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Article

Marine Organisms Fouling on Ghost Nets in the Sounio Marine Protected Area (Greece)

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Abstract

Ghost nets are the result of fishing nets ending up at sea by fishing vessels during operations, repairs, accidental loss, and from aquaculture activities. This is a major threat to the marine environment due to the entrapment of marine species, which often leads to the mortality of important species, the alteration of the marine benthic habitat, and the release of microplastics. In the current study, the authors conducted underwater clean-up activities in the marine protected area of Sounio in Greece (NATURA2000) to identify, evaluate whether they can be removed, and remove ghost nets. A total of 1200 Kg of ghost nets was removed within one year, with 68 different species reported to have colonized the nets. The reported groups were Mollusca, Porifera, Chordata, Arthropoda, Echinodermata, Bryozoa, Ochrophyta, Tracheophyta, Rhodophyta, Cnidaria, Chlorophyta, and Annelida. The species were not listed as threatened by the IUCN conservation status, while 86% were native, and 14% were invasive in the Mediterranean Sea. The current work presents the need to expand research efforts in the field of underwater plastic pollution, implement monitoring campaigns to a greater extent in the study area, and perform an assessment before the removal of ghost nets.

Keywords: ghost nets; conservation; marine organisms; Sounio MPA; Mediterranean Sea

1. Introduction

In the global fishing industry's efforts, approximately 750,000 tonnes of fishing gear end up in the ocean on an annual basis [1]. Fishing gear can be abandoned, discarded, or lost from fishing vessels, constituting the "Abandoned, Lost or Discarded Fishing Gear (ALDFG)", a major contributor to the global aquatic plastic pollution [2,3]. The majority of fishing gear lost at sea is fishing nets, which are then called "ghost nets". Ghost nets are the result of fishing nets being washed overboard by fishing vessels, discarded by fishers during operations, or on board gear repairs while at sea, which can occur both intentionally and unintentionally [2]. The causes are often the weather conditions (such as storms), poor gear maintenance and crew training, ineffective storing of fishing gear, overloaded vessels, and the accidental entanglement of nets on the rocky bottom, among others [4].

The impact of ghost nets on the marine environment is ghost fishing (the incidental catch of aquatic species by discarded fishing nets due to their design) [5]. Ghost fishing has been occurring in every sea since fishers started using fishing nets, but the negative impact on marine flora and fauna has recently started being reported in the literature [6–10]. The

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most significant impacts are the direct mortality of marine organisms and the deterioration of the marine habitat [11–13]. Ghost nets can last several decades in the marine environment and can even be transported by sea currents to different locations, posing a significant threat not only to commercial marine species but also to birds, marine mammals, and sea turtles [1,14,15]. Moreover, ghost nets affect the benthic ecosystems, such as seagrass and coralligenous habitats, by settling on the sea floor and altering the bottom habitats [16–19].

The most common approach to mitigating the issue of ghost nets is monitoring the coastal habitats to locate and remove ghost nets by expert divers [5,20–23]. This method is considered essential (as all clean-ups against plastic pollution) but is also at the epicenter of a debate among researchers, regarding both the positive and negative effects that it may impose for the marine environment [16,24,25]. Taking into account the positive effects, the removal of ghost nets decreases the amount of ghost fishing and the pollution of plastic and microplastics at sea [26], while, on the other hand, the removal of ghost nets is also responsible for the removal of living organisms that have colonized the ghost nets over the years [17]. Removals without an evaluation/assessment of their impact on the marine habitat and biodiversity have been criticized for causing more damage than the ghost nets due to the removal of important marine species (such as sponges, corals, etc.) and to alter the bottom habitat (such as seagrass) [23]. Nevertheless, the colonization is dependent on the amount of time the ghost net has been at sea and seasonal environmental conditions [27].

In this work, the authors performed underwater monitoring and rehabilitation activities in a marine protected area near Athens, Greece, in the Mediterranean Sea. During this work, several ghost nets were located, evaluated to determine whether removing them would be more harmful to the marine habitat, and removed from the bottom of the sea. Here, we report the findings of marine species that colonized the removed ghost nets and discuss the implications for the removal of ghost nets in the study area.

2. Methods

2.1. Study Site

The ghost net removals took place in the area between the mainland East Attica region and the island of Patroklos within the NATURA2000 area of Sounio (SOUNIO-NISIDA PATROKLOU KAI PARAKTIA THALASSIA ZONI Greece (GR3000005)), established on 1 August 1996 (https://natura2000.eea.europa.eu/), in the Saronic Gulf, Greece. The seabed within the study area is characterized by sandbanks under the category of coastal halophytic habitats. The monitoring and removal of ghost nets took place at a depth between 15–25 m in the location shown in Figure 1.

Figure 1. The location of ghost nets removal is shown with a green star, between two active aquaculture companies (orange ellipses), in central Greece (red rectangle in bottom right corner of the figure).

The specific study area was selected as a known hotspot for ghost nets, as shown by the several campaigns that have occurred over the past decade, removing more than 10 tons of ghost nets (https://www.ghostdiving.org/three-tons-of-fish-farm-nets-recovered-in-patroklos-greece/, https://medasset.org/quot-seas-without-plastic-quot-project-2-tons-of-ghostnets-removed-from-the-seabed-near-patroklos-island-in-the-saronic-gulf/, accessed on 10 December 2025).

2.2. Ghost Net Removal Technique

In the framework of a project targeting the rehabilitation of the marine environment through the removal of ghost nets, funded by the foundation of Athina I. Martinou and implemented by the Mediterranean Association to Save the Sea Turtles (MEDASSET) in collaboration with AquaTec Scientific Diving Center, four underwater clean-ups (ghost net removals) were performed in the study area, covering a total surface area of 95,000 m^2. The clean-ups took place in winter and autumn (February, March, October, and November 2025) due to the increased traffic and tourist activity in the study area during the spring and summer months. The weather conditions were fair, with wind intensity less than 3 m/s and clear visibility both above and below the sea surface. During each clean-up, six divers performed a survey to locate ghost nets to be evaluated for potential removal and used diving knives to cut and release the net from the bottom structures it had been entangled with. The released net is surfaced using ropes and lift bags, which assist the boat crew in locating it and lifting it to the boat.

When a ghost net was located, the divers determined in situ whether it should be removed or not based on their multi-year experience in removing ghost nets and marine plastics, and their professional background in marine biology (1000 s of research hours diving experience). Afterwards, to further support their decision, the team also estimated the Gear Removal Index (GRI), an index proposed by Jimenez and Resaikos [23] that assists in evaluating whether a ghost net can be removed safely without disturbing the marine habitat. The GRI incorporates the environmental and seascape impacts, the human risks, and the technical difficulty of removing the ghost net.

2.3. Identification of Marine Life

When located, the ghost nets were scrutinized to identify and photograph all marine life before being evaluated for potential removal and after being removed from the sea floor to report on the aquatic organisms that inhabited them during their stay. The identification of marine species was conducted by experts with the use of identification keys from the WoRMS and SeaLifeBase databases to the level that it was possible [28,29]. The IUCN conservation status for the identified species was evaluated from the IUCN database [30], and the species were also checked to determine whether they are native or invasive in the Mediterranean region. The presentation of the dataset was generated using the RAWGraphs 2.0 software [31].

3. Results

A total of six ghost nets (type: synthetic fibres) weighing approximately 1200 Kg were removed from the marine area of Patroklos island (Table 1, Figure 2). The nets were transported to a specific bin for upcycling fishing nets located in the region of Lavrio, Greece, and operated by the Natural Environment & Climate Change Agency (N.E.C.C.A.) (https://necca.gov.gr/). A total of 68 different species were identified, with Mollusca (18 species) being the most representative group with a higher number of species, followed by Porifera (nine species), Chordata (nine species), Arthropoda (six species), Echinodermata (five species), Bryozoa (four species), Ochrophyta (four species), and Annelida (seven species). The fewest number of species was detected from the Tracheophyta (one species), Rhodophyta (two species), Cnidaria (two species), and Chlorophyta (one species) groups (Table 2, Figure 3). According to the IUCN conservation status, in the Mediterranean region, the majority (67%) of the identified species were either not evaluated or data deficient (DD). Four species were determined to be evaluated as least concerned (LC). Ten species were determined to be invasive, representing 14% of the total species encountered in the ghost nets.

Figure 2. A ghost net being surfaced with the use of lift bags in the study area by the team of scientific divers.

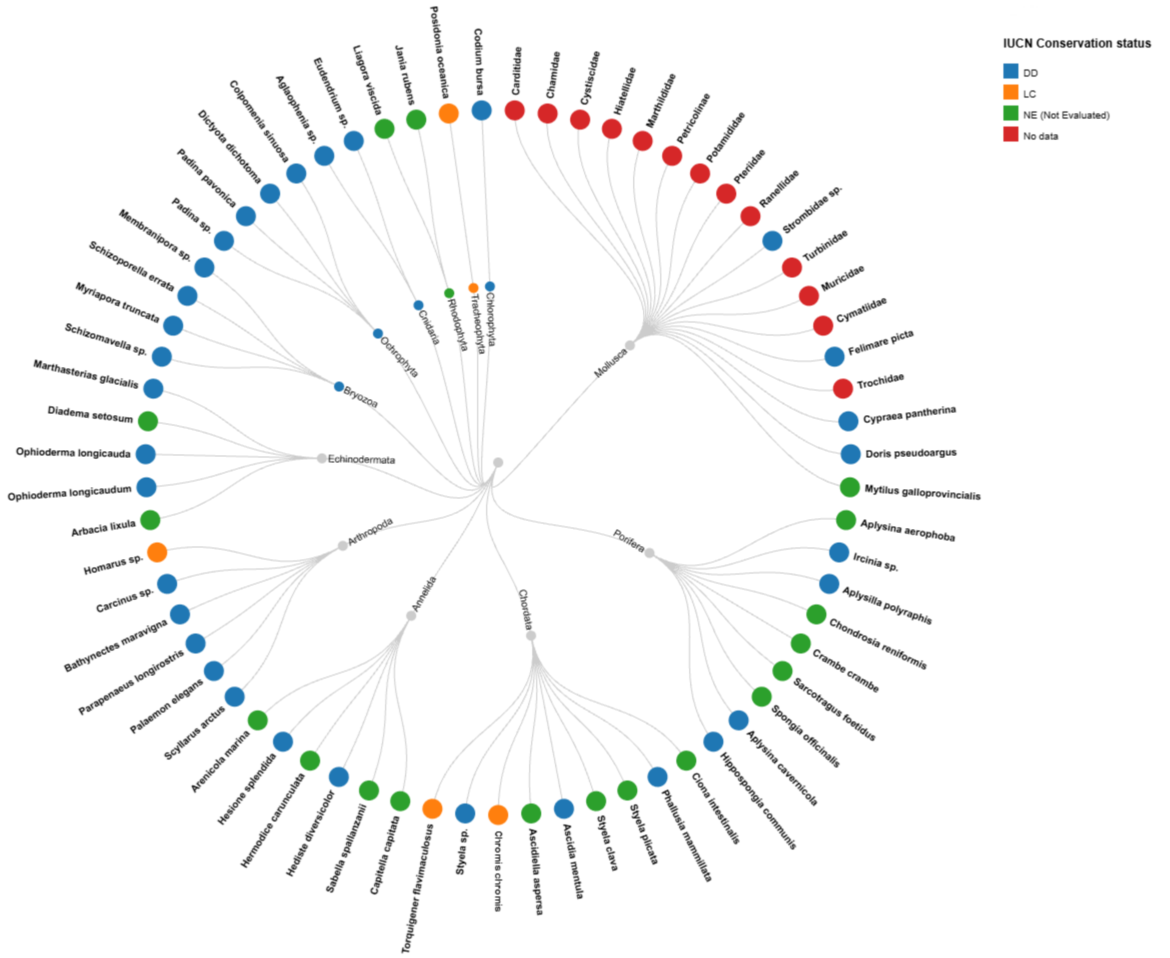

Figure 3. Groups and species occurrence (with IUCN conservation status: DD—data-deficient; LC—least concern) recorded in the removed ghost nets.

Table 1. Details per ghost net removal activity.

Date	Location	Depth	Kg of Nets	No. of Species	Ghost Net Age (Years)	Substrate	GRI Index
15 February 2025	Sounio MPA	25	350	26	>20	Sand	11
15 March 2025	Sounio MPA	20	200	14	>20	Sand	11
19 October 2025	Sounio MPA	19	300	19	>20	Sand	11
2 November 2025	Sounio MPA	23	350	15	>20	Sand	11

Table 2. Occurrence of species in the removed ghost nets.

Phylum/Class	Species	No. of Nets	Phylum/Class	Species	No. of Nets
Porifera/Demospongiae	*Aplysina aerophoba*	6	Porifera/Demospongiae	*Aplysilla polyraphis*	6
Porifera/Demospongiae	*Chondrosia reniformis*	6	Porifera/Demospongiae	*Hippospongia communis*	6
Porifera/Demospongiae	*Crambe crambe*	6	Porifera/Demospongiae	*Sarcotragus foetidus*	5
Porifera/Demospongiae	*Aplysina cavernicola*	6	Porifera/Demospongiae	*Spongia officinalis*	6
Porifera/Demospongiae	*Ircinia* sp.	6	Arthropoda/Malacostraca	*Scyllarus arctus*	4
Arthropoda/Malacostraca	*Parapenaeus longirostris*	6	Arthropoda/Malacostraca	*Palaemon elegans*	6
Arthropoda/Malacostraca	*Carcinus* sp.	6	Arthropoda/Malacostraca	*Bathynectes maravigna*	6
Arthropoda/Malacostraca	*Homarus* sp.	2	Chordata/Ascidiacea	*Styela* sp.	6
Chordata/Ascidiacea	*Phallusia mammillata*	6	Chordata/Ascidiacea	*Styela clava*	6
Chordata/Ascidiacea	*Ascidiella aspersa*	6	Chordata/Ascidiacea	*Ciona intestinalis*	6
Chordata/Teleostei	*Torquigener flavimaculosus*	6	Chordata/Actinopterygii	*Chromis chromis*	4

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Table 2. *Cont.*

Phylum/Class	Species	No. of Nets	Phylum/Class	Species	No. of Nets
Chordata/Ascidiacea	*Styela plicata*	6	Chordata/Ascidiacea	*Ascidia mentula*	6
Mollusca/Gastropoda	Trochidae	6	Mollusca/Gastropoda	*Cypraea pantherina*	6
Mollusca/Bivalvia	Carditidae	6	Mollusca/Bivalvia	Petricolinae	6
Mollusca/Gastropoda	Ranellidae	5	Mollusca/Bivalvia	Pteriidae	5
Mollusca/Gastropoda	Turbinidae	4	Mollusca/Gastropoda	*Strombidae* sp.	5
Mollusca/Bivalvia	Chamidae	6	Mollusca/Gastropoda	Muricidae	6
Mollusca/Bivalvia	Hiatellidae	6	Mollusca/Gastropoda	Cymatiidae	6
Mollusca/Gastropoda	Mathildidae	6	Mollusca/Gastropoda	*Felimare picta*	2
Mollusca/Gastropoda	Cystiscidae	6	Mollusca/Gastropoda	Potamididae	6
Mollusca/Gastropoda	*Doris pseudoargus*	3	Mollusca/Bivalvia	*Mytilus galloprovincialis*	1
Annelida/Polychaeta	*Hediste diversicolor*	6	Annelida/Polychaeta	*Hermodice carunculata*	6
Annelida/Polychaeta	*Capitella capitata*	6	Annelida/Polychaeta	*Arenicola marina*	6
Annelida/Polychaeta	*Hesione splendida*	4	Annelida/Polychaeta	*Sabella spallanzanii*	6
Ochrophyta/Phaeophyceae	*Dictyota dichotoma*	6	Ochrophyta/Phaeophyceae	*Padina* sp.	6
Ochrophyta/Phaeophyceae	*Padina pavonica*	6	Ochrophyta/Phaeophyceae	*Colpomenia sinuosa*	6
Bryozoa/Gymnolaemata	*Schizomavella* sp.	6	Bryozoa/Gymnolaemata	*Schizoporella errata*	6
Bryozoa/Gymnolaemata	*Myriapora truncata*	6	Bryozoa/Gymnolaemata	*Membranipora* sp.	5
Echinodermata/Echinoidea	*Arbacia lixula*	4	Echinodermata/Ophiuroidea	*Ophioderma longicauda*	6
Echinodermata/Ophiuroidea	*Ophioderma longicaudum*	6	Echinodermata/Asteroidea	*Marthasterias glacialis*	1
Rhodophyta/Florideophyceae	*Liagora viscida*	6	Rhodophyta/Florideophyceae	*Jania rubens*	6
Cnidaria/Hydrozoa	*Eudendrium* sp.	6	Cnidaria/Hydrozoa	*Aglaophenia* sp.	6
Echinodermata/Echinoidea	*Diadema setosum*	1	Tracheophyta/Magnoliopsida	*Posidonia oceanica*	5
Chlorophyta/Ulvophyceae	*Codium bursa*	6	-/-	-	-

4. Discussion

Ghost nets are responsible for the entrapment (and most of the time mortality) of several groups of marine organisms, comprising yet another important threat to the already vulnerable species due to anthropogenic impacts [32,33]. This study evaluated the marine flora and fauna on ghost nets removed from a marine protected area (NATURA2000 site) very close to the capital of Greece. It increased our knowledge of the impact of ghost nets in the Mediterranean Sea, by building a reference on the species fouling ghost nets in the selected region.

4.1. Patroklos Island Ghost Net Hotspot

Ghost net accumulation in this region is most probably the result of aquaculture that occurs in the vicinity of the study area (Figure 1). An analysis of the marine species that inhabited the detected ghost nets was necessary in order to identify their conservation status, evaluate the negative effects of removing the net (and choose whether to remove it or not), and establish proper knowledge on the presence of invasive species. The nets were colonized to a great extent by opportunistic algae (Groups: Tracheophyta, Rhodophyta, Ochrophyta, and Chlorophyta) (Figure 3), which are of great ecological importance in the Mediterranean region. The presence of these specific fouling algae species, which are considered vulnerable/important, indicates that ghost nets can host species of great conservation importance, as seen in other studies as well [16,17,34]. The identified species are not threatened with extinction, according to the IUCN conservation status (Figure 3). The majority of the reported species are native to the Mediterranean Sea (86%), while 10 species (*Diadema setosum*, *Carcinus* sp., *Torquigener flavimaculosus*, *Styela* sp., *Ascidiella aspersa*, *Styela clava*, *Lumbriculus variegatus*, *Styela plicata*, *Schizoporella errata*, *Sabella spallanzanii*) were determined to be invasive (14%).

An important observation from the last clean-up activity (2 November 2025) was the presence of several individuals of the invasive *Diadema setosum* on the removed ghost net

(Figure 4). The species has entered the Mediterranean Sea through the Suez Canal and was first reported in the Kas peninsula (Turkey) in 2006 [35,36]. Since 2006, the species has been reported to increase its population and distribution, reaching the coasts of Lebanon, Egypt, Israel, Turkey, Libya, Syria, Cyprus, and Greece [37–44]. Its presence in the Mediterranean can lead to competitive exclusion and a negative impact on native species (such as native echinoids) [36,44,45]. Pathogenic infections are known to cause mass mortality events for the species, leading to a reduction in its abundance that, nevertheless, has not affected its expansion [46]. The presence of 18 *Diadema setosum* individuals in the net, but not in its surrounding region (mostly sandbanks), suggests that the species encountered were grazing on the algae species covering the ghost net, since algae from hard substrates are a main food source for the species [47,48].

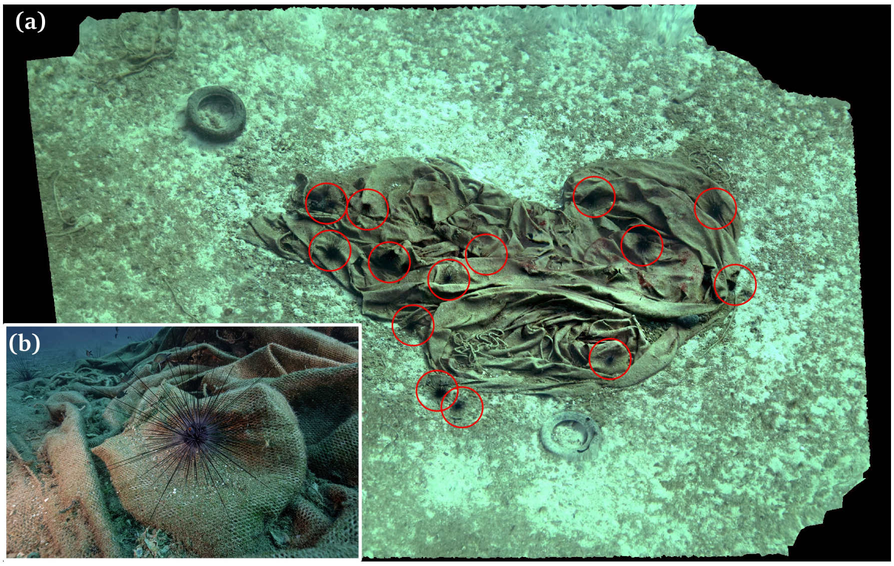

Figure 4. (**a**) The ghost net located during the last clean-up on 2 November 2025. The red circles show the location of *Diadema setosum* on the net. (**b**) Detail of one *Diadema setosum* individual on the ghost net.

4.2. Mitigating Ghost Net Impacts

Approximately 6% of all fishing nets around the globe are lost annually, adding to the already tremendous amounts of plastic pollution in the marine environment [4]. Finding ways to decrease the amount of lost fishing gear is essential for both ecological and economic reasons. Recent recommendations include restricting the number of granted fishing licenses, raising awareness and educating the fishers on best practices and methods to reduce discarting fishing nets on the sea, more strict law enforcement to ensure that fishing vessels are not overloaded, especially in coastal areas, supporting the early-reporting of lost fishing gear from fishers, and supporting and increasing fishing gear waste facilitied in ports and fishing harbours [1–3,12,15,49–56]. Mitigating the problem at the source can provide better results than solely relying on mitigating the impact [57,58]. Considering the fishing nets that have already been lost at sea, reinforcing their removal at early stages is critical to prevent their submersion (as sometimes smaller parts can float before fouling occurs and they sink) or entanglement on substrates, or eventually trapping marine organisms. The use of drones and/or satellites for monitoring coastal fishing grounds can maximize the opportunities for quick recoveries of lost fishing gear and assist in the conservation of marine life [3]. Furthermore, tagging fishing nets can be beneficial to both marine life (due to the recovery of lost nets) and also to the fishers who can easily retrieve their nets and avoid economic losses [3]. This is a viable solution for nets that are being lost or moved to different locations due to weather conditions, and since fishers cannot retrieve them, the fishing nets immediately become ghost nets. This generates great opportunities for collaborative activities with fishers, increasing local awareness, and supporting the best practices for the protection of the marine environment. Finally, the removal of ghost nets by experienced scientific divers is one of the most common techniques and is also very important under the right circumstances (considering that sometimes removing a net can be more harmful for the benthic marine habitat).

Considering the study area, ghost net removal can be highly beneficial for various reasons. Ecologically, the area is protected under the NATURA2000 network, and it is home to several marine megafauna species, such as dolphins, sea turtles, and monk seals, that are known to be impacted by the entrapment on ghost nets in the Mediterranean region [5]. Economically, the area is characterized by high marine traffic and anchoring, as it is a very important recreational/touristic area near the capital of Greece. The presence of ghost nets can result in the entanglement of vessel anchors and/or propellers, resulting in mechanical/financial issues. Considering the substrate, the sandy sea floor was not determined to be affected by the presence of the ghost nets.

4.3. Should We Remove the Identified Ghost Nets?

The ghost net issue gained international attention in the past 50 years but has not yet been incorporated in systematic management actions and normatives, considering the different approaches used to tackle this issue around the globe [15]. Ghost nets are manufactured to kill, so they are extremely harmful and their removal from the marine environment is considered the obvious solution by most researchers and activists [16]. Also, it also common for ghost nets to pose a threat to recreational divers (scuba or free diving), which should also be considered as an important factor for removing them from the marine environment [59]. Nevertheless, their removal may also include risks for marine life [16,23,24]. Considering the study area, the GRI was calculated to be eleven for all six nets, which corresponds to "highly advised" removal of ghost nets, according to the decision-making tool (Table 3) [23,25]. Thus, the decision to remove the ghost nets is supported by the GRI Index.

Table 3. Decision-making levels according to the GRI values, from Jimenez and Resaikos [23].

GRI Value	Removal of the Ghost Net	Priority
$30 \leq \text{GRI} \leq 40$	absolutely advised	1
$20 \leq \text{GRI} \leq 30$	very highly advised	2
$10 \leq \text{GRI} \leq 20$	highly advised	3
$0 \leq \text{GRI} \leq 10$	advised	4
$-15 \leq \text{GRI} \leq 0$	not recommended	5

4.4. Future Work

In the framework of the current underwater clean-up project, four campaigns were implemented in the area of Patroklos Island, Athens, Greece. Monitoring the study area revealed large amounts of ghost nets, primarily from the local aquaculture activities (Figure 1). Future work should include more surveys in a greater extent of the island's coastline to locate, evaluate (GRI Index), and potentially remove ghost nets. This will not only be highly beneficial for marine life but will also provide more data (such as abundance/frequency of ghost nets, seasonal types of organisms, types of ghost nets, types of substrates with ghost nets, influence of weather conditions, etc.) to the research community to understand the impacts of plastic pollution and will enable local stakeholders to advocate for improved regulations and actions by the local authorities. Furthermore, aerial surveys and coastal clean-ups in all seasons, in combination with measurements of wind and current intensity, would help evaluate the impact of traveling/floating ghost nets and identify potential hotspot areas.

Finally, communicating the findings of these actions to the local stakeholders (such as fishers, aquaculture managers, MPA managers, coast guard, etc.) and evaluating the best practices to mitigate the issue at the source is highly suggested as the best potential option for removing this pollutant from the marine region of Patroklos Island, Athens, Greece.

5. Conclusions

The current work builds a reference on the presence and use of ghost nets by marine life in the NATURA2000 marine protected area of Sounio (GR3000005). Overall, 1200 Kg of ghost nets were removed after applying the GRI index to evaluate the impact on the marine biodiversity, and decide whether to act or not. The nets were found to be colonized by several species, of which 14% are invasive to the Mediterranean region. The extensive colonization by algae and the presence of the invasive species suggest that the ghost nets can become a significant "oasis" for native marine species and invasive species (such as the *Diadema setosum*). The GRI was calculated to be eleven for all six nets, which corresponds to "highly advised" removal of ghost nets. Hence, the decision to remove the ghost nets is supported by the GRI Index. The findings of this study show the need to expand research efforts in the field of underwater plastic pollution, a necessity for implementing monitoring campaigns to a greater extent in the marine protected area of the Mediterranean region, and for using the GRI index to assess the removal of ghost nets.

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