frontiers in Marine Science

ORIGINAL RESEARCH
published: 12 January 2021
doi: 10.3389/fmars.2020.578601

Status and Exploitation of 74 Un-Assessed Demersal Fish and Invertebrate Stocks in the Aegean Sea (Greece) Using Abundance and Resilience

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Specialty section:
This article was submitted to Marine Ecosystem Ecology, a section of the journal Frontiers in Marine Science

Received: 30 June 2020
Accepted: 16 December 2020
Published: 12 January 2021

Citation:
Tsikliras AC, Touloumis K, Pardalou A, Adamidou A, Keramidas I, Orfanidis GA, Dimarchopoulou D and Koutrakis M (2021) Status and Exploitation of 74 Un-Assessed Demersal Fish and Invertebrate Stocks in the Aegean Sea (Greece) Using Abundance and Resilience. Front. Mar. Sci. 7:578601. doi: 10.3389/fmars.2020.578601

Stocks with low market value are rarely included in stock assessments because their catch records are generally lacking, thus adding to the already large number of un-assessed fisheries at a global scale. This deficiency is more evident in the Mediterranean Sea where stock assessments are relatively fewer. A new method (AMSY) has been recently developed to assess stocks for which only abundance trends from scientific surveys are available. The AMSY method was used in the Aegean Sea to assess the status of 74 fish and invertebrate stocks (50 actinopterygians, 4 sharks, 5 rays, 12 cephalopods, and 3 crustaceans) for which catch data are lacking; 20 of them have medium or high market value and are being targeted by fishing fleets, while the remaining 54 are either not targeted, but by-caught and often discarded, or are not exploited at all. Overall, 31 of the 54 non-targeted stocks (57%) were healthy in terms of biomass ($B/B_{msy} > 1$), whereas only 6 of the 20 targeted stocks (30%) were healthy. Of the 23 unhealthy non-targeted stocks, 12 were near healthy ($B/B_{msy} > 0.75$), compared to only 1 of the targeted stocks, whereas 10 non-targeted stocks (19%) and 10 targeted ones (50%) were outside safe biological limits ($B < 0.5B_{msy}$). Cephalopods and crustaceans were generally in a better status compared to fishes. The results confirm that fishing does not only affect commercial stocks, but it may also affect by-catch stocks. In general, stocks that are targeted by fishing fleets are in a worse status in terms of biomass compared to those that are only occasionally collected as by-catch or those that inhabit environments that are not accessible to fishing fleets.

Keywords: stock assessment, fisheries management, non-commercial stocks, Mediterranean Sea, un-assessed fisheries

INTRODUCTION

Commercial fish and invertebrate stocks attract the attention of fisheries scientists at a global (Ricard et al., 2012) and regional (Colloca et al., 2013) scale and, as a result, the vast majority of regular assessments have been performed on fish and invertebrate stocks of high commercial interest (Osio et al., 2015). In the eastern Mediterranean Sea, an extensive assessment of the exploitation and status of commercial fish and invertebrate stocks has been recently performed in Greece (Froese et al., 2018b) and Turkey (Demirel et al., 2020). However, in Greece, the number of stocks that have been regularly and officially assessed is still very low compared to the other European countries of the northern Mediterranean coastline (Osio et al., 2018). One of the reasons for the low number of assessments is the lack of complete fisheries data time-series since 2009 due to administrative and financial constraints, while some of the recent official assessments suffer from various biases, one of which is the mixing of catch time-series from multiple fleets (Tsikliras et al., 2020). The number of official assessments is even lower along the southern Mediterranean coastline, one of the data-poorest regions of the northern hemisphere (Chrysafi and Kuparinen, 2016). The lack of adequate number of assessments is an international issue as un-assessed stocks exceed 80% of total catch, globally (Costello et al., 2012).

All recent assessments (Colloca et al., 2013; Vasilakopoulos et al., 2014; Tsikliras et al., 2015; Froese et al., 2018b) clearly show that the Mediterranean stocks are in bad state as a result of ongoing overexploitation. The overall stock status and exploitation pattern is rather uniform across the Mediterranean, with low stock biomass and high fishing pressure being the common characteristics but with the stock specific biomass and exploitation values varying among ecoregions (Froese et al., 2018b). According to a model approach, even most un-assessed demersal fish species are potentially overexploited in most Mediterranean areas (Osio et al., 2015). In any case, overexploitation of the Mediterranean Sea has been reported to occur since the 1950s, when about 40% of stocks were declining in biomass, as later unmasked by their catch history (Froese and Kesner-Reyes, 2002). Recently, it was reported that the stocks of all target species that have been assessed are overexploited, with hake (*Merluccius merluccius*) being the most overexploited stock across the Mediterranean Sea (Cardinale et al., 2017). According to a recent assessment that covers several areas of the world, the Mediterranean Sea is the most heavily exploited area and its stocks are in worse state compared to all other areas that were assessed (Hilborn et al., 2020). Indeed, the exploitation rate in the Mediterranean has been reported as steadily increasing and gear selectivity as deteriorating; both conditions are suspected to lead to shrinking fish stocks (Vasilakopoulos et al., 2014). Technological advancements that improve catchability (effort creep) also increase the overall effectiveness of fishing (Palomares and Pauly, 2019) and the operation of the Greek fishing fleet to international waters throughout the year is also leading to increased pressure at Aegean stocks (Tsikliras, 2014). Nevertheless, all these assessments include only fish and invertebrate stocks with available catch time-series (the correct term is landings as no official data exists for discarded catch in the Mediterranean Sea), while by-catch and discarded catch had been largely ignored mainly for practical reasons, as there was no method to account for their assessment.

Recently, a new method (AMSY) that can assess the exploitation pattern and status of stocks for which no catch data exist using only time-series of abundance (catch-per-unit-of-effort, CPUE) or biomass has been developed (Froese et al., 2020). Other fisheries independent methods also exist but they are time consuming and costly (e.g., underwater television: Morello et al., 2007). Many of these stocks are regularly collected, often in large quantities, during scientific surveys, but their status is rarely assessed as the data-poor stock assessment methods that were available until recently, require at least a time-series of catch (CMSY: Froese et al., 2017) or length frequency distributions (LBB: Froese et al., 2018a, 2019). Some of these species may also be collected by the commercial fishing fleets, especially bottom-trawlers, as by-catch; stocks with no or very low market value are usually discarded (Machias et al., 2001), although in some cases they are mixed with taxonomically related commercial stocks and marketed. The importance of assessing non-commercial stocks is high for ecosystem models (Dimarchopoulou et al., 2019) and for examining the effects of fishing on all components of the ecosystem, thus facilitating and promoting ecosystem-based fisheries management (Dimarchopoulou, 2020). It has been shown that by-catch demersal species that are collected in high numbers may suffer low biomass and truncated size distributions toward smaller lengths similarly to commercial stocks, while some others that are rarely collected maintain population structure and size (Dimarchopoulou et al., 2018).

The aim of the present work was to assess the status of 74 non-commercial demersal fish and invertebrate stocks in the Aegean Sea with the AMSY method using their abundance trends and resilience. As none of these species had been assessed before, the list of stocks for which there is now an assessment in the Aegean Sea is further increased, given that 42 stocks were recently assessed with the CMSY method (Froese et al., 2018b) and will soon be re-assessed using the updated CMSY + method (Tsikliras et al., unpublished data). Moreover, the assessment of stocks that have never been exploited, not even as by-catch (e.g., deep-water fishes and invertebrates), and are only collected during scientific surveys will provide important information on the effects of environmental (e.g., climate change) or ecological (e.g., prey-predator relationships) forcing on stock biomass and trends.

MATERIALS AND METHODS

Study Area

The Aegean Sea is divided by the Cyclades plateau into two sub-basins, the northern and the southern, which display different hydrographic and ecological characteristics due to the input of brackish water from the Black Sea in the northern part and the influence of Levantine Sea waters in the southern part (Ignatiades et al., 2002). Although the Aegean Sea as a whole is generally an oligotrophic sea (Ignatiades et al., 2002), parts of the northern Aegean Sea exhibit higher primary production and nutrient concentration (Siokou-Frangou et al., 2002).

The eutrophic gradient and the more extended continental shelf in its northern part are the main factors differentiating the subareas of the Aegean Sea in terms of productivity, species composition and species diversity (Stergiou and Pollard, 1994), with the northern Aegean Sea being the area with the highest total catches (Sylaios et al., 2010). European anchovy (*Engraulis encrasicolus*) and European pilchard or sardine (*Sardina pilchardus*) dominate the Aegean pelagic catch, while European hake (*Merluccius merluccius*), red mullet (*Mullus barbatus*) and two crustaceans, caramote prawn [*Melicertus (Penaeus) kerathurus*] and deep-water rose shrimp (*Parapenaeus longirostris*) are the main targeted demersal species (Stergiou et al., 2007a,b).

Selection of Stocks

Out of all fish and invertebrate stocks that are being collected during the experimental Mediterranean bottom trawl survey (MEDITS: Bertrand et al., 2002) and for which no official catch time-series exists (i.e., they are considered non-commercial), 74 stocks were included in the analysis. The catch of some of them is being reported at higher taxonomic level, aggregated together with relative species. For example, the catch of thornback ray (*Raja clavata*) is being reported separately, but all other rays are reported as "other rays" (*Raja* spp.). Species with only sporadic occurrence and very low CPUE values were excluded. The CPUE time-series extends from 1994 to 2018 with several missing years after 2009 (see next section); all surveys take place during the summer months (June and July in most cases).

Stocks with an official record of catch (for a list of species see Tsikliras et al., 2013) that form the prime targets of fisheries were excluded from this analysis but their previous assessment (Froese et al., 2018b) was used for comparability purposes (n = 42; **Table 1**). The remaining ones were divided into three categories based on the literature (Machias et al., 2001) and empirical knowledge: (1) alternative or secondary targeted stocks (stocks with no official catch records that are occasionally targeted and have a market value; n = 20), (2) by-catch stocks (stocks with a low market value that are not targeted but may be occasionally marketed; n = 28), and (3) discards (stocks that have never been exploited not even as by-catch and stocks caught in very small quantities as by-catch and are always discarded; n = 26). Spiny dogfish (*Squalus acanthias*) and musky octopus (*Eledone moschata*) were included because their catch records used in the previous assessment (Froese et al., 2018b) may have included their congeneric species, i.e., longnose spurdog (*Squalus blainville*) and curled octopus (*Eledone cirrhosa*), respectively. The first two categories (prime and alternative targets) formed the targeted part of the catch and the other two (by-catch and discards) were the non-targeted part of the catch. Further subdivision of those two commonly used categories was necessary because the effect of fishing might differ between prime and alternative targets and non-targeted (by-catch) or unwanted (discards) catch.

Data Analysis

Three different scientific bottom trawl surveys take place in the Aegean Sea using the same experimental bottom trawling gear but different vessels (one survey in the northern Aegean and two surveys in the southern Aegean, one of which along the southern Greek coastline and Cyclades Islands and the other one in Dodecanese Islands and Crete). Although the surveys are designed under a common framework, they are executed by different survey teams and are not always running simultaneously, conditions that may result in different levels of bias. For those reasons the CPUE data from the three surveys were considered as three different (multiple) and distinct indices.

The Bayesian state-space framework JARA (Just Another Red-List Assessment: Winker and Sherley, 2019) was used to address the issue of missing values and to combine the three abundance indices into a single one. JARA provides the option for fitting relative abundance indices to estimate a mean trend by allowing the simultaneous analysis of one or multiple abundance indices each of which may contain missing years and extend to different time period (Sherley et al., 2020). The model builds on the approach presented in JABBA for averaging relative abundance indices (Just Another Bayesian Biomass Assessment: Winker et al., 2018) and assumes that the mean underlying abundance trend is an unobservable state variable (Winker and Sherley, 2019). JARA was used to combine the three indices into a single one and to fill in the missing years of data from 2002 onward. Overall, 8 out of the 25 (32%) years of data were filled using JARA.

Stock Assessment Method

AMSY (Froese et al., 2020) is a new data-limited method that estimates fisheries reference points regarding stock status (B/B_{msy}: the ratio of observed biomass, B, to the biomass that would provide maximum sustainable yield, B_{msy}: Tsikliras and Froese, 2019) and exploitation level (F/F_{msy}: the level of relative pressure of fishing, measured as fishing mortality F relative to the one associated with the maximum sustainable yield, F_{msy}: Tsikliras and Froese, 2019) from CPUE data, combined with prior estimates of resilience, such as those that are available in FishBase (Froese and Pauly, 2020)[1] for fishes and in SealifeBase (Palomares and Pauly, 2020)[2] for invertebrates. AMSY is meant for wide-ranging or migratory stocks where CPUE is known from surveys or from observers on some of the commercial boats, but where total catch is unknown or unreliable, as well as for by-catch species where CPUE may be available from surveys but the catch is not officially recorded (Froese et al., 2020). In addition to CPUE and resilience, AMSY needs a prior for relative stock size (B) as a fraction of unexploited biomass (k or B_0), i.e., a range of B/k, between 0 and 1 for one of the years in the time-series. For example, if current stock biomass is known to be small compared to the beginning of the fishery, the B/k prior range can be set to 0.15–0.4 for the latest year with CPUE data while, if the stock at the beginning of the CPUE time-series was known to be under-exploited, the stock size was likely close to the unexploited size and the prior range for the first year with CPUE data could be set to a 0.75–1.0. AMSY uses CPUE, resilience prior and biomass prior in a high number of combinations of productivity (the maximum intrinsic rate of population increase r) and unexploited stock size or carrying capacity (k) for their compatibility with these inputs. A detailed description of the theory and equations behind AMSY is given in Froese et al. (2020).

For all the species included in the analysis, a prior was selected for their initial biomass (in 1995) that was set according to their exploitation at the time based on the following

[1] www.fishbase.org
[2] www.sealifebase.org

TABLE 1 | Analysis of 116 stocks in Aegean Sea with indication of existence of catch records, whether targeted (prime or alternative target), by-catch or discarded, biomass relative to the one that can produce the maximum sustainable yield (B/B_{msy}), fishing mortality relative to the one that can produce the maximum sustainable yield (F/F_{msy}), stock status and exploitation based on B/B_{msy} and F/F_{msy} and reference.

No	Class	Species	Catch records	Targeted	B/B_{msy}	F/F_{msy}	Status	Assessment
1	Ray-finned fishes	*Atherina boyeri*	Yes	Prime	0.19	1.09	B/O	Froese et al. (2018b)
2	Ray-finned fishes	*Belone belone*	Yes	Prime	0.22	2.19	B/O	Froese et al. (2018b)
3	Ray-finned fishes	*Boops boops*	Yes	Prime	0.51	1.01	B/O	Froese et al. (2018b)
4	Ray-finned fishes	*Dentex dentex*	Yes	Prime	0.47	1.18	B/O	Froese et al. (2018b)
5	Ray-finned fishes	*Dentex macrophthalmus*	Yes	Prime	0.84	1.08	B/O	Froese et al. (2018b)
6	Ray-finned fishes	*Dicentrarchus labrax*	Yes	Prime	0.28	3.06	B/O	Froese et al. (2018b)
7	Ray-finned fishes	*Diplodus annularis*	Yes	Prime	0.34	1.47	B/O	Froese et al. (2018b)
8	Ray-finned fishes	*Diplodus sargus*	Yes	Prime	0.27	2.51	B/O	Froese et al. (2018b)
9	Ray-finned fishes	*Engraulis encrasicolus*	Yes	Prime	0.69	1.54	B/O	Froese et al. (2018b)
10	Ray-finned fishes	*Epinephelus marginatus*	Yes	Prime	0.33	2.73	B/O	Froese et al. (2018b)
11	Ray-finned fishes	*Lophius budegassa*	Yes	Prime	0.49	1.39	B/O	Froese et al. (2018a)
12	Ray-finned fishes	*Melicertus kerathurus*	Yes	Prime	0.73	1.03	B/O	Froese et al. (2018a)
13	Ray-finned fishes	*Merluccius merluccius*	Yes	Prime	0.520	1.57	B/O	Froese et al. (2018b)
14	Ray-finned fishes	*Micromesistius poutassou*	Yes	Prime	0.28	2.51	B/O	Froese et al. (2018b)
15	Ray-finned fishes	*Mullus barbatus*	Yes	Prime	0.39	1.970	B/O	Froese et al. (2018b)
16	Ray-finned fishes	*Mullus surmuletus*	Yes	Prime	0.45	1.75	B/O	Froese et al. (2018b)
17	Ray-finned fishes	*Pagellus erythrinus*	Yes	Prime	0.62	1.06	B/O	Froese et al. (2018b)
18	Ray-finned fishes	*Pagrus pagrus*	Yes	Prime	0.62	1.30	B/O	Froese et al. (2018a)
19	Ray-finned fishes	*Pomatomus saltatrix*	Yes	Prime	0.37	1.61	B/O	Froese et al. (2018a)
20	Ray-finned fishes	*Sardina pilchardus*	Yes	Prime	0.66	1.07	B/O	Froese et al. (2018a)
21	Ray-finned fishes	*Sardinella aurita*	Yes	Prime	0.75	1.15	B/O	Froese et al. (2018a)
22	Ray-finned fishes	*Sarpa salpa*	Yes	Prime	0.30	2.15	B/O	Froese et al. (2018a)
23	Ray-finned fishes	*Scomber colias*	Yes	Prime	0.26	1.82	B/O	Froese et al. (2018a)
24	Ray-finned fishes	*Scomber scombrus*	Yes	Prime	0.17	1.09	B/O	Froese et al. (2018a)
25	Ray-finned fishes	*Scophthalmus maximus*	Yes	Prime	0.61	1.45	B/O	Froese et al. (2018a)
26	Ray-finned fishes	*Solea solea*	Yes	Prime	0.27	2.32	B/O	Froese et al. (2018a)
27	Ray-finned fishes	*Spicara smaris*	Yes	Prime	0.21	2.18	B/O	Froese et al. (2018a)
28	Ray-finned fishes	*Spondyliosoma cantharus*	Yes	Prime	0.230	2.59	B/O	Froese et al. (2018a)
29	Ray-finned fishes	*Trachurus mediterraneus*	Yes	Prime	0.35	0.92	B/U	Froese et al. (2018a)
30	Ray-finned fishes	*Trachurus trachurus*	Yes	Prime	0.61	0.71	B/U	Froese et al. (2018a)
31	Ray-finned fishes	*Umbrina cirrosa*	Yes	Prime	0.26	2.46	B/O	Froese et al. (2018a)
32	Ray-finned fishes	*Zeus faber*	Yes	Prime	0.480	1.92	B/O	Froese et al. (2018a)
33	Sharks and rays	*Raja clavata*	Yes	Prime	0.57	0.99	B/U	Froese et al. (2018a)
34	Sharks and rays	*Squalus acanthias*	Yes	Prime	0.55	1.38	B/O	Froese et al. (2018a)
35	Cephalopods	*Octopus vulgaris*	Yes	Prime	0.51	1.15	B/O	Froese et al. (2018a)
36	Cephalopods	*Illex coindetii*	Yes	Prime	0.83	1.27	B/O	Froese et al. (2018a)
37	Cephalopods	*Loligo vulgaris*	Yes	Prime	0.63	1.29	B/O	Froese et al. (2018a)
38	Cephalopods	*Eledone moschata*	Yes	Prime	0.75	0.86	B/U	Froese et al. (2018a)
39	Cephalopods	*Sepia officinalis*	Yes	Prime	0.62	0.94	B/U	Froese et al. (2018a)
40	Crustaceans	*Nephrops norvegicus*	Yes	Prime	0.19	4.01	B/O	Froese et al. (2018a)
41	Crustaceans	*Palinurus elephas*	Yes	Prime	0.77	1.23	B/O	Froese et al. (2018a)
42	Crustaceans	*Parapenaeus longirostris*	Yes	Prime	0.35	2.62	B/O	Froese et al. (2018a)
43	Ray-finned fishes	*Arnoglossus laterna*	No	Alternative	0.318	1.723	B/O	Present study
44	Ray-finned fishes	*Lepidorhombus boscii*	No	Alternative	0.421	1.934	B/O	Present study
45	Ray-finned fishes	*Pagellus bogaraveo*	No	Alternative	0.558	1.392	B/O	Present study
46	Ray-finned fishes	*Phycis blennoides*	No	Alternative	1.135	0.917	G/U	Present study
47	Ray-finned fishes	*Scorpaena notata*	No	Alternative	0.480	1.748	B/O	Present study
48	Ray-finned fishes	*Scorpaena porcus*	No	Alternative	1.973	0.191	G/U	Present study
49	Ray-finned fishes	*Scorpaena scrofa*	No	Alternative	1.477	0.633	G/U	Present study
50	Ray-finned fishes	*Trachurus picturatus*	No	Alternative	0.308	1.628	B/O	Present study
51	Ray-finned fishes	*Dentex maroccanus*	No	Alternative	1.743	0.357	G/U	Present study

(Continued)

TABLE 1 | Continued

No	Class	Species	Catch records	Targeted	B/B_{msy}	F/F_{msy}	Status	Assessment
52	Ray-finned fishes	*Trigla lyra*	No	Alternative	0.216	1.288	B/O	Present study
53	Ray-finned fishes	*Lophius piscatorius*	No	Alternative	0.219	1.398	B/O	Present study
54	Ray-finned fishes	*Pagellus acarne*	No	Alternative	1.829	0.241	G/U	Present study
55	Ray-finned fishes	*Trachurus mediterraneus*	No	Alternative	0.185	1.113	B/O	Present study
56	Ray-finned fishes	*Citharus linguatula*	No	Alternative	0.326	1.888	B/O	Present study
57	Ray-finned fishes	*Chelidonichthys lastoviza*	No	By-catch	1.801	0.310	G/U	Present study
58	Ray-finned fishes	*Chelidonichthys lucerna*	No	By-catch	0.838	1.243	B/O	Present study
59	Ray-finned fishes	*Gaidropsarus mediterraneus*	No	By-catch	0.803	1.261	B/O	Present study
60	Ray-finned fishes	*Lepidopus caudatus*	No	By-catch	0.116	2.593	B/O	Present study
61	Ray-finned fishes	*Lepidotrigla cavillone*	No	By-catch	1.141	0.928	G/U	Present study
62	Ray-finned fishes	*Lepidorhombus whiffiagonis*	No	By-catch	1.951	0.188	G/U	Present study
63	Ray-finned fishes	*Symphurus nigrescens*	No	By-catch	0.178	1.70	B/O	Present study
64	Ray-finned fishes	*Uranoscopus scaber*	No	By-catch	0.230	1.823	B/O	Present study
65	Ray-finned fishes	*Serranus cabrilla*	No	By-catch	0.883	1.246	B/O	Present study
66	Ray-finned fishes	*Conger conger*	No	By-catch	1.929	0.293	G/U	Present study
67	Ray-finned fishes	*Helicolenus dactylopterus*	No	By-catch	1.711	0.386	G/U	Present study
68	Ray-finned fishes	*Trachinus draco*	No	By-catch	0.884	1.137	B/O	Present study
69	Ray-finned fishes	*Trisopterus capelanus*	No	By-catch	0.202	1.375	B/O	Present study
70	Ray-finned fishes	*Argentina sphyraena*	No	By-catch	1.287	0.732	G/U	Present study
71	Ray-finned fishes	*Peristedion cataphractum*	No	By-catch	1.894	0.264	G/U	Present study
72	Ray-finned fishes	*Blennius ocellaris*	No	By-catch	0.875	1.305	B/O	Present study
73	Ray-finned fishes	*Gobius niger*	No	By-catch	0.347	1.970	B/O	Present study
74	Ray-finned fishes	*Arnoglossus rueppelii*	No	Discard	1.110	1.017	G/O	Present study
75	Ray-finned fishes	*Arnoglossus thori*	No	Discard	0.437	1.854	B/O	Present study
76	Ray-finned fishes	*Chelidonichthys cuculus*	No	Discard	0.984	1.021	B/O	Present study
77	Ray-finned fishes	*Lepidotrigla dieuzeidei*	No	Discard	1.760	0.232	G/U	Present study
78	Ray-finned fishes	*Argyropelecus hemigymnus*	No	Discard	0.574	1.532	B/O	Present study
79	Ray-finned fishes	*Benthosema glaciale*	No	Discard	1.704	0.473	G/U	Present study
80	Ray-finned fishes	*Lampanyctus crocodilus*	No	Discard	2.097	0.257	G/U	Present study
81	Ray-finned fishes	*Maurolicus muelleri*	No	Discard	0.759	1.602	B/O	Present study
82	Ray-finned fishes	*Capros aper*	No	Discard	1.844	0.283	G/U	Present study
83	Ray-finned fishes	*Cepola macrophthalma*	No	Discard	0.756	1.501	B/O	Present study
84	Ray-finned fishes	*Chlorophthalmus agassizi*	No	Discard	1.739	0.162	G/U	Present study
85	Ray-finned fishes	*Coelorinchus caelorhincus*	No	Discard	1.877	0.384	G/U	Present study
86	Ray-finned fishes	*Deltentosteus quadrimaculatus*	No	Discard	0.885	1.347	B/O	Present study
87	Ray-finned fishes	*Echelus myrus*	No	Discard	1.743	0.216	G/U	Present study
88	Ray-finned fishes	*Etmopterus spinax*	No	Discard	1.935	0.849	G/U	Present study
89	Ray-finned fishes	*Gadiculus argenteus*	No	Discard	1.789	0.331	G/U	Present study
90	Ray-finned fishes	*Hymenocephalus italicus*	No	Discard	1.141	0.955	G/U	Present study
91	Ray-finned fishes	*Macroramphosus scolopax*	No	Discard	1.748	0.174	G/U	Present study
92	Ray-finned fishes	*Serranus hepatus*	No	Discard	0.411	1.880	B/O	Present study
93	Sharks and rays	*Raja asterias*	No	Alternative	0.520	1.927	B/O	Present study
94	Sharks and rays	*Raja miraletus*	No	Alternative	0.716	1.567	B/O	Present study
95	Sharks and rays	*Raja polystigma*	No	Alternative	0.982	1.098	B/O	Present study
96	Sharks and rays	*Scyliorhinus canicula*	No	Alternative	0.482	1.466	B/O	Present study
97	Sharks and rays	*Galeus melastomus*	No	Alternative	1.980	0.334	G/U	Present study
98	Sharks and rays	*Squalus acanthias*	No	Alternative	0.491	3.417	B/O	Present study
99	Sharks and rays	*Torpedo marmorata*	No	By-catch	1.163	1.101	G/O	Present study
100	Sharks and rays	*Dipturus oxyrinchus*	No	By-catch	0.808	1.531	B/O	Present study
101	Sharks and rays	*Squalus blainville*	No	By-catch	1.792	0.942	G/U	Present study
102	Cephalopods	*Sepia elegans*	No	By-catch	1.881	0.25	G/U	Present study
103	Cephalopods	*Sepia orbignyana*	No	By-catch	0.354	1.552	B/O	Present study
104	Cephalopods	*Loligo forbesii*	No	By-catch	1.627	0.255	G/U	Present study

(Continued)

TABLE 1 | Continued

No	Class	Species	Catch records	Targeted	B/B_{msy}	F/F_{msy}	Status	Assessment
105	Cephalopods	*Octopus salutii*	No	By-catch	1.580	0.479	G/U	Present study
106	Cephalopods	*Eledone cirrhosa*	No	By-catch	0.141	0.933	B/U	Present study
107	Cephalopods	*Eledone moschata*	No	By-catch	0.677	1.341	B/O	Present study
108	Cephalopods	*Todaropsis eblanae*	No	By-catch	1.745	0.218	G/U	Present study
109	Cephalopods	*Todarodes sagittatus*	No	By-catch	1.685	0.447	G/U	Present study
110	Cephalopods	*Alloteuthis media*	No	Discard	1.309	0.766	G/U	Present study
111	Cephalopods	*Rossia macrosoma*	No	Discard	1.172	0.914	G/U	Present study
112	Cephalopods	*Scaeurgus unicirrhus*	No	Discard	0.755	1.512	B/O	Present study
113	Cephalopods	*Sepiola spp.*	No	Discard	0.150	2.344	B/O	Present study
114	Crustaceans	*Chlorotocus crassicornis*	No	Discard	1.755	0.145	G/U	Present study
115	Crustaceans	*Plesionika heterocarpus*	No	Discard	1.754	0.178	G/U	Present study
116	Crustaceans	*Plesionika martia*	No	Discard	1.983	0.161	G/U	Present study

G, good status ($B/B_{msy} > 1$; B: bad status ($B/B_{msy} < 1$; O, overexploited ($F/F_{msy} > 1$); U, sustainably exploited ($F/F_{msy} < 1$). Red background: stocks that are being overfished ($F/F_{msy} > 1$) or have low biomass ($B/B_{msy} < 1$); Green area: stocks subject to sustainable fishing pressure ($F/F_{msy} < 1$) and of a healthy stock biomass ($B/B_{msy} > 1$).

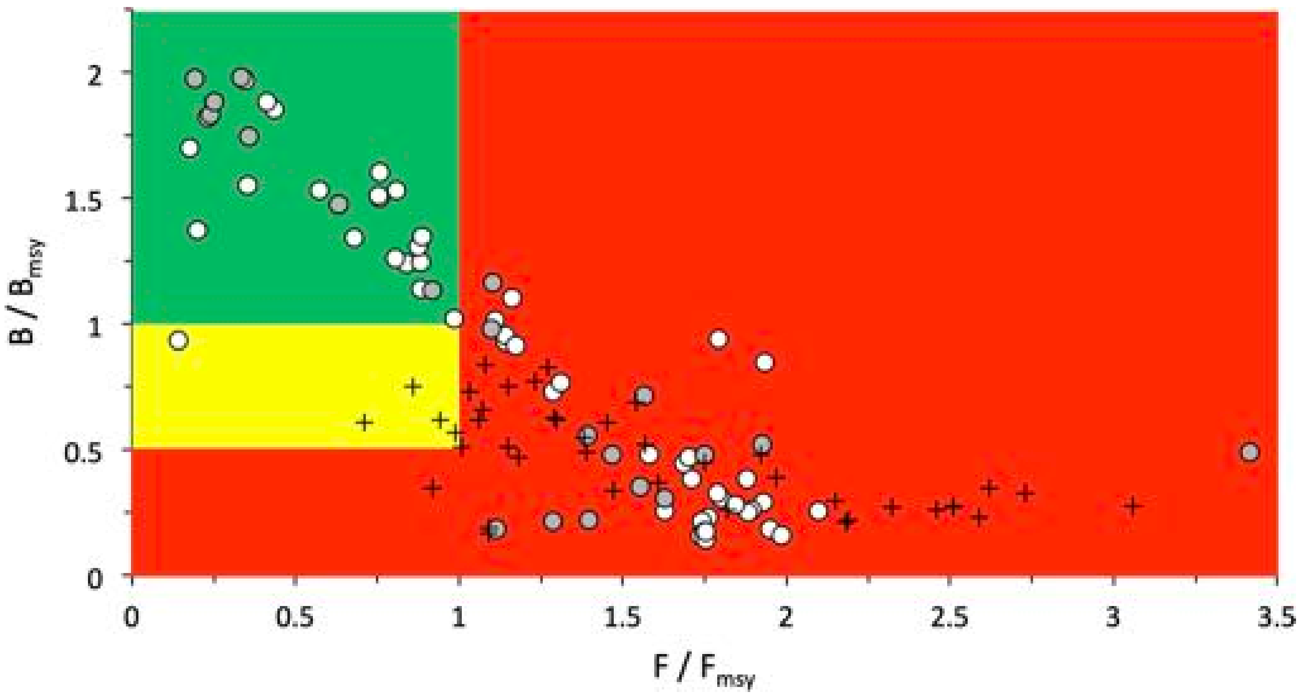

FIGURE 1 | The 74 un-assessed fish and invertebrate stocks of the Aegean Sea presented in a fishing pressure (F/F_{msy}) – stock status (B/B_{msy}) plot. White dots indicate by-catch and discarded stocks (*n* = 54) and gray dots indicate alternatively targeted ones (*n* = 20); black crosses refer to the previous assessment of commercial prime targets (*n* = 42) using the CMSY method (Froese et al., 2018b). Red area, stocks that are being overfished or are outside of safe biological limits; Yellow area, recovering stocks; Green area, stocks subject to sustainable fishing pressure and of a healthy stock biomass.

ranges (Froese et al., 2020) and the following criteria: near unexploited (stocks that have never been exploited not even as by-catch, e.g., deep-water fishes; B/k = 0.75–1.00), more than half (stocks caught in very small quantities as by-catch and have no commercial value, e.g., damselfish *Chromis chromis*; B/k = 0.50–0.85), about half (stocks that are often collected as by-catch and/or stocks with low commercial value and/or commercial stocks that were unexploited or under-exploited in the mid-1990s; B/k = 0.35–0.65), small (commercial stocks with historically maximum catch reached in the mid-1990s and then declined and/or commercial stock with no official catch data that are landed but reported aggregated with other stocks; B/k = 0.15–0.40), very small (commercial stocks with historically maximum catch reached before the mid-1990s and then drastically declined; B/k = 0.01–0.20). The criteria referring to commercial stocks were not applied thus the last two categories were excluded from the analysis.

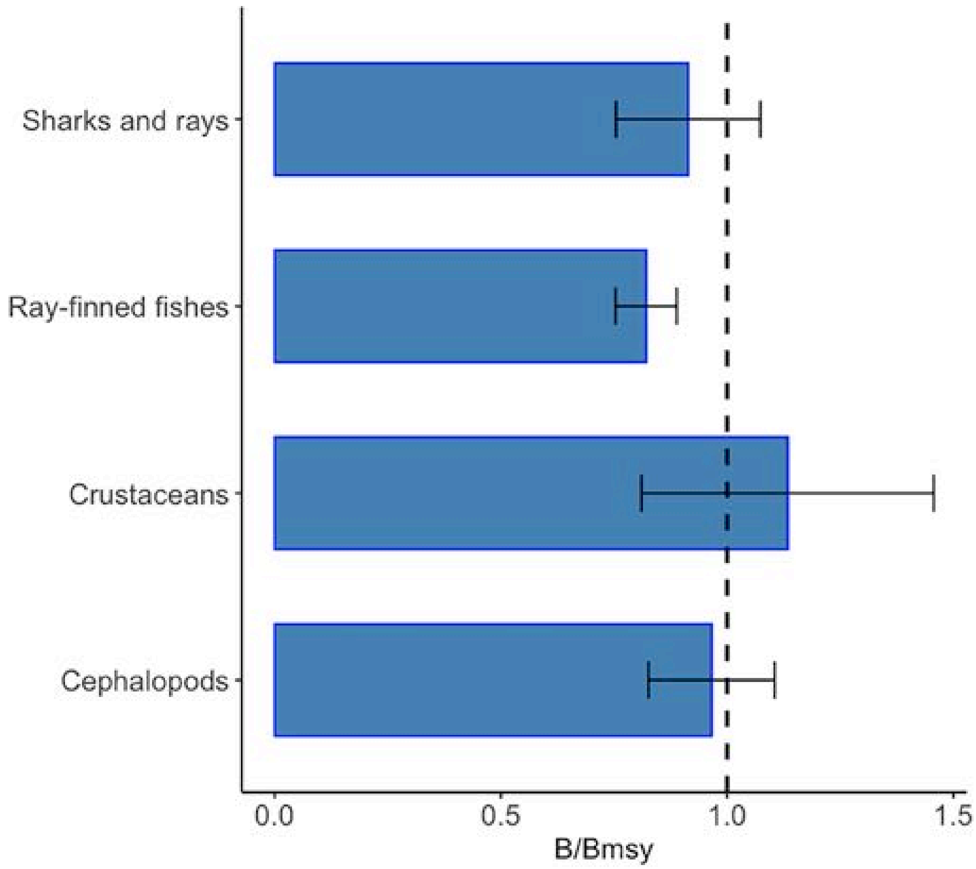

FIGURE 2 | Histogram of the mean B/B_{msy} per taxonomic group for the 74 fish and invertebrate stocks of the Aegean Sea assessed using the AMSY method. The vertical dashed line denotes the limit for healthy stock status ($B > B_{msy}$).

RESULTS

Overall, out of the 100 stocks that fulfilled the criteria of continuous occurrence and CPUE values, 74 stocks, the catch of which is not officially reported by statistical authorities, were included in the present analysis. The remaining 26 stocks were excluded because of sporadic presence (less than 5 years) or negligible biomass. Fifty-nine of those were fish (fifty ray-finned fishes, four sharks and five rays), twelve were cephalopods and three were crustaceans (**Table 1**). Out of the 74 included stocks (**Table 1**), 20 have medium or high commercial values and are being targeted (alternative targets) by fishing fleets, 28 are by-caught and marketed (by-catch) and 26 are discarded (discards).

Based on B/B_{msy} values, the status of non-targeted species (by-catch and discards) was better when compared to targeted (alternative targets) ones that were included in the present study and commercial stocks (prime targets) that had been previously assessed (**Table 1** and **Figure 1**). In the last year with available data, 31 of the 54 non-targeted stocks (57%) were healthy with B/B_{msy} values exceeding 1 whereas only 6 of the 20 targeted stocks (30%) were healthy (**Table 1** and **Figure 1**). Of the unhealthy non-targeted stocks, 12 (22% of the total non-targeted stocks) had B/B_{msy} values exceeding 0.75, compared to only 1 of the targeted stocks (5% of the total targeted stocks). Ten non-targeted stocks (19% of the total non-targeted stocks) and ten targeted ones (50% of the total targeted stocks) were outside of safe biological limits ($B < 0.5\ B_{msy}$). Similarly, 24 of the 54 non-targeted stocks (44%) and 14 out of the 20 targeted ones (70%) were subject to ongoing overfishing ($F > F_{msy}$). Out of fishes, spiny dogfish (*Squalus acanthias*) and silver scabbardfish (*Lepidopus caudatus*) were the most heavily exploited stocks (dogfish: $F/F_{msy} = 3.41$, scabbardfish: $F/F_{msy} = 2.59$), with silver scabbardfish and tonguesole (*Symphurus nigrescens*) exhibiting the lowest biomass (scabbardfish: $B/B_{msy} = 0.12$, tonguesole: $B/B_{msy} = 0.18$).

Cephalopod and crustacean stocks were in a better state compared to ray-finned fishes and sharks and rays (**Figure 2**). Overall, 48% of ray-finned fish stocks were healthy but 54% were subject to ongoing overfishing (**Table 1**). The majority of ray-finned fishes (36 out of 50 stocks, 72%), including several deep-water or mesopelagic stocks, are not targeted by any fisheries. The stocks of six out of nine (67%) sharks and rays, most of which are targeted, were not healthy and subject to ongoing overfishing. Seven out of twelve (58%) cephalopods and all three crustacean stocks were healthy and exploited sustainably. None of the crustaceans and cephalopods are targeted.

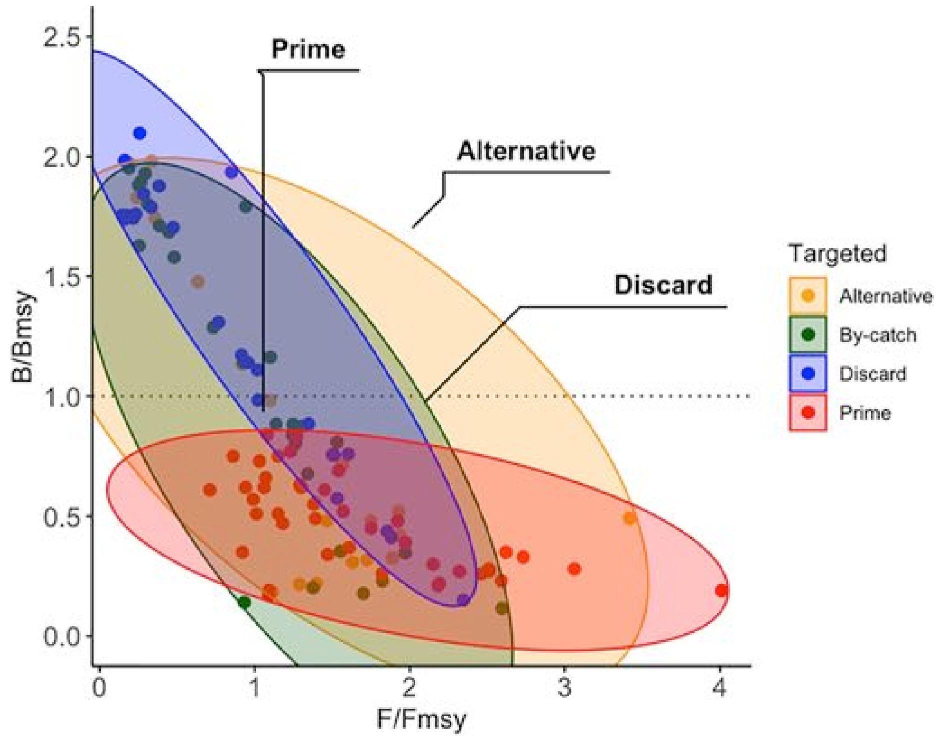

FIGURE 3 | Grouping of 116 fish and invertebrate stocks of the Aegean Sea (42 previously assessed stocks and 74 stocks assessed in the present study) based on their fishing pressure (F/F_{msy}) – stock status (B/B_{msy}) plot. Enclosing ellipses were estimated using the Khachiyan algorithm and expanded to cover all relevant points. Red dots and ellipse indicate prime targets (*n* = 42), orange dots and ellipse indicate alternative targets (*n* = 20), green dots and ellipse indicate by-catch species (*n* = 28) and blue dots and ellipse indicate discarded stocks (*n* = 26).

The status of the four groups of stocks based on their exploitation (prime targets, alternative targets, by-catch, and discards) is distinct for prime targets (none of them is healthy) that all have biomass below B_{msy} and alternative targets that span over a wider area (30% of them are healthy). The enclosing ellipses clearly indicate that some alternative targets are overlapping with prime targets and some others are ordinated among by-catch and discarded stocks. The ellipses of by-catch and discarded stocks largely coincide, with 50% of the by-catch stocks and 65% of the discard stocks being healthy (**Figure 3**). Finally, it appears that the exploitation is stronger for targeted species across taxonomic groups (**Figure 4**). When the targeted stocks (prime and alternative) and non-targeted stocks (by-catch and discards) were grouped together, the mean B/B_{msy} of non-targeted stocks exceeded 1 across taxonomic groups and was well below 1 for targeted stocks (**Table 2**).

DISCUSSION

Globally, only a small proportion of exploited fisheries stocks are being assessed on a regular basis, with the vast majority of commercial stocks and all non-commercial ones never having been assessed (Costello et al., 2012). The number of stocks assessed in this study triples the number of stock assessments in the Aegean Sea, which now sum to 116 stocks accounting for over 95% of the total catch (Stergiou et al., 2007a,b), with the exception of rarely caught species (Vassilopoulou et al., 2007). According to official and empirical catch records, about 200 stocks are being collected by the Greek fishing fleets either as targeted stocks or as by-catch, some of which are discarded (Machias et al., 2001). Therefore, AMSY (Froese et al., 2020) is a valuable method that allows the assessment of true data-poor fisheries without catch records and offers the possibility of the potential assessment of many demersal stocks that are collected in scientific surveys. AMSY requires only CPUE time-series so it can also be used to assess stocks that are only recorded in fisher's logbooks, even if the number of vessels is low, provided that the gear or method of fishing has not changed during the time-series.

There is a clear gradient of stock status that is directly related to the fishing pressure applied upon stocks, which clearly confirms what is already known for the exploited stocks of European fisheries (Froese et al., 2018b). Based on this gradient, the Aegean Sea stocks can be grouped in three main categories each of which suffers different exploitation, subsequently resulting in different biomass levels. The first category includes highly commercial stocks that are the main targets of, often multiple, fishing fleets and have been exploited for many decades. All stocks in this group are prime targets to the fisheries and the majority of them are suffering the highest fishing pressure that has resulted in the lowest biomass

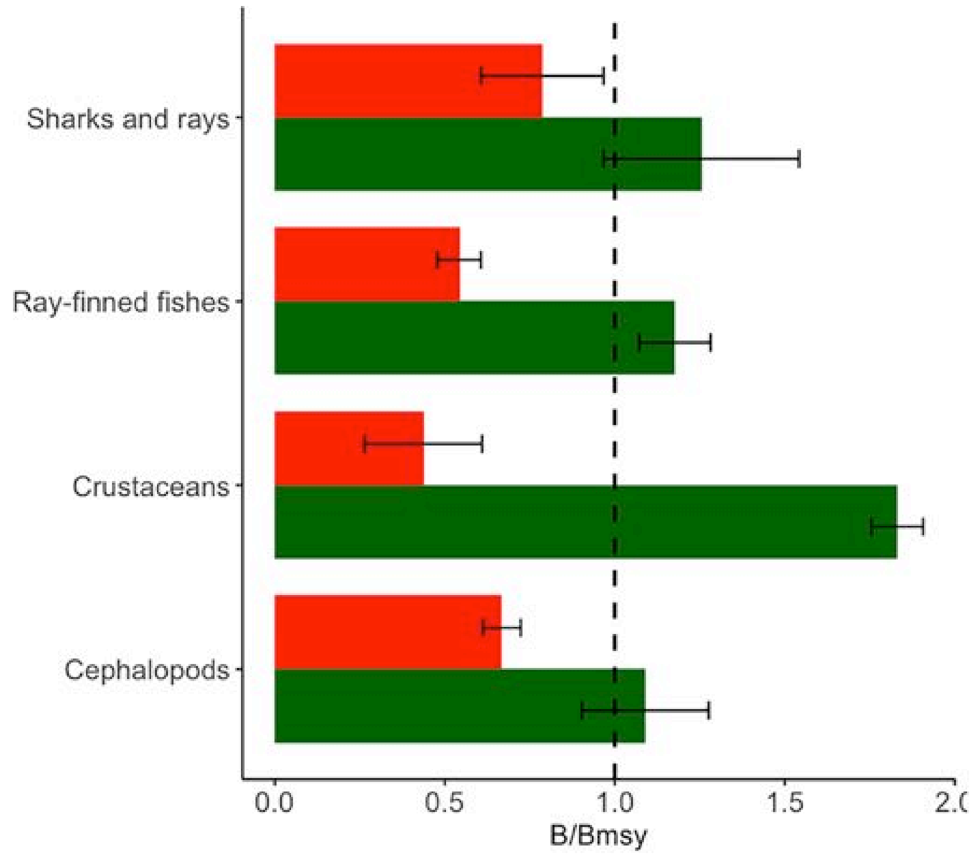

FIGURE 4 | Histogram of the mean B/B_{msy} per taxonomic group for 116 fish and invertebrate stocks of the Aegean Sea (42 previously assessed stocks with the CMSY method and 74 stocks assessed with the AMSY method in the present study). Stocks were grouped as targeted (red bars) that include prime and alternative targets of **Table 1** and non-targeted (green bars) that include by-catch and discard stocks of **Table 1**. The vertical dashed line denotes the limit for healthy status ($B > B_{msy}$).

(**Figure 1**, crosses; data from Froese et al., 2018b). These stocks were included in the most recent assessment of the Aegean and the vast majority of them were overexploited and beyond safe biological limits (Froese et al., 2018b). All recent scientific literature confirms this pattern of overexploitation and bad status of commercial stocks that is evident across the entire Mediterranean Sea (Colloca et al., 2013; Vasilakopoulos et al., 2014; Tsikliras et al., 2015; Stergiou et al., 2016; Cardinale et al., 2017; Hilborn et al., 2020).

TABLE 2 | The mean (±SE) B/B_{msy} of targeted (prime and alternative stocks) and non-targeted (by-catch and discard stocks) fish and invertebrate stocks of the Aegean Sea.

Taxonomic Group	Exploitation	Sample size	Mean B/B_{msy}	SE
Sharks and rays	Targeted	8	0.786	0.180
	Non-targeted	3	1.254	0.287
Ray-finned fishes	Targeted	46	0.542	0.063
	Non-targeted	36	1.176	0.104
Crustaceans	Targeted	3	0.436	0.172
	Non-targeted	3	1.830	0.076
Cephalopods	Targeted	5	0.668	0.055
	Non-targeted	12	1.089	0.186

Red color indicates low biomass ($B/B_{msy} < 1$), while green color indicates healthy stock biomass ($B/B_{msy} > 1$).

The second category refers to stocks with medium commercial value that are targeted by some fisheries, often locally, or are collected as by-catch in large quantities and are marketed (**Table 1**). These stocks, for which no catch records exist, were included in the present work and were assessed for the first time. The majority of these stocks (>60%), which are locally prime targets but in general are alternatively collected, suffer from overexploitation and exhibit declining biomass trends (**Figure 1**, gray dots). However, the stocks of this category span across a wide range of exploitation and status values, indicating that some of them are exploited in some areas but not in others (Machias et al., 2001) or that their exploitation pattern may depend on the availability or catch of prime targets. The status of these stocks can be easily improved with appropriate management (Froese et al., 2018b) as the biomass levels of most of them are still above safe biological limits ($B/B_{msy} > 0.5$). There is no previous assessment of these stocks in the Aegean Sea, but their CPUE data have been included in recent ecological models; declining CPUE trends were apparent especially for those with medium commercial value in heavily exploited areas, such as Thermaikos Gulf, the western part of northern Aegean Sea (e.g., Dimarchopoulou et al., submitted).

Finally, the third category refers to stocks that are only occasionally collected by the fishing fleets or have never been exploited because they live in the mesopelagic zone (there is no gear that exploits mesopelagic waters in the Aegean Sea) or in deep waters (trawling is prohibited beyond 400 m of depth in the Aegean Sea: Petza et al., 2017). The stocks of this category include by-catch species (non-targets that can be occasionally marketed) but also stocks that are always discarded. No catch records exist for these stocks that were included in the present work and were assessed for the first time in the Aegean Sea. Because of their underexploitation, the status of these stocks was much better compared to the previous two categories as the majority of them were healthy (**Figure 1**, white dots). In the absence of intense fishing, any fluctuations in their biomass is attributed to natural population processes that include reproductive success and recruitment (Rothschild et al., 1989) and may be affected by environmental or climatic factors (van Hal et al., 2010) as well as inter-specific relationships (Möllmann et al., 2008). The latter can be indirectly affected by fishing that may potentially remove competitors, predators or prey (Scheffer et al., 2005).

It should be noted here that the status of many stocks that are occasionally collected by either the commercial fleets or scientific surveys, such as large sharks and rays, could never be assessed using the known assessment methodologies that are usually data hungry (Tsikliras and Froese, 2019). Some of these species are listed in the IUCN (International Union for Conservation of Nature) Red List of Threatened Species and are protected in many areas of the world (Dimarchopoulou et al., 2017) including Greek waters (Ministerial Decision 4531/83795/20-7-2016). The inability to assess their status should not be an excuse for continuing their exploitation and masking their catch under broader taxonomic categories, as it commonly happens with large protected sharks.

The results of the present study confirm that fisheries are the main driver of the biomass of exploited marine populations (Pauly et al., 2002) and that large predatory fishes are the prime targets (Myers and Worm, 2003) because of their high commercial value (Tsikliras and Polymeros, 2014). Selective targeting and removal of upper trophic levels by fishing may also affect inter-specific relationships and cause cascading effects across trophic levels (Möllmann et al., 2008). It appears that in the absence of fishing, inter-specific relationships may play a more important role in shaping population biomass and explain the biomass trends of predators and preys (Pinnegar et al., 2000), or at least their role is more apparent.

CONCLUSION

After the present study the number of un-assessed stocks in the Aegean Sea is considerably lower and mainly refers to stocks that cannot be assessed at all. The stocks that are primarily or alternatively targeted by fishing fleets are in a worse status in terms of biomass, compared to those that are only occasionally collected as by-catch or those that inhabit environments that are not exploited by the fishing fleets, such as the midwaters or the very deep waters. The results of the present study are also important for ecosystem models that require data for all ecosystem components in the context of a more integrated ecosystem approach to fisheries management.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

AT conceived the study. KT and DD analyzed the data and prepared the graphs. AP, AA, IK, GO, and MK contributed to data analysis. AT and DD wrote the manuscript with contributions from all authors. All authors contributed to the article and approved the submitted version.

FUNDING

DD, AP, and IK were supported by the European DG-MARE funded project "PROTOMEDEA" (contract number SI2.721917).

ACKNOWLEDGMENTS

The authors would like to thank Rainer Froese and Henning Winker for their valuable suggestions regarding the implementation of the AMSY method.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.