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Holothurian Fisheries in the Hellenic Seas: Seeking for Sustainability

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Abstract: In Mediterranean, the exploitation and exportation of holothurians as food is increasing during the last 25 years, with Turkey and Greece as leading countries. In Greece, the fishery is expanding by the development of two métiers; however, official monitoring is missing, creating concerns on the future viability of the industry. To evaluate the status and future perspectives of holothurian fisheries, an extensive field survey has been completed (May 2019–July 2021) covering 162 sites dispersed in the Hellenic Seas. Field data included the assessment of the abundance of holothurians (via 100 m transect replicates), and catch per unit of effort (C_NPUE and C_BPUE, based on 10-min commercial fishing practices). *H. tubulosa*, *H. poli*, *H. mammata* and *H. sanctori* were fished in 41.35% of the surveyed stations. *H. poli* (C_NPUE 168 specimens, C_BPUE 22.24 kg) and *H. tubulosa* (C_NPUE 127 specimens, C_BPUE14.51 kg) were the most common species, forming locally dense populations. Mean annual catch was 275 metric tons (2016–2021) according to the processing of the units' data; 62% of the production was made by *H. tubulosa* and 38% by *H. poli*. Our results suggest the existence of exploitable grounds in the north Aegean, the central Cyclades, and the north Dodecanese, according to the prevalent environmental conditions (organic load) and fishing pressure.

Keywords: sea cucumbers; Aegean Sea; Ionian Sea; visual census; fishery; CPUE; relative abundance; regulative management

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1. Introduction

Holothurians have been traditionally exploited as gastronomic delicacies and medical cures for centuries [1]. Nowadays, 64 species are commercialized, which are mainly distributed in the tropical and sub-tropical zones, and live in shallow coastal sedimentary muddy habitats [2]. Sea cucumber prices are highly variable according to species, size, and origin. However, mean price in the China's retail market is set around 500 $/kg for the final dried product called "trepang" [3]. The increasing demand from international markets, in combination with the high price and the easiness of collection—often illegal due to the shallow-depth of the fishing grounds—has caused the collapse of about 39% of the natural stocks of tropical sea-cucumber. Moreover, IUCN has assessed 16 commercial holothurians as threatened species [4]. All the above drives the hunting of holothurians towards novel species and grounds, such as the Mediterranean Sea [5–7].

By focusing on the Mediterranean, the systematic fisheries of holothurians started in 1996 from Turkey; Greece, Spain, France, and Italy followed thereafter. Annual landings have been estimated to vary from 23 up to 550 metric tons as the maxima quota per country during the period 2010–2018, with Turkey and Greece leading the fishery market [5,6]. However, the above estimations are undocumented. FAO has just started to officially record landings per country within the relevant fishing area zone (i.e., FAO 37).

In the Hellenic Seas, two species of the genus *Holothuria* constitute the main target, namely *H. tubulosa* Gmelin, 1793 and *H. poli* Delle Chiaje, 1824 (Figure 1). The common

name of the former is the brown sea cucumber and that of the latter is the black sea cucumber. Another three species of the same genus (*H. mammata* Grube, 1840, *H. sanctori* Delle Chiaje, 1823, *H. forskali* Delle Chiaje, 1823) are also edible and harvested in other Mediterranean countries [7], but not in Greece [5]. However, rather recently, specimens of *H. mammata* are sold mixed with *H. tubulosa* from the Greek fleet. According to the Greek fisheries legislation, the genus *Hololthuria* has been officially exploited as fishing bait since 2002 (Presidential Degree 109/2002 "on bait fishing"). Each fisherman was allowed to collect up to 150 specimens of *Holothuria* spp. larger than 15 cm in length from November to May, as a banning season was set from June to October. This national legislation has been repealed, and holothurians' catches are moved from fishing baits to food for human consumption under the Presidential Degree 48/2018 "regulatory measures for fishing *Holothuria* spp.". Hence, sea cucumbers are exclusively collected by certified fishermen that use vessels obligated to record daily catches. The collection is allowed only during daytime (1 h after sunrise and 1 h before sunset), by hand and by diving using a surface air-supply apparatus (*nargileh*) or free dive. The fishing season starts in November and expires at the end of April. Sea cucumbers may be collected from any coastal area of Greece except for: (a) especially restricted areas for fisheries, (b) ports and permanent-anchorage bays, minefields, shipwrecks, ship-routes, and areas restricted due to underwater antiquities, (c) aquaculture facilities, and (d) at a 500 m radial distance from fish-ponds—sea ranches. The daily quota is set at 400 specimens of *Holothuria* spp. per boat; each specimen must weigh at least 180 g (wet weight). The total catch by species must be recorded in an Integrated Electronic System of Fisheries Records created by the relevant ministry. However, the implementation of the recording system is not yet operational. Finally, there is a precaution for implementing additional management measures at a local or national scale to protect natural stocks, based on recorded annual catches and scientific data.

Figure 1. The two target sea cucumber species in Greece, *Holothuria tubulosa* (**left**) and *H. poli* (**right**) (photo C. Antoniadou).

The fishing fleet activated in the Hellenic Seas ranges between 90–150 vessels which all belong to the small-scale fisheries [8]. The larger part of the fleet is composed of shell-fishers; these divers collect both shells and sea cucumbers. They fish in shallow bays and inlets, always very close to the shore and the port of origin. However, there are also some vessels, constituting of about 15–20% of the fleet, which originate from sponge fishing and now exclusively hunt holothurians. This part of the fleet consists of former sponge fishermen that shifted to sea cucumbers after the collapse in the richness of sponge grounds [9]. They perform large fishing trips moving offshore over the Aegean and the Ionian Seas

and operate much deeper that the former. Therefore, the Hellenic Sea cucumber fleet is constituted of two different métiers which follow different fisheries tactics, a fact which should be considered in management efforts.

Considering all the above, the present study aims to evaluate the current status and future perspectives of holothurians' natural fishery stocks in the Hellenic Seas by combining data from the field and the trepang processing units. More specifically, this work assesses: (i) the different species exploited and commercialized, (ii) the relevant fishery grounds over the Greek territory, and (iii) the density of natural stocks through fishing effort, in order to propose regulatory management options of the fishery, as best practices, based on the original data gathered.

2. Materials and Methods

The present study was carried out in the coastal waters of the Aegean and the Ionian Seas. The selection of specific survey localities was based on published information on the *Holothuria* spp. distribution [5,10], and on the opinions of fishermen and experts. Accordingly, the north Sporades and the north Aegean islands, the Cyclades plateau, the Dodecanese Island complex, and the Ionian islands were surveyed under multiday fishery trips, as well as the main shallow-water bays where holothurians are fished (Kavala, Thermaikos, Toroneos, Pagasitikos, Amvrakikos and Messiniakos gulfs) under daily trips (Figure 2). Overall, 162 sampling stations were set at 48 different islands and islets and six coastal bays.

Figure 2. Overview of the survey location in the Hellenic Seas, where 162 stations were set (source: Google Earth, modified by this research).

Samplings were made from May 2019 to July 2021 in depths down to 25 m by one scientist and one sea-cucumber fisherman using the surface air supply diving method [9] and a licensed small-scale fishery boat. They included a combination of visual censuses to assess abundance through the semi-quantitative ACFOR scale of relative abundance along three replicate 1 × 100 m belt transects [11] by the scientist, and a 10-min collection of sea cucumbers by the fisherman applying standard commercial fishing practices, to assess catch per unit effort (C_NPUE), as the total number of specimens caught per hour (N/h) [5,12]. Total catch was weighted on board to the nearest g using an electronic scale, to assess C_BPUE. Concurrently, seawater temperature, salinity, pH, and dissolved oxygen were recorded with an autographic conductivity-temperature-depth sensor, CTD (SeaBird Electronics, Washington, DC, USA).

An analysis of variance was applied to examine spatial differences in CPUE of holothurians using the general linear model [13]. Prior to the analyses, data were tested for normality with the Anderson—Darling test, while the homogeneity of variances was tested with Cohran's test. The Fisher LSD test was used for post hoc comparisons. ANOVAs were performed using the SPSS software package (IBM SPSS statistics v.25, IBM Corp, Armonk, New York, NY, USA).

As the Greek authorities have not implemented the official recording system for sea cucumber landings yet, the internal holothurian quantities per species trade-in by the 'Nautilus Seafood' processing company were collected for the period 2016–2021 and analyzed to construct annual catch. This processing unit covers about the 20% of the internal trade of sea cucumbers fished over the Hellenic Seas.

3. Results

3.1. Diversity, Distribution, and Relative Abundance of Commercial Holothurian Species

Overall, four commercial sea cucumber species were recorded, namely *H. tubulosa*, *H. poli*, *H. mammata* and *H. sanctori*. These species were found in 67 of the 162 surveyed stations (Figure 3). *Holothuria poli* and *H. tubulosa* were the most common species, found in 39 and 37 stations, respectively. On the contrary, *H. sanctori* and *H. mammata* were occasionally found and in very low abundance, except for one station at Kalymnos (Therma beach), where the species was assessed as frequent (i.e., population density from 20 to 40 N/100 m^2). In this station a thermal spring exists and the sea bottom consists of gravel and rocky plates interspersed in a seagrass meadow, as opposed to all other stations where the seabed is covered by sandy to muddy detritic sediments, mixed with patches of extensive *Posidonia oceanica* beds, and rocks here are only scattered or founds bordering the shoreline of a bay.

According to the ACFOR scale of relative abundance, *H. poli* was the most dominant species followed by *H. tubulosa*. *Holothuria poli* was present in nine stations (Pr), had sparse (O, R) populations in fifteen stations, and dense (A, C, F) populations in another fifteen stations (Figure 3). Therefore, its natural stocks may be considered as exploitable in those latter fifteen stations, which are mainly located in the Aegean Sea (Thermaikos, Toroneos and Pagasitikos gulfs, Alonissos and Kyra-Panagia islands in the National Marine Park of Alonissos Northern Sporades -NMPANS, Paros, Ios, Serifos and Milos islands in Cyclades, and Patmos, and the Agathonissi islands in the north Dodecanese). *Holothuria tubulosa* was present in eighteen stations (Pr), had sparse (O, R) populations in eight, and dense (A, C, F) populations in eleven stations (Figure 3). Those latter stations with exploitable stocks are also located in the Aegean Sea (Thermaikos and Toroneos, Kyra-Panagia Island in NMPANS, Paros, Naxos, Ios, and the Milos islands in Cyclades). *Holothuria sanctori* was recorded at 25 stations, being either present (20 stations) or rare (4 stations), and frequent (F) only in one surveyed station of Kalymnos Island (Dodecanese), whereas *H. mammata* was only recorded at six stations (Sporades, Cyclades and Dodecanese), being either present or rare in these locations (Figure 3).

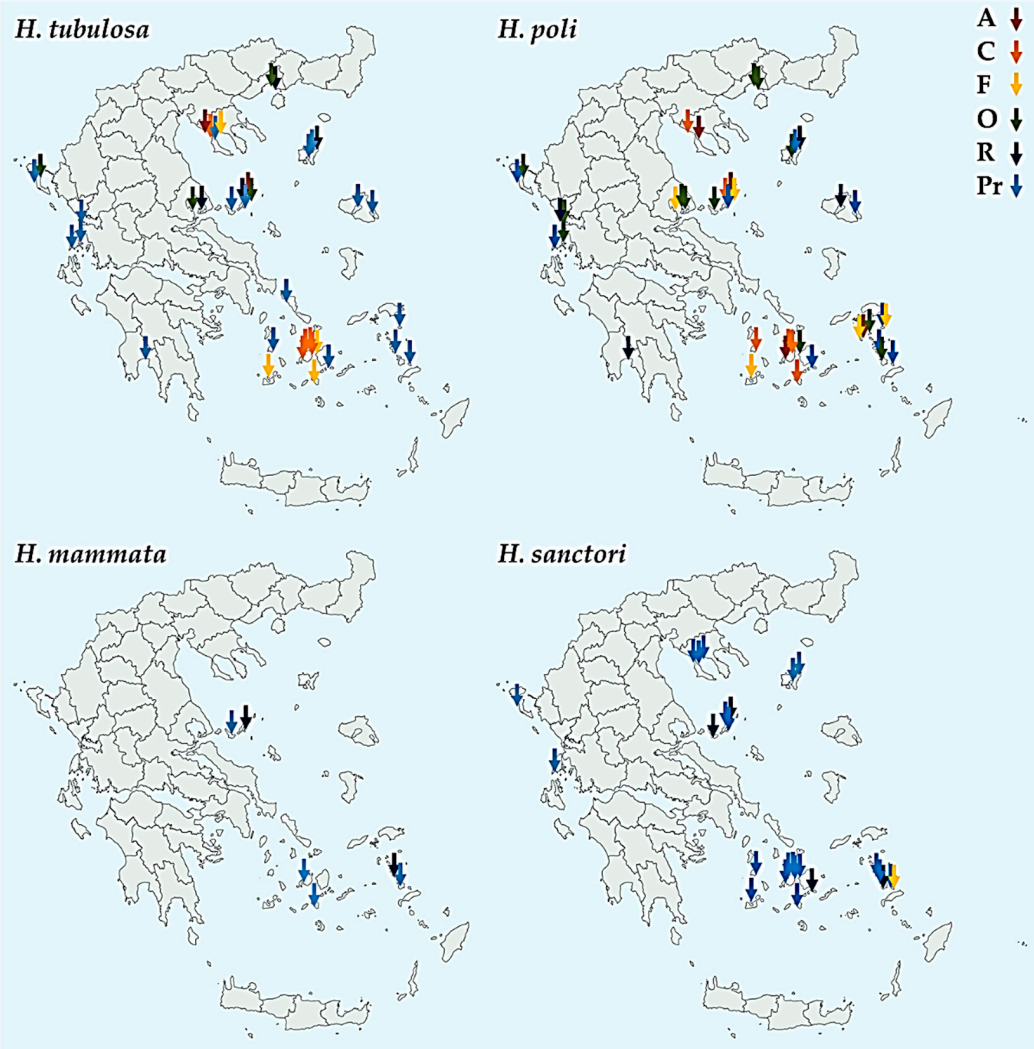

Figure 3. Occurrence of the commercial *Holothuria* species in the Hellenic Seas (source: created by this research).

3.2. Holothurians Catch per Unit Effort C_NPUE C_BPUE

Overall, 779 specimens of the species *H. tubulosa* were caught, ranging from 1 to 221 specimens/10′ dive. Accordingly, C_NPUE ranged from 6 to 1326 with an overall mean at 126.97 specimens. The highest C_NPUE values were recorded in the Thermaikos Gulf, Kyra-Panagia (Planitis Bay), and the Paros islands (Figure 4A). Over the Dodecanese Island complex, the species had a very low abundance as only three specimens were caught at three different islands (Agathonissi, Leros, Pserimos), all located in the northern sector. C_BPUE ranged from 0.67 to 93.25 kg (Figure 4B) with an overall mean at 14.51 kg. The highest C_BPUE values were recorded in Kira Panagia and Thermaikos, followed by the Cyclades islands of Ios, Naxos, and Paros; therefore, *H. tubulosa* fisheries are profitable in these grounds. C_NPUE had much higher values in the Aegean compared with Ionian stations ($F = 6.48$ $p < 0.05$). By focusing on the Aegean Sea, significant differences in C_NPUE were also found according to the geographic area ($F = 5.42$ $p < 0.05$), with increased values in north Aegean gulfs, Cyclades, and north Sporades islands (Figure 5). C_BPUE was significantly higher in the Aegean compared with the Ionian stations ($F = 9.41$ $p < 0.01$); relevant C_BPUE differences between the geographical areas of the Aegean Sea were also significant ($F = 4.21$ $p < 0.05$), with a similar trend to C_NPUE (Figure 5).

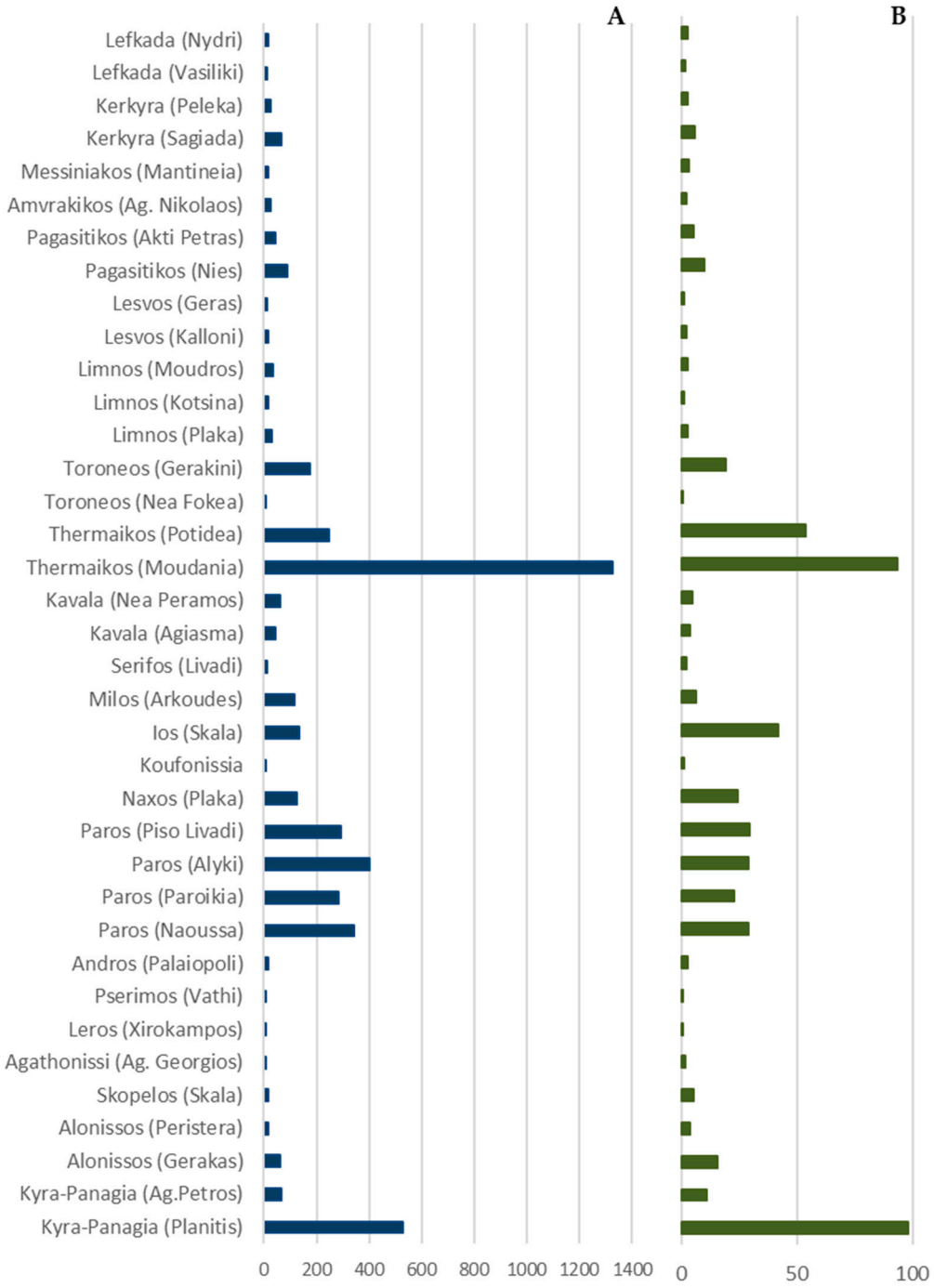

Figure 4. CPUE of *H. tubulosa* (**A**) C_NPUE, (**B**) C_BPUE per sampling site in the Hellenic Seas. Zero-value sites are excluded from the graph (source: created by this research).

Based on CPUE values (C_N and C_B) the natural stock of the species is made up of small-sized individuals in the Thermaikos Gulf, as opposed to Kyra Panagia.

Overall, 1375 specimens of *H. poli* were caught, ranging from 1 to 115 specimens/10′ dive. Accordingly, C_NPUE ranged from 6 to 690 with an overall mean at 167.69 specimens. C_NPUE was significantly higher in the Aegean compared with the Ionian Sea ($F = 12.64$ $p < 0.01$). Focusing on the Aegean, significant differences in C_NPUE were also found between geographical areas ($F = 4.69$ $p < 0.05$), with increased values found in north Aegean gulfs, north Sporades, and Cyclades islands (Figure 6). C_BPUE was higher in the Aegean Seas compared with the Ionian ($F = 12.86$ $p < 0.01$). Relevant C_BPUE differences

between the Aegean geographical areas were also significant (F = 4.23 $p < 0.05$), with a similar trend ensuing with C_NPUE (Figure 6).

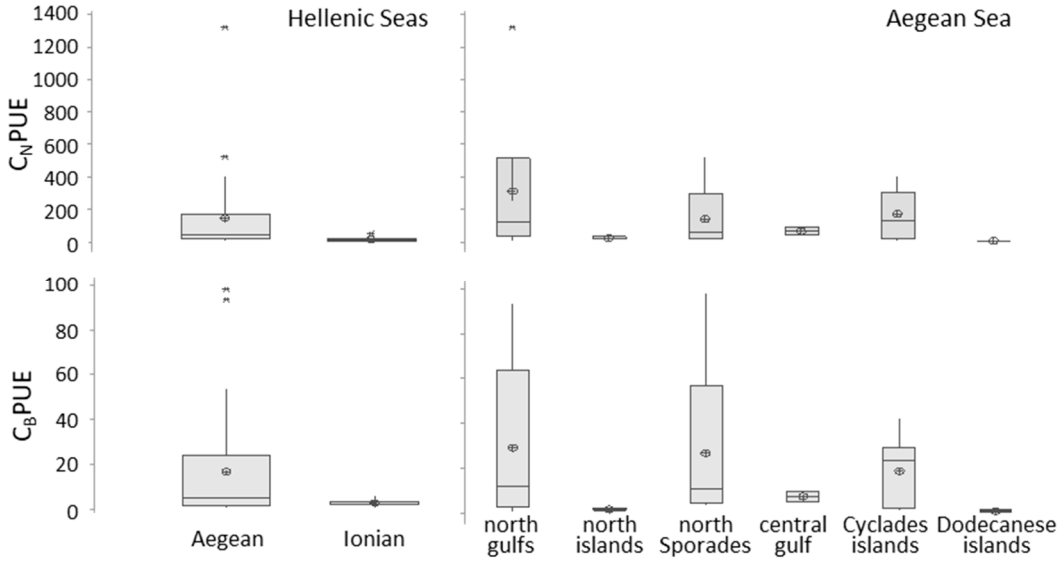

Figure 5. Boxplot of C_NPUE and C_BPUE of *H. tubulosa* in the Hellenic Seas (**left** graph) and the Aegean Sea (**right** graph), after excluding zero-value stations; cross in circle symbol = mean, asterisk symbol = outliers, horizontal within box line = median, box = Q1 to Q3 quartiles, vertical line = whisker (source: created by this research).

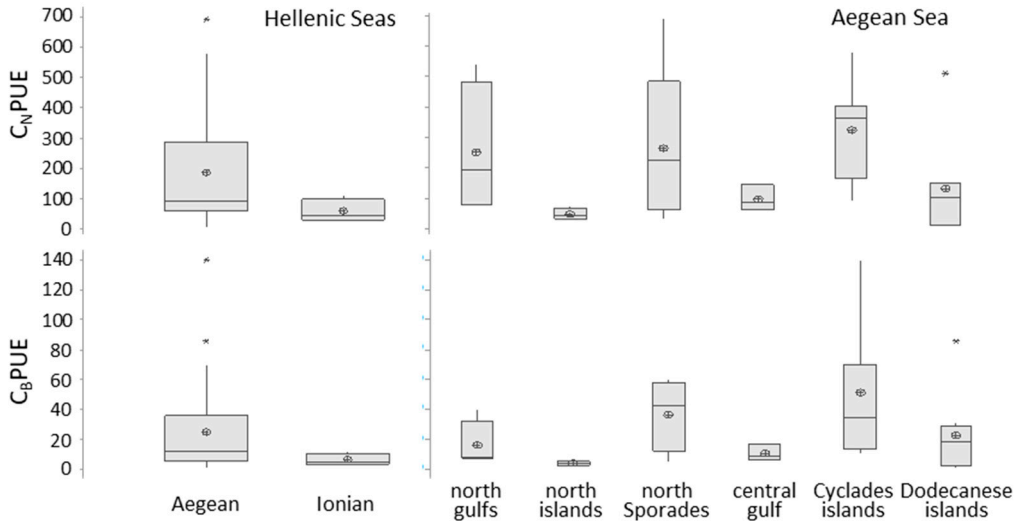

Figure 6. Boxplot of C_NPUE and C_BPUE of *H. poli* in the Hellenic Seas (**left** graph) and the Aegean Sea (**right** graph), after excluding zero-value stations; cross in circle symbol = mean, asterisk symbol = outliers, horizontal within box line = median, box = Q1 to Q3 quartiles, vertical line = whisker (source: created by this research).

The highest C_NPUE values were recorded in Kyra-Panagia (Planitis Bay), Paros (Alyki), and Patmos islands, and in the Toroneos Gulf (Figure 7A). C_BPUE ranged from 1.05 το 139.94 kg (Figure 7B) with an overall mean at 22.24 kg. The highest C_BPUE values were recorded in Paros, Ios, Serifos (Cyclades), Patmos (Dodecanese), Alonissos, Kira Panagia (North Sporades), and the Toroneos Gulf; therefore, *H. poli* fisheries are profitable in these grounds.

Based on CPUE values (C_N and C_B) the natural stock of the species is made up of small-sized individuals in Kyra Panagia and the Toroneos gulf, as opposed to all other islands where medium to large-sized individuals prevailed.

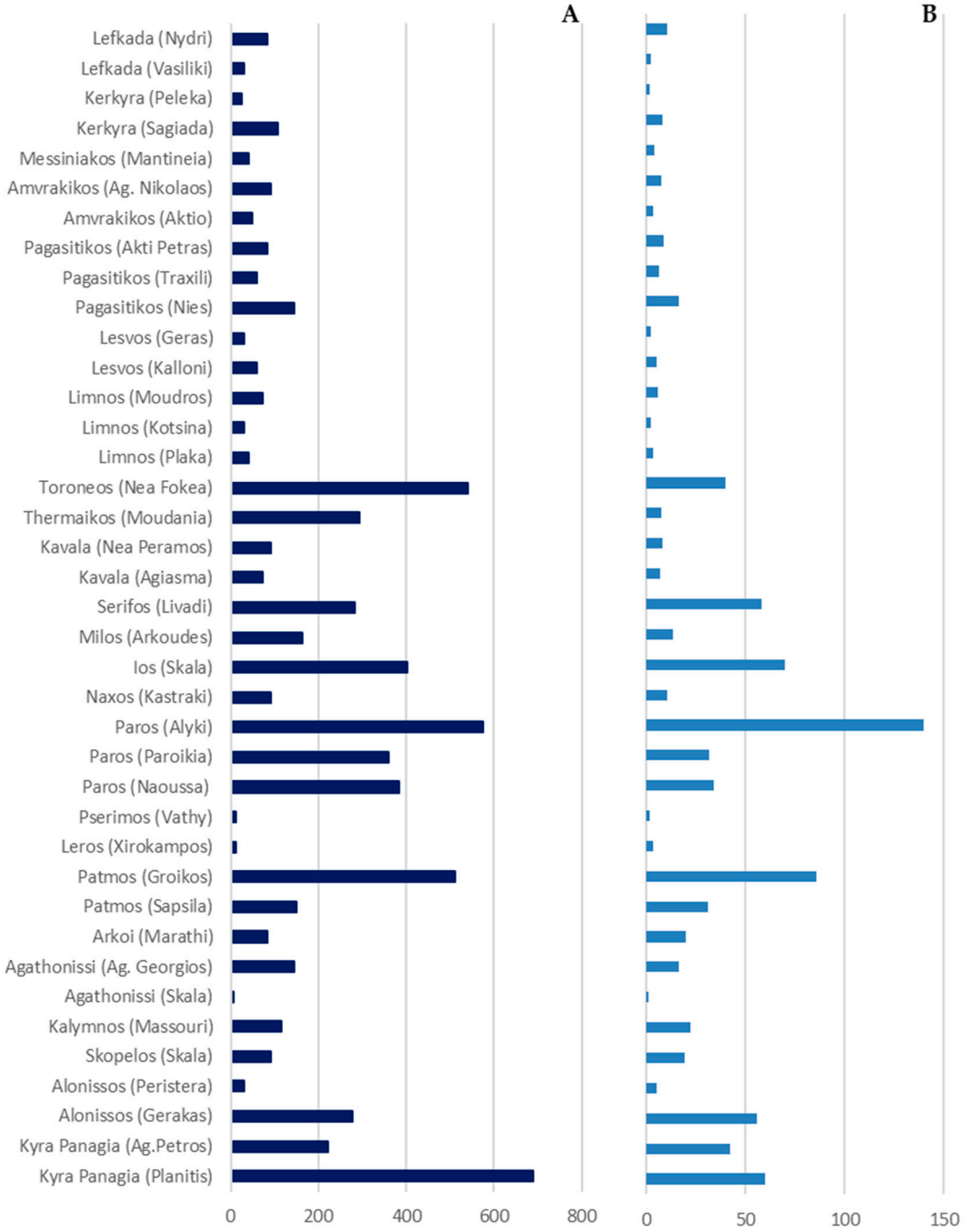

Figure 7. CPUE of *H. poli* (**A**) C_NPUE, (**B**) C_BPUE per sampling site in the Hellenic Seas. Zero-value sites are excluded from the graph (source: created by this research).

Considering both *H. sanctori* and *H. mammata*, very few specimens were caught (94 and 56, respectively); fishing effort ranged from 1 to 19 specimens-/10′ dive and from 1 to 9 specimens/10′ dive for the former and the latter species, respectively.

C_NPUE of *H. sanctori* showed increased values in the Aegean compared with the Ionian Sea ($F = 5.95$ $p < 0.05$, Figure 8), whereas the relevant differences for C_BPUE (Figure 8) were not significant ($F = 4.48$ $p = 0.053$). Both C_NPUE and C_BPUE showed non-significant differences between the subareas of the Aegean Sea ($F = 1.57$ $p = 0.306$ and $F = 1.37$ $p = 0.296$, respectively). According to C_NPUE and C_BPUE the highest quota was found in Kalymnos, Pserimos, and Kyra Panagia (Figure 9).

Holothuria mammata was found only in the Aegean Sea. C_NPUE showed non-significant differences between the subareas of the Aegean Sea ($F = 1.52$ $p = 0.419$). C_BPUE of

H. mammata had very low values in Cyclades compared to Sporades and Dodecanese islands (Figure 10). The relevant spatial differences were non-significant (F = 22.39 p = 0.066), although the p value was close to the 0.05 significance level. According to C_NPUE and C_BPUE, the highest quota was found in Leros and Alonissos (Figure 11).

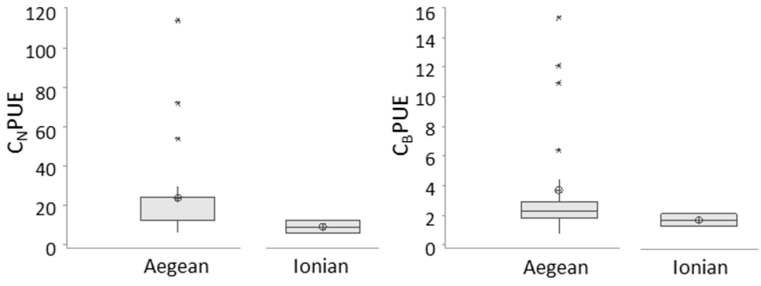

Figure 8. Boxplot of C_NPUE and C_BPUE of *H. sanctori* in the Hellenic Seas, after excluding zero-value stations; cross in circle symbol = mean, asterisk symbol = outliers, horizontal within box line = median, box = Q1 to Q3 quartiles, vertical line = whisker (source: created by this research).

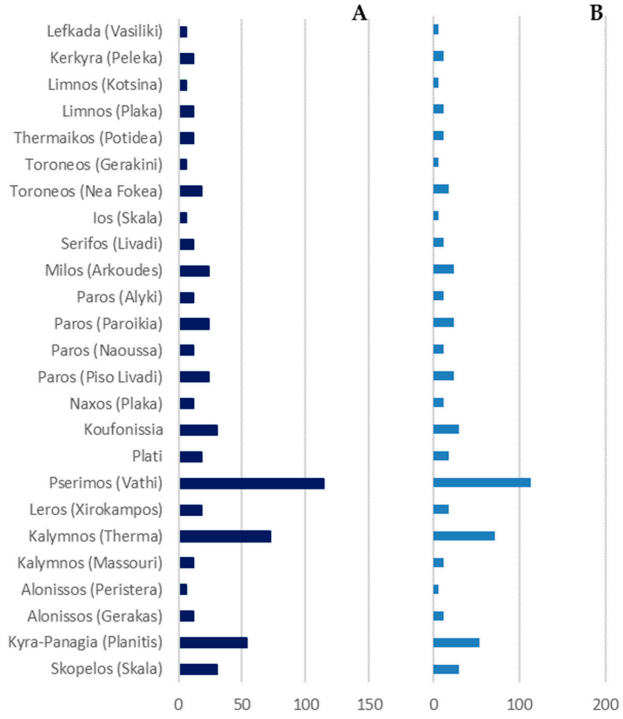

Figure 9. CPUE of *H. sanctori* (**A**) C_NPUE, (**B**) C_BPUE per sampling site in the Hellenic Seas. Zero-value sites are excluded from the graph (source: created by this research).

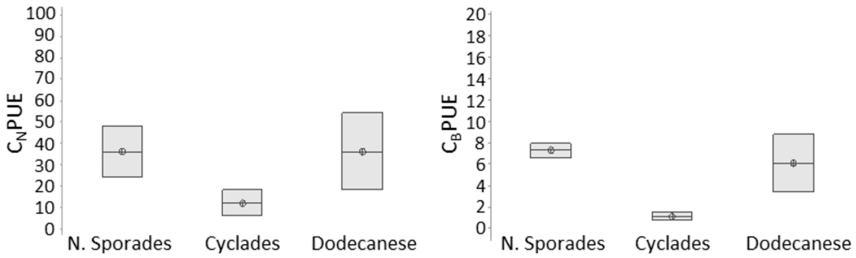

Figure 10. Boxplot of C_NPUE and C_BPUE of *H. mammata* in the subareas of the Aegean Sea, after excluding zero-value stations; cross in circle symbol = mean, asterisk symbol = outliers, horizontal within box line = median, box = Q1 to Q3 quartiles, vertical line = whisker (source: created by this research).

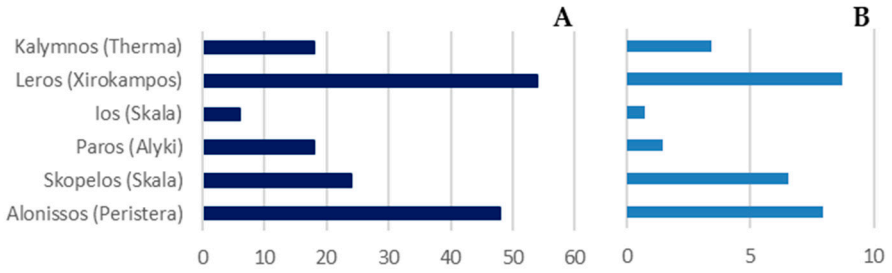

Figure 11. CPUE of *H. mammata* (**A**) C_NPUE, (**B**) C_BPUE per sampling site in the Hellenic Seas. Zero-value sites are excluded from the graph (source: created by this research).

3.3. Annual Sea Cucumber Catch

The mean annual catch of holothurian landings processed in the "Nautilus Seafood" company varies from 16.65 to 137.82 metric tons during the period 2016–2021, with a steady prevalence of the species *H. tubulosa* (Figure 12). These landings originated mainly from the Cyclades plateau, Paros Island in particular. A vast drop in the production of holothurians is obvious after the 2017–2018 pick. This is due to a temporary ban on the fishing of holothurians in the island of Paros due to local antiphons and, thereafter, to the COVID-19 lockdown effect.

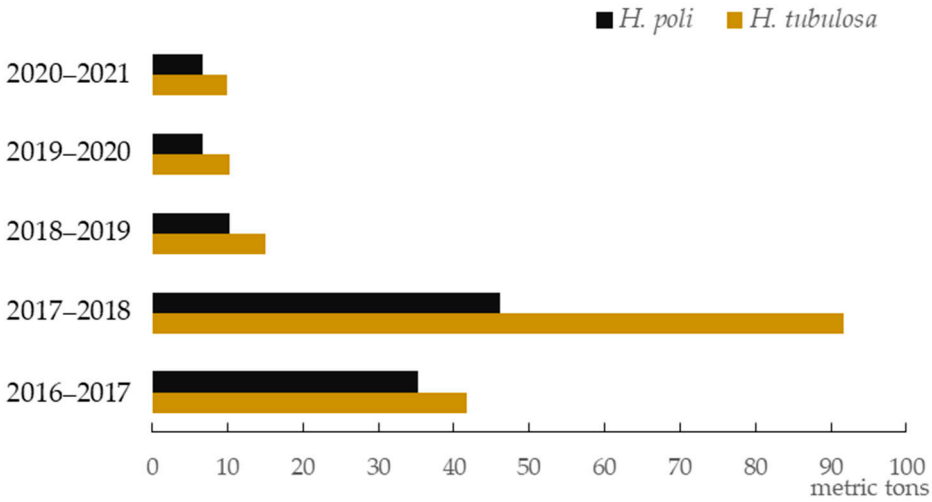

Figure 12. Total weight of sea cucumbers (*H. tubulosa* and *H. poli*) fished in the Hellenic Seas (mainly from the Cyclades Island of Paros) and processed by the "Nautilus Seafood" company, per fishing season (source: created by this research).

By extrapolating the above data over the Greek territory, the mean annual catch of holothurian landings from the Hellenic Seas is estimated at 275 metric tons; 62% of the production (170 t) is made by the harvesting of the species *H. tubulosa* and 38% (105 t) by *H. poli*, respectively.

4. Discussion

Sea cucumber fisheries are of increasing socioeconomic importance in the Hellenic agricultural sector. Holothurians appeared as an alternative biological resource to the decimated sponge fisheries [5,9] and to the suppressed shellfish fisheries [14]. As a result, many small-scale fishery vessels (ranging annually from 90 to 150) shifted to the harvesting of holothurians during the last five years. The active holothurian fleet follows different fishery strategies, either by performing large trips over the Hellenic Seas and hunting holothurians offshore and in the deep, or by diving in very shallow coastal bays right after the port of origin. These different strategies infer, therefore, the existence of two different métiers [8]. Moreover, for over the last century sea cucumbers have been collected by hand or hooks and utilized as bait in long-line fisheries, especially in the Dodecanese island

complex [5]. Overall, the exerted fishing pressure on natural holothurian stocks is steadily increasing over the Hellenic Seas and the threat of overexploitation seems to be a reality for prominent *Holothuria* species or local populations, despite the existing fisheries regulations.

The monitoring of holothurian fishery stocks revealed the exploitation and commercialization of four species of the genus *Holothuria*, namely *H. tubulosa*, *H. poli*, *H. mammata,* and *H. sanctori* in the Greek territory. These holothurians were found in 42% of the surveyed area (67 out of the 162 sites). They formed sparse populations in most cases, being absent or rare over the south—southeastern Dodecanese islands. Locally dense populations (i.e., population densities of over 20 holothurians per 100 m^2) of specific species appeared in 16% of the surveyed marine area (26 out of the 162 sites). These sites are exclusively located in the Aegean Sea, as the density of holothurians was rather low in the surveyed sites of the Ionian Sea. Therefore, exploitable natural stocks may be inferred in the north Aegean (Thermaikos, Toroneos and Pagasitikos gulfs, Alonissos, Kyra Panagia, and north Sporades islands), the central Cyclades (Paros, Antiparos, Naxos, Ios, Serifos, and Milos islands), and the north Dodecanese (Patmos, Agathonissi, and Kalymnos islands). These marine areas provide favorable environmental conditions for holothurian feeding by holding an increased trophic state due to organic inputs (natural topography, urbanization) or strong marine currents. Holothurians, as typical deposit-feeding animals [15], may flourish only in organically enriched habitats or under currents in the Aegean Sea [5,8,10]. Important stocks may also exist in the Limnos and Ionian islands, though the relative abundance of *Holothuria* species was much lower. However, the sampling effort devoted to holothurian stocks was also inferior in the Ionian Sea. As previous data on holothurian stocks are available only for the north Dodecanese islands and the Pagasitikos Gulf [5,10], it is evident that much more effort is needed to precisely assess the fishery grounds of holothurians in the Hellenic Seas.

Overall, holothurians follow a patchy pattern of distribution in the Hellenic Seas, with very dense local populations in proximity with extremely sparse or null populations. A similar spatial pattern has also been reported for many species of the genus *Holothuria* from various Mediterranean and adjacent Atlantic coast areas [16–19]. This pattern, though not completely understood, has been attributed to habitat topographies, such as sediment granulometry, organic content, vegetation type and coverage, shell, or other biogenic debris. These factors are related with improved alimentary conditions rather than to a massive settlement of holothurian larvae [15,17,20]. Seabed rugosity seems to be of particular importance by setting available benthic refuges and affecting the "homing" behavior of holothurians after their nocturnal movement patterns for feeding. This patchiness is size-dependent as well, with small-sized holothurians of the same or congeneric species aggregating in higher densities in areas of increased rugosity, which are typically found in shallower waters. Under strong hydrodynamics, holothurians are moved in deeper and sustain sparser but larger-sized populations [19].

According to presented results, the species *H. poli* dominates over the surveyed areas in both the Aegean and the Ionian seas, and especially in shallow habitats. Though this was the general pattern, there were some exceptions. For example, in the Thermaikos Gulf, the species *H. tubulosa* prevailed over *H. poli* and in Kyra-Panagia (Planitis Bay, NMPANS) both species coexisted in a similar proportion. It is also worth noting the locally important presence of *H. sanctori*, especially in sedimentary habitats surrounded by rocky cliffs or mixed with rocky reefs and boulders. Accordingly, this species may be exploited in additional locations with specific habitat characteristics. *H. sanctori* has been rather recently included in edible Mediterranean holothurians [21,22]. It is exploited in Turkey and other Mediterranean countries, often together with its congeneric *H. forskali*, and in Spain, experimental cultures of the above species are in progress [23,24]. Despite the commercial importance of *H. sanctori*, the Greek fishers avoid this species, as its handling is problematic due to the expulsion of adhesive Cuvierian tubules. On the contrary, the presence of *H. mammata* seems to be restricted in the Hellenic Seas, although it is often included in fishery productions from the Turkish Aegean [6,7].

According to catch per unit effort results (C_NPUE, C_BPUE), the yield of two species, *H. tubulosa* and *H. poli* (>40 N/10′ experimental fisheries quota), may be considered as commercially exploitable in several fishery grounds of the Aegean Sea. The *Holothuria sanctori* quota may be also exploitable in specific habitats (19 N/10′ experimental fisheries quota), if fishermen start to collect the species and overlook handling difficulties (i.e., Cuvierian tubules) from collection to commercialization. Relevant data for *H. mammata* were too few. Accordingly, its fishing is unlikely in the Hellenic Seas, despite it covering 22% of the annual sea cucumber production in Turkey [6] and is considered among the most commercially important Mediterranean holothurians [3,25]. The highest reported C_NPUE for *H. mammata* in the study area is 55 individuals. In most Mediterranean areas its populations are sparse, with densities ranging around 12 individuals/100 m^2 [19]. The density of *H. mammata* varies with habitat type and the species prefer rocky sedimentary bottoms with coarse sand [15]. It is, therefore, possible that the species sustain exploitable populations, at least at some of the surveyed areas with suitable habitats, that were overlooked by fishermen during the experimental trials. Professional sea-cucumber fishers target *H. tubulosa* and *H. poli*, which are hunted over sandy-muddy bottoms either vegetated or not, as this is the typical and preferred habitat type for those species [10,26–28]. Additional monitoring efforts are required, therefore, to assess the population status of *H. mammata* and its fisheries' profitability in the Hellenic Seas.

Unfortunately, there are too few previous data on *Holothuria* fisheries and stock assessments in the Hellenic Seas, impeding our capacity to estimate the current pressure on fisheries. More explicitly, the relevant information is limited to a pilot survey (2006–2008 period) of edible *Holothuria* (*H. tubulosa* and *H. poli*) over the north Dodecanese [5,29] and Pagasitikos Gulf [10,27]. By comparing these studies with current results, the population density of *H. tubulosa* and *H. poli* seem to have remained rather stable. In the mesotrophic Pagasitikos Gulf, *H. tubulosa* had and still has moderate abundance, which is, however, lower than in other Mediterranean areas [10]. In the oligotrophic Dodecanese Island complex, where long-term fishing for holothurian baits was common—though unrecorded, both *H. tubulosa* and *H. poli* had an overall low abundance. Local moderately dense populations occurred only in very sheltered natural harbor bays (i.e., Astypalea, Arkoi, Agathonissi) or in proximity to maricultures (i.e., Pserimos), where deposited organic matter is sufficient for feeding [5]. Currently, holothurian stocks remain, overall, in low abundance. Former moderately dense populations have declined in contrast with some sparse populations that have grown (i.e., Patmos). These results suggest spatiotemporal fluctuations in the abundance of holothurians, according to prevalent environmental conditions (organic load) and the activity of fisheries.

The severe impact of fisheries may be indirectly highlighted in the case of the NMPANS marine protected area [30]. Within the strictly protected Zone A area of the park in Planitis Bay (Kyra-Panagia Island), extremely dense populations of the species *H. tubulosa* and *H. poli* were found. The surveyed bay is enclaved, and forms two totally sheltered main coves that communicate to the open sea through a very narrow entrance channel. The enclaved marine area is shallow (max depth 16 m) and is one of the biggest Mediterranean natural harbors (0.65 km^2). The shoreline of the bay is rocky with muddy sands mixed with shell fragments, sponges, algae, and seagrasses covering the sea bottom. Organic input is increased due to the geomorphology and the extremely small fetch of the bay, as well as due to the intense anchorage of yachts and fishing boats [30]. Therefore, the habitat seems to be particularly favorable for the establishment of sea cucumbers and may function as a natural reservoir ensuring the viability of holothurian populations. Moreover, besides being a biodiversity repository, it may serve as a main source for restocking overfished populations of the Aegean Sea.

The accurate assessment of annual production is a crucial dimension of sustainable exploitation of marine natural resources. Annual production per holothurian species and fishery ground is completely missing over the Greek territory. Besides, the obligation for implementing the Electronic Reporting System (ERS) that could enable theassessment and

regulative management of stocks, has been delayed for holothurian fisheries. Accordingly, annual production can be estimated only indirectly, through processing companies and field fishery surveys. Based on the data derived from the "Nautilus Seafood" company landings, the mean annual production of holothurians is estimated to 275 metric tons over the Greek territory and clearly targets *H. tubulosa*. During the period 2010–2018 a maximum yield of 353 t has been estimated for the Greek fisheries sector [3], which is much lower than the estimated maxima based on the processing company data (689 t). The annual production of holothurians largely fluctuates at both spatial and temporal scales [3,5–7,31,32]. To deal with the increased uncertainty of relevant estimations, FAO has just started their attempts to record the annual production of Mediterranean holothurian fisheries.

Considering the discussed results on the current state of holothurian fisheries in the Hellenic Seas, and the difficulties that artisanal sponge and shellfish fisheries face, some additional regulatory management options, as best practices, are examined. Accordingly, the strict delineation of exploitable grounds and the rotation of fisheries within subareas of each ground may be an option for the recovery of holothurian natural stocks. By following the different métiers in holothurian fisheries, the relevant grounds may be diversified to coastal shallow-water gulfs and to offshore island areas. Each type may be separated geographically to a north and a south sector that would be exploited under a two-year rotation period. Daily quota (400 specimens) and the applied hunting methods seems to be adequate, at least for the coastal shallow-water gulfs métier. In the case of the offshore islands' métier, the daily quota should be substituted by a proportional monthly or annual quota. Offshore fishermen have to face much harsher weather conditions and the actual fishing days are much reduced, causing severe viability problems and increasing the human risk. Moreover, as this métier operates in much deeper waters, the tube length of the breathing apparatus should be enlarged to at least 150 m for safety reasons. Of particular importance is the immediate implementation of the ERS to create data series on daily quotas per area and species. This basic recording is essential for the evaluation of the applied regulative measures. Ideally, ERS data should be combined to field fisheries surveys and to scientific monitoring of the métier's data for adaptive fishery management towards the viability of holothurians and the conservation of exploited ecosystems.

Another severe issue to deal with is illegal fishing [3,5,33,34]. Non-licensed SCUBA divers are hunting holothurians, especially in shallow-depth coastal areas, such as the Thermaikos gulf. Illegal fishing is practiced quite often in nighttime when the animals are more active and more easily detected by non-specialists. This unfair competition is a global phenomenon in sea cucumber fisheries, and the enhancement of surveillance and the capacity for enforcement seems to be the only solution to halt it [1,2,32,34]. Moreover, illegal hunters are opportunist with short-term interest on the fishery, and so, they are unaware on the future viability of natural stocks. As they collect all kind of holothurians with no size or quantity restrictions, they may easily cause the local depletion of populations. As holothurians are highly susceptible to the "Allee effect" [35] a reproductive failure is quite common in depleted populations beyond a certain threshold due to the sparsity of breeding adults [36–39]. In such cases, conventional management measures are insufficient for the replenishment of natural stocks and restocking of spawning densities by importing recruits from other source populations may be the only option [37].

The source populations of *H. tubulosa* and *H. poli* within the NMPANS marine protected area, is therefore of particular importance for the viability of the species and for the restoration of overfished areas. A shift towards the development of integrated maricultures is an alternative option, especially considering the current progress in the hatchery and rearing of the Mediterranean species *H. arguinensis* [18,40,41], *H. forskali* [23,42], *H. mammata* [43], *H. poli* [44], and *H. tubulosa* [45,46]. Even though the aquaculture of Mediterranean *Holothuria* spp. is not yet operational, the experimental production of larvae and young recruits offer possibilities for restocking and the enhancement of stocks harvested from sea cucumber populations. Hatchery reared holothurians may be released in

wild fisheries grounds to safeguard production, as successfully implemented for the species *Apostichopus japonicus* in Japan and China [47]. However, such management actions should be precautionarily applied to preserve the genetic diversity of existing stocks and only in cases where the breeding of natural populations has failed. Thorough studies emphasized on the species biology of breeding stocks and population diversity at the genetic level are prerequisite before relevant management attempts are carried out. As fishing pressure is steadily increasing for both target-species in Greek sea cucumber fisheries, and signs of overfishing are evident at least in some locations, the Thermaikos Gulf for example, the long-term sustainability of *Holothuria* fisheries is questionable. The combination of the proposed best practices in holothurian fisheries with restocking action plans for the suppressed natural populations may be the solution to enhance sustainability.

5. Conclusions

This is the first comprehensive survey of holothurian fisheries in the Hellenic Seas. The discussed results demonstrated that the exerted fishing pressure is steadily increasing, threatening prominent *Holothuria* species or local populations despite the existing regulations. *Holothuria tubulosa* and *H. poli* were the target species; they generally form sparse populations interrupted with locally dense aggregations (over 20 holothurians per 100 m^2) in areas with increased organic input or under currents. These areas represent exploitable fisheries grounds and are mainly found in the north Aegean, the central Cyclades, and the north Dodecanese. This patchy pattern of distribution conforms to previous studies and, accordingly, seems to be an intrinsic feature of Mediterranean *Holothuria* populations. The existence of very dense *H. tubulosa* and *H. poli* populations within a Marine Protected Area is of particular importance for future sustainability, representing a biodiversity repository strictly protected from fisheries. Holothurians are typical sediment-feeder animals; as keystone species in the trophic ecology of benthic ecosystems, the conservation of viable populations is crucial for the maintenance of a good environmental status in the marine environment. The safeguarding of sustainable breeding populations fulfilling their functional role in benthic ecology and avoiding cascade effects is decisive. The recursive monitoring of the fishery by combining field and ERS data is imperative for the regulatory management of holothurians' fisheries under the ecosystem-based auspices [32].

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Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy reasons.

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References

1. Toral-Granda, V.; Lovatelli, A.; Vasconcellos, M. *Sea Cucumbers: A Global Review of Fisheries and Trade*; FAO Fisheries and Aquaculture Technical Paper, 516; FAO: Rome, Italy, 2008; pp. 1–317.
2. Purcell, S.W.; Samyn, Y.; Conand, C. *Commercially Important Sea Cucumbers of the World*; FAO Species Catalogue for Fishery Purposes. No. 6; FAO: Rome, Italy, 2012; pp. 1–150.
3. Gonzalez-Wangüemert, M.; Domínguez-Godino, J.; Cánovas, F. The fast development of sea cucumber fisheries in the Mediterranean and NE Atlantic waters: From a new marine resource to its over-exploitation. *Ocean. Coast. Manag.* **2018**, *151*, 165–177. [CrossRef]
4. Conand, C.; Polidoro, B.; Mercier, A.; Gamboa, R.; Hamel, J.F.; Purcell, S. The IUCN Red List assessment of aspidochirotid sea cucumbers and its implications. *Beche-de-mer Inf. Bull.* **2014**, *34*, 3–7.
5. Antoniadou, C.; Vafidis, D. Population structure of the traditionally exploited holothurian *Holothuria tubulosa* in the south Aegean Sea. *Cah. Biol. Mar.* **2011**, *52*, 171–175.
6. González-Wangüemert, M.; Aydin, M.; Conand, C. Assessment of sea cucumber populations from the Aegean Sea (Turkey): First insights to sustainable management of new fisheries. *Ocean. Coast. Manag.* **2014**, *92*, 87–94. [CrossRef]
7. González-Wangüemert, M.; Valente, S.; Henriques, F.; Domínguez-Godino, J.; Serrão, E. Setting preliminary biometric baselines for new target sea cucumbers species of the NE Atlantic and Mediterranean fisheries. *Fish. Res.* **2016**, *179*, 57–66. [CrossRef]
8. Vafidis, D.; Antoniadou, C. *Fisheries Exploitation and Management of Holothurians (Holothuria spp.): Processing (Food and Biotechnological Products) and Stock Sustainability*; Technical Report; University of Thessaly: Volos, Greece, 2022; pp. 1–115.
9. Voultsiadou, E.; Dailianis, T.; Antoniadou, C.; Vafidis, D.; Dounas, C.; Chintiroglou, C. Aegean bath sponges: Historical data and current status. *Rev. Fish. Sci.* **2011**, *19*, 34–51. [CrossRef]
10. Kazanidis, G.; Antoniadou, C.; Lolas, A.; Neofitou, N.; Vafidis, D.; Chintiroglou, C.; Neofitou, C. Population dynamics and reproduction of *Holothuria tubulosa* (Holothuroidea: Echinodermata) in the Aegean Sea. *J. Mar. Biol. Assoc.* **2010**, *90*, 895–901. [CrossRef]
11. Vafidis, D.; Antoniadou, C.; Voulgaris, K.; Varkoulis, A.; Apostologamvrou, C. Abundance and population characteristics of the invasive sea urchin *Diadema setosum* (Leske, 1778) in the south Aegean Sea (eastern Mediterranean). *J. Biol. Res. Thessaloniki* **2021**, *28*, 11. [CrossRef]
12. Antoniadou, C.; Vafidis, D. First assessment of *Microcosmus sabatieri* (Tunicata: Ascidiacea) small-scale artisanal fishery in the South Aegean Sea (Eastern Mediterranean). *Cah. Biol. Mar.* **2008**, *49*, 97–100.
13. Underwood, A.J. *Experiment in Ecology: Their Logical Design and Interpretation Using Analysis of Variance*; Cambridge University Press: New York, NY, USA, 1997; pp. 1–504.
14. Damianidis, P.; Karachle, P.; Chintiroglou, C. Population structure of clam *Venus verrucosa* Linnaeus, 1758 harvested in Thermaikos Gulf, NW Aegean Sea, Greece. *Int. J. Fish. Aquat. Stud.* **2016**, *4*, 393–401.
15. Navarro, P.G.; Garcia-Sanz, S.; Barrio, J.M.; Tuya, F. Feeding and movement patterns of the sea cucumber *Holothuria sanctori*. *Mar. Biol.* **2013**, *160*, 2957–2966. [CrossRef]
16. Bulteel, P.; Jangoux, M.; Coulon, P. Biometry, bathymetric distribution, and reproductive cycle of the holothuroid *Holothuria tubulosa* (Echinodermata) in Mediterranean seagrass beds. *Mar. Ecol.* **1992**, *13*, 53–62. [CrossRef]
17. Simunovic, A.; Piccinetti, C.; Bartulovic, M.; Grubelic, I. Distribution and abundance of the species *Holothuria tubulosa* Gmelin, 1788 and *Holothuria forskali* Delle Chiaje, 1823 (Holothuria, Echinodermata) in the Adriatic Sea. *Acta Adriat.* **2000**, *41*, 3–16.
18. Domínguez-Godino, J.A.; González-Wangüemert, M. Habitat associations and seasonal abundance patterns of the sea cucumber *Holothuria arguinensis* at Ria Formosa coastal lagoon (South Portugal). *Aquat. Ecol.* **2020**, *54*, 337–354. [CrossRef]
19. Félix, P.M.; Pombo, A.; Silva, F.A.; Simões, T.; Marques, T.; Melo, R.; Rocha, C.; Sousa, J.; Venâncio, E.; Costa, J.L.; et al. Modelling the distribution of a commercial NE-Atlantic sea cucumber, *Holothuria mammata*: Demographic and abundance spatio-temporal patterns. *Front. Mar. Sci.* **2021**, *8*, 675330. [CrossRef]
20. Tolon, T.; Emiroglu, D.; Gunay, D.; Saygi, H. Effect of sediment grain size on growth performance of juvenile sea cucumber (*Holothuria tubulosa*). *Turkish J. Fish. Aquat. Sci.* **2015**, *15*, 555–559. [CrossRef]
21. Navarro, P.G.; Garcia-Sanz, S.; Tuya, F. Reproductive biology of the sea cucumber *Holothuria sanctori* (Echinodermata: Holothuroidea). *Sci. Mar.* **2012**, *76*, 741–752. [CrossRef]
22. Neghli, L.; Mezali, K. Algeria's sea cucumber fishery: Challenges for a new fishery. *Beche-de-mer Inf. Bull.* **2019**, *39*, 71–75.
23. Laguerre, H.; Raymond, G.; Plan, P.; Améziane, N.; Bailly, X.; Le Chevalier, P. First description of embryonic and larval development, juvenile growth of the black sea-cucumber *Holothuria forskali* (Echinodermata: Holothuroidea), a new species for aquaculture in the North-Eastern Atlantic. *Aquaculture* **2020**, *521*, 734961. [CrossRef]
24. Magdy, M.; Otero-Ferrer, F.; Courtois de Viçose, G. Preliminary spawning and larval rearing of the sea cucumber *Holothuria sanctori* (Delle Chiaje, 1823): A potential aquaculture species. *Aquac. Rep.* **2021**, *21*, 100846. [CrossRef]
25. Dereli, H.; Aydın, M. Sea cucumber fishery in Turkey: Management regulations and their efficiency. *Reg. Stud. Mar. Sci.* **2021**, *41*, 101551. [CrossRef]
26. Tortonese, E.; Vadon, C. Oursins et Holothuries. In *Fiches FAO D'identification Des. Espèces Pour Les. Besoins de la Pêche (Révision 1)—Méditerranée et Mer. Noire. Zone de pêche 37*; Fischer, W., Bouchon, M.L., Scneider, M., Eds.; FAO Publications: Rome, Italy, 1987; pp. 743–760.
27. Kazanidis, G.; Lolas, A.; Vafidis, D. Reproductive cycle of the traditionally exploited sea cucumber *Holothuria tubulosa* (Holothuroidea: Aspidochirotida) in Pagasitikos Gulf, western Aegean Sea, Greece. *Turk. Zool. Derg.* **2014**, *38*, 306–315. [CrossRef]

28. Boncagni, P.; Rakaj, A.; Fianchin, A.; Vizzini, S. Preferential assimilation of seagrass detritus by two coexisting Mediterranean sea cucumbers: *Holothuria polii* and *Holothuria tubulosa*. *Estuar. Coast. Shelf Sci.* **2019**, *231*, 106464. [CrossRef]
29. Vafidis, D.; Tsagridis, A.; Chintiroglou, C.; Antoniadou, C. *Fisheries Exploitation, Processing and Trade of Holothurian Stocks in the South Aegean Sea*; Technical Report; University of Thessaly: Volos, Greece, 2008; pp. 1–85.
30. Paraskevopoulos, S. Tourism in protected areas: The case of the National Marine Park of Alonissos-Northern Sporades in Greece. *Eur. J. Soc. Sci. Stud* **2019**, *2*, 116–132. [CrossRef]
31. Adyin, M. The commercial sea cucumber fishery in Turkey. *Beche-de-mer Inf. Bull.* **2008**, *28*, 40–41.
32. Purcell, S.; Lovatelli, A.; Vasconcellos, M.; Ye, Y. *Managing Sea Cucumber Fisheries with an Ecosystem Approach*; FAO Fisheries and Aquaculture Technical Paper, 516; FAO: Rome, Italy, 2010; pp. 1–157.
33. Meloni, D.; Esposito, G. Hygienic and commercial issues related to the illegal fishing and processing of sea cucumbers in the Mediterranean: A case study on over-exploitation in Italy between 2015 and 2017. *Reg. Stud. Mar. Sci.* **2018**, *19*, 43–46. [CrossRef]
34. Conand, C. Recent information on worldwide illegal fisheries for sea cucumbers. *Beche-de-mer Inf. Bull.* **2018**, *38*, 68–71.
35. Stephens, P.A.; Sutherland, W.J.; Freckleton, R.P. What is the Allee effect? *Oikos* **1999**, *87*, 185–190. [CrossRef]
36. Uthicke, S.; Benzie, J. Effect of bêche-de-mer fishing on densities and size structure of *Holothuria nobilis* (Echinodermata: Holothuroidea) populations on the Great Barrier Reef. *Coral Reefs* **2000**, *19*, 271–276. [CrossRef]
37. Bell, J.D.; Purcell, S.W.; Nash, W.J. Restoring small-scale fisheries for tropical sea cucumbers. *Ocean. Coast. Manag.* **2008**, *51*, 589–593. [CrossRef]
38. Pasquini, V.; Giglioli, A.A.; Pusceddu, A.; Addis, P. Biology, ecology and management perspectives of overexploited deposit-feeders sea cucumbers, with focus on *Holothuria tubulosa* (Gmelin, 1788). *Adv. Oceanogr. Limnol.* **2021**, *12*, 9995. [CrossRef]
39. Yu, Z.; Zhang, Y.; Zhou, L.; Sun, H. The effects of hypoxia and anthropogenic disturbance on the distribution, abundance and recruitment of the sea cucumber *Holothuria leucospilota* at the mouth of a subtropical bay, China. *Front. Mar. Sci.* **2021**, *8*, 739657. [CrossRef]
40. Domínguez-Godino, J.A.; Slater, M.J.; Hannon, C.; González-Wangüermert, M. A new species for sea cucumber ranching and aquaculture: Breeding and rearing of *Holothuria arguinensis*. *Aquaculture* **2015**, *438*, 122–128. [CrossRef]
41. Rodriguez, T.; Azevedo e Silva, F.; Sousa, J.; Félix, P.M.; Pombo, A. Effect of enriched substrate on the growth of the sea cucumber *Holothuria arguinensis* Koehler and Vaney, 1906 juveniles. *Diversity* **2023**, *15*, 458. [CrossRef]
42. Santos, R.; Dias, S.; Pinteus, S.; Silva, J.; Alves, C.; Tecelao, C.; Pedrosa, R.; Pombo, A. Sea cucumber *Holothuria forskali*, a new resource for aquaculture? Reproductive biology and nutraceutical approach. *Aquac. Res.* **2015**, *47*, 2307–2323. [CrossRef]
43. Domínguez-Godino, J.A.; González-Wangüemert, M. Breeding and larval development of *Holothuria mammata*, a new target species for aquaculture. *Aquac. Res.* **2018**, *49*, 1430–1440. [CrossRef]
44. Rakaj, A.; Fianchini, A.; Boncagni, P.; Scardi, M.; Cataudella, S. Artificial reproduction of *Holothuria polii*: A new candidate for aquaculture. *Aquaculture* **2019**, *498*, 444–453. [CrossRef]
45. Rakaj, A.; Fianchini, A.; Boncagni, P.; Lovatelli, A.; Scardi, M.; Cataudella, S. Spawning and rearing of *Holothuria tubulosa*: A new candidate for aquaculture in the Mediterranean region. *Aquac. Res.* **2018**, *49*, 557–568. [CrossRef]
46. Sadoul, B.; Caprioli, J.P.; Barrier-Loiseau, C.; Cimiterra, N.; Laugier, T.; Lagarde, F.; Chary, K.; Callier, M.D.; Guillermard, M.O.; Roque d'Orbcastel, E. Is *Holothuria tubulosa* the golden goose of ecological aquaculture in the Mediterranean Sea? *Aquaculture* **2022**, *554*, 738149. [CrossRef]
47. Lovatelli, A.; Conand, C.; Purcell, S.; Uthicke, S.; Hammel, J.F.; Mercier, A. *Advances in sea Cucumbers Aquaculture and Management*; FAO Fisheries and Aquaculture Technical Paper, 463; FAO: Rome, Italy, 2004; pp. 1–425.