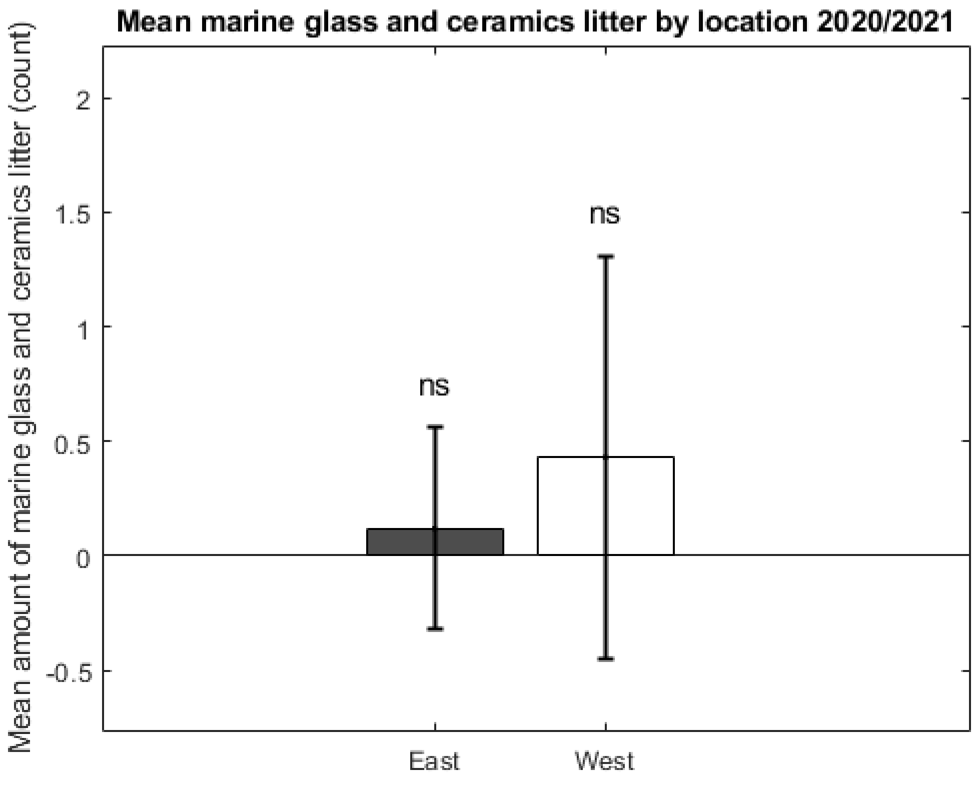

Figure 32: Mean marine glass and ceramic litter items by location (east and west of the Maltese Islands) 2020/2021. The analysis visualised in the figure shows no significant difference (´ns`) in the amount of glass and ceramic litter items found on the east and west side.

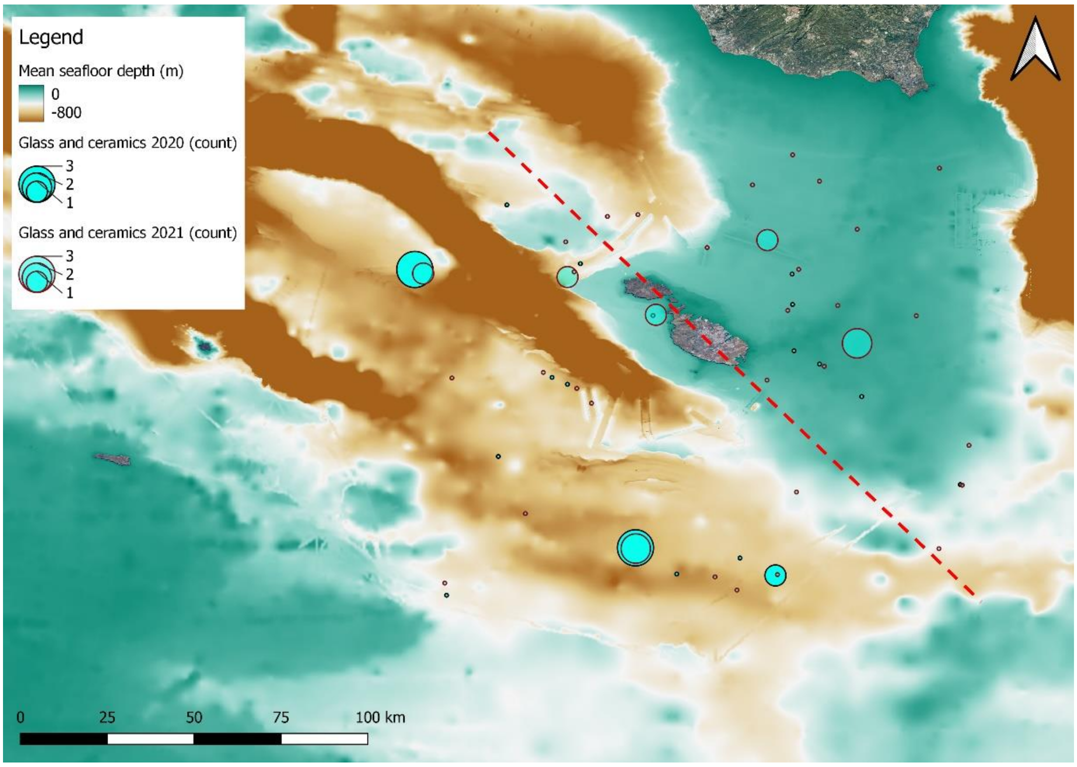

Figure 33: Proportional symbol map indicating marine glass and ceramics litter items collected during trawls in 2020 and 2021. The map additionally shows the seafloor bathymetry in m and the characterisation of east and west trawls.

4.3.2.5 Cloth and neutral fibres

The analysis with the two-sided independent *t*-test in the statistical software SPSS shows a statistically insignificant difference between the assigned groups East and West for the litter category ´cloth and neutral fibres`. The mean value for the litter category is ~ 0.12 for the East and ~ 0.39 for the West (see Table 17). The Levene test performed had a *p*-value < 0.05 (0.002), which means that the alternative hypothesis (H1) for the analysis is accepted (Table 16). Consequently, the *p*-value for the assumption of unequal variances is 0.085, indicating statistical insignificance (Table 17).

Table 16: Results of Levene's Test to check for equal variances in cloth and neutral fiber litter data.

Levene's Test

	F	*P*-value
Amount of litter	11.176	.002

Table 17: Statistical data of the two-sided independent t-test performed on cloth and neutral fibres litter.

Independent Samples T-Test

	Location	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	East	25	.12	.332	.066
	West	28	.39	.737	.139

t(38.405) = 1.768, p = 0.085

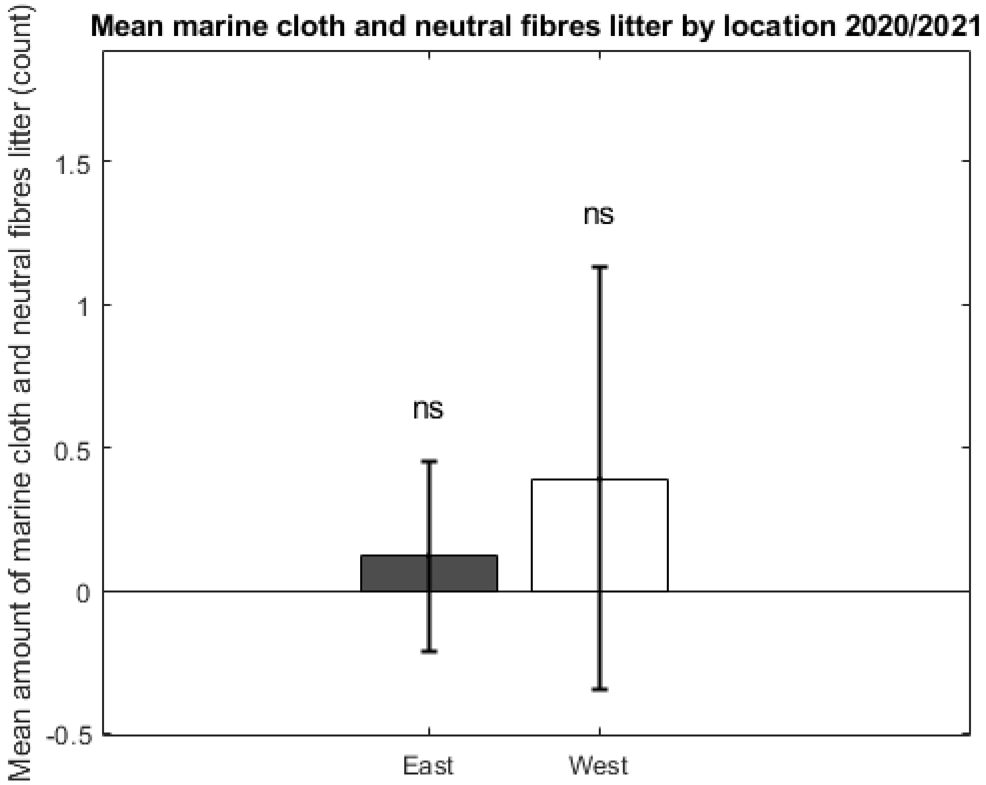

Figure 34: Mean marine cloth and neutral fibres litter items by location (east and west of the Maltese Islands) 2020/2021. The analysis visualised in the figure shows no significant difference (´ns`) in the amount of cloth and neutral fibres litter items found on the east and west side.

Although the visual representation on the map (Figure 35) shows a higher concentration of textiles and neutral fibers along the western side, a higher occurrence of dots can be detected along the eastern side. Here, the litter was found to be more evenly distributed, whereas in the west, the textile and fiber materials appear to be clustered in specific locations rather than having a broad individual distribution.

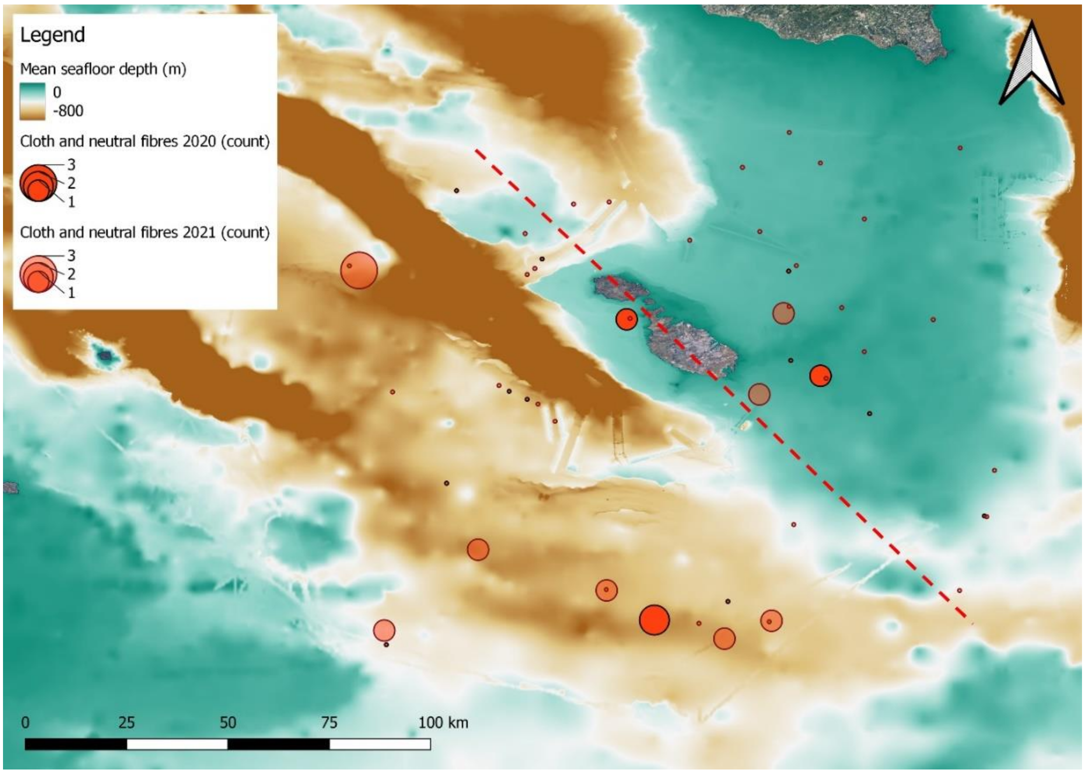

Figure 35: Proportional symbol map indicating marine cloth and neutral fibres litter items collected during trawls in 2020 and 2021. The map additionally shows the seafloor bathymetry in m and the characterisation of east and west trawls.

4.3.2.6 Other marine litter

In the MEDITS survey, an average of ~ 0.60 items per unit were found for the litter category ´other litter` east of Malta and ~ 0.11 items per unit west of Malta in 2020 and 2021 (see Table 19). The *p*-value was selected based on the assumption of the alternative hypothesis (H1) after performing the Levene test which resulted in unequal variances (*p*-value = < 0.001 (< 0.05)) (Table 18).

Table 18: Results of Levene's Test to check for equal variances in other litter data.

Levene's Test

	F	*P*-value
Amount of litter	16.049	.000

Table 19: Statistical data of the two-sided independent t-test performed on other litter.

Independent Samples T-Test

	Location	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	East	25	.60	1.225	.245
	West	28	.11	.315	.060

t(26.835) = 1.955, p = 0.061

With a *p*-value of 0.061, a statistical non-significance is shown between the two groups East and West for the category ´other litter` (Figure 36). The distribution of this litter category in the surveyed areas is shown in Figure 37.

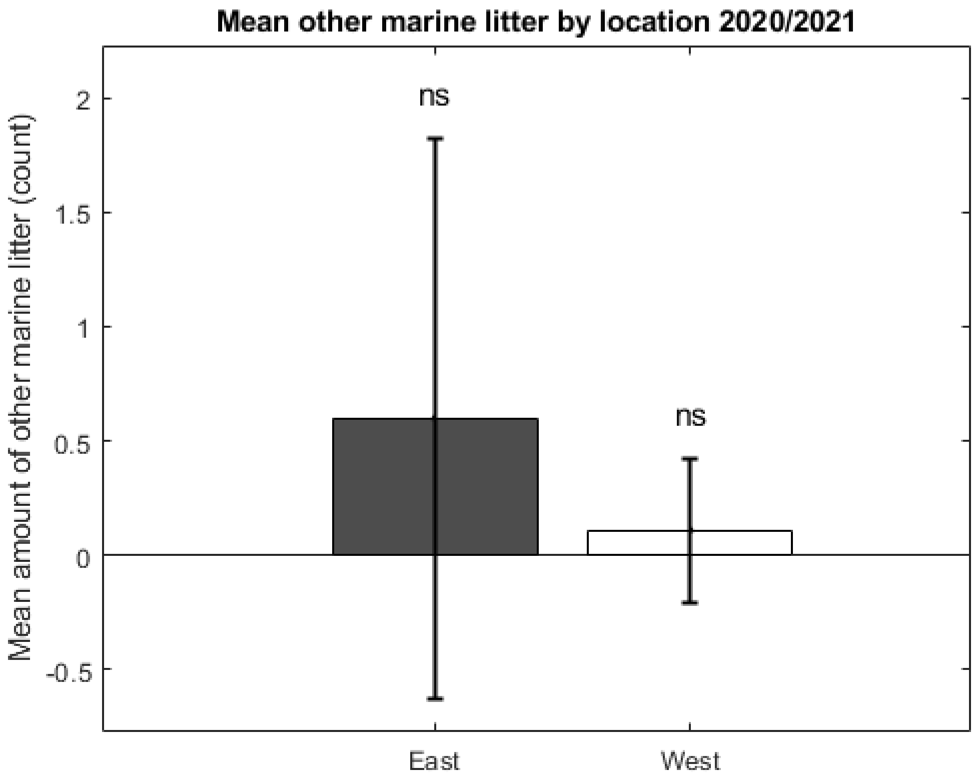

Figure 36: Mean of other litter items by location (east and west of the Maltese Islands) 2020/2021. The analysis visualised in the figure shows no significant difference (´ns`) in the amount of other litter items found on the east and west side.

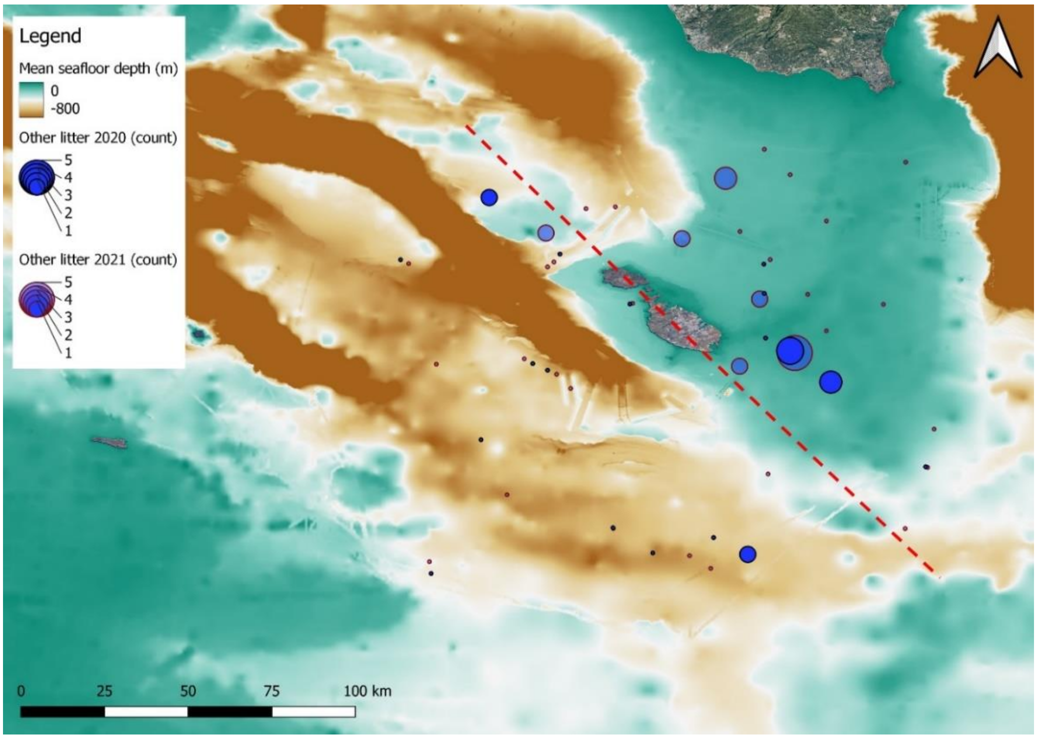

Figure 37: Proportional symbol map indicating other marine litter collected during trawls in 2020 and 2021. The map additionally shows the seafloor bathymetry in m and the characterisation of east and west trawls.

4.3.2.7 Concluding insights: spatial patterns of marine litter obtained from the MEDITS survey

In summary, only east-west differences for the category ´plastic litter` were found to be statistically significant.

4.3.3 Temporal distribution

The present study deals with the temporal analysis of the sampled seabed litter from 2020 and 2021. The results were obtained by applying the two-sided independent *t*-test as well as a geographical representation of the litter amounts and these were displayed using a bar chart.

4.3.3.1 Total litter

The analysis of the temporal distribution of all marine litter shows an average value of 7.06 items of litter for 2020. In 2021 this value is 3.71 (see Table 21). The Levene test performed in SPSS (Table 20) generates a *p*-value of 0.000. Therefore, the alternative hypothesis (H1) is accepted and the *p*-value for unequal variances is chosen, which is 0.049 (>0.05), indicating statistical significance in the amount of marine litter found (in count) between the years 2020 and 2021. This statistical significance is illustrated in Figure 38.

Table 20: Results of Levene's Test to check for equal variances in total litter data.

Levene's Test

	F	*P*-value
Amount of litter	15.900	.000

Table 21: Statistical data of the two-sided independent t-test *performed on total litter.*

Independent Samples T-Test

	Year	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	2020	18	7.06	6.458	1.522
	2021	35	3.71	2.750	.465

t(20.231) = 2.099, p = 0.049

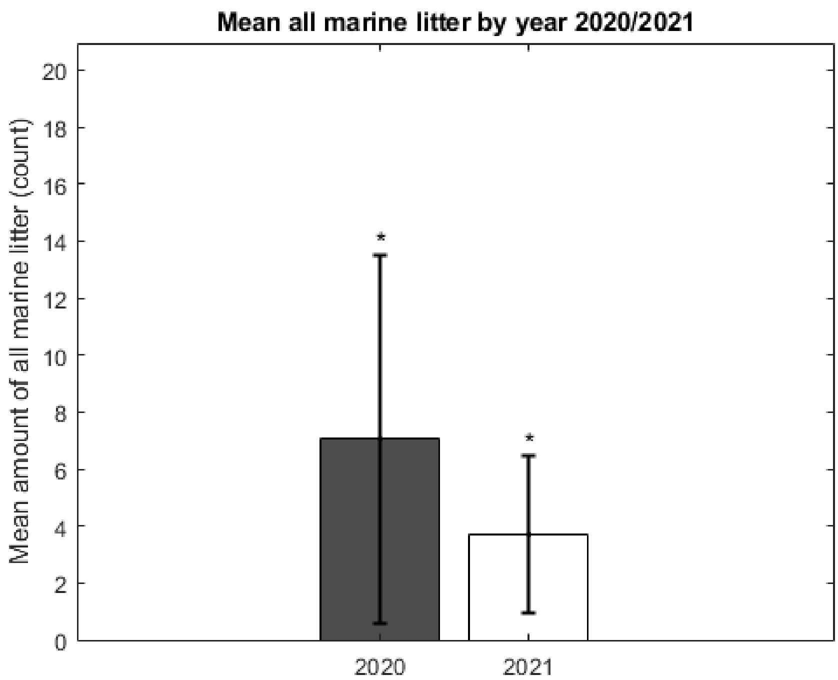

Figure 38: Mean all marine litter by year 2020/2021. The analysis visualised in the figure shows a significant difference (´´) in the amount of total litter found in 2021 and 2021 at a confidence level of 95%.*

Furthermore, despite a lower number of sampling in 2020 (n=18) compared to 2021 (n=35), a geographical comparison of the amount of marine litter found over the two years confirms a greater amount of marine litter for 2020 (see Figure 39). The reasons that may have led to this significantly-different temporal distribution are elaborated upon in the discussion.

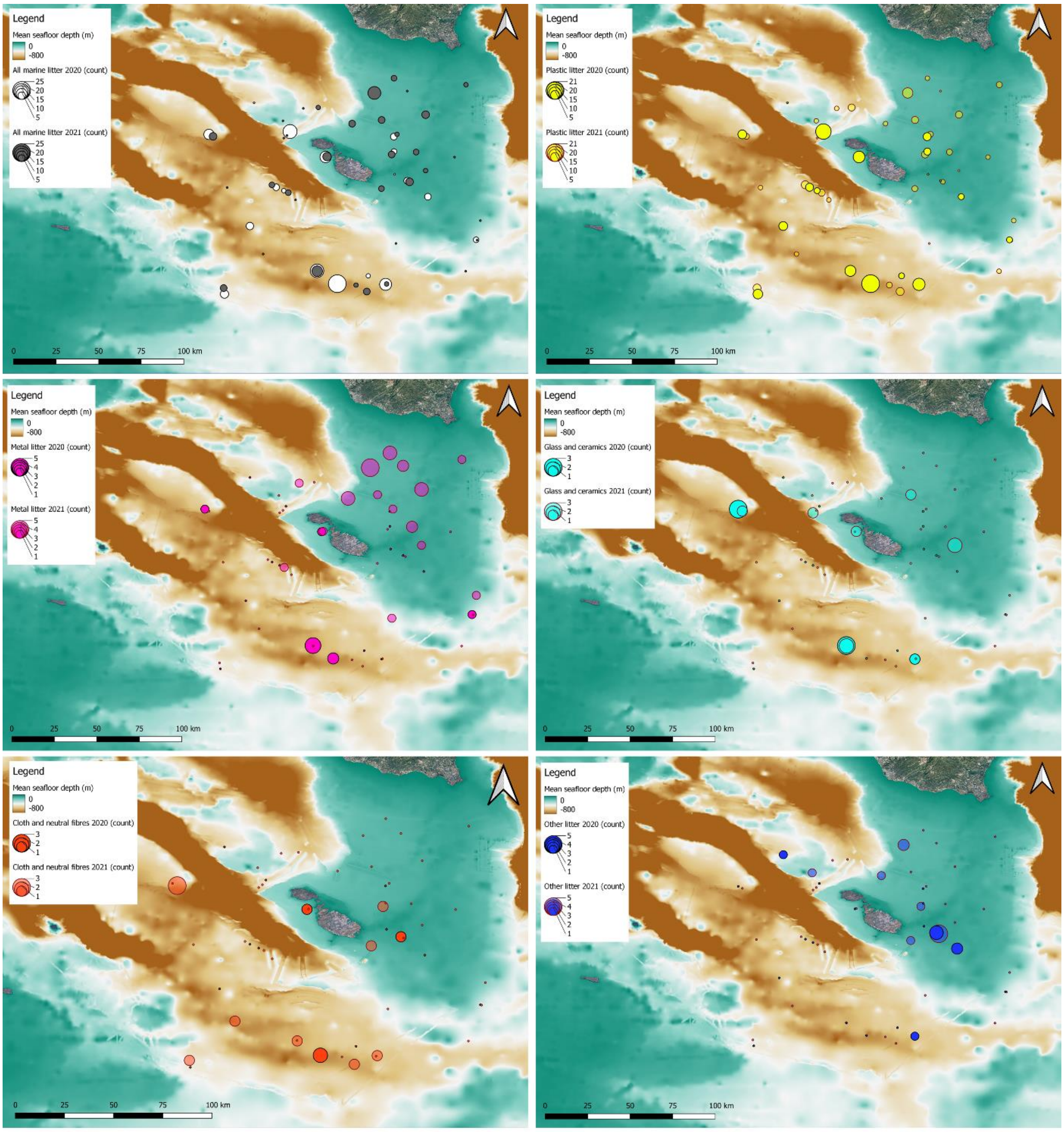

Figure 39: Temporal distribution of total litter and its categories (2020/2021).

4.3.3.2 Plastic litter

The mean value for plastic litter items in 2020 and 2021 were 5.50 and 2.09, respectively (see figure and table). After performing Levene's test, the alternative hypothesis (H1) was accepted ($p > 0.05$) (see Table 22). The *p*-value of the two-sided independent samples *t*-test is 0.022 (Table 23). This indicates statistical significance regarding the amount of plastic litter items in the comparison between 2020 and 2021.These results are shown graphically in Figure 40.

A spatial representation (see Figure 39) confirms the results of the statistical analysis. The results obtained are further analysed and interpreted in the discussion.

Table 22: Results of Levene's Test to check for equal variances in plastic litter data.

Levene's Test

	F	*P*-value
Amount of litter	16.881	.000

Table 23: Statistical data of the two-sided independent t-test performed on plastic litter.

Independent Samples T-Test

	Year	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	2020	18	5.50	5.639	1.329
	2021	35	2.09	1.755	.297

$t(18.713) = 2.507$, $p = 0.022$

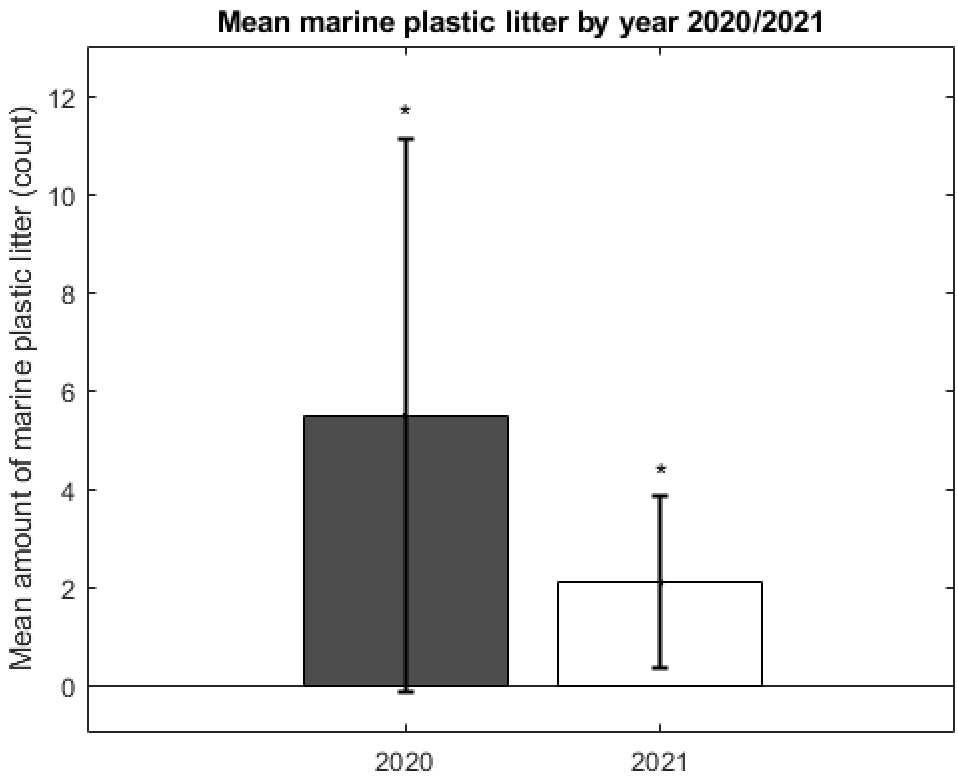

Figure 40: Mean marine plastic litter items by year 2020/2021. The analysis visualised in the figure shows a significant difference (´´) in the amount of plastic litter items found in 2021 and 2021 at a confidence level of 95%.*

4.3.3.3 Metal litter

In 2020, an average of 0.50 metal items were found, while one year later, in 2021, the average was 0.77 items (see Table 25). To analyse the possible statistical significance of these values, Levene's test was first performed to check the homogeneity of the variances. The resulting *p*-value of Levene's test is 0.477 (Table 24), which leads to the assumption that the variances are equal and therefore the null hypothesis (H0) is accepted. This scenario results in a *p*-value of 0.417 in the two-sided independent samples *t*-test (Table 25). Below the predefined significance level of 95%, this result is not statistically significant. This is also illustrated graphically in Figure 41. It should be noted that this analysis was also performed with unequal sample sizes (see Table 25).

The geographical representation of metal litter items in both years, as shown in Figure 39, confirms the results explained above and shows an equal amount of metal litter items in both years.

Table 24: Results of Levene's Test to check for equal variances in metal litter data.

Levene's Test

	F	*P*-value
Amount of litter	.512	.477

Table 25: Statistical data of the two-sided independent t-test performed on metal litter.

Independent Samples T-Test

	Year	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	2020	18	.50	1.043	.246
	2021	35	.77	1.190	.201

$t(51) = 0.818$, $p = 0.417$

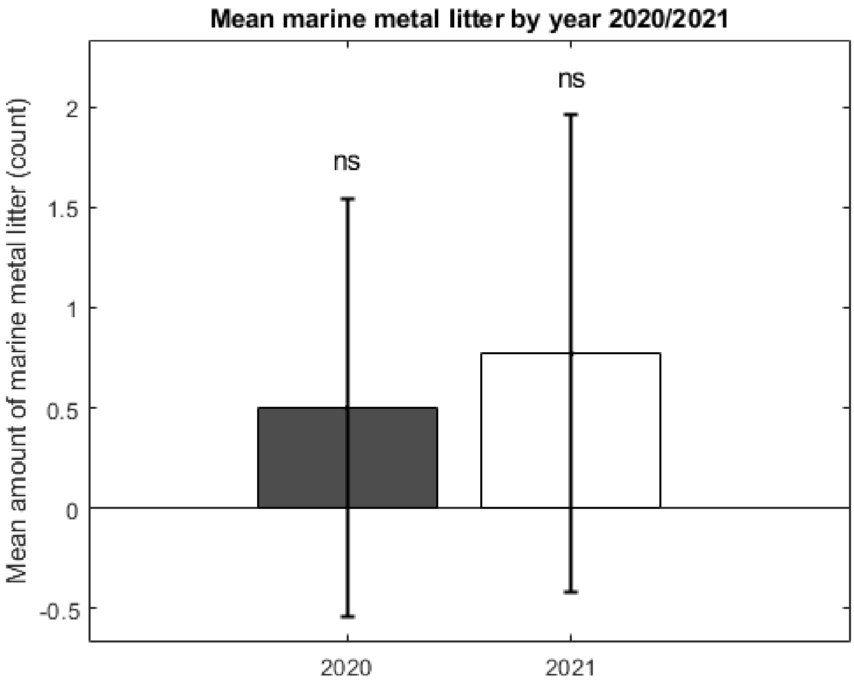

Figure 41: Mean marine metal litter items by year 2020/2021. The analysis visualised in the figure shows no significant difference (´ns`) in the amount of metal litter items found in 2020 and 2021.

4.3.3.4 Glass and ceramics litter

In 2020, an average of 0.39 glass and ceramic items was found, compared to an average of 0.23 items in 2021 (see Table 27). To investigate a possible significance between these two values, Levene's test was first performed. The result led to the acceptance of the null hypothesis (H0), as the *p*-value of 0.81 was < 0.05 (Table 26). Therefore, the *p*-value for assumed equal variances was used for the two-sided independent samples *t*-test ($p = 0.446$). This *p*-value indicates no statistical significance between the two groups. This result is also shown graphically in Figure 42.

The geographic distribution, as shown in Figure 39, confirms the statistical analysis results and visualises a homogeneous amount of litter found in both years.

Table 26: Results of Levene's Test to check for equal variances in glass and ceramics litter data.

Levene's Test

	F	*P*-value
Amount of litter	3.172	.081

Table 27: Statistical data of the two-sided independent t-test performed on glass and ceramics litter.

Independent Samples T-Test

	Year	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	2020	18	.39	.979	.231
	2021	35	.23	.547	.092

$t(51) = 0.768$, $p = 0.446$

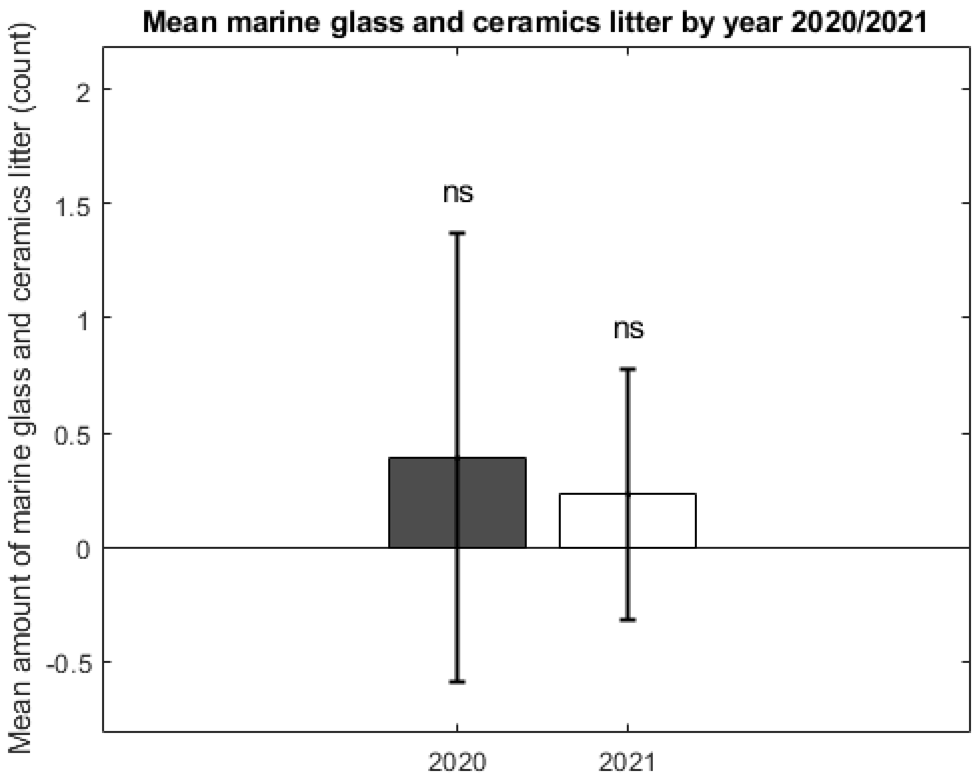

Figure 42: Mean marine glass and ceramics litter items by year 2020/2021. The analysis visualised in the figure shows no significant difference (´ns`) in the amount of glass and ceramics litter items found in 2020 and 2021.

4.3.3.5 Cloth and neutral fibres litter

A statistical analysis was also performed for the ´cloth and neutral fibres` litter category. The mean values for the years 2020 and 2021 were 0.22 and 0.29, respectively (Table 29). Levene's test yielded a *p*-value of 0.565 (Table 28), leading to the acceptance of the null hypothesis. Accordingly, the *p*-value of the two-sided independent samples *t*-test is 0.716 (see Table 29). This *p*-value indicates statistical insignificance. This result is also expressed graphically in Figure 43.

The geographical representation of the quantities for the years 2020 and 2021 is shown in Figure 39. It confirms the results of the statistical analysis by visualising an equal amount of cloth and neutral fibres litter items in both years.

Table 28: Results of Levene's Test to check for equal variances in cloth and neutral fibres litter data.

Levene's Test

	F	*P*-value
Amount of litter	.335	.565

Table 29: Statistical data of the two-sided independent t-test performed on cloth and neutral fibres litter.

Independent Samples T-Test

	Year	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	2020	18	.22	.548	.129
	2021	35	.29	.622	.105

$t(51) = 0.366$, $p = 0.716$

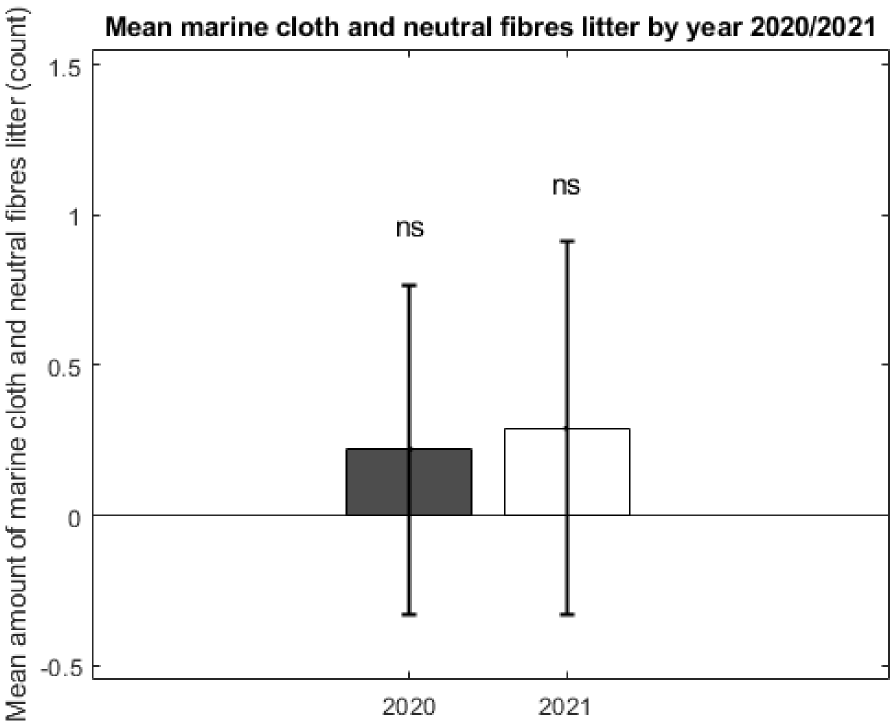

Figure 43: Mean marine cloth and neutral fibres litter items by year 2020/2021. The analysis visualised in the figure shows no significant difference (´ns`) in the amount of cloth and neutral fibres litter items found in 2020 and 2021.

4.3.3.6 Other litter

The statistical analysis in SPSS regarding the litter category ´other litter` shows the following mean values: 0.39 for 2020 and 0.31 for 2021 (Table 31). The subsequent Levene's test resulted in a *p*-value of 0.685 ($p < 0.05$), which led to the acceptance of the null hypothesis (H0) (see Table 30). The *p*-value generated by the *t*-test was 0.778 (Table 31) and the difference in the amount of other litter items between the two years can therefore be considered as statistically insignificant. This result is also illustrated in Figure 44.

The geographical representation of the quantities of this specific litter category found can be seen in Figure 39. It confirms the results of the two-sided independent samples *t*-test and shows a homogeneous amount of litter in the two years studied.

Table 30: Results of Levene’s Test to check for equal variances in other litter data

Levene's Test

	F	*P*-value
Amount of litter	.167	.685

Table 31: Statistical data of the two-sided independent t-test performed on other litter.

Independent Samples T-Test

	Year	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	2020	18	.39	.850	.200
	2021	35	.31	.932	.158

$t(51) = 0.284$, $p = 0.778$

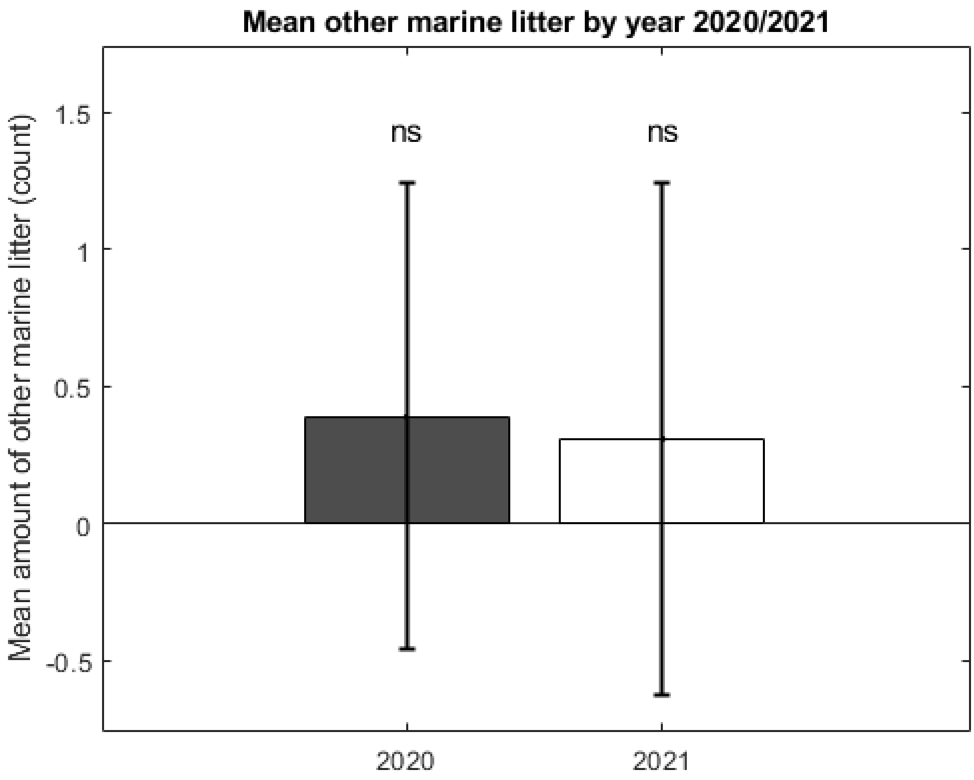

Figure 44: Mean of other litter items by year 2020/2021. The analysis visualised in the figure shows no significant difference (´ns`) in the amount of other litter items found in 2020 and 2021.

4.3.3.7 Concluding insights: temporal patterns of marine litter obtained from the MEDITS survey

In the analysis of the temporal distribution of total litter and the different litter categories, both ´total litter` and ´plastic litter` items showed statistical significance in relation to the amount of litter items found in 2020 and 2021. All other litter categories showed statistical insignificance.

In general, it should be noted that the standard deviations in all analyses of the litter categories were considerably high. This indicates a high degree of dispersion of the data points around the mean, which in turn indicates a significant variance in the data. Consequently, it can be assumed that there are considerable differences between the individual station values (i.e. a high degree of variability). This observation will be further explored and interpreted in the discussion.

4.3.4 Depth-related distribution

The following study conducts a depth-related analysis of the marine litter found during the MEDITS survey 2020/2021. The results were obtained by means of the two-sided independent *t*-test and are displayed using a bar chart.

4.3.4.1 Total litter

Prior to a detailed examination of each litter category, an analysis of the depth distribution of all marine litter was performed. Levene's test was applied, which resulted in a *p*-value of 0.078 (see Table 32), allowing the assumption of equal variances. Under this assumption, the null hypothesis (H0) is accepted. The means for total litter are 1.41 for shallow depths and 1.65 for deep depths (see Table 33). Assuming the null hypothesis, the accepted *p*-value is 0.321 (Table 33), indicating statistical non-significance. This is also confirmed by the graphical representation in Figure 45. The use of the symbol ´ns` here stands for ´not significant` and shows the result of the two-sided independent *t*-test for all marine litter in shallow and deep waters. Therefore, there is no statistical difference between the occurrence of marine litter in shallow and deep waters.

Table 32: Results of Levene's Test to check for equal variances in total litter data.

Levene's Test

	F	*P*-value
Amount of litter	3.155	.078

Table 33: Statistical data of the two-sided independent t-test performed on total litter.

Independent Samples T-Test

	Depth	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	shallow	76	1.41	1.048	.120
	deep	91	1.65	1.876	.197

t(165) = 0.995, p = 0.321

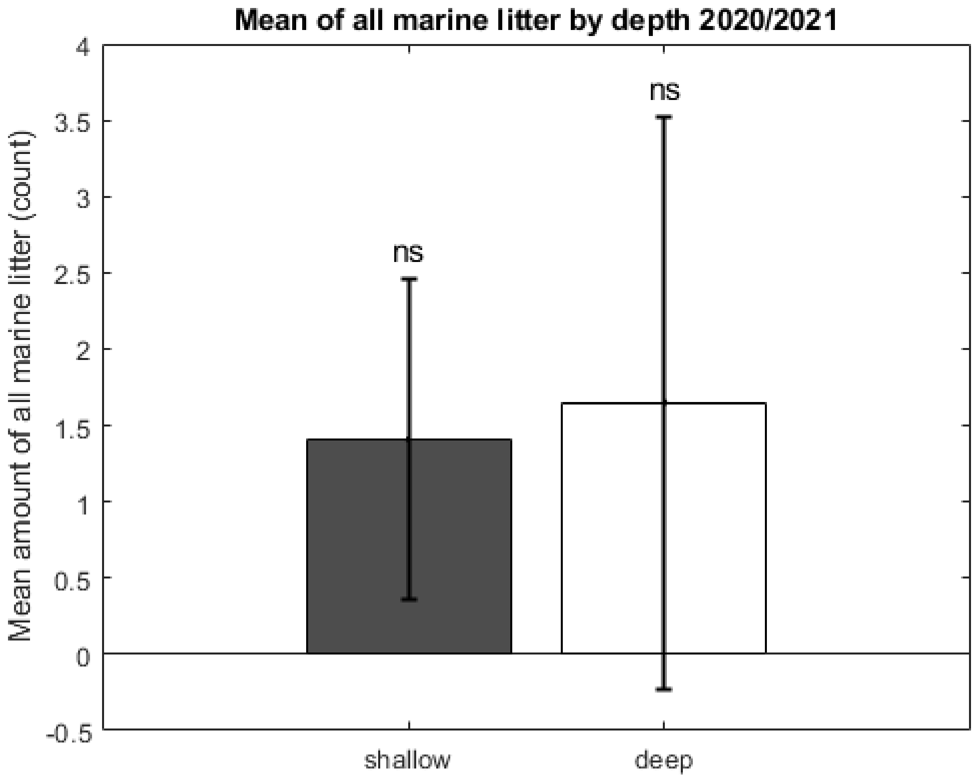

Figure 45: Mean of all marine litter by depth. The analysis visualised in the figure shows no significant difference (´ns`) in the amount of total litter found in shallow and deep depth.

4.3.4.2 Plastic litter

The comparison of the number of plastic items identified in the shallow seafloor (up to 400 m) compared to the deep seafloor (400 - 800 m) resulted in a *p*-value of 0.413 (Table 35), which does not imply statistical significance. Acceptance of this *p*-value was within the null hypothesis, with the prior Levene's test indicating consistent variances with a *p*-value of 0.176 > 0.05 (see Table 34). It should be noted that the mean for shallow water was 1.51 and the mean for deep water was 1.84 (Table 35). Despite these differences, the two-sided independent *t*-test showed no statistical significance, indicating that there were no significant differences in the abundance of plastic litter items between shallow and deep habitats, as visually illustrated in Figure 46.

Table 34: Results of Levene's Test to check for equal variances in plastic litter data.

Levene's Test

	F	*P*-value
Amount of litter	1.856	.176

Table 35: Statistical data of the two-sided independent t-test performed on plastic litter.

Independent Samples T-Test

	Depth	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	shallow	37	1.51	1.325	.218
	deep	63	1.84	2.201	.277

$t(98) = 0.821$, $p = 0.413$

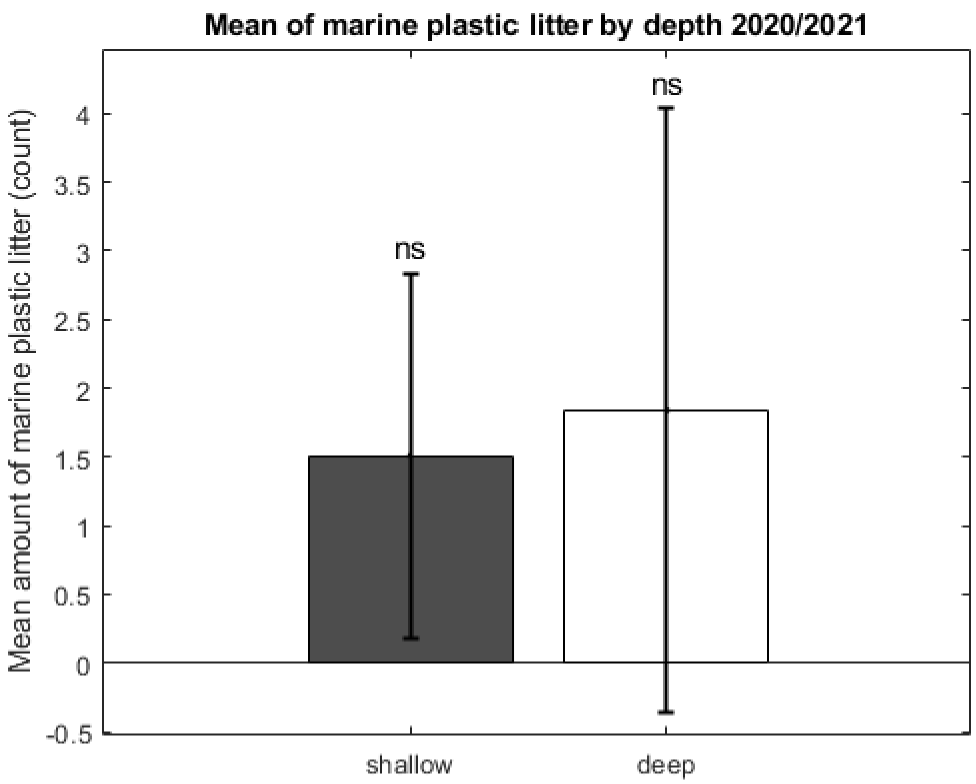

Figure 46: Mean of marine plastic litter items by depth. The analysis visualised in the figure shows no significant difference (´ns`) in the amount of plastic litter items found in shallow and deep depth.

4.3.4.3 Metal litter

The mean value determined from the MEDITS survey for metal litter items at shallow depths is 1.24 items, while at deep depths it is 1.25 items (Table 37). A visual inspection of the quantity distribution in Figure 47 suggests that the quantities are almost identical. This impression is supported by performing the two-sided independent *t*-test. Assuming the null hypothesis (0.765 > 0.05) (Table 36), the test yields a *p*-value of 0.961 (Table 37), indicating statistical insignificance. The graph in Figure 47 illustrates this non-significance by using the symbol ´ns`. Thus, it can be concluded that there is no significant difference in the amount of metal litter items between the shallow and deep seafloor, as characterised in the methodology Section 3.4.

Table 36: Results of Levene's Test to check for equal variances in metal litter data.

Levene's Test

	F	*P*-value
Amount of litter	.091	.765

Table 37: Statistical data of the two-sided independent t-test performed on metal litter.

Independent Samples T-Test

	Depth	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	shallow	21	1.24	.539	.118
	deep	8	1.25	.707	.250

t(27) = 0.049, p = 0.961

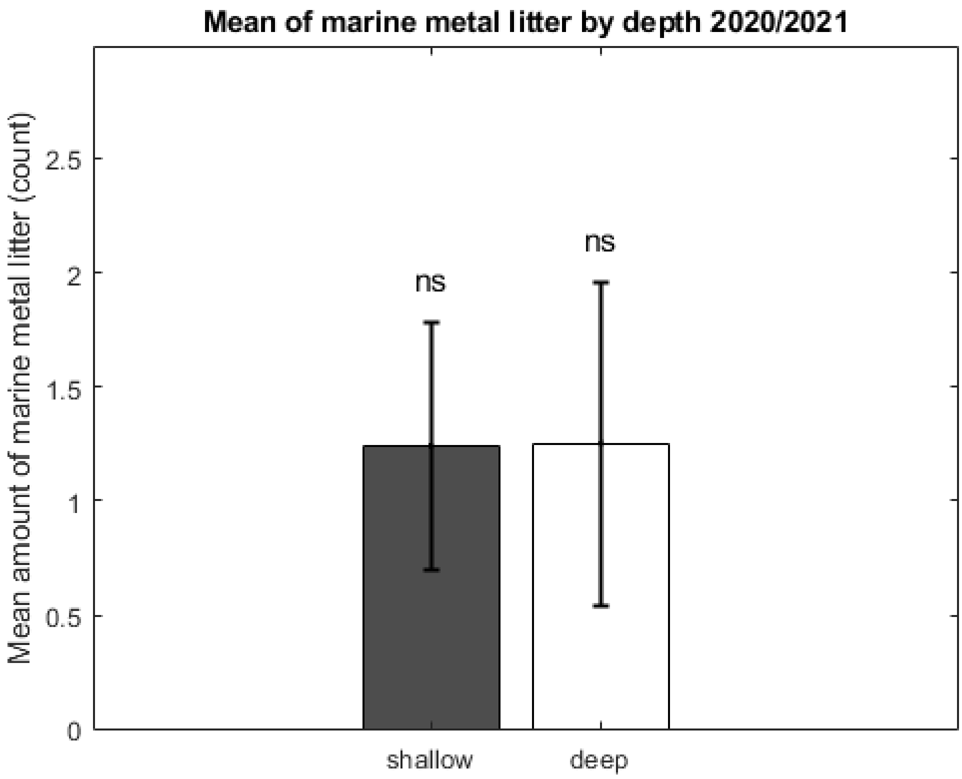

Figure 47: Mean of marine metal litter items by depth. The analysis visualised in the figure shows no significant difference (´ns`) in the amount of metal litter items found in shallow and deep depth.

4.3.4.4 Glass and ceramics litter

The Levene's test for glass and ceramic litter items yields a *p*-value of 0.019 (Table 39). This *p*-value leads to the rejection of the null hypothesis (H0) in favor of the alternative hypothesis (H1), which indicates unequal variances (see Table 38). Under this assumption, the *p*-value of the two-sided independent samples *t*-test (0.169) indicates statistical insignificance for the mean values 1.00 (shallow waters) and 1.22 (deep waters) (Table 39). The statistical result is also shown graphically in Figure 48 and underlines the non-significance by using the symbol ´ns`. This shows that there is no significant discrepancy in the amount of glass and ceramic litter items between shallow and deep seabeds.

Table 38: Results of Levene's Test to check for equal variances in glass and ceramics litter data.

Levene's Test

	F	*P*-value
Amount of litter	7.582	.019

Table 39: Statistical data of the two-sided independent t-test performed on glass and ceramics litter.

Independent Samples T-Test

	Depth	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	shallow	4	1.00	.000	.000
	deep	9	1.22	.441	.147

$t(8.00) = 1.512$, $p = 0.169$

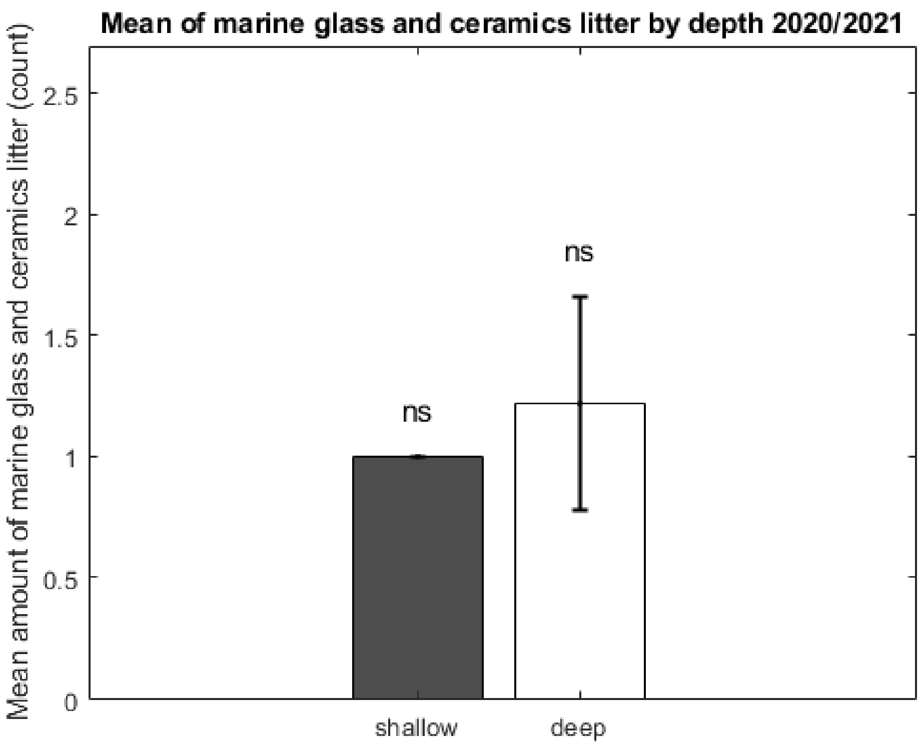

Figure 48: Mean of marine glass and ceramics litter items by depth. The analysis visualised in the figure shows no significant difference (´ns`) in the amount of glass and ceramics litter items found in shallow and deep depth.

4.3.4.5 Cloth and neutral fibres litter

The mean values for cloth and neutral fibres litter items are 1.00 and 1.25 items for shallow and deep waters, respectively (Table 41). Levene's test was performed prior to the statistical test for potential significance, which yielded a *p*-value of 0.138 (Table 40). This leads to the acceptance of the null hypothesis (H0) of equal variances. Accordingly, the accepted *p*-value for the two-sided independent *t*-test is 0.506 (Table 41). This indicates statistical insignificance. This finding is illustrated in Figure 49. As a result, it can be concluded that there is no significant difference in the amount of cloth and neutral fibre litter item deposition detected between shallow and deep seabeds.

Table 40: Results of Levene's Test to check for equal variances in cloth and neutral fibres litter data.

Levene's Test

	F	*P*-value
Amount of litter	2.593	.138

Table 41: Statistical data of the two-sided independent t-test *performed on cloth and neutral fibres litter.*

Independent Samples T-Test

	Depth	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	shallow	4	1.00	.000	.000
	deep	8	1.25	.707	.250

t(10) = 0.690, p = 0.506

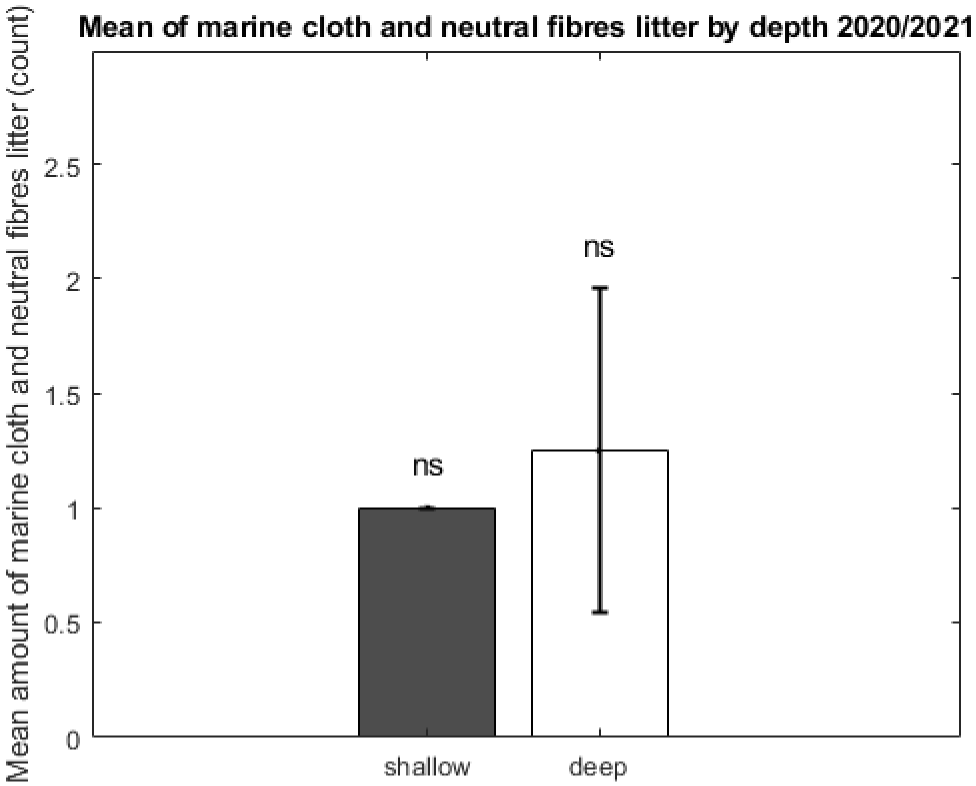

Figure 49: Mean of marine cloth and neutral fibres litter items by depth. The analysis visualised in the figure shows no significant difference (´ns`) in the amount of cloth and neutral fibres litter items found in shallow and deep depth.

4.3.4.6 Other litter

The mean values determined for the last litter category ´other litter` amount to 1.78 items (shallow waters) and 1.00 items (deep waters) according to Table 43. The Levene's test carried out results in a *p*-value of 0.08 (Table 42), which supports the assumption of the null hypothesis, as 0.08 > 0.05. This results in an accepted *p*-value of 0.359 for the two-sided independent samples *t*-test (see Table 43), which indicates statistical non-significance between the ´shallow` and ´deep` groups. This non-significance is also illustrated geographically in Figure 50 by the use of the label ´ns`. It can therefore be concluded that there is no significant difference in the amount of ´other litter` identified between deep and shallow sea depths.

Table 42: Results of Levene's Test to check for equal variances in other litter data.

Levene's Test

	F	*P*-value
Amount of litter	3.881	.080

Table 43: Statistical data of the two-sided independent t-test performed on other litter.

Independent Samples T-Test

	Depth	N	Mean	Std. Deviation	Std. Error Mean
Amount of litter	shallow	9	1.78	1.093	.364
	deep	2	1.00	.000	.000

$t(9) = 0.966$, $p = 0.359$

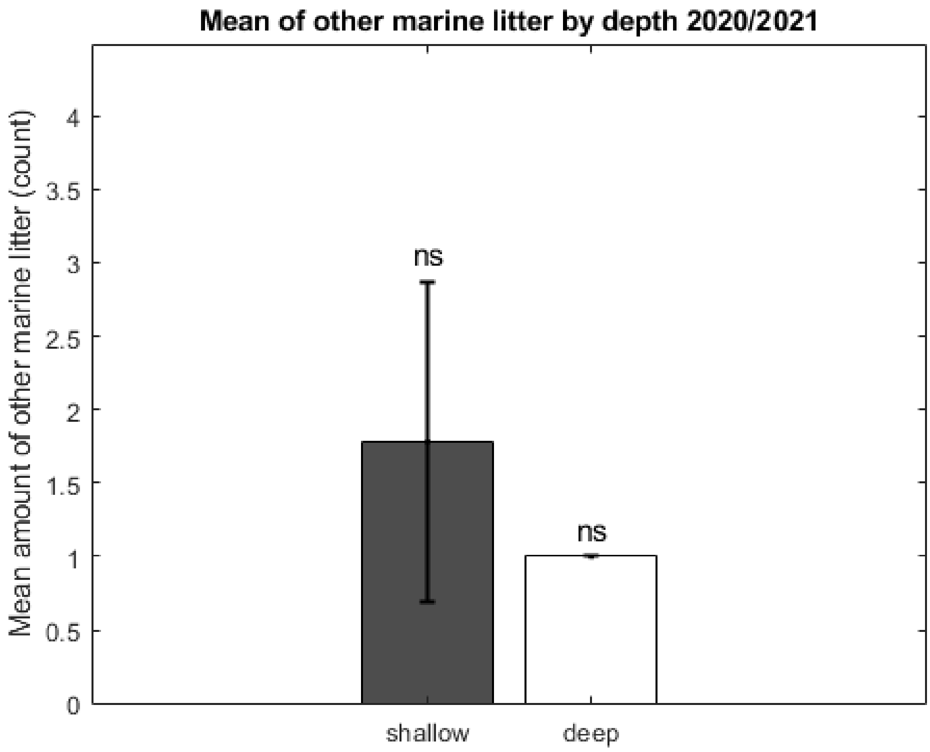

Figure 50: Mean of other litter items by depth. The analysis visualised in the figure shows no significant difference (´ns`) in the amount of other litter items found in shallow and deep depth.

4.3.4.7 Concluding insights: depth-related patterns of marine litter obtained from the MEDITS survey

Finally, it can be stated that the depth-dependent distribution for total litter categories shows no statistically significant difference between the ´shallow` (0-399m) and ´deep` (400-800m) seabed. Potential explanations for this are examined in detail in the discussion. In this context, attention will be paid to the number of samples in the two categories, as it can be observed that these can be considerably disparate depending on the litter category.

4.4 Overlay of litter amount with sub-surface currents and anthropogenic activities

4.4.1 Subsurface currents

To put the above results in context with the subsurface currents of the Mediterranean Sea, the currents were generated using QGIS, as described in Section 3.5. Overall, the subsurface currents at 1m, 10m, 20m, 50m, 100m, 200m, 500m, and 1000m were plotted. In the maps, the direction of the arrows indicates the direction of the subsurface current, while their length reflects the strength of the current. The stronger the current, the longer the arrow. Each current map shows the average current for a total of 13 months (June 1, 2020 - September 30, 2021).

Looking at the map, it can be observed that the underwater currents are different at each sea depth level. The following is a description of the distinctive features of the subsurface currents at each abovementioned sea depth.

4.4.1.1 Subsurface current 1m

The prevailing underwater current in Figure 51 (here at 1m depth) is characterised by a dominant southward and westward orientation. The occurrence of a gyre northwest of Malta at a depth range of about 250 – 1330m is distinctive (see blue star in Figure 51). This hydrodynamic phenomenon indicates a complex current system that could be influenced by the seafloor topography. There is a strong current in the Malta-Sicily Channel (see yellow star). This could be related to the relatively shallow water depth in the region, which is only ~140m here. Furthermore, in the southwestern part of Malta a zone can be identified where currents of different directions meet and converge and thereby create a convergence zone (see green star).

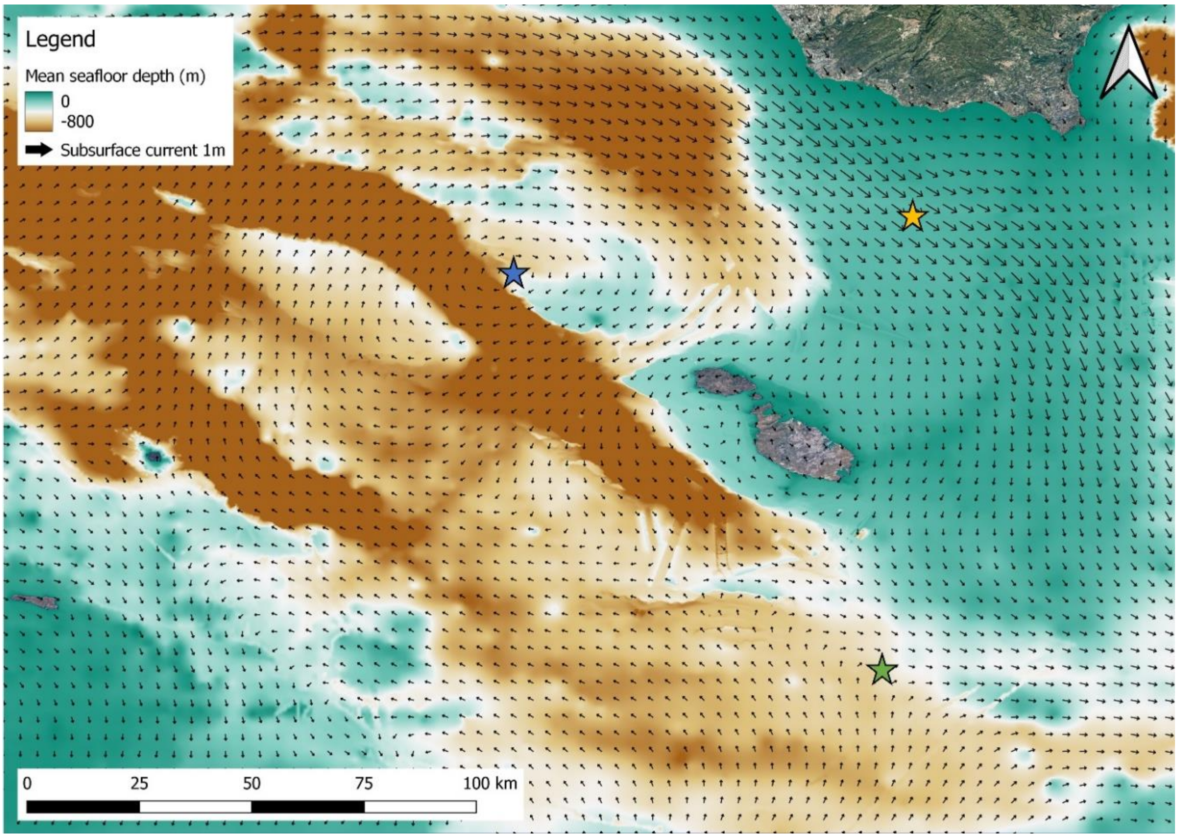

Figure 51: Subsurface currents around the Maltese Islands at 1m depth. The stars indicate distinctive observations: (1) blue star: gyre, (2) yellow star: strong/weak current, (3) green star: convergence zone. Source: (Copernicus Marine Service, 2020, 2021).

4.4.1.2 Subsurface current 10m

The predominant flow direction of the subsurface current at a depth of 10m shows an orientation to the south and west, as can be seen in Figure 52. In the region northwest of Malta, a similar gyre to that observed for the subsurface current at 1m is observed (see blue star). Along the western coast of the Maltese islands, another gyre can be identified, but it is in shallower waters and of smaller extent, indicated by a blue star in Figure 52. The channel between Malta and Sicily shows strong currents in a southeasterly direction (see yellow star). There are no other areas of significantly increased or decreased current velocities. However, at a depth of 10m, the same current convergence zone is observed as at a depth of 1m, located southwest of Malta (see green star).

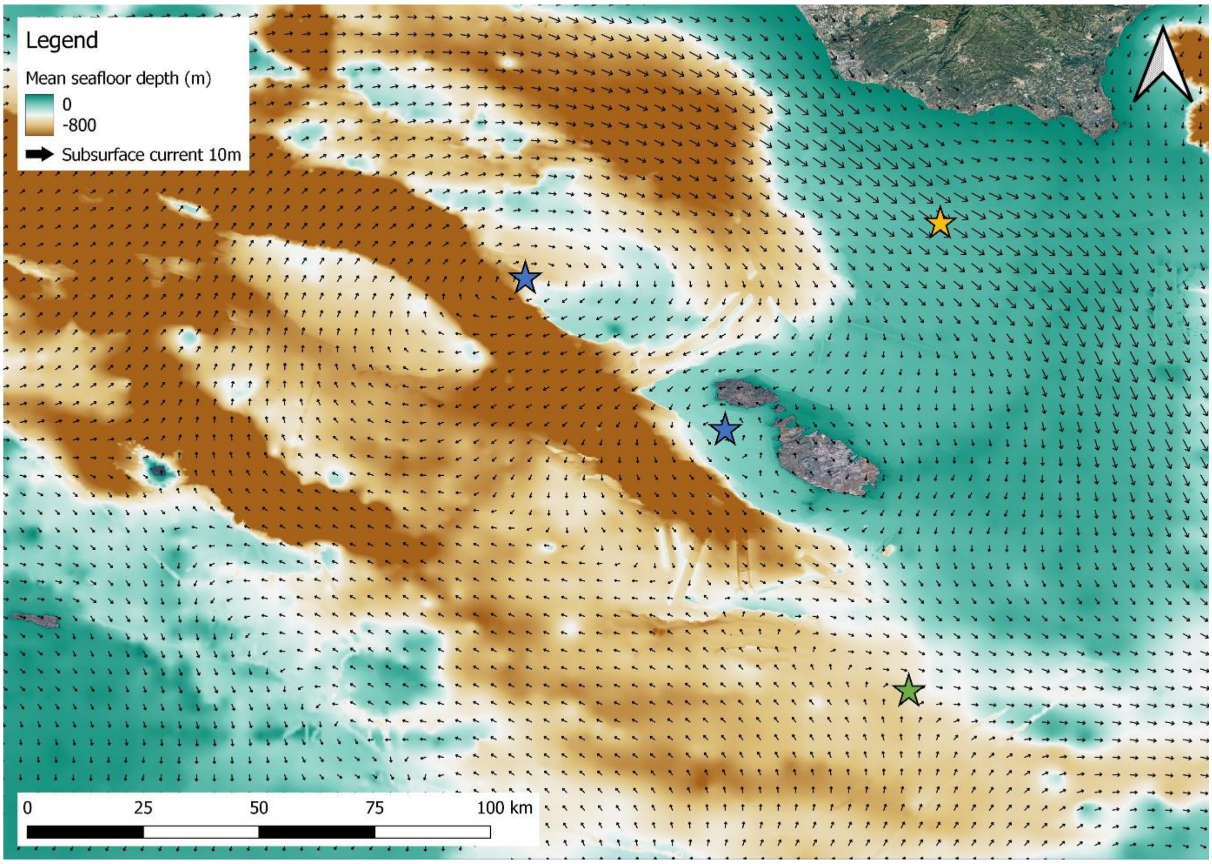

Figure 52: Subsurface currents around the Maltese Islands at 10m depth. The stars indicate distinctive observations: (1) blue star: gyre, (2) yellow star: strong/weak current, (3) green star: convergence zone. Source: (Copernicus Marine Service, 2020, 2021).

4.4.1.3 Subsurface current 20m

The subsurface current at a depth of 20m shows a clear orientation to the south and west. Analogous to the subsurface current at 10m, two notable gyres can be identified (see blue stars). The first is located northwest of Malta in deeper waters, while the second is localised along the western coast of Malta and Gozo in shallower waters (Figure 53). Moreover, the Malta-Sicily Channel shows a remarkably pronounced current that shifts significantly in a southeasterly direction (see yellow star). The only observable current convergence zone at 20m depth remains the one already detected at 10m and 1m, indicated by a green star.

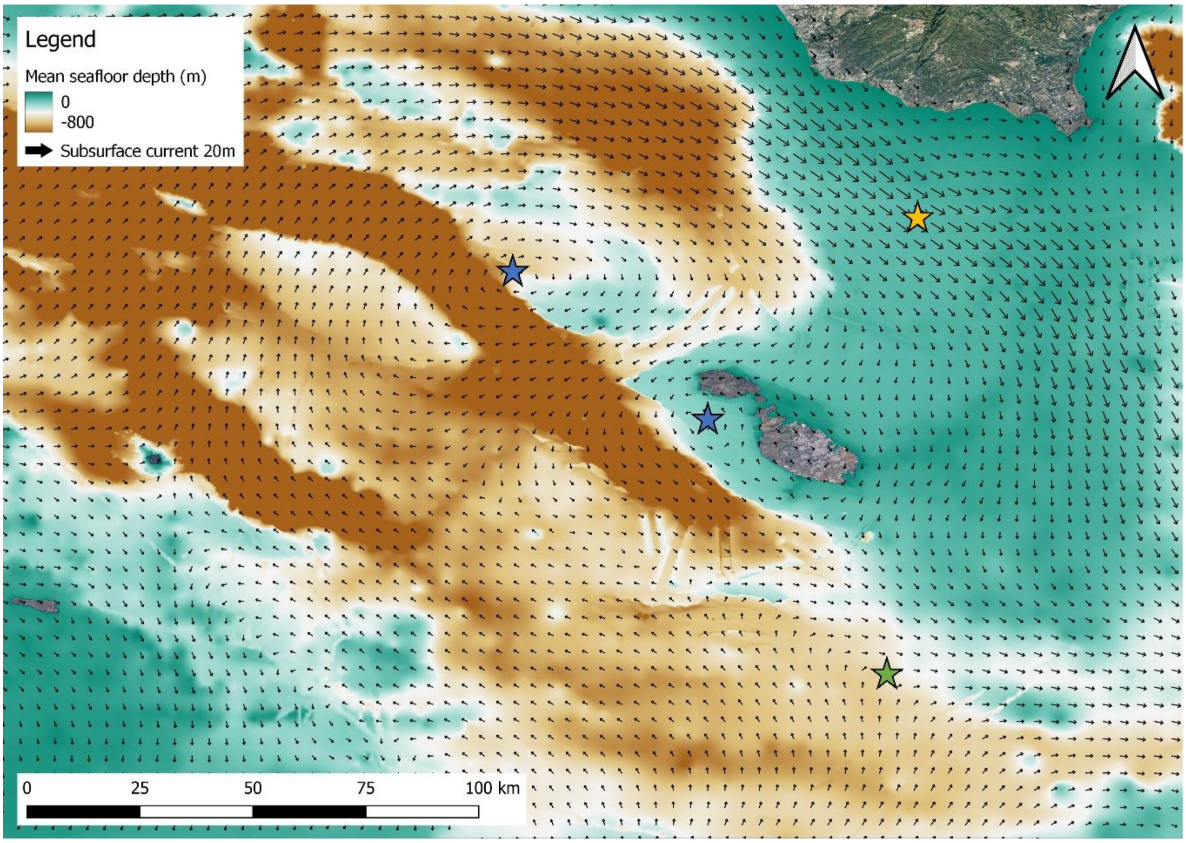

Figure 53: Subsurface currents around the Maltese Islands at 20m depth. The stars indicate distinctive observations: (1) blue star: gyre, (2) yellow star: strong/weak current, (3) green star: convergence zone. Source: (Copernicus Marine Service, 2020, 2021).

4.4.1.4 Subsurface current 50m

Analogous to the subsurface currents at other depths, the current at 50m water depth also shows a predominant flow direction in a southerly and westerly direction. Two notable gyres are observed: the first is located northwest of Malta at a depth of ~400m, the second along the western coast of Malta and Gozo (see blue stars in Figure 54). The latter gyre manifests itself in shallower waters and has a smaller size compared to the first gyre but reaches a larger dimension at a depth of 50 meters compared to the previous depths (1m-20m). Highlighted areas with particularly high or low current strengths are the Malta-Sicily Channel and another area south of Malta (see yellow stars). Here, there is a stronger current extending eastward. The current convergence zone at 50m depth corresponds to that observed at the previously described depths (see green star).

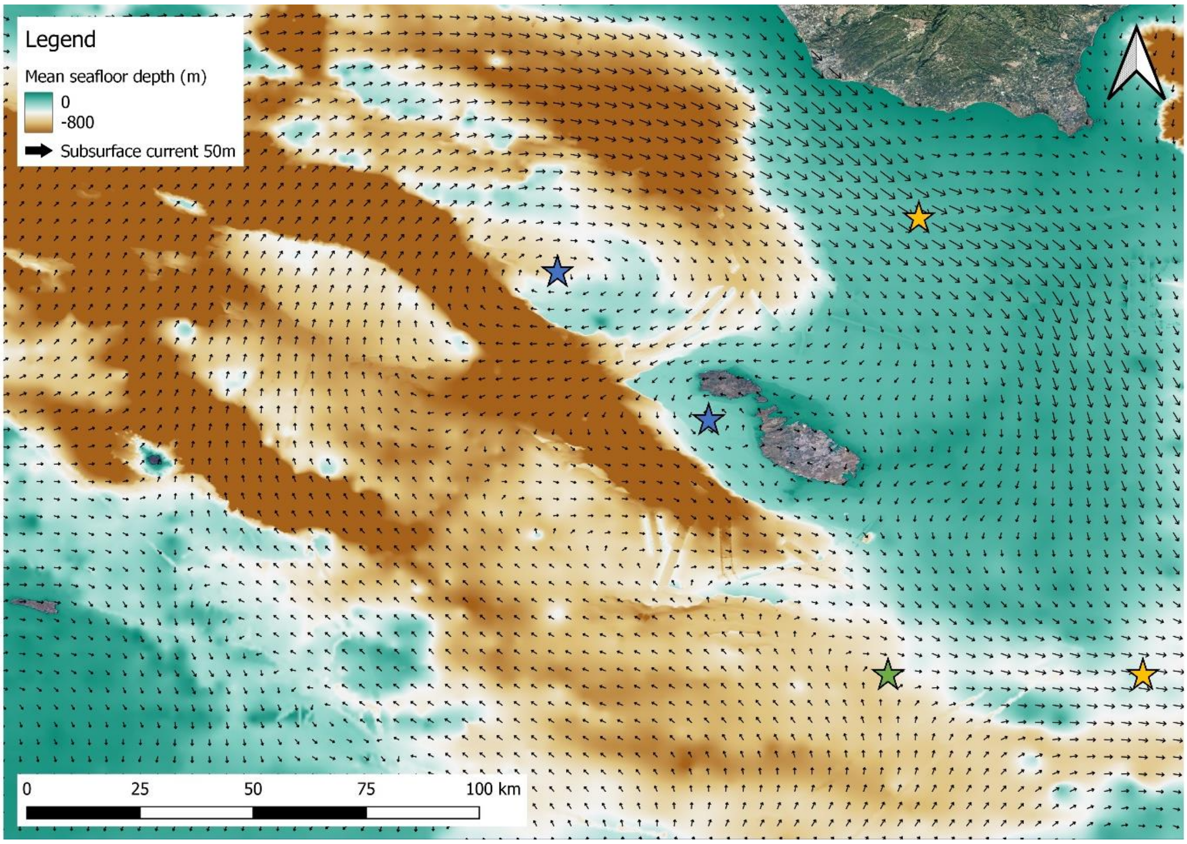

Figure 54: Subsurface currents around the Maltese Islands at 50m depth. The stars indicate distinctive observations: (1) blue star: gyre, (2) yellow star: strong/weak current, (3) green star: convergence zone. Source: (Copernicus Marine Service, 2020, 2021).

4.4.1.5 Subsurface current 100m

In the subsurface current at 100m depth, a significant change in the dominant flow direction is observed for the first time, which is now oriented both southward and northward. There are also significant changes in the gyre distribution and structure at this depth. The larger gyre, which has already been seen at depths 1m-50m, persists although it moves to the east. However, the smaller gyre west of Malta and Gozo is no longer visible. Instead, a newly formed gyre far off the western coast of Malta is observed (see blue stars in Figure 55). The Malta-Sicily Channel again indicates an area of particularly high current velocity. In addition, intensified currents are observed south of Malta, moving eastward (see yellow stars). The current convergence zone at 100m depth corresponds to that already observed in shallower current areas (see green star in Figure 55).

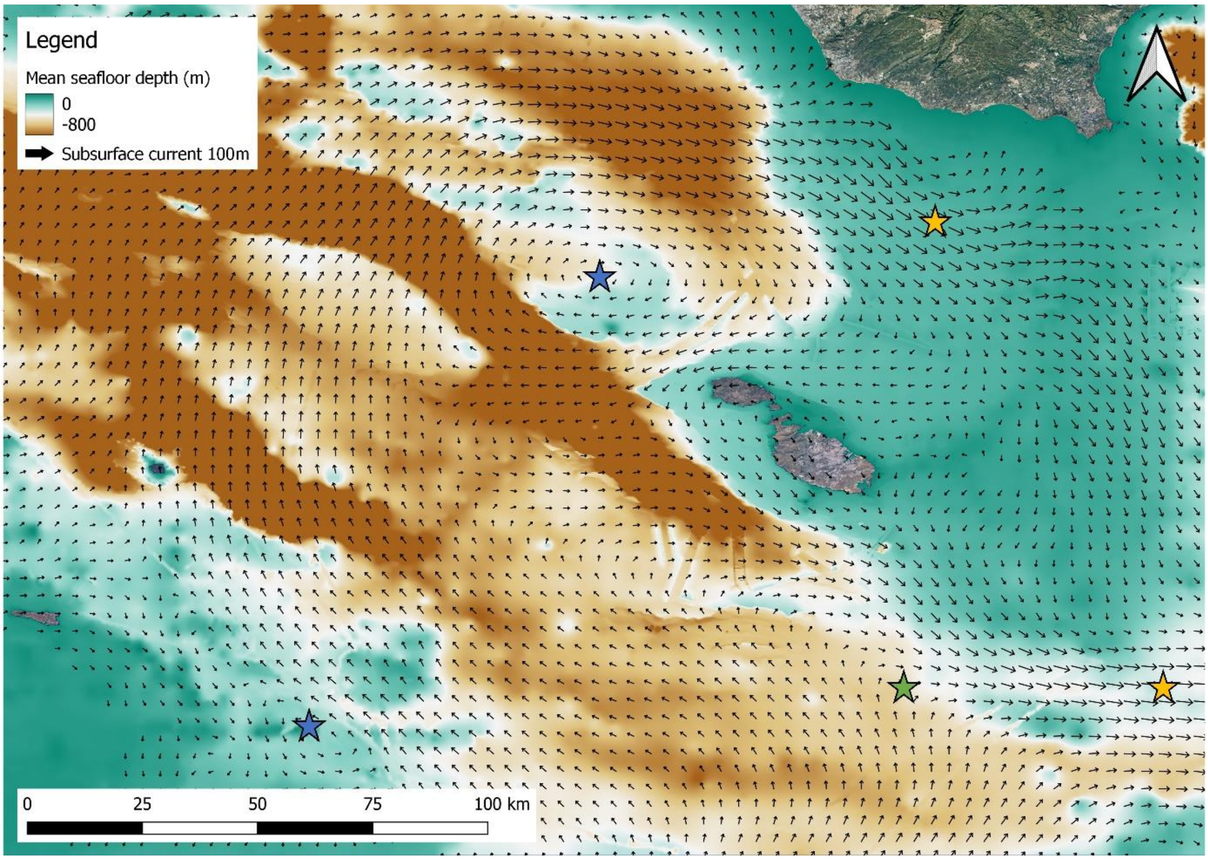

Figure 55: Subsurface currents around the Maltese Islands at 100m depth. The stars indicate distinctive observations: (1) blue star: gyre, (2) yellow star: strong/weak current, (3) green star: convergence zone. Source: (Copernicus Marine Service, 2020, 2021).

4.4.1.6 Subsurface current 200m

At 200m the subsurface current has no dominant direction. However, west of Malta and Gozo there is a change in the direction of the currents (indicated by an orange star in Figure 56). A prominent gyre is the gyre we already know from previous depths. However, two smaller gyres are also developing west of the Maltese islands (see blue stars in Figure 56). The areas of strong and weak currents are changing as well. Strong currents are observed in the west and south of Malta (see yellow stars). The known current convergence zone is no longer visible.

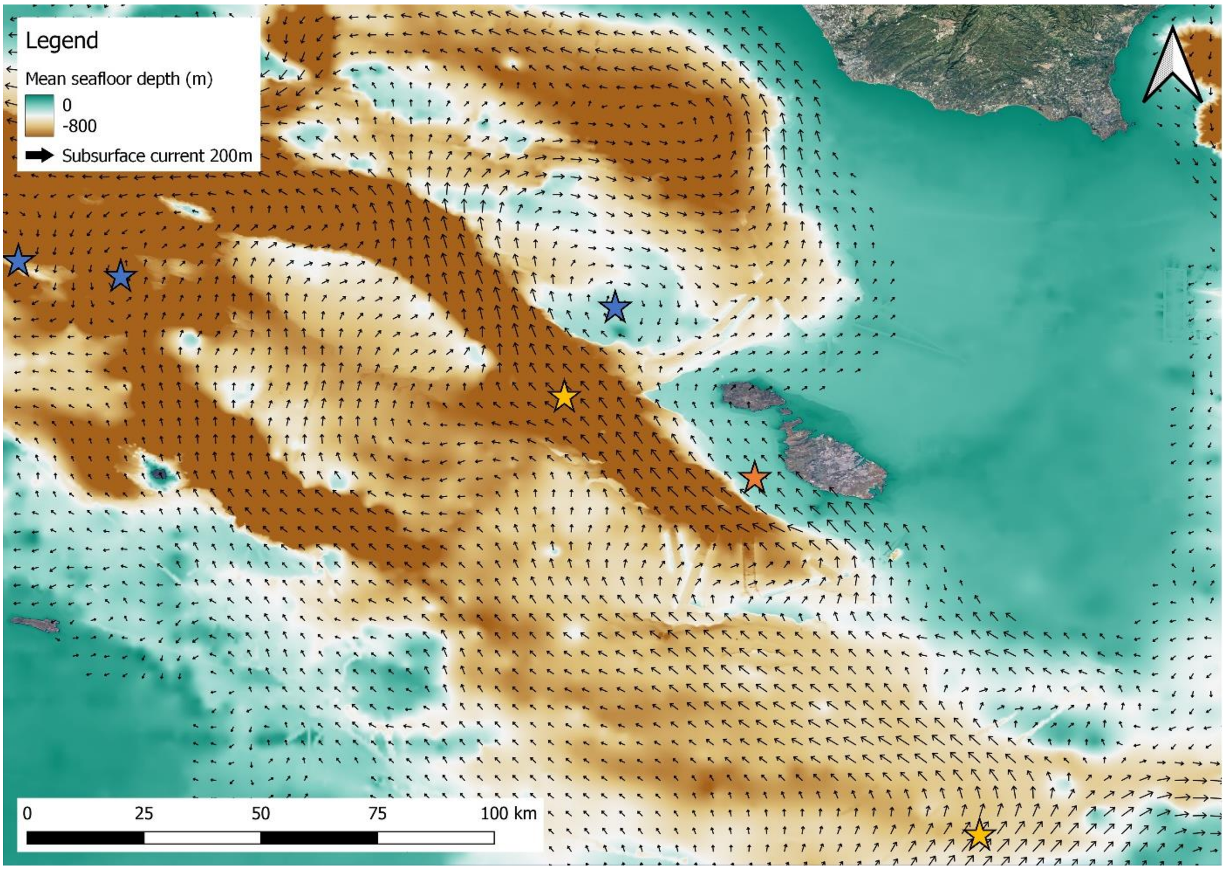

Figure 56: Subsurface currents around the Maltese Islands at 200m depth. The stars indicate distinctive observations: (1) blue star: gyre, (2) yellow star: strong/weak current, (3) green star: convergence zone, (4) orange star: change in flow direction. Source: (Copernicus Marine Service, 2020, 2021).

4.4.1.7 Subsurface current 500m

The subsurface current at 500m depth shows no dominant flow direction. Notable gyres manifest themselves in the form of two small gyres west of Malta (see blue stars in Figure 57). In terms of areas of significantly low or high current velocities, there is only one small area of strong current in the immediate vicinity of Malta as well as south of Malta (see yellow stars). A new current convergence zone can be identified south of Malta and is indicated in Figure 57 using a green star.

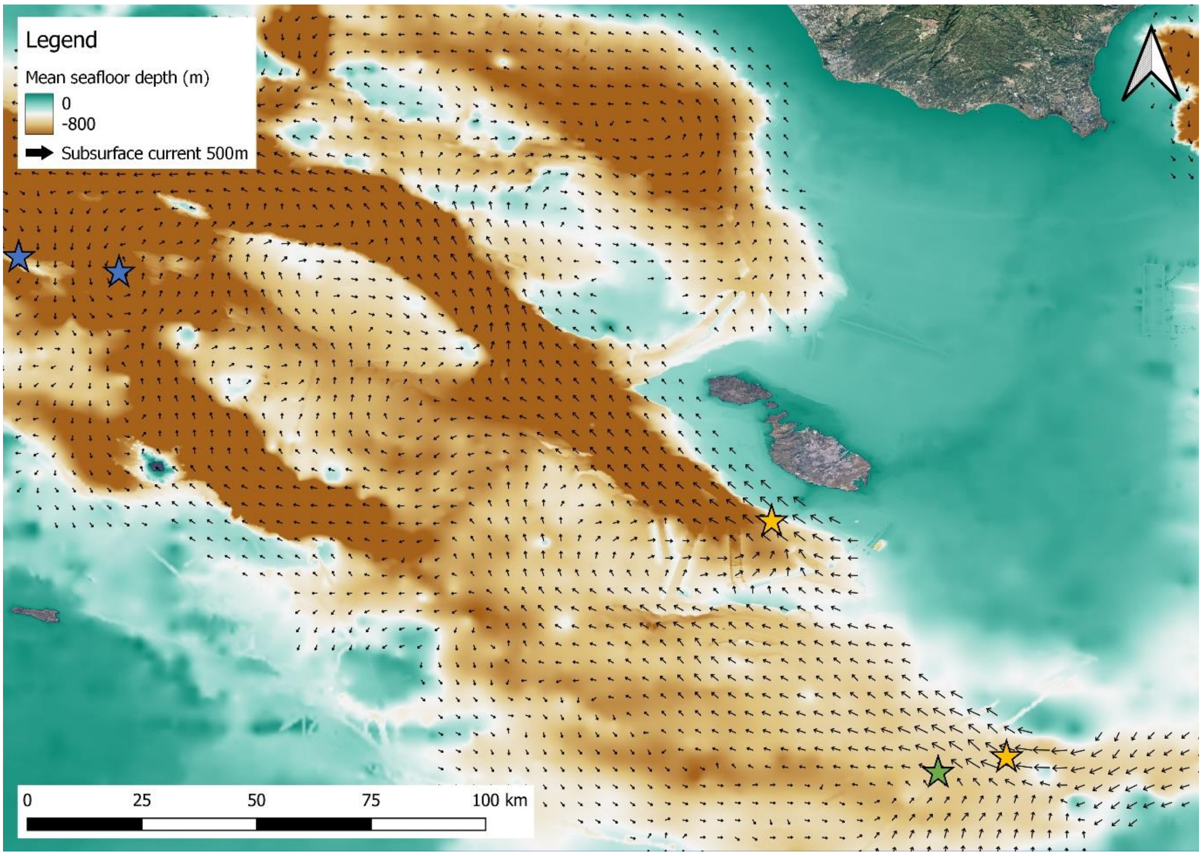

Figure 57: Subsurface currents around the Maltese Islands at 500m depth. The stars indicate distinctive observations: (1) blue star: gyre, (2) yellow star: strong/weak current, (3) green star: convergence zone. Source: (Copernicus Marine Service, 2020, 2021).

4.4.1.8 Subsurface current 1000m

The deepest subsurface current considered in this study is at a depth of 1000m and shows no dominant flow direction. The direction of the current is highly irregular. However, there is a change in flow direction west of Malta at this depth (see orange star in Figure 58). The is no distinctive gyre at this depth. It is also noticeable that the currents at this depth are generally more pronounced compared to the previously analysed depths and have several convergence and divergence zones (see green stars in Figure 58). Overall, the condition at this depth can be characterised as irregular and does not show uniform dominance.

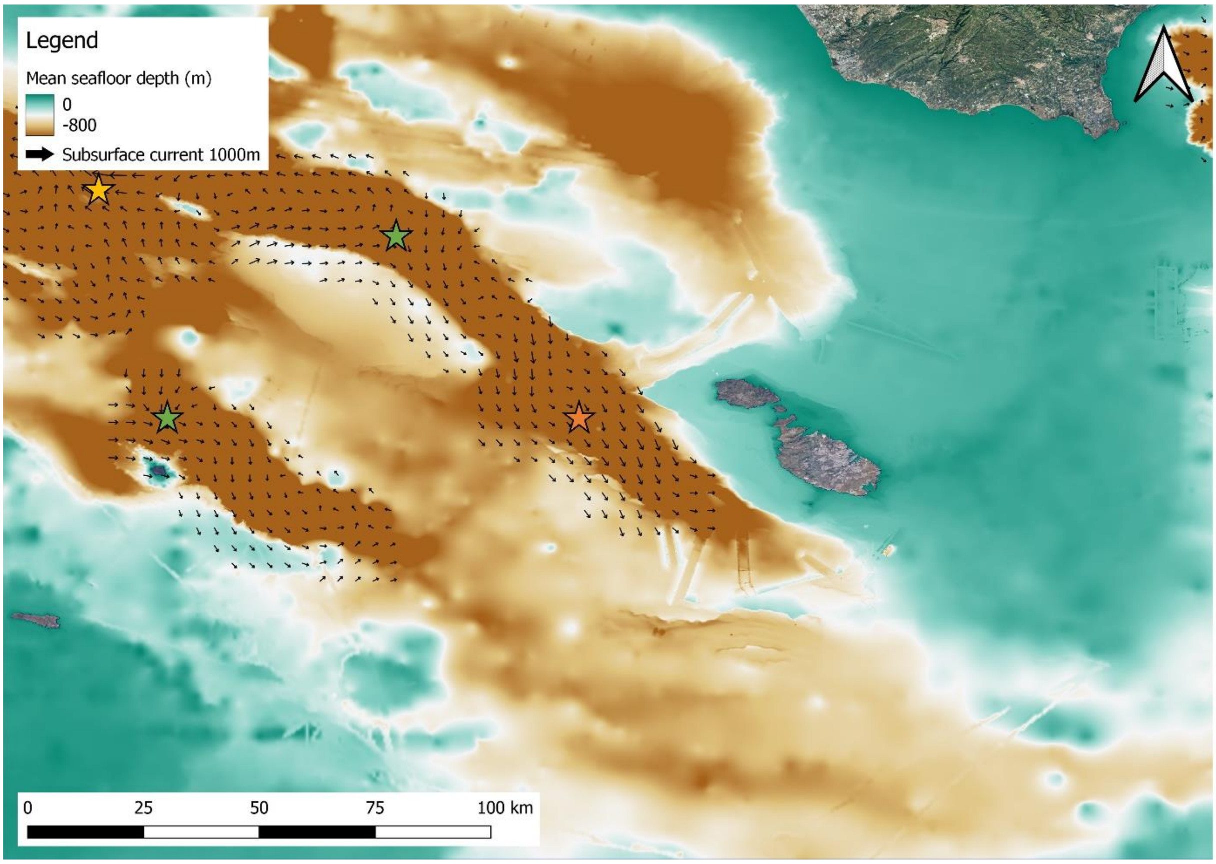

Figure 58: Subsurface currents around the Maltese Islands at 1000 m depth. The stars indicate distinctive observations: (1) yellow star: strong/weak current, (2) green star: convergence zone, (3) orange star: change in flow direction. Source: (Copernicus Marine Service, 2020, 2021).

4.4.1.9 Overlay with marine litter quantities

Two observations can be made regarding the overlay with litter quantities: (1) One of the gyres located in the immediate vicinity of the west coast of Malta (visible from 1m-50m subsurface currents) (i.e. blue star in Figure 54) correlates with a significant occurrence of marine litter on the seafloor in 2020 and 2021. (2) In addition, the marine litter detected in the Malta-Sicily Channel on the eastern side of Malta manifests itself in a region influenced by strong currents from the northwest. This suggests the hypothesis of a possible origin of marine litter found from this direction. These occurrences can be seen in Figure 59. No further substantial observations can be made.

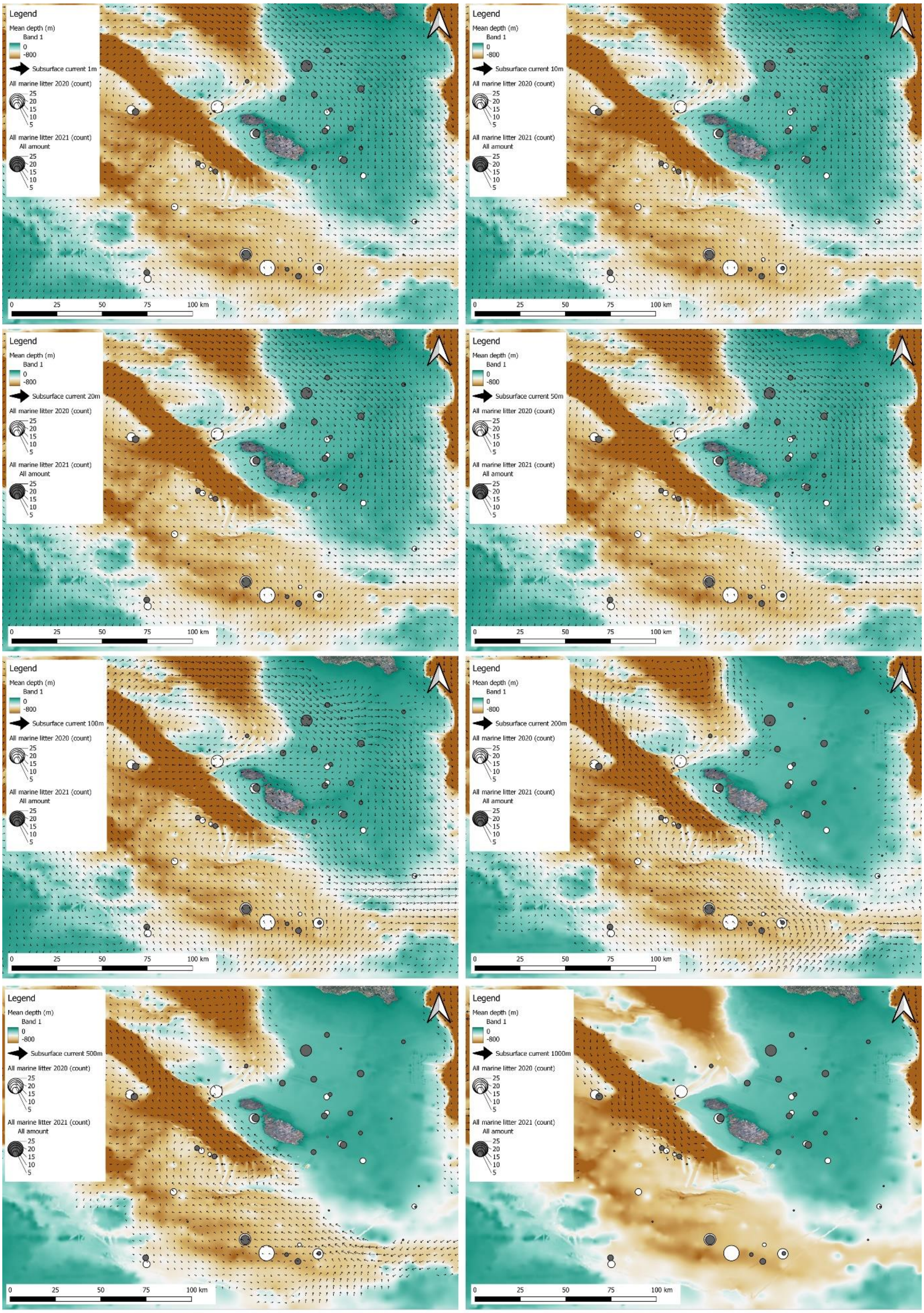

Figure 59: The overlay of marine litter amounts (in count) found in 2020 and 2021 with the local subsurface currents going from 1m-1000m in depth. Source: (Copernicus Marine Service, 2020, 2021).

4.4.1.10 Concluding insights: depth-related patterns of marine litter obtained from the MEDITS survey

The extent to which the collected results of the subsurface currents around the Maltese Islands will provide insights for understanding the spatial distribution of marine litter in the investigated region is unclear and will be analysed and interpreted in more detail in the discussion in the context of this master's thesis.

4.4.2 Anthropogenic factors

The anthropogenic factors of influence, including trawling areas, bunkering zones, Natura 2000 areas, shipping traffic, aquaculture facilities, swimming zones and fishing activities, were overlaid below with the geographical location and quantity of the identified litter categories to explore possible correlations. It should be noted that there is a high degree of connectivity in the marine domain. Therefore, larger aggregations that are not directly in an area of anthropogenic activity, but close to it, are also emphasised. The consideration of larger aggregations in the vicinity of activity areas, despite the lack of direct assignment to these areas, is justified by the possibility of influence from these activities or from underwater currents.

4.4.2.1 Trawling

Figure 60 shows the officially amended trawl areas around the Maltese Islands. The largest of these areas extends southeast of Malta and a total of 12 different trawl areas have been identified. With the exception of two areas west of Malta, they are all in shallower waters.

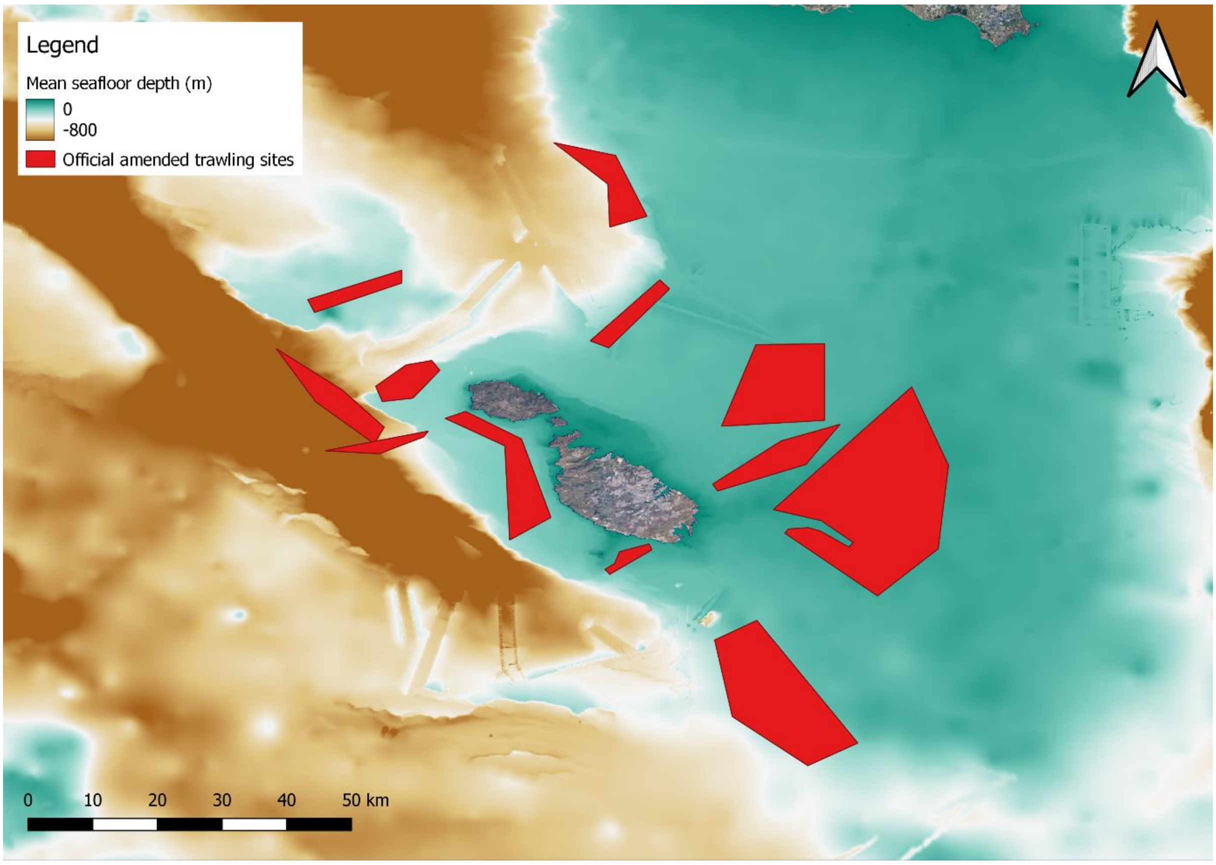

Figure 60: Areas of officially registered trawling activities around the Maltese Islands. Source: AMAre (Actions for Marine Protected Areas) project provided by the Oceanography Malta Research Group.

The officially designated trawl areas were overlaid on the identified litter categories and the observations are described below. Interestingly, no significant presence of certain litter categories was detected in the officially amended trawl areas (Figure 61). In the case of metal marine litter, an increased abundance was observed near the larger trawl areas east of Malta (see Figure 61). In contrast, almost no significant accumulation of plastic litter was observed in the trawl areas (Figure 61). However, this observation could be due to the influence of subsurface currents, with a possible correlation being discussed in more detail in the following discussion.

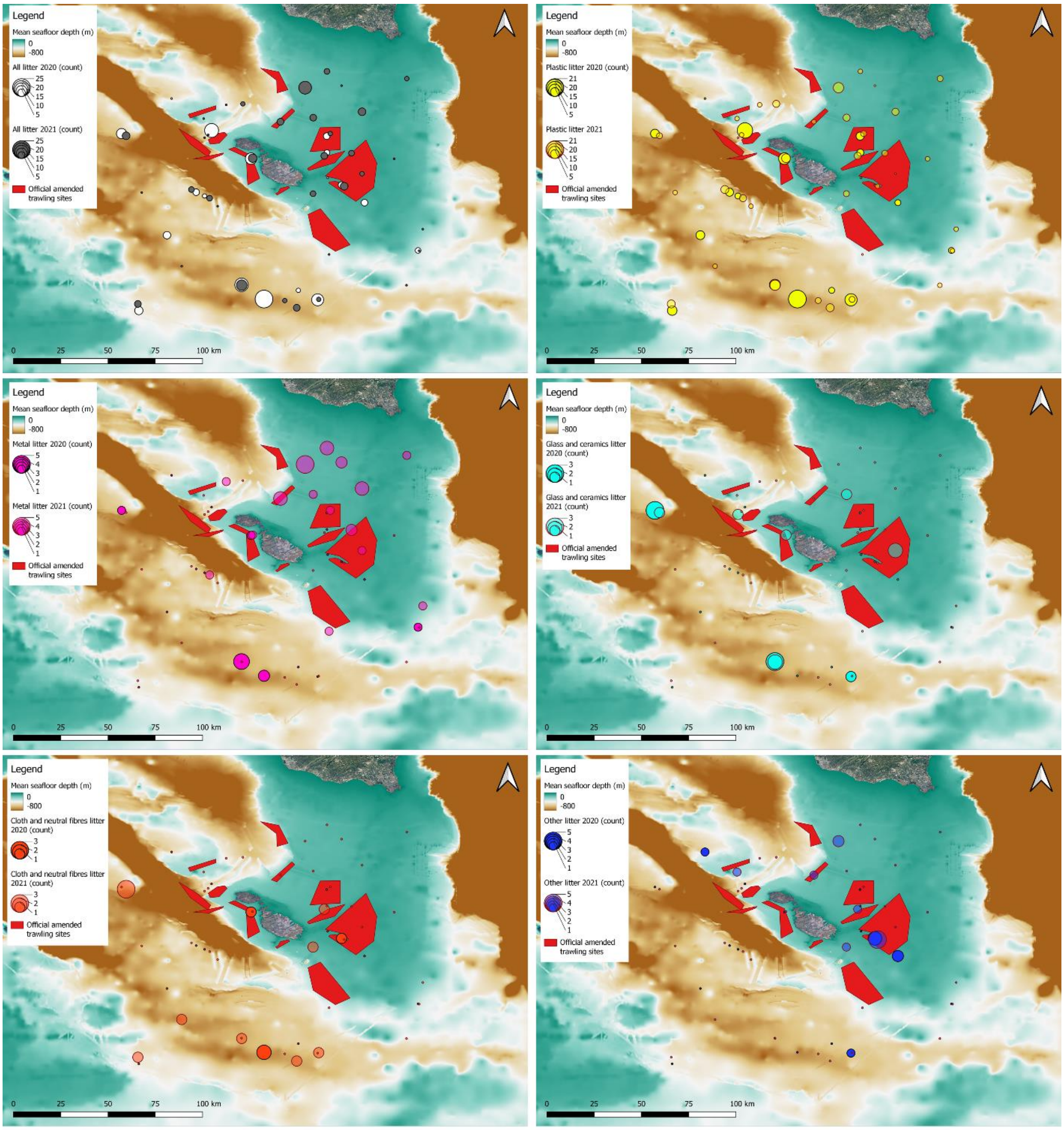

Figure 61: Areas of officially registered trawling areas around the Maltese Islands superimposed with the marine litter (in their categories) found during the MEDITS survey. Source: AMAre (Actions for Marine Protected Areas) project provided by the Oceanography Malta Research Group.

4.4.2.2 Bunkering zones

The bunkering zones included in this study are located close to the Maltese islands, with most areas located along the east coast as a result of the presence of large ports. However, there are also two smaller bunkering zones along the west coast. All areas, including Hurd's Bank, the main and largest bunkering zone off the coast of Malta, where the transfer of goods between large vessels with different destinations takes place, can be seen in Figure 62.

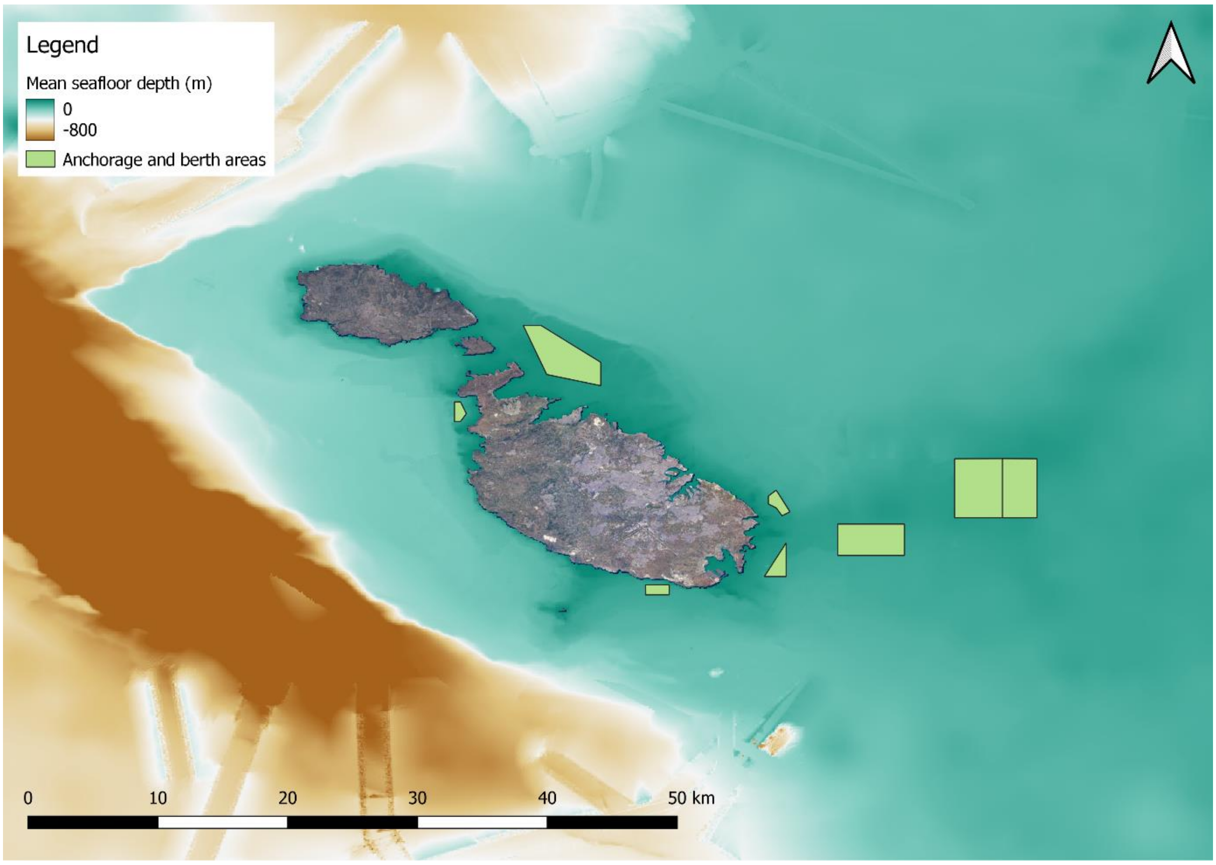

Figure 62: Bunkering zones around the Maltese Islands, including Hurd's Bank. Source: AMAre (Actions for Marine Protected Areas) project provided by the Oceanography Malta Research Group.

With regard to the occurrence of all marine litter categories, it should be noted that only metal litter, other litter and cloth and neutral fiber litter items were quantitatively noticeable in the trawling operations carried out near these areas (see Figure 63). The largest amount of other litter items found in all trawls in the MEDITS survey was in the vicinity of Hurd's Bank and, as described in Table 1, includes items such as capacitors, sponges, limestone slabs (not from fishing gear) and plastic jumbo bags with a capacity of approximately 2 tons. All other categories of marine litter showed no significant presence in the region of the bunkering zones.

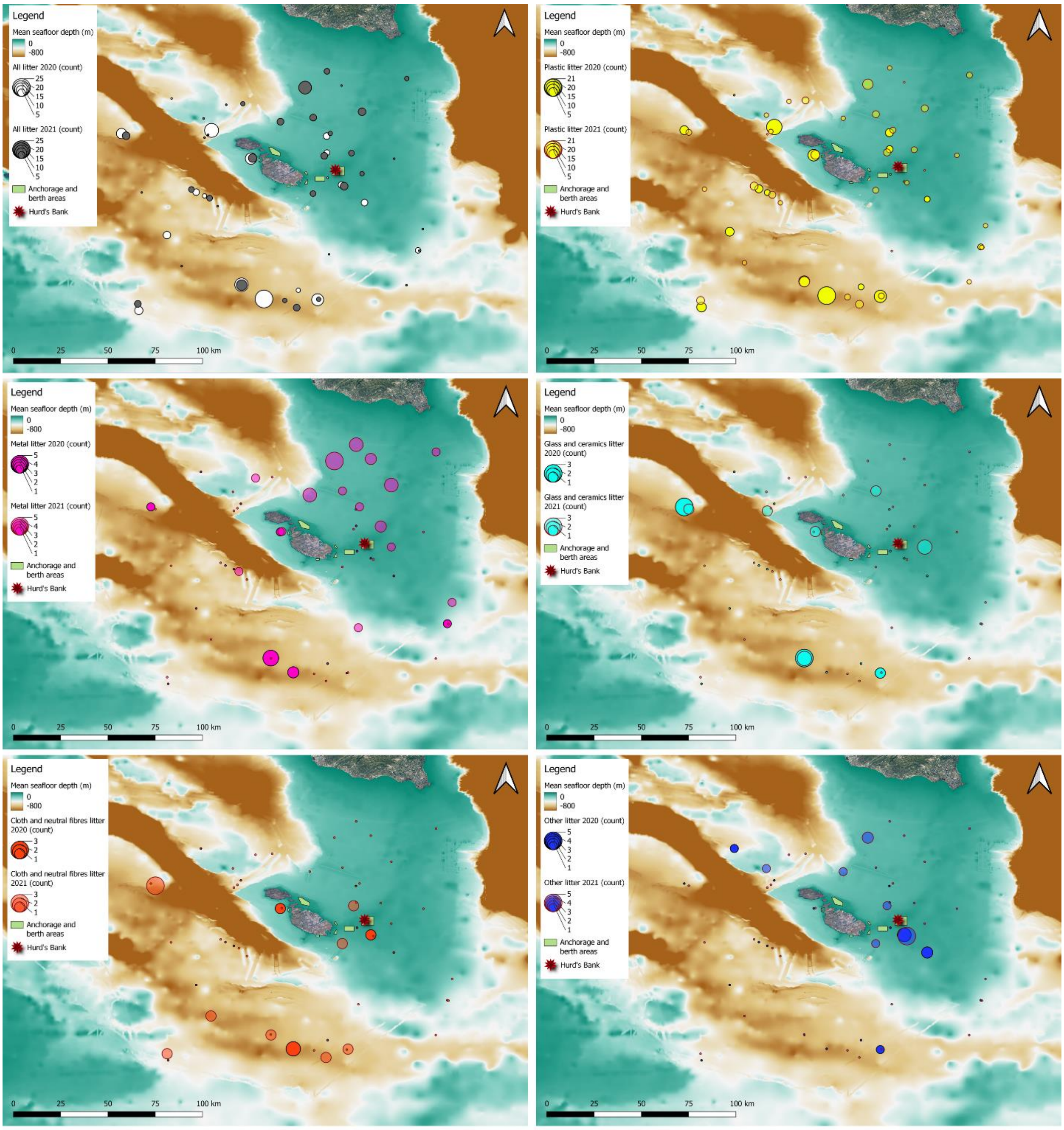

Figure 63: Bunkering zones around the Maltese Islands superimposed with the marine litter (in their categories) found during the MEDITS survey. Source: AMAre (Actions for Marine Protected Areas) project provided by the Oceanography Malta Research Group.

4.4.2.3 Natura 2000 sites

According to the Environmental Resource Authority (ERA), 18 marine sites in Malta have been designated as Marine Protected Areas (MPAs) within the Natura 2000 network (Environment & Resources Authority, n.d.c). These areas are shown in Figure 64.

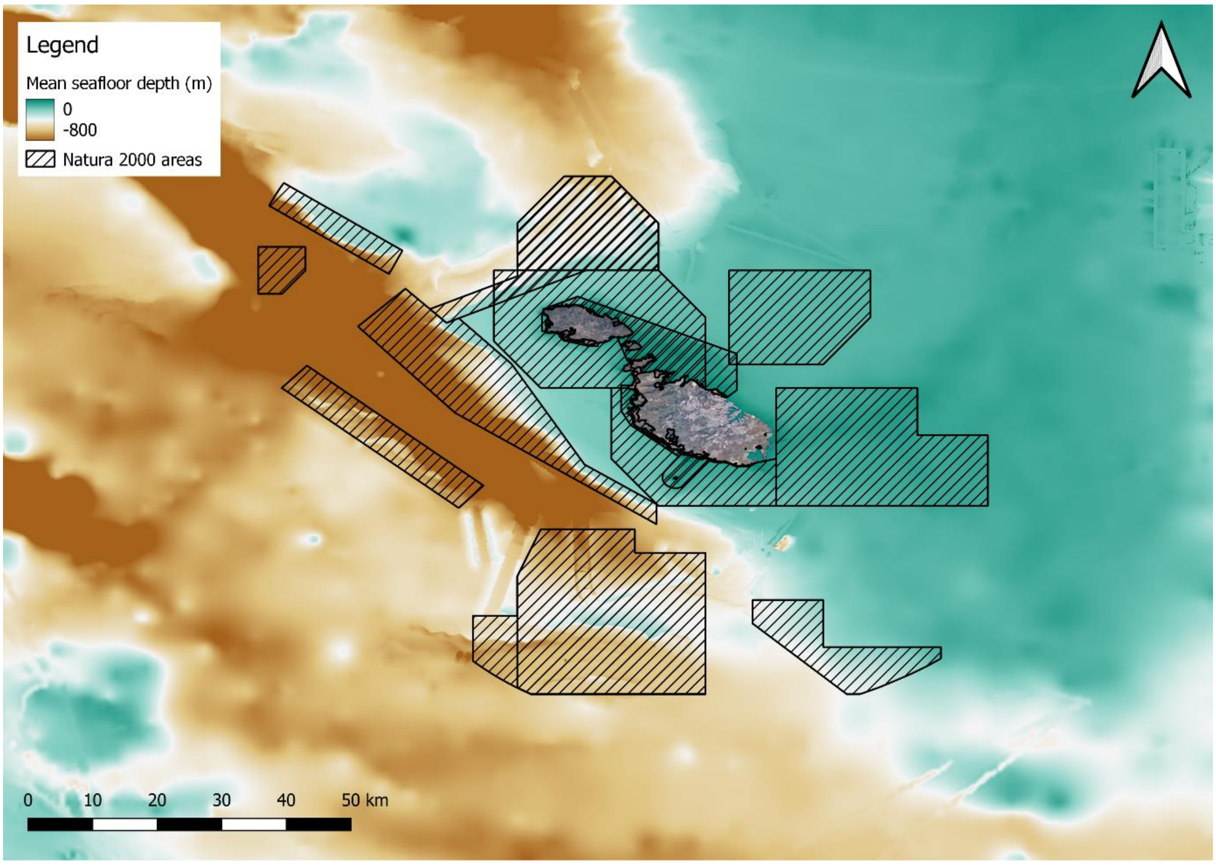

Figure 64: Natura 2000 sites around the Maltese Islands. Source: AMAre (Actions for Marine Protected Areas) project provided by the Oceanography Malta Research Group.

An analysis of the litter categories from the MEDITS survey overlaying these Natura 2000 sites, as visualised in Figure 65, shows that plastic litter, cloth and neutral fiber litter, and other litter items were particularly prevalent in the Natura 2000 areas. The potential impact of this presence on such a repository of Europe's most valuable and threatened species and habitats will be elaborated in the discussion.

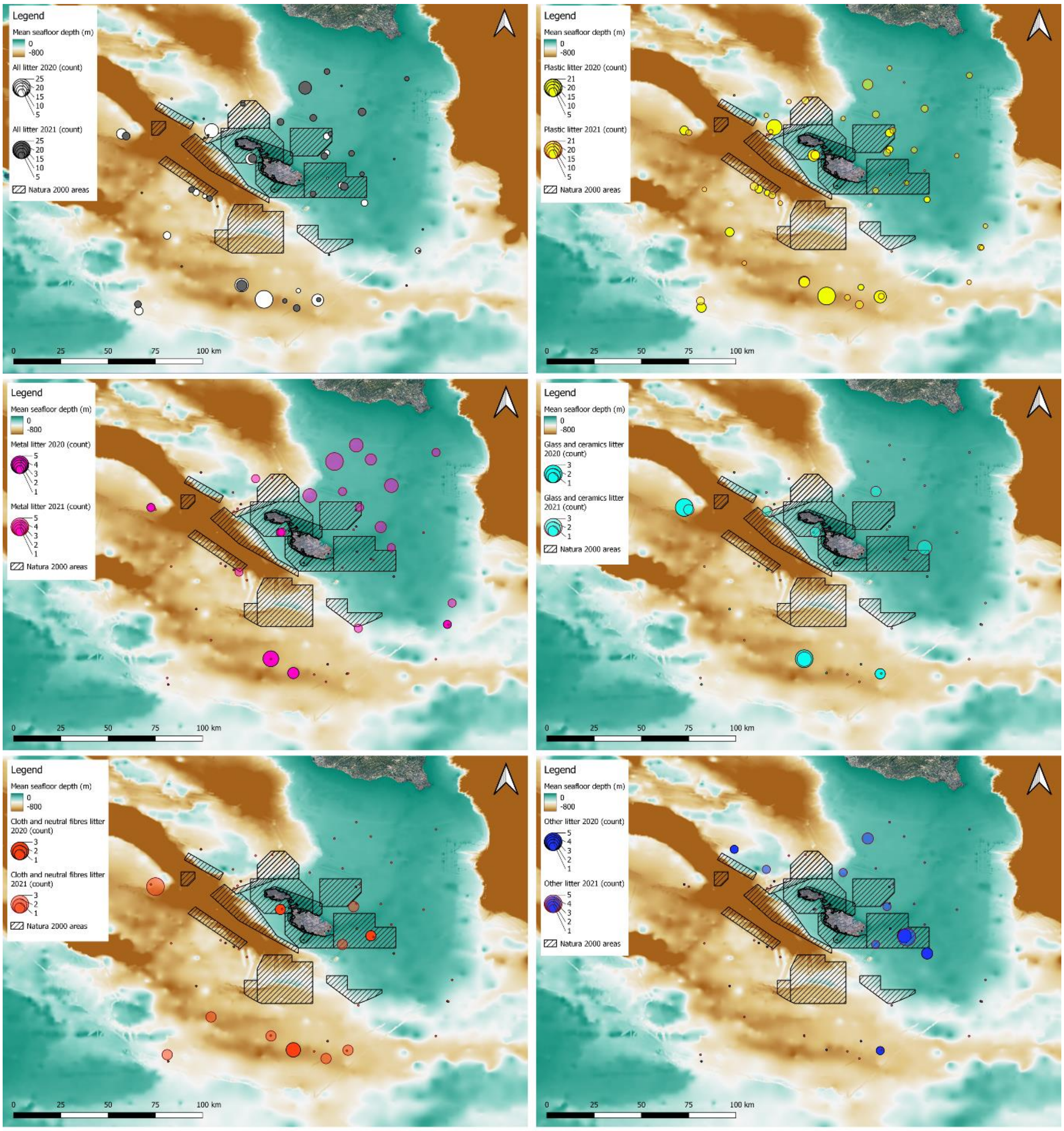

Figure 65: Natura 2000 sites around the Maltese Islands superimposed with the marine litter (in their categories) found during the MEDITS survey. Source: AMAre (Actions for Marine Protected Areas) project provided by the Oceanography Malta Research Group.

4.4.2.4 Ship traffic

The intensity of vessel traffic (in routes per km^2 per year) along the Maltese coast and in the Maltese ports is particularly high. In addition, the Malta-Sicily Channel spanning between Malta and Sicily has a high route density as it is heavily frequented by various vessels and serves as an important transit route (see Figure 66).

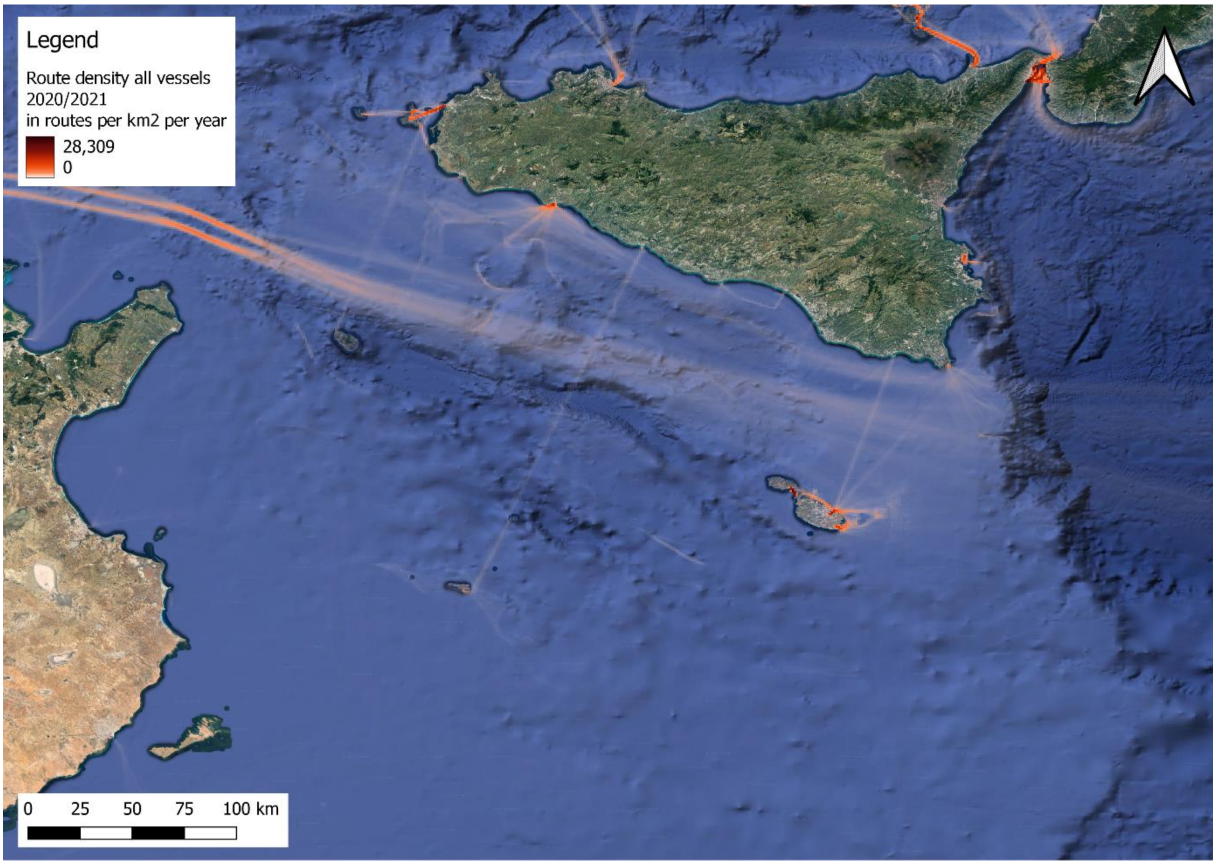

Figure 66: Averaged ship traffic of 2020/2021 (route density of all vessel types) around the Maltese Islands in routes per km² per year. Source: (EMODnet, n.d.)

Looking at the types of marine litter identified in the MEDITS survey, it can be seen that metal litter items, in particular, occur most frequently in the vicinity of shipping lanes (Figure 67). Plastic litter, cloth and neutral fibres litter and other litter items can also be detected in areas with particularly high route density (Figure 67).

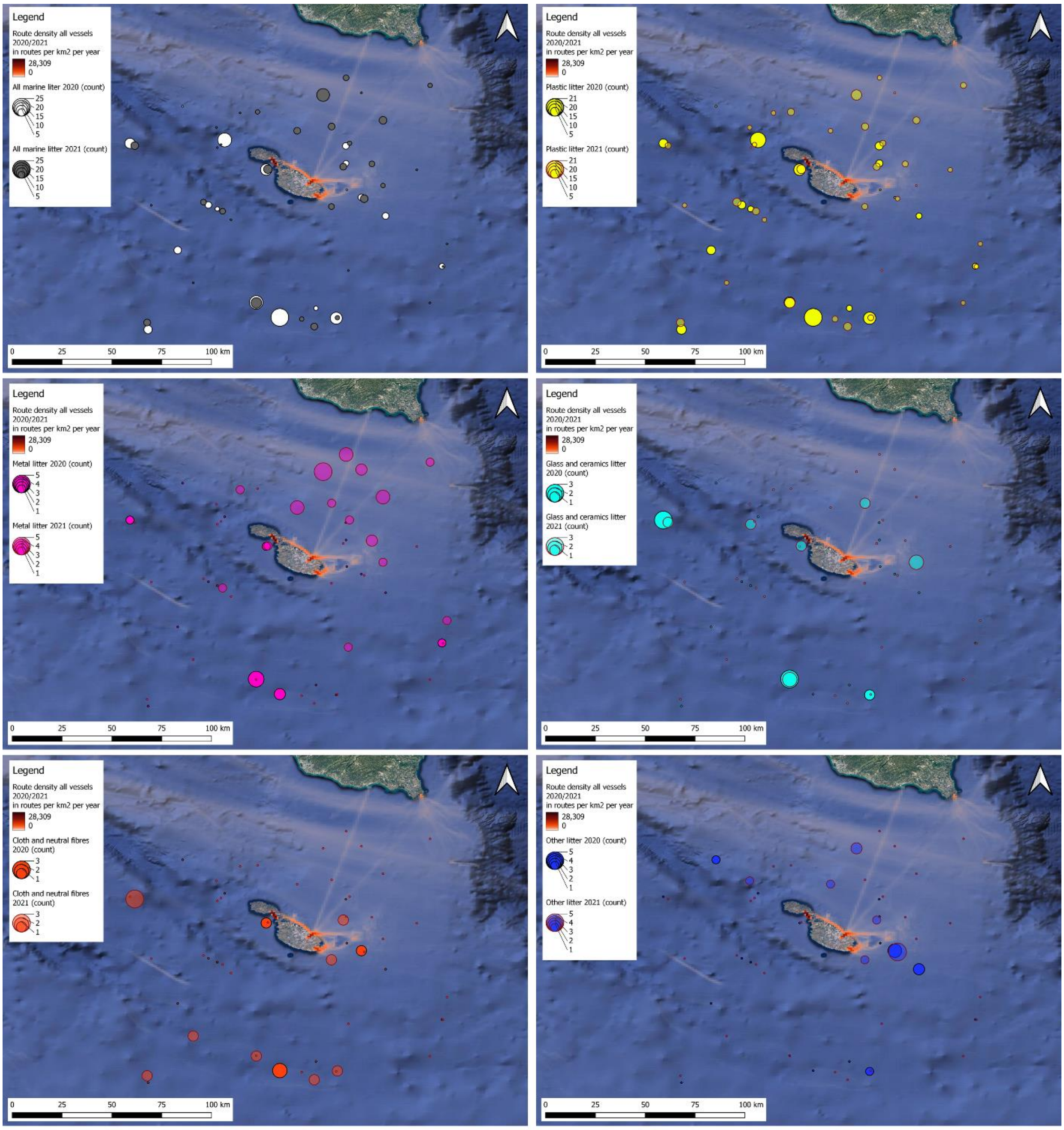

Figure 67: Averaged ship traffic of 2020/2021 (route density of all vessel types) in routes per km² per year around the Maltese Islands superimposed with the marine litter (in their categories) found during the MEDITS survey. Source: (EMODnet, n.d.)

4.4.2.5 Aquaculture farms

The local aquaculture farms in Malta are located along the east and south coasts, as shown in Figure 68. The two largest aquaculture farms, known as ´Tuna Cage 1-4`, are located further out to sea and are home to wild Atlantic bluefin tuna. The other inshore aquaculture farms are known as ´Mistra`, ´St. Pauls Islands`, ´Mellieha`, ´Qajjenza` and ´Muxar Reef` and contain fish species such as gilthead seabream

(*Sparus aurata*), European seabass (*Dicentrarchus labrax*) and common meagre (*Argyrosomus regius*).

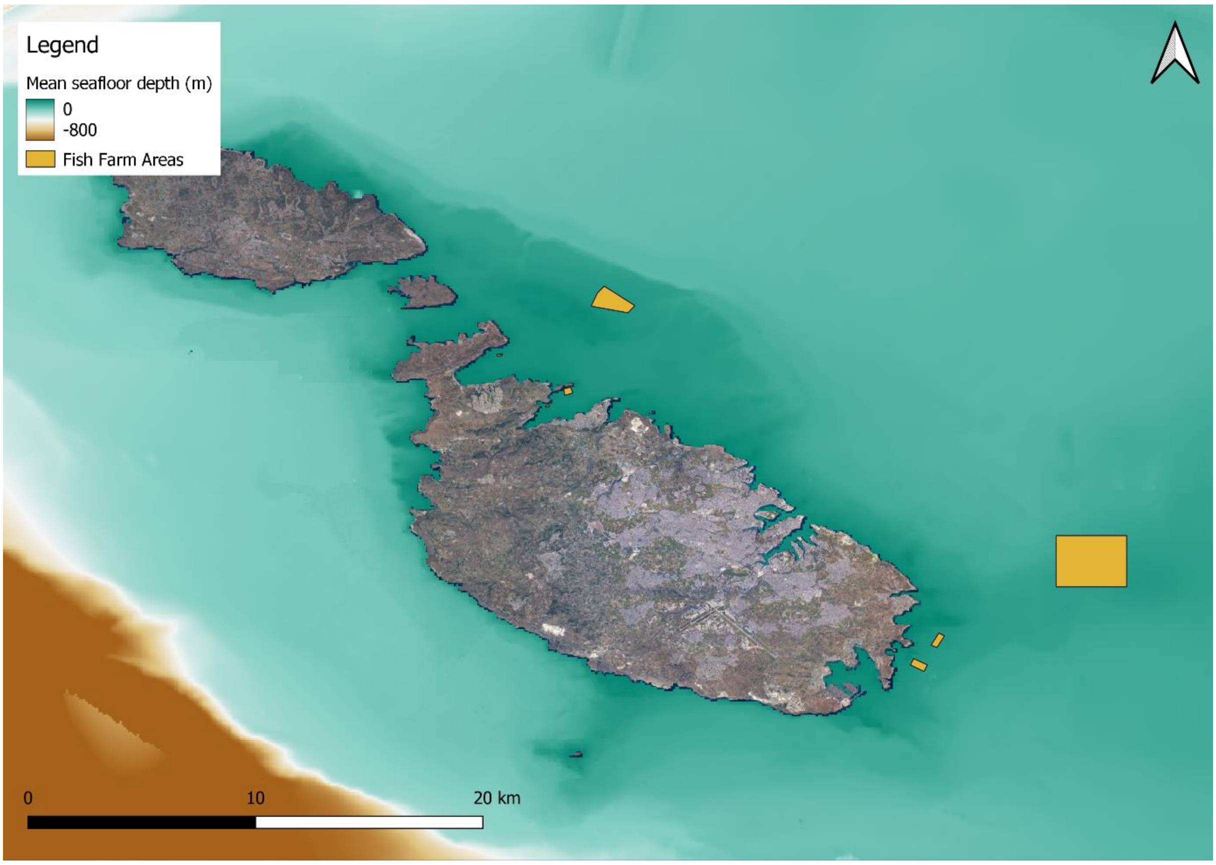

Figure 68: Aquaculture farms operated around the Maltese Islands. Source: AMAre (Actions for Marine Protected Areas) project provided by the Oceanography Malta Research Group.

The litter categories ´other litter` and ´cloth and neutral fibres litter` are quantitatively conspicuous in the vicinity of all aquaculture farms (see Figure 69). Trawl catches in the vicinity of these farms show only small amounts of metal and glass and ceramic litter items. Plastic litter items are present in moderate amounts. A closer look at the ´cloth and neutral fiber litter` category, as shown in Table 1, reveals that this category includes items such as a baseball cap (blue/white), a piece of cloth (cotton, wool, unknown material), a brown T-shirt, a yellow cotton cloth, and a safety shoe. The ´other litter` category includes capacitors, sponges, limestone slabs (not from fishing gear), and jumbo plastic bags with a capacity of approximately 2 tons (Table 1).

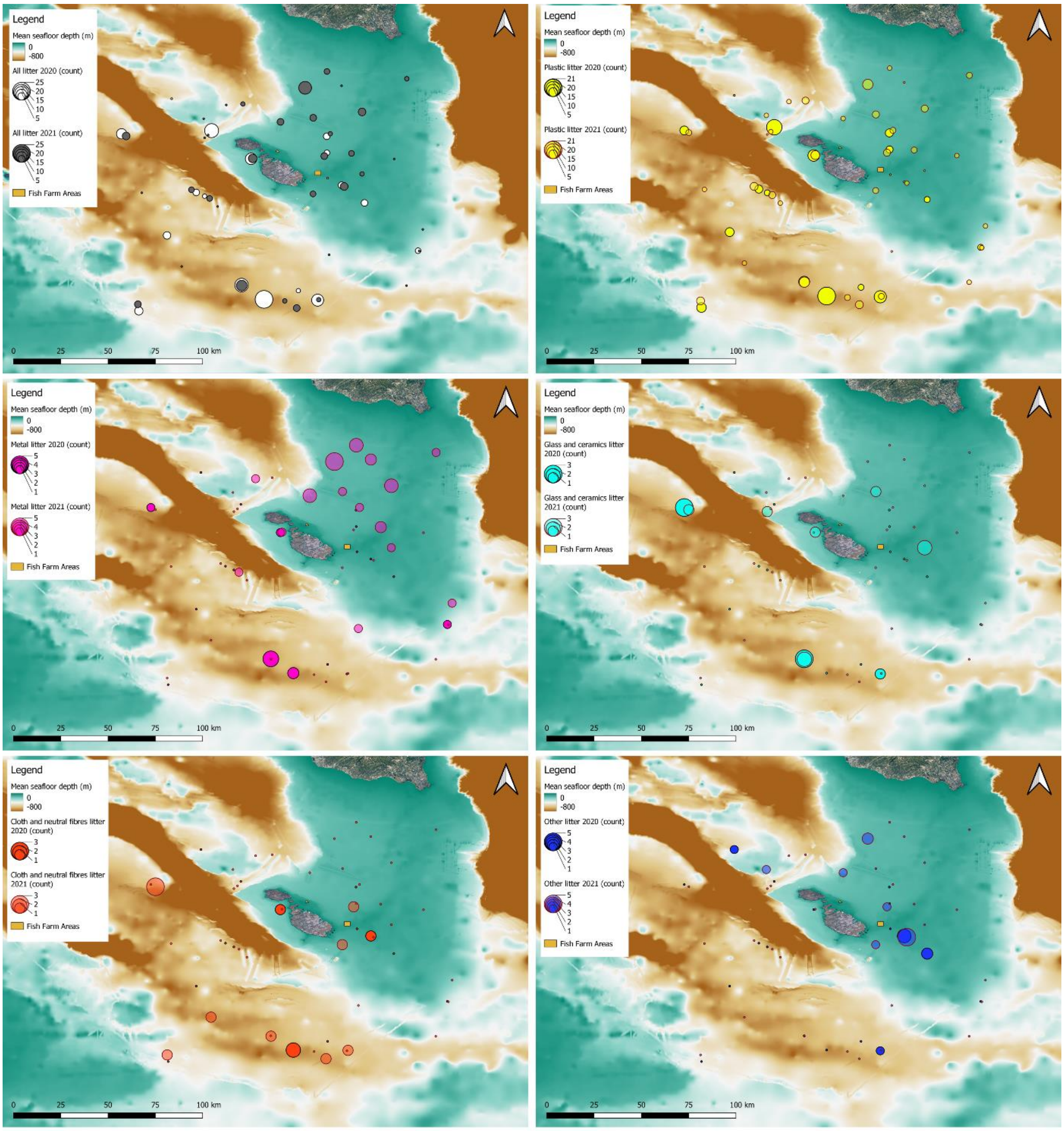

Figure 69: Aquaculture farms around the Maltese Islands superimposed with the marine litter (in their categories) found during the MEDITS survey. Source: AMAre (Actions for Marine Protected Areas) project provided by the Oceanography Malta Research Group.

4.4.2.6 Swimming zones

Figure 62 clearly shows that the majority of bathing areas in the Maltese islands are located along the east coast or in the south (Figure 70). There is no significant visual trend when comparing the distribution and amount of marine litter found within different bathing areas (Figure 71).

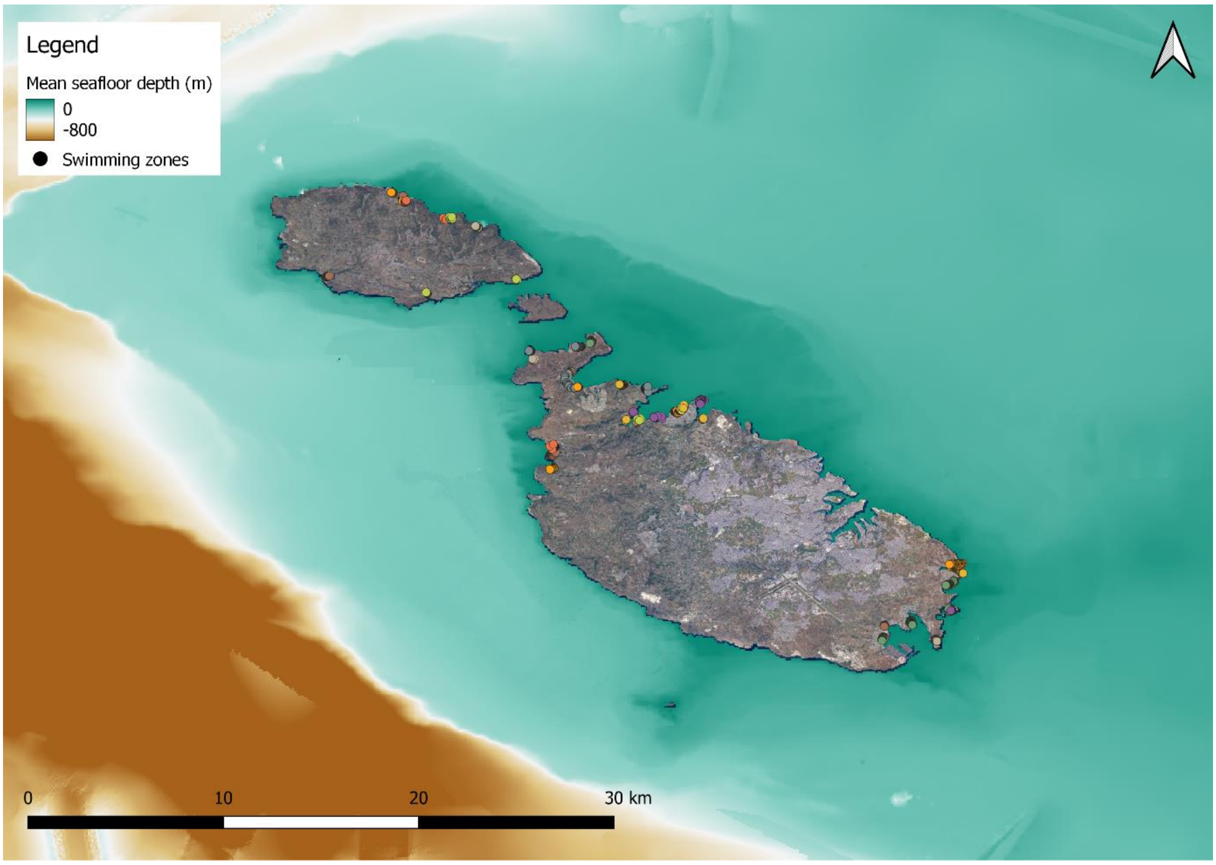

Figure 70: Swimming zones implemented around the Maltese Islands. Source: AMAre (Actions for Marine Protected Areas) project provided by the Oceanography Malta Research Group.

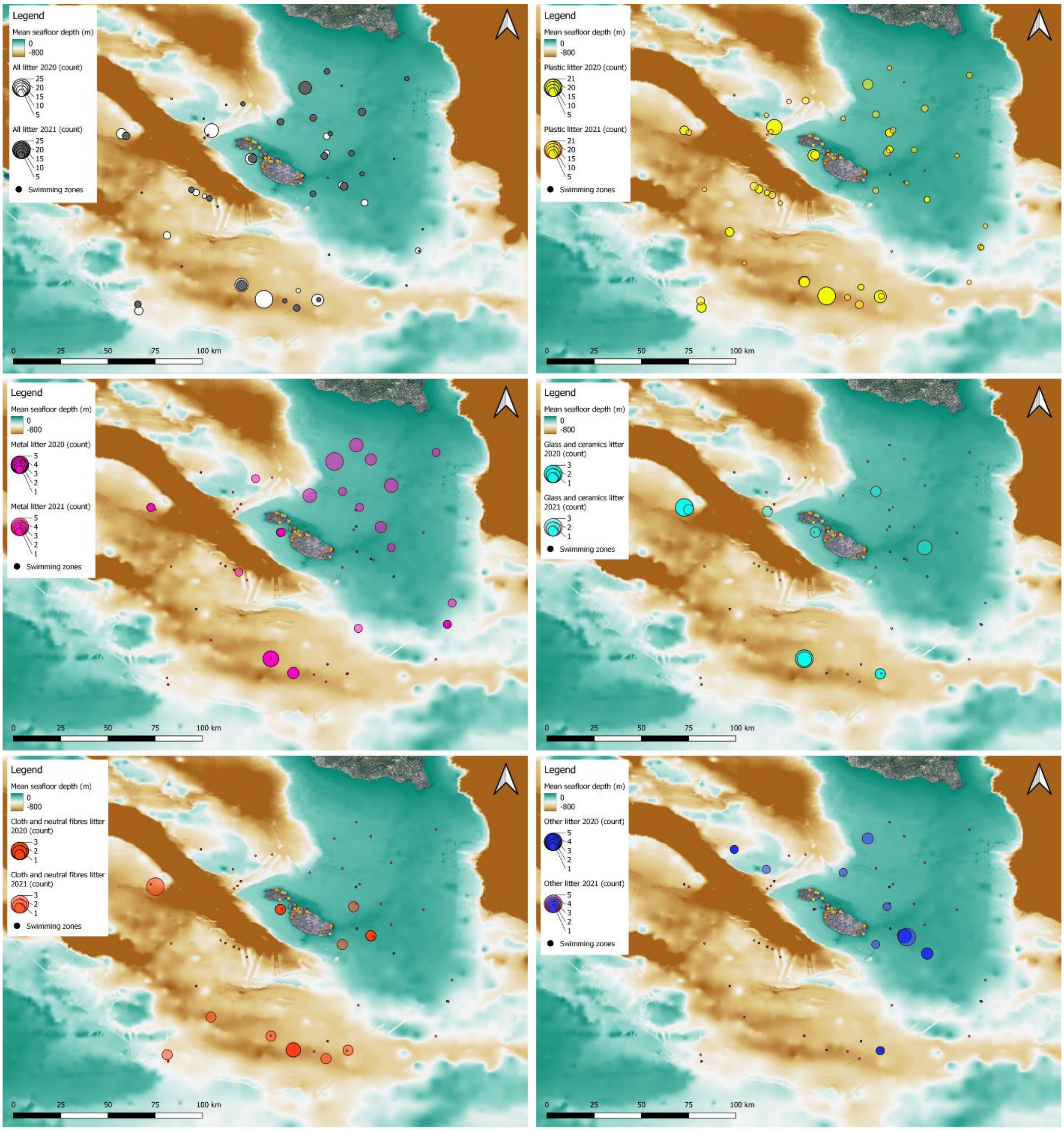

Figure 71: Swimming zones around the Maltese Islands superimposed with the marine litter (in their categories) found during the MEDITS survey. Source: AMAre (Actions for Marine Protected Areas) project provided by the Oceanography Malta Research Group.

4.4.2.7 Fishing activities

Figure 72 shows the fishing activity around the Maltese islands in terms off fishing trips conducted per km^2 per year. It can be seen that the predominant fishing activity is concentrated mainly in the immediate vicinity of the southern and eastern coasts of Malta, as well as along the coast of Sicily and in isolated areas to the west of Malta. Fishing activity is particularly intense in the ports of Porto Sciacca and Porto Portopalo

(Sicily) and in the areas of Marsaxlokk and Valletta (Malta), as shown by the dark red markers in Figure 72.

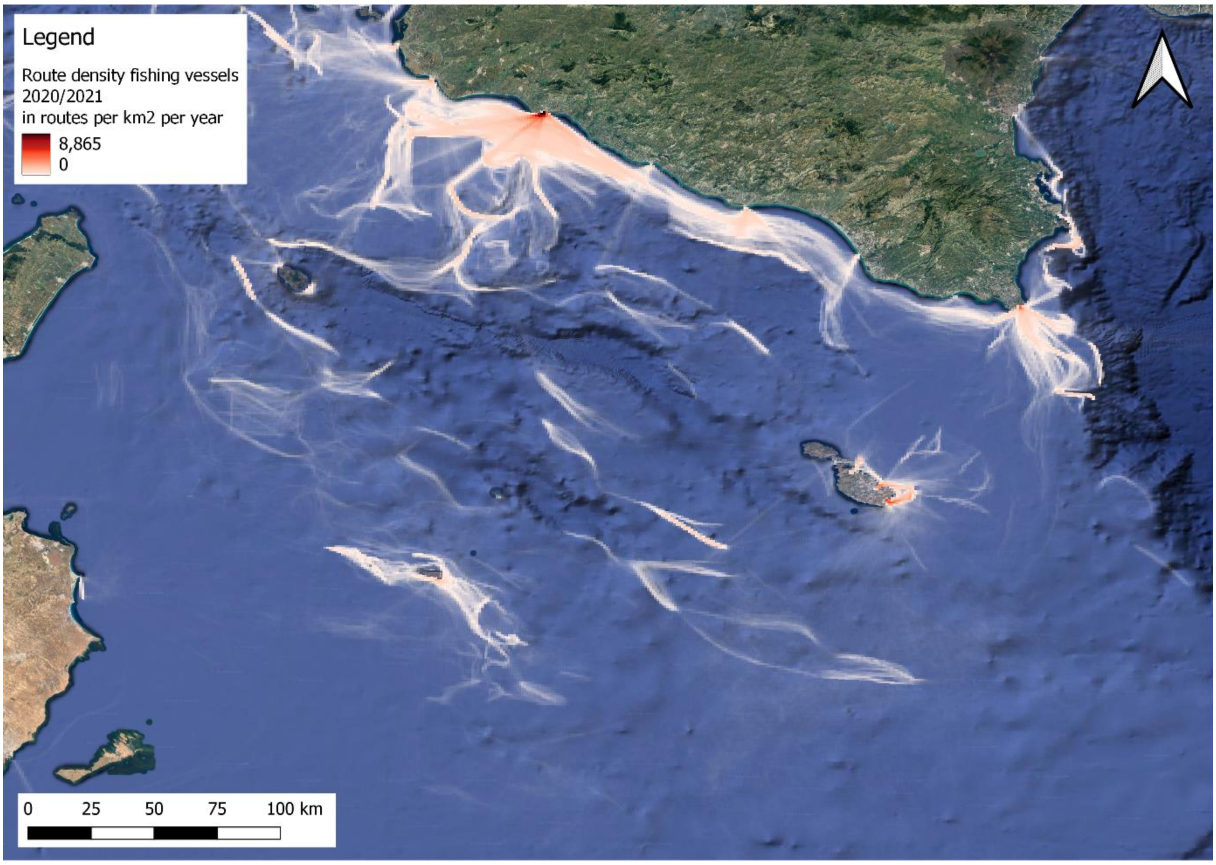

Figure 72: Averaged route density of fishing vessels in 2020/2021 in routes per km^2 per year. Source: (EMODnet, n.d.).

All categories of litter items were found in areas where fishing activity is common. However, the considerable accumulation of plastic, metal and cloth and neutral fibers litter items in a fishing area west of Malta should be highlighted (see Figure 73). Furthermore, metal litter items were found in the fishing zone off Porto Portopalo.

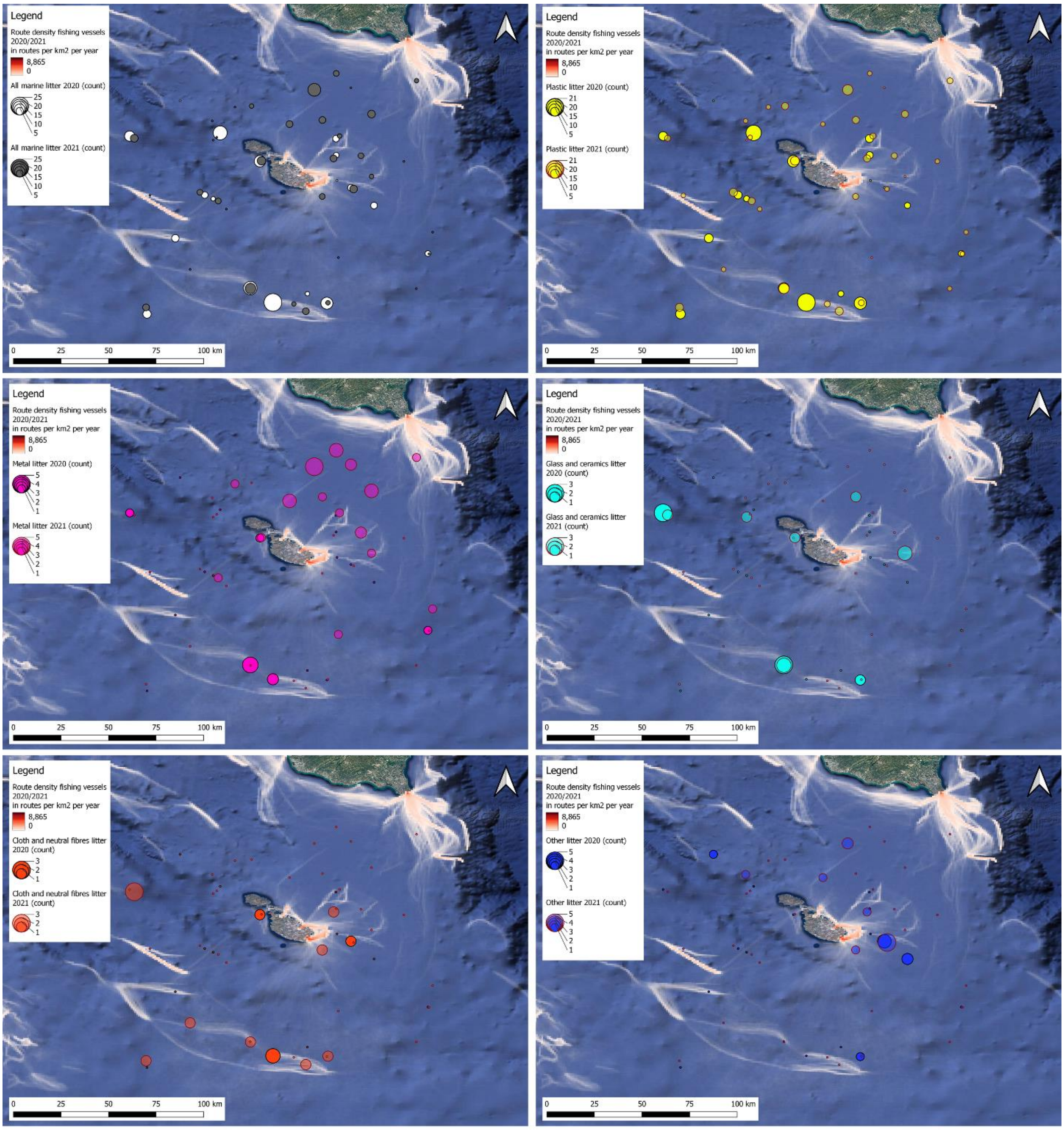

Figure 73: Averaged ship traffic of 2020/2021 (route density of fishing vessels) in routes per km^2 per year around the Maltese Islands superimposed with the marine litter (in their categories) found during the MEDITS survey. Source: (EMODnet, n.d.).

5 Discussion

5.1 Statistical interpretation

5.1.1 Qualitative analysis

5.1.1.1 Material composition

The majority of the identified marine litter turned out to be plastic litter (see Section 4.2). This finding is consistent with the findings of numerous other scientific studies carried out both in the Mediterranean Sea in general, and in Malta (see (Angiolillo et al., 2015; Consoli et al., 2018; Consoli, Scotti, et al., 2020; Ramirez-Llodra et al., 2013; Spedicato et al., 2020; Watson et al., 2006)). These studies also show that metal litter and glass and ceramic litter are the most common litter items after plastic litter ((Consoli, Scotti, et al., 2020; Ramirez-Llodra et al., 2013; Spedicato et al., 2020)). Table 44 shows the percentage composition of litter reported in this study in direct comparison with the results of other studies. Therefore, in terms of material composition, the type of marine litter found on different Mediterranean seabeds seems to be largely consistent. This observation also extends to categories of litter that have not been detected. For example, Spedicato et al. (2020) report in their results that no rubber litter (L2) was found in GSA 15 (Malta). This finding is consistent with the results of the MEDITS 2020/2021 study.

Table 44: The table shows percentile amounts of marine litter categories found in this study compared to other studies in the Mediterranean Sea.

Percentage amount	**Study**
Plastic	
67.36%	*MEDITS 2020/2021*
54.50%	(Consoli, Scotti, et al., 2020)
58-99%	(Spedicato et al., 2020)
Metal	

13.95%	*MEDITS 2020/2021*
23.46%	(Consoli, Scotti, et al., 2020)
20-30%	(Spedicato et al., 2020)
Glass and ceramics	
5.58%	*MEDITS 2020/2021*
11.40%	(Consoli, Scotti, et al., 2020)
20-30%	(Spedicato et al., 2020)
Cloth and neutral fibres	
5.43%	*MEDITS 2020/2021*
20-30%	(Spedicato et al., 2020)

The reason for the disproportionate presence of plastic litter items compared to other litter categories is well known and can be traced back to the exponential increase in the production and use of plastics since the 1950s (Worm et al., 2017). In addition, our ´throwaway lifestyle` (Fortibuoni et al., 2019, p. 421), tourism, poor litter management and our alienation from nature, combined with a corresponding lack of respect towards the environment, contribute significantly to this large amount of plastic (Consoli, Scotti, et al., 2020).

5.1.1.2 Use composition

The present analysis shows that fishing litter makes up a moderate proportion (2020: 18.11%, 2021: 21.54%) of the total litter in this study. This is in contrast to the results of Consoli et al. (2019) who claim that fishing litter makes up the majority of the litter they identified. Yet, the study was performed in areas where the fishing sector is economically important, such as the western Mediterranean, which could be a reason for the significant variation in proportion (Consoli et al., 2019).

However, the majority of studies in the Mediterranean region show a similar distribution of use categories to this study, as shown in Table 45. Watson et al. (2006) highlight that most of the marine litter, more specifically plastic litter, found in the Mediterranean Sea comes from land-based sources. This is in line with the results of the 2020/2021 MEDITS study, in which 55.12% in 2020 and 46.92% in 2021 of marine litter was attributed to the category ´tourism and household items` (see Section 4.1.2). Fishing-related marine litter ranks second in most studies (see Table 45). Globally, the percentage distribution is also similar to that in the 2020/2021 MEDITS study for fishing litter. Hinojosa & Thiel (2009) report that globally, 18% of marine litter in the oceans can be attributed to the fishing industry.

Table 45: The table shows percentile amounts of marine litter use categories found in this study compared to other studies in the Mediterranean Sea.

Percentage	Study	Category name chosen by study
Tourism and household-related		
2020: 55.12% 2021: 46.92%	*MEDITS 2020/2021*	-
42.3%	(Scotti et al., 2021)	Tourism and beach users
Montenegro: 73.7% Albania: 47.4% Greece: 46.1% Slovenia: 45.1% Croatia: 28% Italy: 25.5%	(Vlachogianni et al., 2018)	Shoreline sources

Fishing-related		
2020: 18.11% 2021: 21.54%	*MEDITS 2020/2021*	-
15.7%	(Scotti et al., 2021)	Fishing
Italy: 13.73% Greece: 11.72%	(Vlachogianni et al., 2018)	Fisheries and Aquaculture
Shipping industry-related		
2020: 6.3% 2021: 10.77%	*MEDITS 2020/2021*	-
11.3%	(Scotti et al., 2021)	Yachting
Albania: 4.72%	(Vlachogianni et al., 2018)	Shipping

Looking at the specific items in the different categories also shows similarities. For example, Topçu et al. (2013) highlight that plastic bags, food and beverage packaging, and fishing gear are the most common items found on beaches. With regard to the category of ´fishing-related` items, Cau et al. (2024) describe that fishing lines, fishing lead, lures and hooks, synthetic ropes, and fishing nets were found. Table 5 in Section 4.1.1 shows similar items for this category. Scotti et al. (2021) identified the most common items found on the seabed along the Italian coast as items such as plastic bags, aluminum beverage cans, glass bottles, and cigarette butts, all items that the author himself described as ´strongly correlated with tourism - beach user` (Spedicato et al., 2020, p. 209), thereby showing yet again consistency with the results of the MEDITS 2020/2021 study.

The results of this study indicate that the main source of marine litter on the seabed in Malta is tourism and household litter, followed by fishing litter, which is supported by numerous studies in the Mediterranean and worldwide. Regarding the classification of shipping industry related marine litter used in this study, limited information could be found in Mediterranean studies. Scotti et al. (2021) solely describe that smaller contributions of marine litter have been attributed to, for example, litter from sewage or urban runoff.

This analysis has clarified which sources, both land-based and ocean-based, make the largest contribution to marine litter on the seafloor. While the classification of litter into different categories can never be 100% accurate, it can be based on experience and other studies subsequently provides a solid knowledge base and a high level of confidence. Ultimately, the information on use categories can be used to introduce targeted management and reduction measures (Scotti et al., 2021) .

5.1.2 Quantitative analysis

In 2020, as already described in the results Section, ~ 2.29 items of marine litter were detected per km^2. In 2021, this number decreased to ~ 0.93 litter items km^{-2}. This significant discrepancy could be due to the Covid-19 pandemic that occurred in December 2019, which led to a significant decrease in tourism and shipping, resulting in less litter entering the oceans, as already discussed in Section 5.1.4.

A similar study was conducted in 2013, which found 97 ± 78 pieces of litter per km^2 on the seabed off Malta (Mifsud et al., 2013). At the time, the seabed was described as ´clean when compared to most other areas in the Mediterranean` (Mifsud et al., 2013, p. 302). However, Mifsud et al. (2013) go on to describe that the other studies they refer to were mainly conducted in ports or near large cities. For example, 40 litter items per km^2 were found in the Strait of Sicily (Mifsud et al., 2013),15,000 litter items per km^2 in Greece (Katsanevakis & Katsarou, 2004), and 1,935 ± 633 in the NW Mediterranean (Galgani et al., 1995, 2000). This comparison showed that the seafloor around Malta was relatively clean in 2013 compared to other regions .

An important aspect is the comparison of the MEDITS 2020/2021 study with that of Mifsud et al. (2013), which shows that the accumulation of litter on the seafloor around Malta has decreased considerably since 2013. This is also shown through the study by Spedicato et al. (2020), which shows a seabed litter density of 32 items of litter per km^2 in Malta in the time period of 2013-2015. Possible reasons could be due to measures taken to reduce marine litter (e.g. incentives for fishing gear recovery, clean-up efforts by local organisations, deposit-refund schemes for plastic bottles), which does not necessarily have to come from Malta itself. There is also the possibility that the litter found in Malta is not necessarily of Maltese origin, especially if on average 67.05% of the litter is plastic (see Section 4.2). Plastic litter can travel for a long time in the sea due to its light weight and longevity, as already described in Section 5.1.3 by Ryan et al. (2009). Another possible reason could be the Covid-19 pandemic, which has led to a sharp reduction in litter pollution (see Section 5.1.4).

The study by Cau et al. (2024) offers a comparison of the quantitative results of this study with a similar study that examined other Mediterranean regions in the period from 2013 to 2019, therefore a similar time frame as this study. Their research shows that, in particular, the northern part of the Western Mediterranean has been continuously heavily affected by marine pollution (Cau et al., 2024). This region includes GSA 9 (Northern Tyrrhenian Sea), GSA 10 (Southern Tyrrhenian Sea) and GSA 7 (Gulf of Lyon) (Cau et al., 2024). Up to 10^5 pieces of litter per km^2, both fishery-related and non-fishery-related plastic litter items, were found there (Cau et al., 2024). Similar figures were found for the region of the east coast of Corsica (Gerigny et al., 2019). Another study from the Strait of Sicily by Garofalo et al. (2020) confirms a 5-year average seafloor density of 79.6 litter per km^2 for the period 2015 - 2019. All these values are higher than the amount of litter items per km^2 found in this current study. Again it is evident that the seabed around Malta is relatively clean compared to other Mediterranean regions. This may be related to the strong hydrodynamics in the waters around Malta, which contribute to this relative lack of seafloor litter deposition in the same waters. However, a comprehensive comparison with subsurface currents in other regions of the Mediterranean is needed to fully confirm this.

However, it should be noted that these abovementioned regions of the western Mediterranean are characterised by intensive fishing activities and commercial shipping (Cau et al., 2024), in comparison to Malta, where fisheries only account for 0.1% of the GDP (FAO, 2016). Another reason for this big difference in amount of marine litter found could be the data collection procedure (Ramirez-Llodra et al., 2013). Ramirez-Llodra et al. (2013) state in their study that marine litter collected with trawl surveys result in less amounts than if it would be recorded by means of visual census, such as using divers or an ROV, since the latter can take record of small fragments that would escape a trawling net. Cau et al. (2024) and Spedicato et al. (2020) also describe that this large accumulation could be due to a specific local circulation pattern. GSA 16 (Sicily), close to the Maltese islands, and GSA 11 (Sardinia) showed a lower amount of marine litter (Cau et al., 2024). However, this changes when looking at the weight of marine litter found (Cau et al., 2024). As published by Smith & Turrell (2021), monitoring marine litter in the context of quantity (in count) or weight (in kg) can lead to different results. The presence of a single mega-litter item (e.g. metal litter) can lead to a strong bias in the results (Smith & Turrell, 2021). Therefore, a combination of both analyses is recommended (Smith & Turrell, 2021). While the results of this study focused mainly on the amount of marine litter in count, Figure 74 shows the marine litter found in kg per km^2.

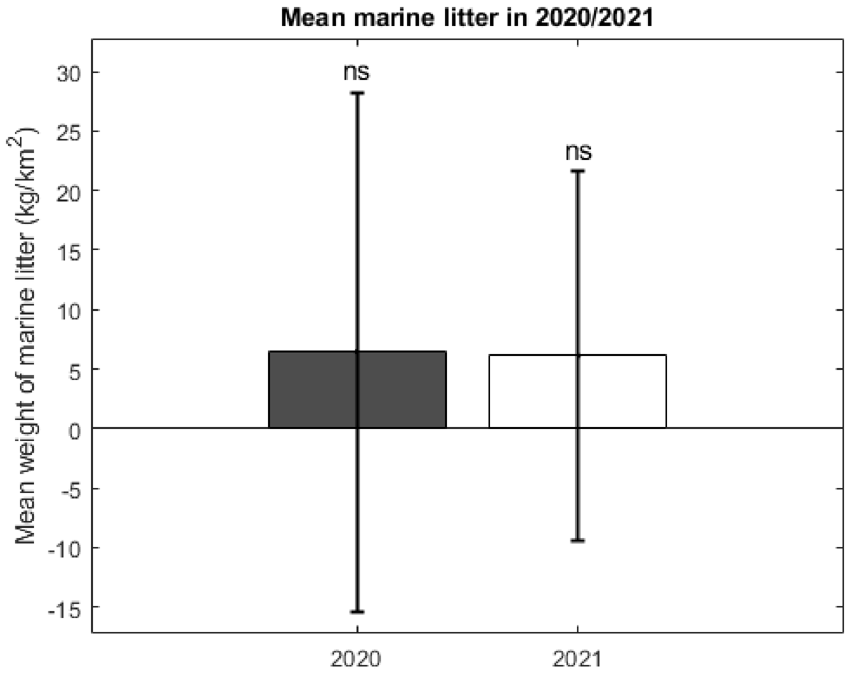

Figure 74: Mean amount of marine litter in 2020 and 2021 in kg km^{-2}. The label ´ns` shows that there is no statistical significance between the two years.

When looking at the spatial distribution analysed, it becomes clear that the statistical interpretation of the data changes. In terms of weight in kg, metal litter items are significantly more abundant to the west of Malta in the Malta-Sicily Channel (Figure 75). Cloth and neutral fiber litter items are significantly more abundant in the east, while plastic litter shows no statistically significant difference in abundance between waters off the west and east coast of the islands (Figure 75). The interpretation of the results may therefore change and show that, for example, in the Malta-Sicily Channel there is less litter in terms of quantity of individual items but more in terms of weight. This could be due to the fact that in the Malta-Sicily Channel macro-litter exhibits greater weight compared to other areas, possibly due to strong currents that prevent lighter marine litter from being deposited on the seafloor, as suggested by Cau et al. (2024). In the northern part of the western Mediterranean, more plastic litter items were found in terms of quantity but less in terms of weight, which, according to Cau et al. (2024), indicates a synergy between two factors: a hydrodynamic regime that favors stagnation and accumulation, and the presence of three major rivers, the Tiber, the Arno and the Rhone.

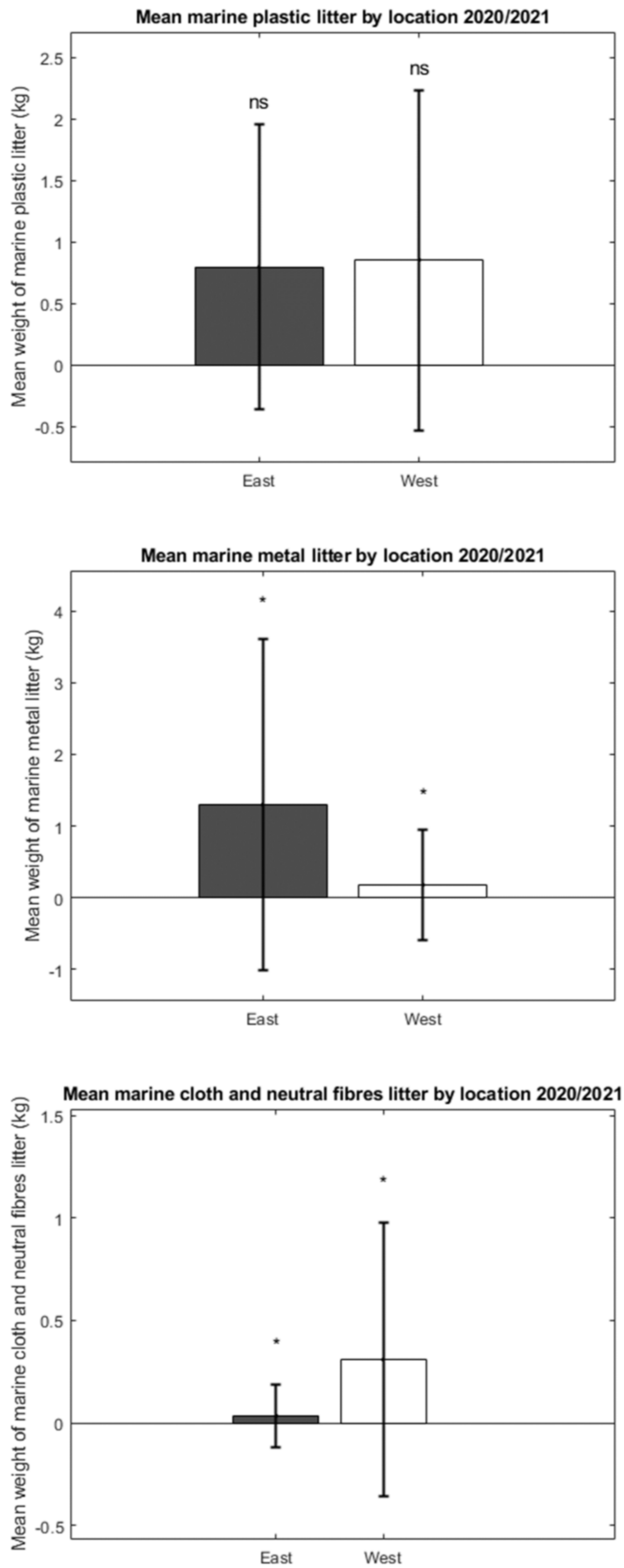

Figure 75: Plastic litter, metal litter and cloth and neutral fibres litter items in kg km^{-2}, showing different results than statistical analysis with amount of marine litter in count. Plastic litter shows no statistical significance in this case, while both metal litter and cloth and neutral fibres litter items do show statistical significance.

To summarise the status of marine litter on the seabed around the Maltese islands, this study and others (Cau et al., 2024; Garofalo et al., 2020; Spedicato et al., 2020) confirm that, while the Mediterranean Sea is a marine pollution hotspot, the seabed around the Maltese Islands is less affected by marine litter than many others in the Mediterranean Sea.

5.1.3 Spatial distribution

In the study of the spatial distribution of marine litter, statistical significance was only found for plastic litter items, with a significantly higher concentration in the west compared to the east (Figure 28)

With regard to anthropogenic activities around the Maltese Islands, it can be stated that many of these activities take place east of Malta, such as the berthing zones (Figure 62), shipping traffic (Figure 66) and aquaculture farms (Figure 68), or are evenly distributed on both sides, such as trawl zones (Figure 60). The only exception is the fishing activity west of Malta which is higher compared to east of it (Figure 72). In the west, high route density areas are found where plastic litter items are more prevalent. However, the evaluation of catch yields in these areas revealed that fishing gear was not exclusively found in these specific hauls, as described in detail in Table 46. Studies suggest that in an area of high fishing vessel route density, this fishing gear would be the highest proportion of litter found (Consoli et al., 2019). Studies also emphasise that these figures often represent countries where fishing accounts for a significant proportion of the economy (Angiolillo et al., 2015; Bo et al., 2014; Consoli et al., 2018). Despite its prominence, fishing on the Maltese Islands contributes only 0.1% to the national gross domestic product (GDP) according to the FAO (FAO, 2016). There is also no discernible link between tourism in Malta and the accumulation of plastic litter items in the west, as most tourism activities take place along the eastern coast. These results may reflect a combination of bathymetric and hydrodynamic differences between the western and eastern coasts. Deeper waters along the west coast allow litter to accumulate in areas unaffected by surface phenomena, while shallower waters and strong currents along the east coast make litter accumulation less likely (see Figure 55).

Table 46: Plastic litter items found in hauls west of Malta that were within areas of high fishing activity.

Haul	Year	Item
M22	2020	Plastic Bags: White, Yellow & Blue Transparent Plastic Bottle (500ml) Pasta plastic wrapper White Plastic Container (Vasketta-2kg)
M23	2020	Various bits of plastic 5 Pieces of bottles & 2 Transparent Bottles Large mesh Netting (Piece/Trawling) White Plastic Container (Vasketta-2kg)
M24	2020	Transparent plastic
M25	2020	Transparent, white, brown, white,black bags Yellow Bottle Packet of Sweets (Wrapper) Grey Plastic Sheet
22	2021	Piece of Net Nylon Fishing Line (Longline) Orange Squid Lure (Longline) White Plastic Container (Vasketta-2kg) Plastic Bags: White, Black & Transparent
23	2021	White Plastic Container (Vasketta-2kg) Small Piece of Net (Codend)
24	2021	Plastic Bags: White & Transparent White Plastic Container (Vasketta-2kg)
25	2021	Disposable White plastic cup Nylon Fishing Line (Longline)

Furthermore, studies have attributed extensive accumulation of plastic litter items to structurally rich, rocky habitats (Angiolillo et al., 2015; Consoli et al., 2018, 2019). It is pointed out that an above-average amount of so-called ´Abandoned, Lost or Discarded

Fishing Gear` (ALDFG) is found in such habitats (Angiolillo et al., 2015; Consoli et al., 2018, 2019). However, the review of the habitat map around the Maltese Islands does not fully confirm this assumption, as the areas with high plastic accumulation are mainly coarse sediment rather than rocky habitats (Figure 76, Appendix 1).

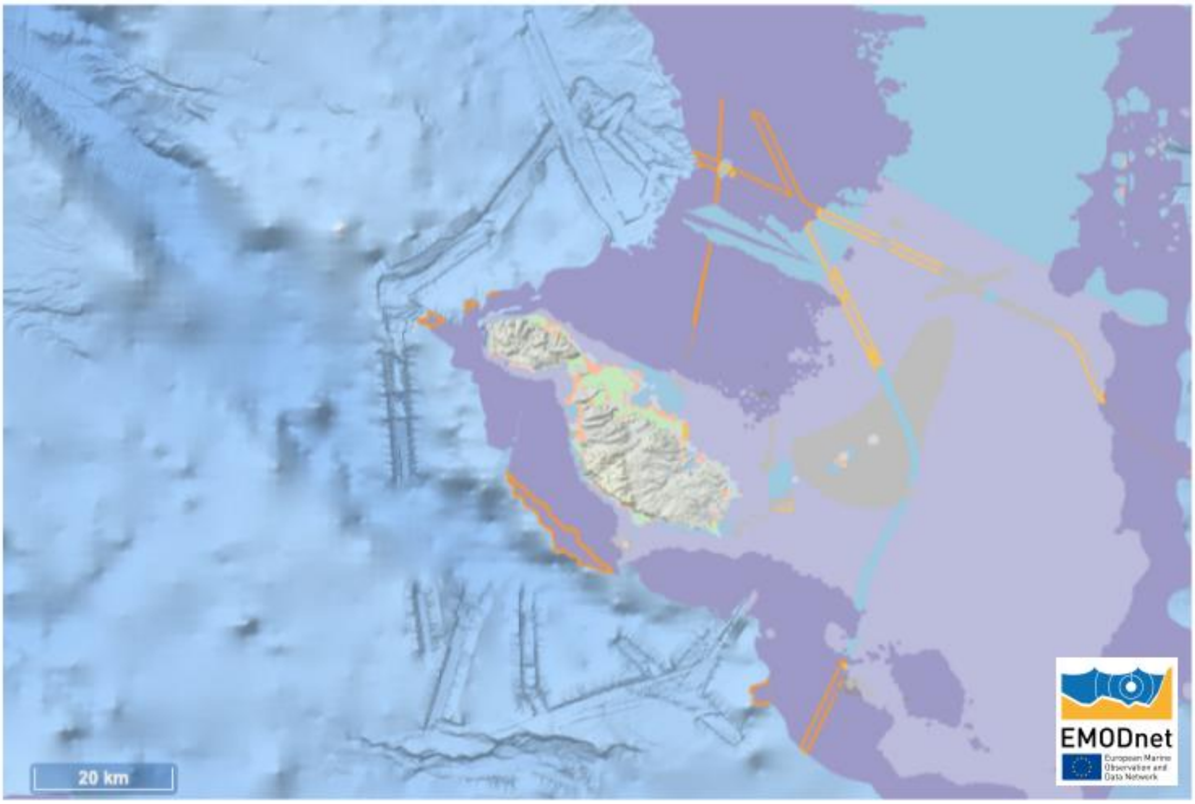

Figure 76: Habitat map of the seafloor off Malta. The different colours on the map visualise the following habitat: (1) blue: coarse sediment, (2) orange: mud, (3) light purple: rock, (4): dark purple: mixed sediment. A more detailed overview of the legend is found in the appendix (Appendix 1). Source: (EMODnet, n.d.)

A 2013 study analysing MEDITS data around the Maltese Islands showed, through an ANOVA analysis, that seabed litter was significantly more concentrated in the south of the islands compared to other areas (Mifsud et al., 2013). Although the study refers to the south, a map comparison makes it clear that this is the same area of high accumulation as in the present study (Figure 77). The cause of this strong accumulation could not be clearly determined back then, with a lack of data on subsurface currents being cited as a limitation (Mifsud et al., 2013). The present study, which has access to this data, indicates that no definitive statement can be made on the issue. Subsurface currents from the south and east may have transported the plastic litter items from other countries (see Section 4.4.1). It is generally difficult to determine the origin of plastic litter due to its low weight compared to denser materials such as metal or glass and its longer life expectancy in water compared to materials such as paper (Ryan et al., 2009).

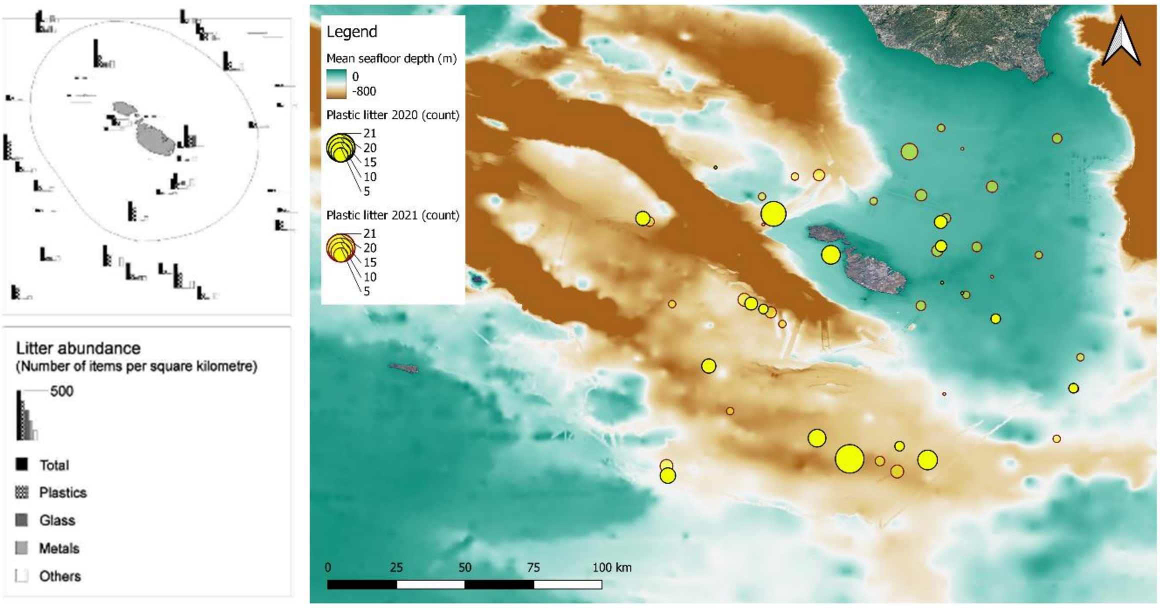

Figure 77: Comparison of the study by Mifsud et al. (2013) (left) with this study (right). Both maps show the spatial distribution of marine litter around the Maltese islands, with a high prevalence of plastic litter items in the south.

Ramirez-Llodra et al. (2013) attribute the increased occurrence of plastic litter in deeper waters, far from coastal regions (as described in this study and the 2013 study (Mifsud et al., 2013)) to multiple possible reasons. For example, the accumulation could be due to improper litter disposal by shipping and fishing (Ramirez-Llodra et al., 2013). In addition, currents in areas with abrupt depth changes tend to concentrate or swirl, which can lead to an accumulation of plastic litter in these areas (Ramirez-Llodra et al., 2013) (explained in more detail in Section 5.1.5). However, such eddies cannot be identified in this study. Clear recognition would be associated with a pronounced circular pattern that manifests itself at a drop-off, i.e. a geographical point that connects two areas with a considerable difference in depth (see Figure 51 - Figure 58). On the other hand, García-Rivera et al. (2017) describe the opposite observation in their study in Alicante, where most of the plastic was found in the immediate vicinity of the coast.

The reason why the spatial distribution of the remaining litter categories showed no statistical significance might be due to the even distribution of anthropogenic activities as mentioned above. With the exception of other litter and metal litter, all other litter categories were more common along the western part, although this difference from waters off the eastern flank was not statistically significant. On the other hand, other litter and metal litter items were more abundant along the eastern part of Malta. The eastern part includes the Malta Sicily Channel and it is clear to see from Figure 66 that there is significant shipping in this region. According to Ramirez-Llodra et al. (2013), it has been suggested that areas with intensive shipping tend to have higher proportions of heavy litter, including metal and fabric. In general, therefore, it can be inferred that plastic is more likely to be found in nearshore areas, while increased levels of heavy litter, including metal and fabric, are indicative of a shipping origin and are found in areas with moderate to intensive shipping lanes.

In conclusion, it can be stated that the spatial distribution of marine litter depends on various factors that interact synergistically (Bauer et al., 2008). These factors include the weight, shape, composition of the litter and climatic factors such as water circulation, wind and waves as well as the topography of the seabed (Bauer et al., 2008). According to Lobelle & Cunliffe (2011), even seawater productivity has an influence on distribution, as it affects the formation of early microbial biofilms, which in turn influence the buoyancy of plastic litter. In addition, trawling activities themselves can contribute to a redistribution of litter on the seabed (Mifsud et al., 2013). The exact cause of the significantly higher concentration of plastic litter items in the west cannot therefore be clearly attributed to a single factor. However, it can be estimated that geomorphological features, hydrodynamics and human factors are strong influences (Galgani, Hanke, Werner, L, et al., 2013).

5.1.4 Temporal distribution

In terms of temporal distribution, a significant difference over time was found only for total marine litter. A statistically significant higher amount of marine litter was found in 2020 compared to 2021, although fewer samples were collected in 2020. It is expected that, with an even number of samples, this discrepancy would be even more pronounced. This observation could be due to the effects of the COVID-19 pandemic.

COVID-19 disease, caused by the novel coronavirus SARS-CoV-2, was first identified in Wuhan, China, in December 2019 (Buzzi et al., 2022). The disease quickly became a global public health emergency (Cascella et al., 2023; Lokhandwala & Gautam, 2020). The pandemic had a widespread impact on various anthropogenic activities, including tourism and shipping in particular (Buzzi et al., 2022; Jiang et al., 2022). Studies show a significant decline in tourism as a result of the pandemic (Pereira et al., 2021). The reduced number of tourists led to a reduced presence of people on beaches and in public places, resulting in less pollution. As a result, the oceans, including the Mediterranean Sea, experienced a period of recovery that contributed to the restoration of ecological functions (Jiang et al., 2022). The impact of this recovery varies by marine area, geographical space and sector, due to the different policies that countries have adopted to deal with the pandemic (Jiang et al., 2022). It should be noted that these pollution impacts caused by the pandemic will remain relevant in the long term (Jiang et al., 2022).

Similarly, the Maltese Islands, which have a significant annual influx of tourists and are economically heavily dependent on tourism, experienced a dramatic economic downturn during the pandemic (Briffa & Agius, 2021). By the end of 2020, Malta recorded a 76% decrease in tourist arrivals compared to 2019, which ultimately led to an 80% decrease in total tourism revenues (National Statistics Office, 2020).

It remains to be seen whether marine pollution has increased as a result of the increased production of protective equipment, or whether it has offset the decrease in litter generation due to the lack of tourism. The amount of medical litter is significant, with more than 25,000 tons of plastic litter dumped into the oceans in connection with the pandemic, including mainly medical litter from hospitals and protective equipment such as face masks (Jiang et al., 2022).

Another interesting aspect is that the implementation of the MEDITS survey in 2020, in addition to the decrease in anthropogenic activities, led to the cleaning of the disposal sites and the removal of litter in these areas. This annual cleaning process may have contributed to the ´recovery` of the survey areas within one year. However, this may have been different during the COVID-19 pandemic. This can only be confirmed by analysing the survey results from subsequent years.

Other factors that could contribute to the statistically significant discrepancy were not conclusively considered. For a more comprehensive analysis of the temporal distribution, a comparison with data from other years would be of interest to determine whether the statistical significance in this study is primarily due to the pandemic or whether other influences, such as weather events, may lead to a comparable discrepancy.

5.1.5 Depth-related distribution

As explained in the results, the present study shows no statistical significance with respect to marine litter and its distribution at different depths. However, an increased accumulation of litter was found in the ´deep` classification for the categories ´total litter`, ´plastic litter`, ´glass and ceramic litter` and ´cloth and natural fibers litter`, although this was not statistically significant. In contrast, more litter items were found in shallow water for the litter category ´other litter`. The proportion of metal litter items was the same for both classifications.

A comparison with the literature shows that other studies in the Mediterranean have come to similar findings regarding the depth distribution of marine litter. For example, a study by Olguner et al. (2018) in the eastern Mediterranean, in Antalya Bay, found that the accumulation of litter increased with increasing depth, both in terms of weight and litter density. Ramirez-Llodra et al. (2013) conducted a study in the deep waters of the Mediterranean and found that litter is transported down-slope and accumulates at depth. She goes further into the different categories of litter and suggests that litter accumulating in canyons, which is mainly plastic, can be transported to the canyon by its strong currents, while heavier litter remains on the slope of the canyon (Ramirez-Llodra et al., 2013). The study by Galgani et al. (2000) calls this the ´wash-down effect`. Galgani et al. (2000) claim that more marine litter accumulates on the seafloor in deeper waters because subsurface currents push this litter to the depths. With regard to the drop-offs around Malta, it can be observed that despite the absence of clear strong currents at these drop-offs, lighter litter, such as plastic litter, can still be transported downwards. Cau et al. (2024) suggest, based on the RF model used in the study, that heavier items such as metal litter items are as likely to be found in deep water as in shallow water, which is consistent with the results of the MEDITS 2020/2021 study (see Figure 47). This could be due to the fact that, as explained in Section 5.1.2, heavy litter remains where it is deposited, while lighter litter can be transported and deposited, for example, in submarine canyons, which are known to carry large amounts of macro-litter (Ramirez-Llodra et al., 2013). As can be seen in Figure 67, the localisation of heavy litter (i.e. metal litter items), for example, coincides with busy shipping lanes. Another reason why lighter litter is found on the seafloor at great depths is due to the mechanism of biofouling, which causes lighter litter to become heavier over time (Amaral-Zettler et al., 2021).

In conclusion, the results of the MEDITS 2020/2021 study do not provide a clear direction or insight into the depth distribution of marine litter on the seafloor, as suggested by other studies, as no statistical significance was found between the two categories ´shallow` and ´deep`. Possible reasons for this could be attributed to the chosen analytical design of this study. For example, a more detailed and comprehensive classification and selection of litter categories could lead to more differentiated results. In addition, the classification of 400 m and shallower depths as ´shallow` may have been too generic. The choice of statistical test applied may also be reconsidered; instead of the two-sided independent *t*-test, a correlation analysis may be more appropriate to better detect an increase with depth, as described by Olguner et al. (2018). For a more in-depth analysis of the depth distribution of marine litter on the seafloor off Malta, more intensive sampling and an advanced analysis design are therefore recommended.

In conclusion, studies in the Mediterranean that have been used for comparative purposes show consistent results on the depth distribution of marine litter on the seabed. Slight differences could be due to the different sampling areas and their unique subsurface water current regimes, submarine canyons and to the different intensities of anthropogenic influences. These anthropogenic influences and their effect on the distribution of marine litter will be discussed in more detail in the next chapter.

5.2 Most potential sources of marine litter in the area

In this study, information on anthropogenic activities was primarily used as a basis for analysing the spatial, temporal and depth distribution of marine litter. The results of the analysis were carefully contextualised in an attempt to attribute specific distribution patterns to specific human activities. However, it should be noted that the clear attribution of marine litter to a specific activity is challenging due to the possible transport in the sea, with the exception of heavy litter (such as metal litter items), as already confirmed by sources (Ryan et al., 2009). Therefore, it was particularly important to focus on the classification of the litter.

However, after a detailed analysis of the mapped anthropogenic activities, some conclusions can be drawn and interpreted from this study:

(1) Fishing activities: In the MEDITS 2020/2021 study, it appears that fishing activities have led to an accumulation of marine litter on the seabed. This finding is supported by several other studies in the literature (Angiolillo et al., 2015; Bo et al., 2014; Consoli et al., 2018).

(2) Natura 2000 site: Marine litter has also been detected in Natura 2000 sites, indicating that these protected areas should be monitored more closely, given their importance in conserving the marine environment. Studies, such as Compa et al. (2022) are conforming the presence of marine litter in MPAs, stating that sometimes higher amounts of marine litter have been identified in protected areas compared to areas that are highly influenced by anthropogenic drivers (Compa et al., 2022).

(3) Shipping routes: Marine litter hotspots have been identified along busy shipping routes such as the Malta-Sicily Channel and the Malta-Comino Channel. The Malta-Comino Channel, for example, is heavily used by ferries, while the Malta-Sicily Channel is an important shipping route in the Mediterranean. In these areas, plastic and metal litter items were the main types of litter found.

(4) Berthing areas: Marine litter has been found in areas where ships frequently berth (e.g. Hurds Bank). Sources confirm that litter classified as ´cloth and neutral fibers litter` is often found in berthing areas (Ramirez-Llodra et al., 2013).

(5) Tourism: Classified plastic litter items mainly come from household and tourist activities. However, the spatial distribution of the plastic litter found alone does not allow a clear determination of the source, as plastic is easily transported in the sea (Ryan et al., 2009). For example, tourism in Malta is concentrated on the east coast, but significantly more plastic litter items were found in the west (see Figure 28). However, this could also be related to other factors such as distance from the coast.

In summary, there are anthropogenic activities that have a major impact as sources of marine litter, but not necessarily on its spatial, temporal or depth distribution. Fishing, shipping, and tourism are major sources of marine litter on the Maltese seabed.

5.3 Future recommendations

The 2020/2021 MEDITS study highlights the significant challenges associated with marine litter pollution on the seabed in the Mediterranean, with Malta not being spared from this problem despite the comparatively low amount of litter found on the seabed. The impact on the deep sea ecosystem can be significant despite its low quantitative presence, as marine litter is inappropriate in this sensitive ecosystem. There is an urgent need for action on the part of society and decision-makers for the Mediterranean deep-sea.

Previously introduced measures, such as the MSFD, require Good Environmental Status and specifically address Descriptor 10, which deals with marine litter (Ramirez-Llodra et al., 2013). The MSFD, in collaboration with the UNEP Mediterranean Action Plan, aims to expand deep-sea research to identify and fill knowledge gaps and collect standardised data on this fragmented ecosystem (Ramirez-Llodra et al., 2013). The data and analysis collected through this and other MEDITS surveys will provide baseline information on the deep sea and give a detailed picture of the distribution of marine litter, from which the potential impact on the ecosystem can be inferred (Ramirez-Llodra et al., 2013). In particular, this refers to MSFD indicator 10.1.2, which aims to identify ´trends in the amount of litter in the water column (including floating at the surface) and deposited on the seafloor, including analysis of its composition, spatial distribution and, where possible, source` (European Union, 2015, p.10), and EcAp EO10, which describes the objective that ´marine and coastal litter does not adversely affect coastal and marine environments` (SPA/RAC, n.d., ´EO10: Marine Litter`). This analysis thus contributes to the efforts of the MSFD indicator 10.1.2 and the UNEP Global Marine Litter Initiative as suggested by Ramirez-Llodra et al. (2013). However, further studies using the same standardised methodologies are needed to inform policy reforms. It is crucial to identify the main causes and sources of marine litter in order to address the problem with targeted measures and awareness raising activities (Consoli, Scotti, et al., 2020; Ramirez-Llodra et al., 2013).

In addition to these general considerations, more specific recommendations are emerging within the scope of the MSFD and the EcAp as well as in general:

(1) Further development of MSFD indicators

It is essential that the development of MSFD indicators is continuously advanced on the basis of relevant experience to ensure their applicability in sub-regions such as the North Sea (European Union, 2015). Emphasis should be placed on the adaptability of the indicators, particularly with regard to their relevance to the biological effects of marine litter and microparticles (European Union, 2015). Ongoing development is necessary to ensure that the indicators remain accurate and informative and reflect the specific circumstances of different marine environments.

(2) Improving data quality and quantity

Investment in research is of paramount importance to provide more comprehensive and accurate data in the context of MSFD indicator 10.1.2 (European Union, 2015). This requires not only an intensification of data collection, but also the exploration and implementation of new technologies or methods for data collection. Targeted research efforts can thus improve both the quantity and quality of available data, which in turn will allow for a more accurate and comprehensive assessment of the marine pollution situation.

(3) Incentives

Introduce financial incentives and reward schemes for fisheries and aquaculture to encourage proper disposal of marine litter and to assist in the recovery of lost or abandoned fishing gear (e.g. FADs). A similar reward system should also be introduced for shipping to encourage active measures to minimize environmental impacts.

(4) Collaboration with local NGOs

Working with local NGOs such as Zibel in Malta could be beneficial to fishermen. Fishermen who spend a lot of time on the water could inform Zibel about nets or remnants of FADs so that Zibel's professional divers can safely remove them.

(5) Awareness and Accountability

Create accountability for proper litter disposal on beaches and in tourist areas. The public should be made aware that deep-sea waters are a hotspot for marine litter, possibly through pictorial representations.

(4) Collaborative research and monitoring

Encourage cooperation between Mediterranean countries for joint research and monitoring programs using standardised methods.

(5) Promoting circular economy

Implement policies to promote circular economy practices to minimize litter, promote recycling and reduce the use of single-use materials (Vince & Hardesty, 2018). In Malta, this could specifically target the high consumption of plastic bottles as a source of drinking water by making recycling stations more accessible. Therefore, the recycling infrastructure needs to be improved and innovation needs to be encouraged (Environment & Resources Authority, 2021).

(6) Strong legislation and enforcement

Review and strengthen laws related to the improper disposal of marine litter and strictly enforce these laws.

The positive impact of these initiatives lies in the creation of tangible measures at global, EU and local levels to combat plastic pollution and marine litter in general. The focus on people's behaviour is crucial, as sustainable change can only be achieved through broad participation.

6 Conclusion

The analysis of marine litter collected during the MEDITS survey in 2020 and 2021 provides insights into the amount and type of marine litter, its distribution in different regions and the potential causes for its occurrence on the seabed around the Maltese Islands in the central Mediterranean Sea. The abundance of marine litter on the seafloor is influenced by a number of factors, which at times made the interpretation of the results of the analyses complex. These factors include the spatial, temporal and depth distribution of marine litter due to displacement by trawling, resuspension, especially for lighter categories of litter, and embedding of litter due to geomorphological and hydrological conditions.

Despite these challenges, this study has provided valuable insights for future research, especially in the context of the Mediterranean region, which is considered a biodiversity hotspot. However, little research has been done on deep-sea ecosystems, despite the fact that the deep sea is already known to be a depositional site for human-generated and discarded marine litter.

The analysis of data from the 2020 and 2021 MEDITS therefore is a crucial contribution to the scientific assessment of the current pollution status of our seabed, especially in the specific context of the seabed around the Maltese Islands. In particular, plastic litter items were found to be present in significant quantities on the seabed. Further studies are needed to monitor the status quo, accompanied by appropriate measures to allow the deep-sea ecosystem to recover and to protect it from the effects of marine pollution. This includes the removal of macro marine litter from the ocean and the implementation of regulations to reduce the production of plastics and other ecologically harmful substances.

Through this study, it is hoped that the standardised sampling methodology of MEDITS will be recognised and used more widely in other regions so that future comparative studies can be conducted under the same conditions that are relevant to policy makers. All of this is intended to help ensure that the current geological era, the Anthropocene, which is heavily influenced by human activity, becomes the era in which we ultimately clean up and adequately protect our oceans and in which seafloor litter is acknowledged and as much as litter found on the beach.

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7 Appendix

Appendix 1: The legend of the EUSeaMap 2023 habitat types map.

EUSeaMap (2023) habitat types (Barcelona Convention - Mediterranean only)

EUSeaMap 2023 Broad-Scale Predictive Habitat Map for Europe Barcelona Convention classification system 800m simplification

- MB1: Infralittoral rock
- MB2: Infralittoral biogenic habitat
- MB3: Infralittoral coarse sediment
- MB5: Infralittoral sand
- MB5: Infralittoral mud or MB6: Infralittoral mud
- MB6: Infralittoral mud
- MC1: Circalittoral rock
- MC2: Circalittoral biogenic habitat
- MC3: Circalittoral coarse sediment
- MC4: Circalittoral mixed sediment
- MC5: Circalittoral sand
- MC6: Circalittoral mud or MC4:Circalittoral mixed sediment or MC3: Circalittoral coarse sediment
- MC6: Circalittoral mud
- MD1: Offshore circalittoral rock
- MD4: Offshore circalittoral mixed sediment
- MD6: Offshore circalittoral mud
- MD6: Offshore circalittoral mud or MD4: Offshore circalittoral mixed sediment
- ME1: Upper bathyal rock or MF1: Lower bathyal rock
- ME6: Upper bathyal muds or MF6: Lower bathyal muds
- MG1: Abyssal rock
- MG6: Abyssal muds