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Capacity-building paper

A comparison of market landings during fish spawning seasons to better understand the effectiveness of the temporal fishery closure in Turkey

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ABSTRACT

Seasonal fishery closures, are an input control measure to reduce fishing pressure on spawning stocks in fisheries management. Despite the huge foregone economic losses from such closures, the efficacy of them has yet to be examined in Turkey. This study compares the monthly landed catch distribution for commercial marine species averaged for 12 years (2006–2017) from Istanbul fish market, to catch rates of those species during the spawning seasons. Our results revealed that at first glance, most commercially important fish species examined here have their spawning seasons protected under the Turkish industrial seasonal closure period, especially for small and medium pelagics, as well as some demersals. On the other hand, taxa with winter spawning seasons such as *Merlangius merlangus*, John dory *Zeus faber*, brown meagre *Sciaena umbra*, big-scale sand smelt *Atherina boyeri*, and bogue *Boops boops* do not benefit from the commercial fisheries summer closure (>50% of their catch total). Also, some species are still heavily fished (>35% of their catch total) during the closure implying they are mainly targeted by small-scale fisheries (SSF). To help rebuild the commercial fisheries, we recommend the accompaniment of the industrial closure with the use of 'Real Time Closures' (RTCs) applied to all fishing sectors for species highly fished during their spawning periods and spawning habitats.

1. Introduction

Fisheries management is dedicated to managing resource use in order to maximize potential long-term sustainable fisheries catches (Beverton and Holt, 1957). The EU Common Fisheries Policy (CFP) strongly recommends that management measures should ensure the long-term Maximum Sustainable Yield (MSY) of fisheries while implementing ecosystem-based fisheries management (EBFM) and reducing unwanted catches. Yet, some fisheries are managed using single species assessment models that do not incorporate key ecological processes (such as species interactions) and bio-/socio-economic matters, ultimately compromising the sustainability of fisheries. Sustainable fisheries require efficient and innovative fisheries management measures which balance biological, ecological, economic and societal benefits.

There are various control measures available to effectively manage fish stocks, which have the principal aim of limiting catches either directly or indirectly (Colloca et al., 2013). Catch quotas are a form of direct control with defined limits for catching fish. Indirect controls, such as gear type restrictions intend to reduce the catching of immature/juvenile fish and discards, while temporal and spatial closures aim to reduce fish exploitation rates. Both direct and indirect harvest controls are commonly used around the world in both small-scale to large and industrial fisheries (Maynou, 2020). Eight common methods are currently applied as direct and indirect controls: i) catch limits, ii) minimum mesh sizes, iii) minimum landing sizes, iv) limiting fishing power, v) limiting fishing vessels, vi) controlling fishing activities, vii) temporary/seasonal closures, and vii) spatial closures. Generally, fisheries management incorporates a combination of these control measures.

Fishery closures are simple and effective management options since they are relatively easy to implement to primarily reduce effort (Lleonart and Franquesa, 1999), allowing stocks to rebuild and/or be protected in critical seasons to improve their overall success. A subject of central importance to fisheries management and science is the exact duration of a fishes spawning period (Holt and Byrne, 1898). When a species is fished during a spawning aggregation, its catchability is extremely high and there is a high chance of fishers' landing a majority of the matured spawning stock, greatly reducing reproductive potential,

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thus compromising the future of the stock. Many fishers are aware of spawning aggregations, since these events can be extremely economically beneficial to the fishers, but at the expense of stock sustainability. The protection of spawning, reproduction, and even juvenile recruits, help to ensure that new recruits enter the system. Thus, fishery closures can be very beneficial, especially if the aggregation site is unknown, or if it varies either geographically or temporally (Sadovy et al., 2005). Seasonal closures help to ensure the survival of an adequate spawning stock to ensure the stocks perpetuation (Skud, 1985) and can be implemented at either daily, seasonal, or trigger-based scales (Demestre et al., 2008). According to Article 19 of Council Regulation (EU, 2006) for the Mediterranean, spatial and temporary/seasonal closures are mainly implemented for trawling; spatial closures prohibit fishing 3 nautical miles from the coast, and temporal closures for bottom and mid-water trawl are applied from between 30 and 45 days in the summer (Demestre et al., 2008; Cardinale et al., 2017).

The effectiveness of seasonal closures have been widely evaluated across the globe (Hunter et al., 2006; Loher, 2011; McGarvey et al., 2011; Fouzai et al., 2012; Zhang et al., 2016; Eero et al., 2019). However, their design can be flawed if they are primarily designed to reduce effort and increase revenues, rather than protect key commercial stocks during vulnerable spawning and recruitment periods (McClanahan, 2010; Samy-Kemal et al., 2015; Tserpes et al., 2016). On the other hand, several studies emphasize that seasonal closures can be an effective measure to help rebuild depleted fish stocks, as long as: i) accompanying knowledge is considered, such as trophic relations and ecosystem shifts (Zhang et al., 2016); ii) a deeper analysis of spawning dynamics are examined (Loher, 2011); and iii) additional measures such as catch control and gear restrictions are implemented (Jennings et al., 2001). Pipitone et al. (2000) evaluated the effects of a four-year bottom trawling ban in Sicily enacted in 1990, and found demersal species increased by an overall factor of eight after the cessation, from 1.2-fold for musky octopus (*Eledone moschata*) to an incredible 497-fold increase for gurnard (*Lepidotrigla cavillone*). In addition, modeling studies in multi-gear and multi fisheries areas show seasonal closures mainly benefited demersal fish (Fouzai et al., 2012), Baltic cod (Vinther and Eero, 2013) and European hake in the Western Mediterranean (Goñi et al., 1999). However, for areas involving mixed-species fisheries, closures will always benefit some species, but will not be able to benefit all, thus some species not protected in such closures may need additional management intervention.

1.1. Fisheries in Turkey

Turkey shares three seas: the Mediterranean Sea, Aegean Sea, and Black Sea, and has one inland sea- Marmara Sea, which connects to the Black Sea via the Bosphorus Strait, and to the Aegean Sea via the Dardanelles Strait (Fig. 1). There are some spatial variations in fisheries management measures in Turkey, but most fisheries are of a coastal nature. The basis of these distinctions are determined by the different geographical conditions and ecological characteristics of each regional sea, and the specific stock characteristics of the fish inhabiting them. Despite its small total area, Marmara Sea contributed 18.4% of total fisheries catches of Turkey in 2017 (Gül and Demirel, 2016), and is a very important ecological gateway to the Mediterranean. The industrial coastal fisheries mainly target migratory pelagic fish by purse seine and benthic species by bottom and beam trawling. In the Marmara region, many pelagic species are caught during their seasonal migrations to and from the Mediterranean to the Black Sea such as bonito (*Sarda sarda*), bluefish (*Pomatomus saltatrix*), and horse mackerel (*Trachurus* spp.) [Table 1].

The Turkish marine fisheries have been in decline since the late 1990s, and if fishing continues as usual, the entire industry is at serious risk of collapsing. In a recent stock assessment study on Turkish stocks, the majority (85%) of commercial stocks were found to be exploited outside their safe biological limits (Demirel et al., 2020), and thus can be deemed overfished. In Marmara Sea, only two stocks, sardine *Sardina pilchardus* and Mediterranean horse mackerel *Trachurus mediterraneus* are not yet overfished. However, due to the rapidly declining trends of the fisheries, it is obvious that current management measures are inadequate in decelerating the declining numbers of marine wild fish. Due to the scale of fishery declines and overfished species, there is no one size fits all remedy that can be applied. Since Turkey is the country with the highest fish catches in the Mediterranean and Black Seas, its level of resource use, and its worrisome unsustainable trend in declining catches is of utter importance to all Mediterranean basin countries, as many of these stocks are shared between countries. Solutions to reverse the decline have to be adaptive and compatible with each other.

1.2. Temporal fishery closures

The main controls currently implemented in Turkey as management measures include [from Official Gazette, No: 29,800 #2016/35, the

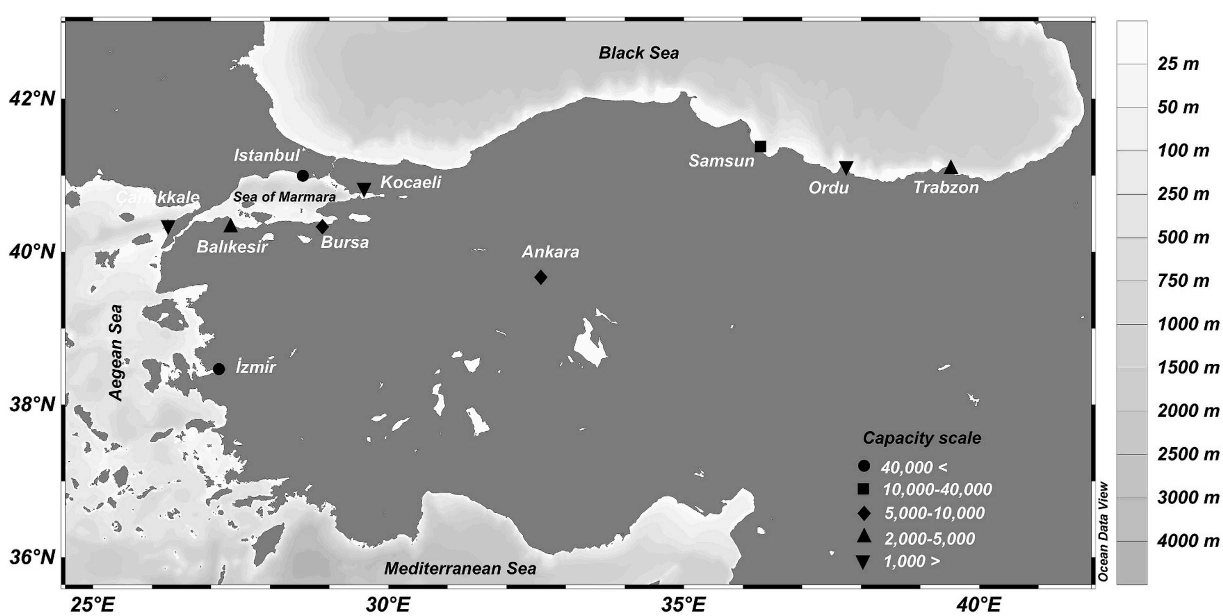

Fig. 1. Locations of the major fish markets according to their capacity (Emiroğlu et al., 2017) in Turkey.

Table 1
Common fishing methods, main targeted fish species and their by-catch in Marmara Sea.

Marmara Sea				
	Beam trawl	Beach seine	Purse seine	Gillnet
Target	*Parapenaeus longirostris*	*Parapenaeus longirostris*	*Engraulis encrasicolus*	*Merluccius merluccius*
			Sardina pilchardus	
		Rapana venosa	*Trachurus* (sp.)	
		Chamelea gallina	*Scomber colias*	
			Sarda sarda	
			Pomatomus saltatrix	
Bycatch	*Merluccius merluccius*	*Mullus barbatus*	*Sprattus sprattus*	*Raja* (spp.)
	Raja (spp.)	*Trachurus mediterraneus*	*Mullus barbatus*	*Trigla* (spp.)
	Trigla (spp.)	*Solea solea*	*Merluccius merluccius*	
		Scopthalmus maximus	*Merlangius merlangus*	

formal national publication for fisheries laws]: (i) Temporal industrial fishing bans for all Turkish seas from April 15 to September 1, and a spatial trawling ban in Marmara Sea and the Bosphorus and Dardanelles Straits (Turkish Strait System-TSS); (ii) Minimum Landing Size (MLS) regulations for most commercial taxa; (iii) Vessel licensing restrictions; (iv) Minimum mesh size regulations; and (v) Protected/prohibited species. It should be noted however, that despite the bottom trawling ban in the Sea of Marmara, there is a loophole which permits dredging for shrimp, somewhat negating effects of the trawling ban.

There are two types of temporal closures in Turkey, one imposed on specific taxa to protect them in their spawning seasons, and the generally imposed summer ban on industrial fisheries operations. Specific closed seasons are implemented for eight marine fish species and for 14 invertebrates. The industrial fishing ban from 15 April – 1 September is the longest imposed industrial fishing ban in the Mediterranean, which was implemented to promote stock rebuilding following extensive studies on fish biology, reproduction, and migration undertaken in the 1950s. The first specified marine taxa incorporated under the temporal closure were dolphins (Delphinidae) in 1956, followed by swordfish (*Xiphias gladius*) in 1957, and the incorporation of some invertebrates in 1983. The temporal industrial fisheries closure began in 1976 for bottom trawling, 1987 for coastal seining, and 1989 for purse seining and pelagic trawling (Supplementary Table 1). Until the early 2000s, temporal closures were generally implemented on a regional level, but recently the practice has become more centralized and is applied to all Turkish waters. The earliest period of the bottom trawling prohibition was 61 days for the Black Sea, and 91 days for the Aegean and Mediterranean Seas. At present, the closure duration has increased to 139 days for the Black Sea, 139 days for the Aegean, and 154 days for the Mediterranean Sea. For purse seining, the closure duration also increased from 140 days in 1989 for all seas to 153 days under the

Table 2
Spawning periods of 39 fish species in Turkish water. (Species groupings- SP: Small pelagic; MP: Medium pelagic, D: Demersal. Regions- AS: Aegean Sea; NAS, North Aegean Sea; MS: Marmara Sea; BS: Black Sea; Med S: Mediterranean Sea).

Scientific name	English name	Species Grouping	Spawning period	Reference	Region
Alosa immaculata	Pontic shad	SP	May–August	Froese and Pauly (2020)	BS
Argyrosomus regius	Meagre	D	April–July	Tokaç et al. (2017)	AS
Atherina boyeri	Big-scale sand smelt	D	April–August	Slastenenko (1956)	MS
Auxis rochei	Bullet tuna	MP	May–September	Kahraman et al. (2010)	Med S
Belone belone	Garfish	MP	March–August	Slastenenko (1956)	MS
Boops boops	Bogue	D	March–May	Cengiz et al., 2019	NAS
Chelidonichthys lastoviza	Streaked gurnard	D	February–May	İşmen et al. (2010)	NAS
Chelidonichthys lucerna	Tub gurnard	D	December–March	İşmen et al. (2010)	NAS
Diplodus annularis	Annular seabream	D	March–May	Torcu-Koç et al. (2002)	NAS
Engraulis encrasicolus	European anchovy	SP	April–September	Genç and Dağtekin (2014)	BS
Epinephelus aeneus	White grouper	D	July–August	Gökçe, 2003	Med S
Euthynnus alletteratus	Little tunny	MP	May–September	Kahraman et al. (2008)	Med S
Gaidropsarus mediterraneus	Shore rockling	D	October–February	Daban and İşmen (2020)	NAS
Lithognathus mormyrus	Sand steenbras	D	April–May	Emre, 2010	Med S
Lophius budegassa	Anglerfish	D	December–March	Yiğin et al. (2015)	NAS
Merlangius merlangus	Whiting	D	November–April	Atasoy et al. (2006)	MS
Merluccius merluccius	European hake	D	June/October–December	Kahraman et al. (2017)	MS
Micromesistius poutassou	Blue whiting	D	January–March	İşmen et al. (2010)	NAS
Mullus barbatus	Red mullet	D	April–July	Arslan and İşmen (2014)	NAS
Mullus surmuletus	Surmullet	D	April–September	Torcu-Koç et al. (2015)	NAS
Pleuronectes flesus	European flounder	D	December–January	Genç et al. (1998)	BS
Pomatomus saltatrix	Bluefish	MP	May–August	Atılgan et al., 2016	MS, BS
Scopthalmus maximus	Turbot	D	April–June	Eryılmaz and Dalyan (2015)	BS
Sarda sarda	Atlantic bonito	MP	June–July	Kahraman et al. (2014)	MS
Sardina pilchardus	European pilchard	SP	December–February	Cihangir (1996)	AS
Sarpa salpa	Salema	D	March–May/September–November	Bektaş (2017)	NAS
Sciaena umbra	Brown meagre	D	May–August	Engin and Seyhan (2009)	BS
Scomber colias	Atlantic chub mackerel	MP	June–August	Cengiz (2012)	NAS
Scomber scombrus	Atlantic mackerel	MP	March–June	Slastenenko (1956)	MS
Scorpaena porcus	Black scorpionfish	D	June–August	Ünsal and Oral (1996)	MS
Seriola dumerili	Greater amberjack	D	May–July	Froese and Pauly (2020)	Med S.
Solea solea	Common sole	D	December–April	Oral (1996)	MS
Spicara maena	Blotched picarel	MP	April–June	Cengiz et al., 2019	NAS
Trachurus mediterraneus	Mediterranean horse mackerel	SP	May–September	Demirel and Yuksek, 2013	MS
Trachurus trachurus	Atlantic horse mackerel	SP	May–July	Slastenenko (1956)	MS
Trigla lyra	Piper gurnard	D	January–February	İşmen et al. (2010)	NAS
Umbrina cirrosa	Shi drum	D	June–July	Slastenenko (1956)	MS
Xiphias gladius	Swordfish	MP	May–July	Alıçlı et al. (2012)	AS
Zeus faber	John dory	D	January–June/August–September	İşmen and Arslan, 2013	NAS

current 2016–2020 regulations for the Mediterranean Sea, but decreased to 138 days for other seas (Supplementary Table 1). The scale of the Turkish industrial fisheries are enormous, with 12,129 (39%) registered fishers compared to just 18,148 (61%) registered small-scale fishers in 2018 (Tokaç et al., 2017), so the industrial ban certainly alleviates some pressure from commercial stocks. The industrial seasonal closure reduces fishing effort irrespective of whether fishing is occurring on spawning stocks.

Here, this study is unique in using monthly fish landings data over a 12-year period to compare species' spawning seasons, catch seasons and market relationships for commercial fish in Istanbul Turkey, to determine if the industrial fishing ban is an efficient measure at protecting key commercial species during reproductive seasons. Due to the rapidly declining state of nearly all marine resources, additional management measures likely to benefit reproductive success are also provided.

2. Material and methods

2.1. Fish markets in Turkey

In Turkey, there are a total of ten large municipal seafood markets located in Istanbul, Ankara, Izmir, Kocaeli, Bursa, Samsun, Trabzon, Çanakkale, Ordu and Bandırma provinces (Fig. 1). By far, the largest is the Istanbul fish market (locally called *Kumkapi Balik Hali*), where a substantial 1/3rd of total fish catches are sold in the country (Özgen, 2008). Thus, half of wholesale fish market transactions for the country occur in the Marmara Province (including the Istanbul megapolis), 30% in the Black Sea, and 10% each in the Aegean and Central Anatolian Region (Fig. 1).

Istanbul, Turkey's most populated city with over 15 million inhabitants, is naturally equipped with Turkey's largest fish market to meet the food demands of the densely populated society. Istanbul's fish market holds considerable commercial importance at the national level due to its: i) proximity to three important fishing grounds (Marmara Sea, Black Sea, North Aegean Sea); ii) proximity to local markets; iii) high demand from tourist facilities such as hotels and restaurants for fish and other aquaculture; and iv) high export opportunities [major transportation hub, airports, trains etc.] (Doğan and Timur, 2009). Despite the incredible wealth of fisheries data collected at the Istanbul fish market, relatively few studies have utilized this wealth of data in the last century (See: Deveciyan, 1926; Türkmen, 1953; Dozbay, 1970; Timur and Doğan, 1999; Erdoğan and Düzgüneş, 2020; Erdoğan-Sağlam et al., 2008), most of which mainly examined the operations of the fish market, as in the diversity of landed species, and landed volume of some important taxa.

The ownership, control and management of the fish markets in Turkey falls under the responsibility of municipalities. The municipality manages the marketing plan and execution, such as where the fish are displayed and sold, office placement and cold storage. Sales are monitored by administrative personnel, who record the daily sales, fish sizes (albeit non-regularly), and fish prices in logbooks. Thus, the Istanbul Fish Market provides an incredible wealth of knowledge on fish diversity, sizes, prices, and particularly monthly sales, which can be used to conduct market analyses. The majority of fish sold in this market are caught from the Marmara Sea and Western Black Sea, while Eastern Black Sea, Aegean Sea and Mediterranean Sea catches are typically landed in other ports.

2.2. Data collection by istanbul fish market

Marine fish and invertebrates are delivered to the Istanbul fish market by commercial fishing boats (both industrial and small-scale) registered in the Istanbul Provincial Directorate of Agriculture, each night around 2:00 a.m. Preliminary inspections of all products are performed first-hand by the control staff based on the declarations of fishers. Then the quantity of each product in number, weight (kg), and value (TRY-Turkish Lira as unit price) are recorded, before their inclusion into the auction area, and these records are regularly reported to the Turkey Statistical Institute (Turkish Statistical Institute TUIK, 2018) and the Provincial Directorate of Agriculture.

The official statistics from the Istanbul Fish Market are available online by the Municipality of Istanbul (https://gida.ibb.istanbul/tarim-ve-su-urunleri-mudurlugu/su-urunleri-istatistikleri.html), and monthly records from 2006 to 2017 were used for this study. The data incorporates landings for 104 fish species, and of those, the data from 39 marine fish species were used in this study. Some marine species were excluded which have different landing ports such as bluefin tuna (*Thunnys thynnus*), sprat (*Sprattus sprattus*), and all freshwater species, as they do not represent the regions' (Black Sea and Marmara Sea) true catches. Although sprat is a major catch component of the national catch statistics, its fishery is mainly conducted in the Eastern Black Sea with most catches directly sent to fish oil/flour processing plants, thus the minor portion sold in Istanbul Fish Market grossly underrepresents its real catch. Additionally, all cultured species (sea bass, sea bream, two-banded bream, saddled seabream, common pandora, and common dentex) were also excluded, but their wild counterparts included. In addition, elasmobranches were excluded, as their catches are generally recorded under the 'dogfish' umbrella term, not allowing for the delineation of species. Some exported species such as salmon and Atlantic chub mackerel were also excluded from this study as these species are not fished from Turkish waters.

2.3. Literature review for spawning period

Spawning periods for marine fish were collected from a literature review of peer-reviewed articles, local journals, conference proceedings, theses, and technical reports (Table 2) covering the period from 1956 to 2020 (oldest available to most up-to-date). The spawning periods for the taxa examined here were principally collected for Marmara Sea when possible. If sources for Marmara Sea were unavailable, sources from the next closest waters (Black Sea or Aegean Sea) were used, or from the spawning seasons provided in FishBase (Froese and Pauly, 2020). For the literature review, the terms "reproduction", "reproductive biology", "spawning", and "spawning aspects" were the key search terms used in both Turkish and English, along with both common and scientific names of the species. The spawning periods (in months) for each species were recorded from the determination from the studies, as well as the period of increased gonadosomatic index (GSI)- the ratio of gonad mass to total body mass, regardless of the evaluation method used for estimation (macroscopic or histologic examination), as GSI is the best spawning period predictor (Tsikliras et al., 2013). Research on spawning periods based on ichthyoplankton surveys were not used. Species names were validated using FishBase (Froese and Pauly, 2020). The habitat of each species was assigned as follows: demersal (D), small pelagic (SP), and medium pelagic (MP). The availability of spatially specific data is extremely important in providing advice on Marmara Sea stocks, since it is a transition zone, on top it is akin to the Black Sea, while the bottom is akin to the Aegean Sea, with a permanent stratification ranging between 20 and 30 m in depth. Therefore, Aegean Sea studies can only be applicable to Marmara Sea for demersal species, and Black Sea studies only applicable for coastal and pelagic species.

3. Results

3.1. Landed catch in istanbul fish market

Catches averaged over 12 years were mainly represented by anchovy *Engraulis encraiscolis* (47% of catches), followed by Mediterranean horse mackerel, Atlantic bonito, bluefish, whiting *Merlangius merlangus*, surmullet *Mullus surmuletus*, and European pilchard *Sardina pilchardus*. Just ten landed species represented over 95% of total catches sold at Istanbul fish market (Fig. 2a and b).

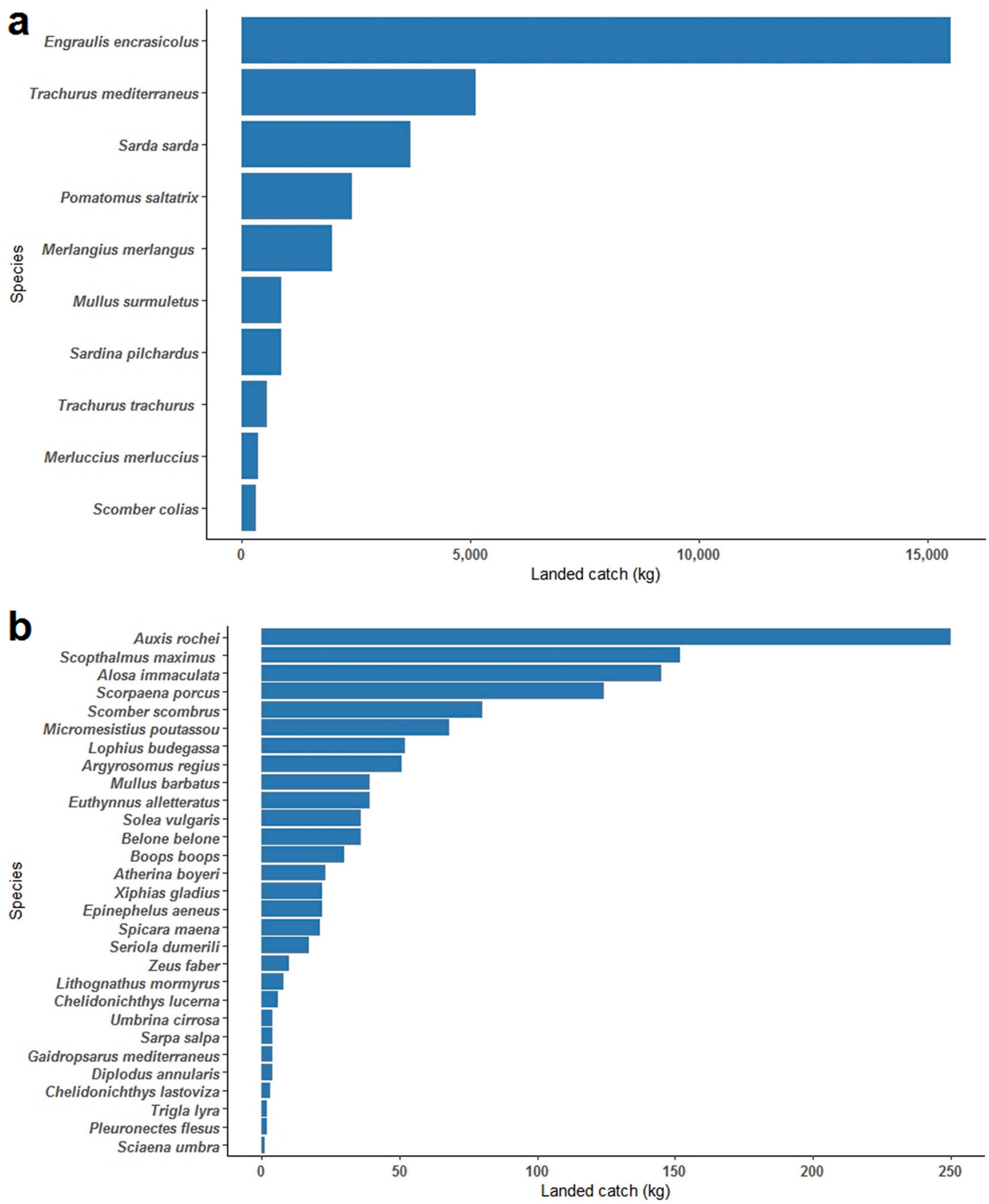

Fig. 2. Landed catches from Istanbul fish market averaged for 12 years for a) the top ten landed taxa, and for b) the remaining 29 taxa (2006–2017).

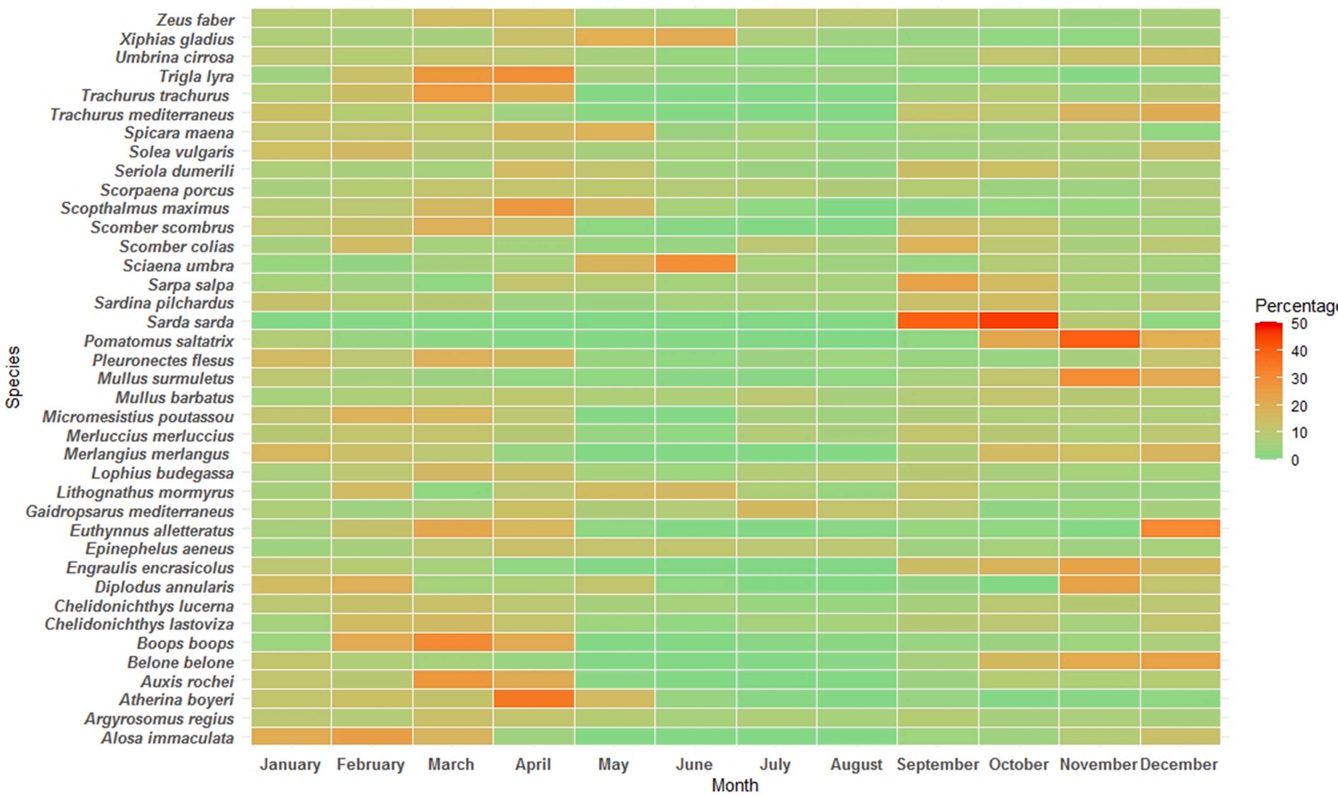

Fig. 3. Heat map for the monthly weighted landings distribution in Istanbul fish market averaged over 12 years for 39 taxa (2006–2017).

Table 3
Changes in the landed catch of fish groups during different periods in Istanbul fish market.

Groups	Landed Catch	
	Total (t)	Closure Period 15 April- 1 September (t)
Small pelagics	22,153	460
Without anchovy	6638	371
Medium pelagics	6470	107
Demersal	3968	350
Total	32,591	918

Monthly catch distributions of landed species are presented as a heatmap (Fig. 3). For at least ten species (mostly small and medium pelagics), their catches during summer dropped lower than 10% due to the industrial closure season. Both Atlantic bonito and bluefish had high catches of about 40% between September and November showing a strong seasonal trend. All catches considered, the monthly distribution of catches were non-homogenous.

Total landed catches decreased by approximately 95% during the industrial seasonal closure, and pelagic fish were mainly caught, with demersal species showing the strongest fishery reductions of approximately 85% (Table 3).

3.2. Comparison of peak catch season and spawning season for istanbul landed fish

Monthly spawning periods for landed species are presented as a heatmap in Fig. 4. *Epinephelus aeneus, Lithognathus mormyrus, Umbrina cirrosa, Platichthys flesus*, and *Sarda sarda* have the shortest spawning seasons lasting about two months, with *Zeus faber* having the longest spawning season (approximately 8 months), followed by *Merlangius merlangus, Mullus surmuletus, Belone belone and Engraulis encrasicolus* (approximately 6 months).

Percentages of landed catches for Istanbul fish market during spawning periods of the wild commercial species examined here ranged from low (0.06% for Atlantic bonito) to high (78.3% for whiting) (Fig. 5). The temporal closure did overlap with the spawning period of 27 landed species examined, demonstrating effectiveness of the ban for the majority of commercial species examined here. However, the species which did not benefit from their spawning seasons protected under the temporal ban are ranked according to spawning period catch percentage (>50% of their catch total) are included whiting *Merlangius merlangus*, John dory *Zeus faber*, brown meagre *Sciaena umbra*, big-scale sand smelt *Atherina boyeri*, and bogue *Boops boops* (Fig. 5). Contrarily, little tunny *Euthynnus alletteratus*, bullet tuna *Auxis rochei*, shi drum *Umbrina cirrosa*, bluefish *Pomatomus saltatrix*, Atlantic horse mackerel *Trachurus trachurus*, and Atlantic bonito *Sarda sarda* were caught in low amounts during their spawning seasons with overlapping percentages under 10%. Additionally, if total catches for each species were averaged for 12 months, then the estimated catch during the 3.5 month closure period (if they were stable) would equate to roughly 30%, hence, species with catches higher than 35% during the closure period, hence warranting closer inspection of their catches and spawning seasons included six species: brown meagre *Sciena umbra,* swordfish *Xiphias gladius*, Atlantic chub mackerel *Scomber colios* and white grouper *Epinephelus aeneus* (Table 4). While two species had low variation to their catches during the closure period, red mullet *Mullus barbatus barbatus* and black

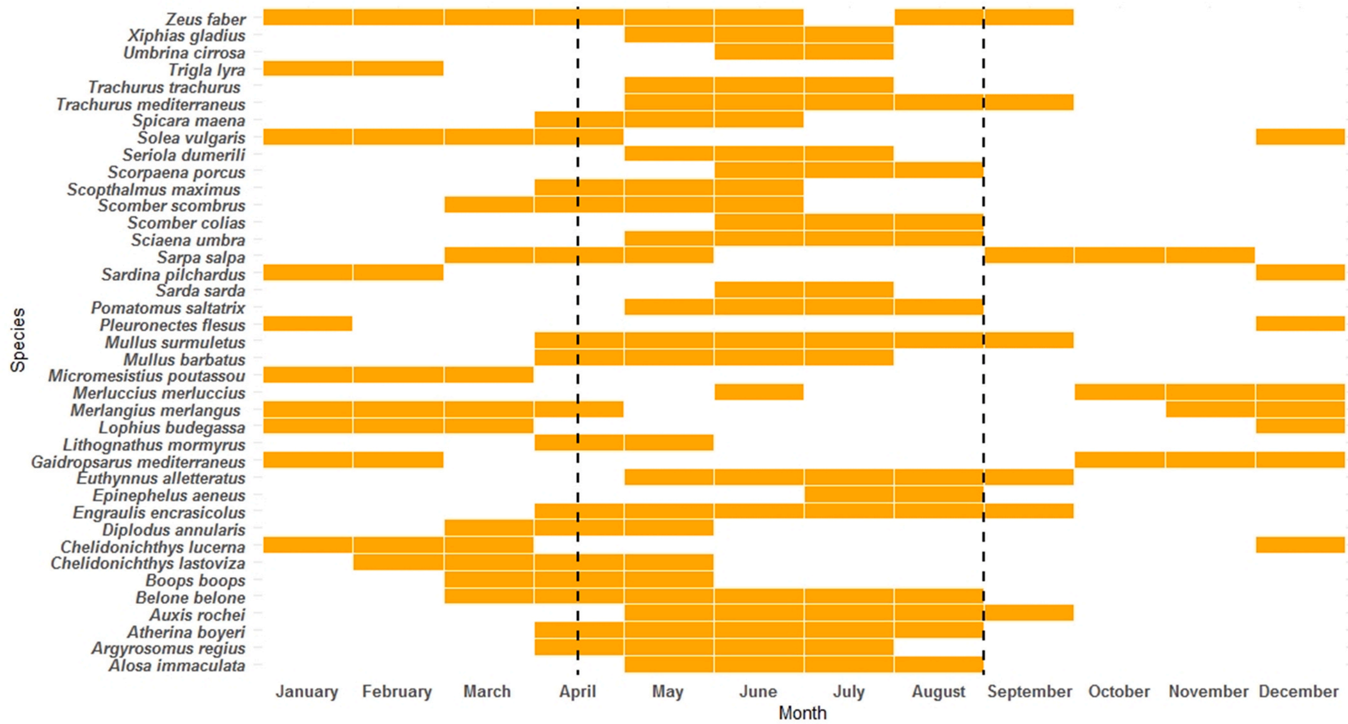

Fig. 4. Spawning seasons (orange) of fish species landed in Istanbul fish market based on the studies presented in Table 2. Dashed lines indicate the closure period for industrial fishery in Turkey. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

scorpionfish *Scorpaena porcus* (Fig. 5).

4. Discussion

Despite the various measures aimed at rebuilding fish stocks and the adverse socio-economic effects some of these impose, this is the first Turkish study investigating the relationship between peak catches and spawning seasons for commercial marine fish in the Marmara region to assess the usefulness of the industrial fishing ban in protecting the spawning seasons of commercial species, which was the bans specific intention. The industrial fishing closure is a very effective measure as 95% of catches were reduced during its period to the largest fish market in Turkey. However, additional reparative measures are needed to help rebuild the fisheries, which are alarmingly in decline. The biological health of Marmara Sea is of vital importance to the region as it is an ecological gateway for migratory species, directly feeding into both the neighbouring Black and Mediterranean Seas. It is unfortunately situated amidst Istanbul's sprawling megalopolis, and thus suffers from intensive fishing pressure from all sectors.

As the industrial ban cannot be effective at protecting all species' spawning seasons, this study highlights specific cases of species with winter spawning seasons which could benefit from additional measures to foster their success. Spawning seasons of small and medium pelagics occur mainly in late spring and summer, while demersals shows a high range of heterogeneity, spawning in nearly all seasons. Specifically, whiting *Merlangius merlangus*, John dory *Zeus faber*, brown meagre *Sciaena umbra*, big-scale sand smelt *Atherina boyeri*, and bogue *Boops boops,* do not benefit from the industrial fishing closure having over half their catches caught during their spawning seasons (Fig. 5). This study also revealed that despite the industrial fishing ban, some species are still heavily fished (>35% of their catch total, Table 4) during this restriction, implying high cumulative effort by small-scale fisheries (SSF), especially for highly valuable brown meagre *Sciena umbra,* swordfish *Xiphias gladius*, Atlantic chub mackerel *Scomber colios* and white grouper *Epinephelus aeneus*. While red mullet *Mullus barbatus barbatus* and black scorpionfish *Scorpaena porcus* had little change in their catches during the ban, suggesting that these too are likely heavily targeted by SSF (Fig. 5). SSF and recreational fisheries (RF) are still permitted to fish freely during the industrial ban, as there are no accompanying imposed measures for the use of set nets, longlines or rods. Thus, the industrial ban may only benefit fisheries where industrial fishing are heavily practiced (i.e., Black Sea, Marmara Sea, Central Aegean Sea and Easternmost Mediterranean), but not the remainder of Turkish waters where SSF triumph (i.e., the Aegean Coast and southern Mediterranean coast). Thus, we strongly feel the SSF, numerous in both fishers and effort, should also be made to contribute to rebuilding the fisheries. Unfortunately, catches from the RF sector in Turkey, as in most of the Mediterranean are not yet recorded, but have shown that they even equate to catches of the small-scale sector in certain cases (Ünal et al., 2010).

Closed seasons are often implemented during spawning periods of commercial species to boost their reproductive success (Froese et al., 2016). As this measure is based on effort control to help improve stock size, it is still dependent on fisher behaviour for success (Casey and Myers, 1998). Also, fishers may fish at higher intensities both before and after the ban, thus compromising this tactic (Cardinale et al., 2017), noticed for many species here just precluding to the ban. For most fishes, their reproductive cycle is linked to seasonal events and social cues, so that reproduction occurs under optimal environmental conditions (Eddy and Handy, 2012). Spawning migrations and aggregations are highly variable both spatially and temporally, and can last from just a few hours, to daily or monthly, some following the lunar cycle, or triggered by temperature regimes or tidal patterns (Sadovy and Cheung, 2003). In a warming climate, spawning periods are likely to be triggered earlier and such changes should be assessed accordingly. Very interestingly, this study shows that catches of some species increased two-to three-fold just prior to their spawning periods and commencement of the ban in April (Fig. 5), especially notable for the flatfish turbot, *Scophthalmus maximus* and other demersals such as big-scale sand smelt *Atherina*

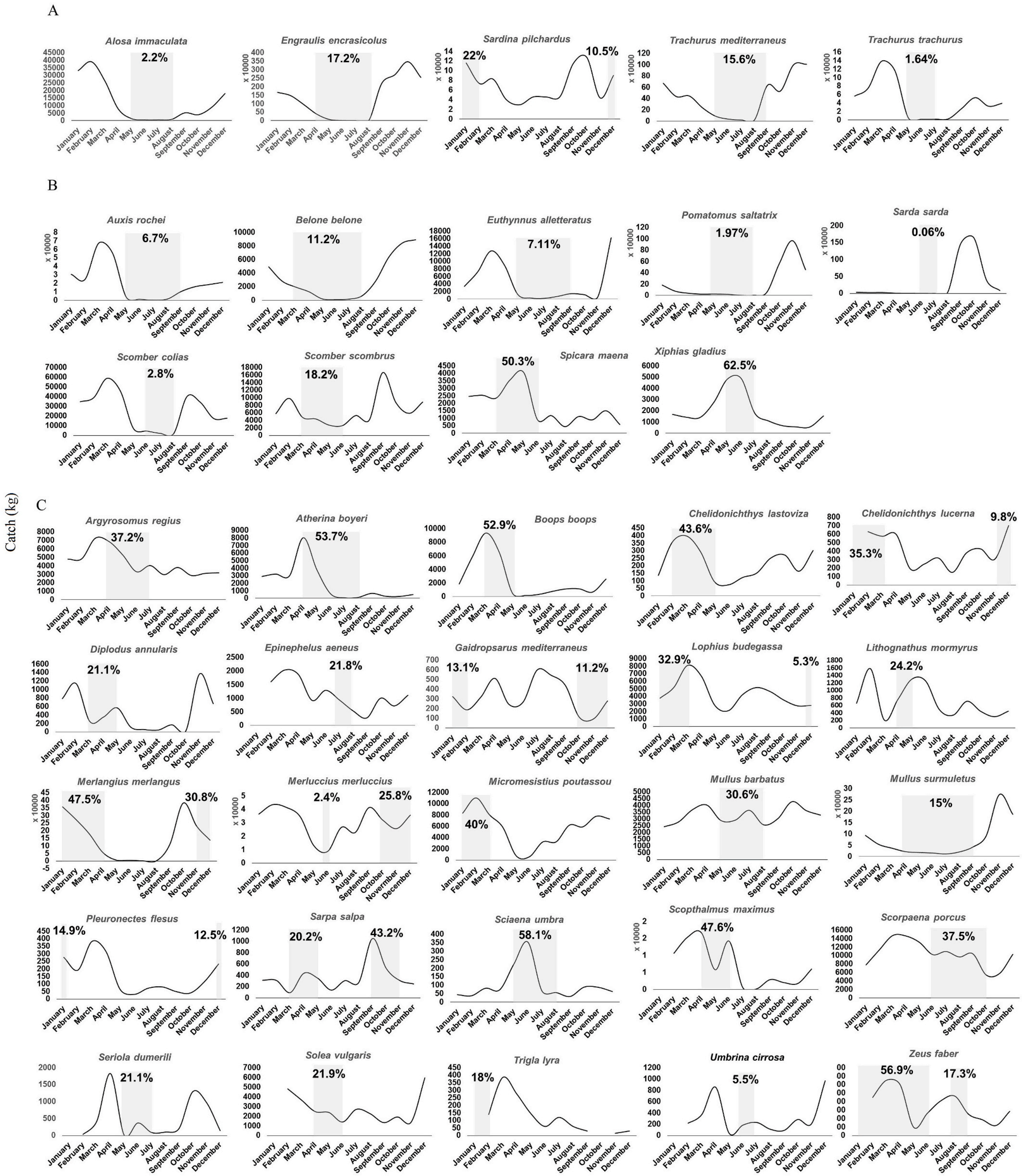

Fig. 5. Monthly catch (kg) of A) small pelagics, B) medium pelagics, and C) demersal fish species, with their catch ratios (% shown in grey area) during their individual spawning seasons.

Table 4
Landed catch percentage of each fish species during their spawning period, seasonal closure and in April with species-specific regulation (Official Gazette, 2016).

Landed fish species	% of landed catch during Closure	Species-specific regulations
Merlangius merlangus	2.06	
Zeus faber	29.68	
Sarpa salpa	24.54	
Solea solea	21.89	15 Dec. - 31 Jan.
Sciaena umbra	58.13	
Atherina boyeri	19.49	
Boops boops	5.67	
Xiphias gladius[a]	54.32	15 Feb. - 15 Mar./1 Oct. - 30 Nov.
Scopthalmus maximus	24.15	15 Apr. - 15 Jun.
Chelidonichthys lucerna	19.73	
Chelidonichthys lastoviza	16.93	
Micromesistius poutassou	11.62	15 Dec. - 31 Jan.
Scomber colias[a]	58.13	
Spicara maena	30.42	
Lophius budegassa	27.55	
Argyrosomus regius	29.81	
Mullus barbatus	30.66	
Sardina pilchardus	19.60	
Merluccius merluccius	19.66	
Platichthys flesus	13.28	
Scorpaena porcus[a]	35.37	
Lithognathus mormyrus[a]	39.77	
*Epinephelus aeneus****	46.04	
Diplodus annularis	14.17	
Seriola dumerili	24.00	
Scomber scombrus	18.50	
Trigla lyra	17.54	
Engraulis encrasicolus	0.58	
Trachurus mediterraneus	3.30	
Mullus surmuletus	7.67	
Belone belone	2.92	
Euthynnus alletteratus	4.48	
Auxis rochei	2.65	15 Apr. – 31 Aug.
Pomatomus saltatrix	1.97	
Trachurus trachurus	2.14	
Umbrina cirrosa	14.77	
Sarda sarda	1.00	1 Apr. - 31 Aug.

[a] Species with higher catch % amounts (>33.2%) in closure period than annual monthly catch average (100/12 = 8.3% monthly catch average/month).

boyeri and piper gurnard *Trigla lyra*, which do exhibit depth-related spawning migrations and/or aggregate in certain coastal regions. These higher catches may be attributable to the industrial sector operating at higher effort before the commencement of their annual prohibition, to offset future losses, and/or due to the efficiency of the small-scale sectors substituting various gear-types and target species to increase productivity, to ensure their year-round success. Such high catch rates can have dramatic consequences on stock success, especially during spawning aggregations and their period of higher catchability. When catchability is increased due to behavioural changes, then we advise these species have specific protections created.

The diversity of multi-types of fishing gear and target species makes fisheries management applications even more complex. Sustainable fish populations ultimately depend on the collaborative success of their spawning and reproductive seasons, as well as prey availability, especially in changing environments. Fish often move between marine ecosystems making them difficult to track, count and assess (Sinclair and Valdimarsson, 2003). Each species has a unique reproductive strategy and behavioural, physiological, and energetic adaptations, which comprise their ecological niche. Thus, the availability of recent spawning behaviour data from the appropriate region are essential to the designing of species-specific rebuilding measures and improving management capabilities.

4.1. Accompanying management strategies in Marmara Sea

As a direct output control measure, catch quotas are the most efficient (Colloca et al., 2013), which require good knowledge of current stock size, coordinated control at landing sites, and good communication between the responsible monitoring networks and law enforcement. Only four species have catch quotas imposed placed in Turkey: *Thunnus thynnus* and *Xiphias gladius*, both regulated under ICCAT for commercial fishing, and *Chamelea gallina and Scopthalmus maximus* regulated under Turkish law, the latter newly implemented in 2020. Other types of reparative measures should be concurrently used to encourage rebuilding of the fisheries, especially those protecting spawning seasons, spawning habitats, and nursery areas, with each measure tested for effectiveness, and adaptively recalibrating such measures whenever required.

The main management measure we recommend to accompany the industrial seasonal closure to help rebuild the fisheries is the use of 'Real Time Closures' (RTCs), applied to all fishing sectors to protect species fished in their spawning periods (Table 4). RTCs are a dynamic management measure aimed at protecting susceptible fish in mixed-species fisheries (Woods et al., 2018) requiring 'real time' catch data, which have to be quickly processed by capable bodies (the ministry) in order to implement adaptive temporal and/or spatial closures protecting reproductive events. Recent technological advancements have made the rapid processing of such data a viable option (Dunn et al., 2016), and this dynamic method has proven very successful for some taxa (the very lucrative haddock and herring stocks in Iceland; Woods et al., 2018), but not all it has been applied to. Real-time data may be incorporated using live video feeds, on-board observers, the Vessel Monitoring System (VMS) and daily fisher declarations. Also, landing port fisheries observers could monitor GSI of select species to improve their reproductive knowledge and identify any seasonal changes.

Despite the word 'small' in the title 'small-scale fisheries', their scale is anything but considering their combined manpower and effort, sometimes equating to or surpassing catches of the industrial fisheries (Ünal and Ulman, 2020). Economically, it may only be profitable for SSF to target a fish stock when its CPUE is high, as this sector is increasingly becoming marginalized and is currently in decline. Imposing restrictions on SSF may have major economic impacts, which could affect both food security and employment rates in certain communities, but all stakeholders need to contribute in order to benefit the future of the fisheries. Due to the rapid decline of nearly all commercial fish stocks, we endorse the application of scientifically based RTCs for all fishing sectors in the Marmara Sea, to protect both essential fishing habitats and spawning seasons for species which are being fished unsustainably (Demirel et al., 2020), especially those not adequately protected under current protections. Here, seven species (Fig. 5) are recommended to have scientifically-based RTCs designed both for their essential habitats (spatially) and spawning seasons (temporally). However, as already stated above, additional behavioural and spatial data are needed in order to properly design such measures, which could also be determined using traditional ecological knowledge (TEK) of fishers.

Additionally four highly-valued species (common sole *Solea solea*, swordfish *Xiphias gladius*, turbot *Scophthalmus maximus* and blue whiting *Micromesistius poutassou*) have species-specific fishing bans applied for their spawning periods, but still are not adequately protected due to both incompliance and inadequate Monitoring, Control and Sustainability (MCS). Here, we strongly recommend improving compliance, which can easily achievable for example by increasing penalties, which funds could then be used to support improved control capabilities. For multi-species fisheries, including almost all the small-scale sector, and some of the industrial, the implementation of species-specific bans are more complex (Colloca et al., 2013), as fishers sometimes discard prohibited species to evade fines. To reduce such infractions, we recommend patrollers accompany commercial fishing vessels, and if 10% or more of the catch is from a protected species during its spawning season, then the area should be closed to all fishing until the season is finished. Patrollers do not necessarily have to be costly and can even include fisheries science students receiving university credit for this work.

If placed during the right time and space, RTCs either as spatial and/or temporal closures can potentially offer large benefits to fisheries (Erisman et al., 2015). To be able to properly designate key essential fish habitats and RTCs (Caddy, 2015) protecting key spawning and aggregation events (Samy-Kemal et al., 2015), urgent behavioural, reproductive and spatial data needs to be learned, especially incorporating the cumulative knowledge accumulated by fishers, whereas scuba divers should share any video of reproductive behaviour with the appropriate scientific leaders. However, a call for these important input types would have to be well-advertised and organized by a leading institution, whether researcher or governmental. There is a huge scarcity of current reproductive behavioural data for most species in the Sea of Marmara except for European hake, Mediterranean horse mackerel, which urgently needs to be addressed.

5. Conclusion

The Turkish temporal closure for industrial fisheries from 15 April – 1 September is the longest imposed industrial ban in the Mediterranean, with the general aim of protecting key spawning seasons to support sustainability. This study provides the first comprehensive 12-year monthly assessment of fish landings data to gauge the effectiveness of is measure, and advise what other measures could help support fish reproductive success. These findings revealed that spawning seasons for most commercially important fish species are indeed protected under the industrial closure, especially for small and medium pelagics, some flatfish and demersals. On the other hand, taxa with winter spawning seasons such as *Merlangius merlangus*, John dory *Zeus faber*, brown meagre *Sciaena umbra*, big-scale sand smelt *Atherina boyeri*, and bogue *Boops boops* do not benefit from the commercial fisheries summer closure (>50% of their catch total). Those species with winter spawning seasons may require additional protection measures and improved MCS to protect their spawning seasons, such as the use of real-time closures in time and space for essential fishing habitats such as migratory corridors, recruitment areas and spawning seasons, to be applied to all fishers, as the high levels of effort and wide range of sonar do not allow species any privacy from humans during their critical life phases. Some species are still heavily fished (>35% of their catch total) during the closure implying they are mainly targeted by small-scale fisheries (SSF). Several other complementary management measures, such as species-specific temporal regulations, and MLS, do exist, but greatly need improvement to make them effective (Yildiz and Ulman, 2020). To help rebuild the commercial fisheries, we recommend the accompaniment of the industrial closure with the use of 'Real Time Closures' (RTCs) applied to all fishing sectors for species highly fished during their spawning periods and spawning habitats. The recommended measures may seem drastic, but so are the recent decline of the fisheries, which are at greatly risk of disappearing altogether, hence, operating as normal is not an option.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2020.105353.

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