Integrating historical and recent information to understand chondrichthyan dynamics in the Central Mediterranean

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Abstract

Chondrichthyans (sharks, rays, and chimaeras) are highly susceptible to the impacts of fisheries due to their vulnerable life-history traits. Over the last 100 years, several cases of local extinction have been documented in heavily fished areas across the Mediterranean Sea. In the Strait of Sicily (SoS), one of the main demersal fishing grounds of the Mediterranean, chondrichthyans constitute a significant component of both commercial and discarded bycatch. In this area, the lack of long-term data series on these species hinders our ability to fully comprehend the extent of changes due to both overfishing and climate variations. Here we aim to use historical data from the end of the 19th century, provided by Döderlein, to uncover evidence of long-term changes in the occurrence and diversity of these fishes. We employ a semi-quantitative approach to compare past data with recent frequency of occurrence estimates, to improve our ability to propose management advice. We report a decline in both the number of species and the frequency of occurrence of sharks and ray species in the study region over the past 150 years. Our findings shed light on the current status of sharks and rays compared to the historical data from the 19th century and highlight the urgent need to develop management strategies to mitigate the impact of harvesting on these vulnerable species.

Key words: Sharks, rays, assemblages, relative abundance, naturalists' accounts, trawl surveys, rank analyses

Introduction

Chondrichthyans (sharks, rays and chimaeras) are well known to be very sensitive species to the impact of fisheries, due to their peculiar and vulnerable life-history traits (low fecundity, delayed sexual maturity, long lifespan, low growth rates) and a high position in the food web (Stevens et al., 2000; Dulvy et al., 2021). Several works have documented the progressive depletion of shark and skate populations as consequence of increasing of fishing activity and a low resilience in response to overfishing (Stevens et al., 2000; Pacoreau et al., 2021). For example, there are several well documented cases of local extinction of especially sensitive species such as the angelsharks in many areas of the Mediterranean in the last 100 years (Fortibuoni et al., 2016; Gordon et al., 2019: Zava et al., 2020: Zava et al., 2022).

The availability of long time series is crucial to understand the background level of population at sea, thus avoiding the so-called "shifting the baseline syndrome" and comprehending the magnitude and causes of change (Pauly, 1995; Jackson et al., 2001). However, the analyses of historical changes in marine communities often cannot rely on results from structured and standardized monitoring programs, as most of these were established in the very last decades. Indeed, information in the early stage of fisheries development is often unavailable, thus reducing the quantity of information available for stock assessment (Falsone et a., 2021). As consequence, truncated time series often fail to account for important features, such as historical biomass maxima, past recoveries, low abundance levels and biomass fluctuations. The lack of this information can bias reference points and perceptions of stock status, including the estimation of fish stocks productivity (Walters, 1998; Schijns & Pauly, 2022).

This said, considering this frequent lack, gathering information from various sources to assess changes over time, not only in the recent past, of species composition and their relative abundance of chondrichthyan community in areas characterized by intense fishing activity can provide valuable insights into the evolution of vulnerable species under the growing anthropic impacts.

While there is a long history of exploitation and biological studies of marine organisms in the Mediterranean (Farrugio et al., 1993), fishery research has not been a top priority in the region for a long time due to the poor performance of local economies. Consequently, obtaining quantitative information on population size at the beginning of fisheries has been challenging. Although Mediterranean fisheries experienced rapid expansion in the 1960s, the first harmonized fishery data collection program involving all member states of the European Union started in 2002 (EU Data Collection Regulation- DCR). However, it was not until 2017 that the General Fishery Commission for the Mediterranean (GFCM) adopted the Data Collection Reference Framework (DCFR), a regional program aimed at collecting fishery data in a coordinated manner (Damalas, 2017). Nevertheless, in the absence of long-term standardized biological series, historical information from various sources can be utilized to reveal long-term changes in marine populations, assisting in overcoming the shifting baseline syndrome and enhancing our ability to formulate management recommendations. In some areas of the Mediterranean, in fact, historical information collected by naturalists have been used in a semi-quantitative manner to understand the evolution of stocks (Fortibuoni et al., 2010; 2016).

In our study, we aimed to understand the long-term changes in biodiversity and frequency of occurrence of the chondrichthyan community within the Strait of Sicily, which is one of the most important fishing grounds for demersal resources exploited by trawl fisheries in the Mediterranean Sea (Di Lorenzo et al., 2018; Jarboui et al., 2022). Although chondrichthyans are not currently targeted by any fishing activity in the SoS, except for a seasonal fishery targeting *Mustelus spp*. (Colloca et al., 2020), these fish constitute an important component of commercial and discarded bycatch (Falsone et al., 2022). Our aim is to conduct a semi-quantitative comparison of chondrichthyan diversity and occurrence data off the coast of Sicily, as documented by Döderlein (1891) at the end of the 19th century, and data derived from the Mediterranean International Trawl Surveys (MEDITS, Spedicato et al., 2019) conducted off the southern coast of Sicily from the last decade of the 20th century to the first two decades of the 21st century. This comparison is relevant for understanding the variation in biodiversity and relative frequency of occurrence of the chondrichthyan species under the increasing effects of overfishing and climate change.

Materials and Methods

The study area

Sicily is the largest island in the Mediterranean Sea, located in the south-central part of the basin. It is surrounded by three different seas: the Tyrrhenian Sea to the north, the waters of the Strait of Sicily (SoS) to the south and the Ionian Sea to the east (fig.1). The SoS is considered a transitional area between the western and eastern sectors of the Mediterranean to which the Tyrrhenian Sea and the Ionian Sea belong, respectively (Di Lorenzo et al., 2018). Further, this area is recognised as one of the main hotspots for the richness and abundance of chondrichthyans in the Mediterranean. (Colloca et al., 2017; Bradai et al., 2018). Although the entire Sicilian coast has been characterised by intense fishing activity since ancient times, it was mainly from the 1960s onwards that the availability of new technologies and the construction of ever larger fishing vessels led to a great development of the trawling fleet based in the SoS until it became one of the largest in the entire Mediterranean. Since the 1960s, trawling in the SoS has been characterised by two different modes of operation. Coastal trawling, conducted by fleets based in ports along the southern coast of Sicily, primarily operates in Italian territorial waters within the northern sector of the SoS (Geographical Sub Area, GSA,16 of the General Fisheries Commission for the Mediterranean, GFCM). Distant trawling, on the other hand, is mainly practised by the fleet of Mazara del Vallo, which operates in a wide area spanning from the Sardinian Channel (GSA 11) to the Aegean Sea (GSA 24), covering the entire SoS (GSA 12,13,14,15,16 and 21) (Pinello et al., 2018). The trawl fleet based in the Sicilian south coast grew from 1945 and reached peak capacity in terms of number of boats, tonnage, and engine power in the early 2000s. Subsequently, due to the European Union's (EU) policy aimed at reducing the fishing effort of EU fleets, the fleet capacity operating in the Strait of Sicily (GSA 16) has been reduced by approximately 65% in gross tonnage (GT) and 75% in engine power over the last 30 years (Garofalo et. 2003; Falsone et al., 2022). This reduction of the fishing effort concerned mainly the distant trawlers operating in the international waters of the Strait of Sicily (Falsone et al., 2022). Conversely, in the last decades there has been an increase of the effort exerted by the non-EU fleets, contributing substantively to the current conditions of overexploitation that characterize most of the stocks shared among the countries fishing in the SoS (see Paolo et al., 2024).

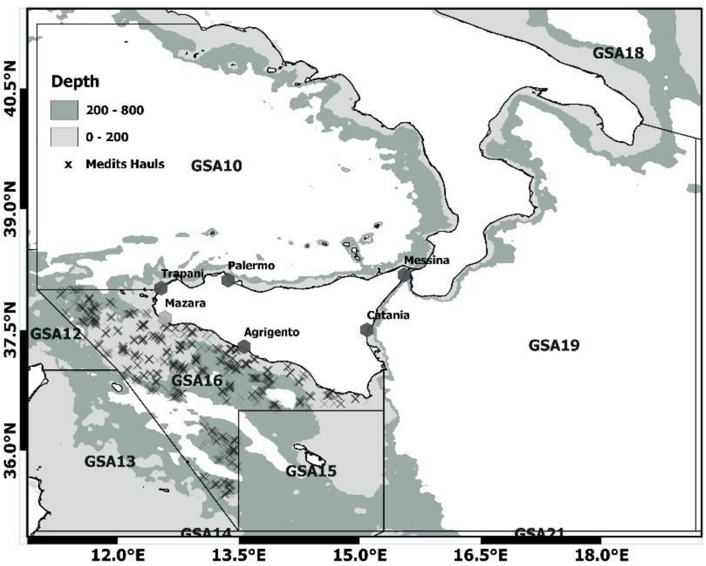

Figure 1 - Points represent the MEDITS hauls during the period 1994-2018. We have indicated the sites where Doderlein collected information on chondrichthyan species. The port of Mazara del Vallo, where is actually based the main trawler fleet in the GSA 16, and the grounds up to 200m depth (light grey) and between 200 and 800m (dark grey) are also shown.

The Döderlein data

Pietro Döderlein (Dubrovnik, Croatia, 2nd February 1809 - Palermo, Italy, 29th March 1895) was a celebrated Italian zoologist and geologist. In particular, being a keen ichthyologist, he enriched the zoological museum of Palermo University, building up a notable collection of fishes from Sicily, either preserved in spirit or as dried specimens, of which he published a catalog (Döderlein, 1878-79; see also Sarà & Sarà, 1990).
This fish catalog reported the most updated information of his time concerning the scientific nomenclature, the vernacular names of the species according to the different dialects of Italy, their foreign names, their synonymy and the iconography. Moreover, the catalog includes information on the frequency, the time of appearance and the reproductive period of the taxa in various areas of the Mediterranean, with particular reference to Sicily.
The information collected in the catalog was successively published in Palermo in 1879-1891, as a handbook, titled ”*Manuale ittiologico del Mediterraneo ossia Sinossi metodica delle varie specie di pesci riscontrate sin qui nel Mediterraneo ed in particolare nelle acque di Sicilia*”.
The accounts concerning Sicilian ichthyology were taken from the daily records kept at the Zoological Museum of Palermo University, where Döderlein served as director from 1869 to 1894. These records covered information on the fish species brought to and sold in the markets of the main towns of Sicily (Palermo, Messina, Catania, Agrigento, and Trapani). Although detailed information on the location, date and method of fishing is not reported, the Döderlein’s data serve as a reference for assessing the composition and frequency of occurrence of elasmobranch species in the in the seas around Sicily during the second half of the XIX century.
Due to the finality of our work, we have selected only the information concerning demersal chondrichthyans. A critical point has been the updating of the taxonomy and nomenclature used by Döderlein regarding the current one. In Table 1 we report the correspondence of the scientific names of the species recorded by Döderlein (1878-79) with the updated binomial nomenclature, according to Serena et al. (2021a), as well as the ranks given by Döderlein to each species abundance.

Table 1 - Current (Serena et al., 2021) and old binomial nomenclature and the abundance ranks of demersal elasmobranchs caught around Sicily as given by Döderlein (1878-79).

Taxonomy by Serena et al. (2021)	Taxonomy by Döderlein (1878-79)	Döderlein’s Ranks	This work Ranks
Squatina squatina (Linnaeus, 1758)	*Squatina angelus*	very frequent	4
Galeus melastomus (Rafinesque, 1810)	*Pristiurus melastomus*	very frequent	4
Raja montagui (Fowler, 1910)	*Raja maculata*	very frequent	4
Centrophorus uyato (Rafinesque, 1810)	*Centrophorus granulosus*	frequent	4
Squatina oculata (Bonaparte, 1840)	*Squatina oculata*	frequent	4
Scyliorhinus canicula (Linnaeus, 1758)	*Scyllium canicula*	frequent	4

Mustelus asterias (Cloquet, 1819)	*Mustelus plebejus*	frequent	4
Dipturus batis (Linnaeus, 1758)	*Leviraya macrorinchus*	frequent	4
Dipturus oxyrinchus (Linnaeus, 1758)	*Leviraya oxyrinchus*	frequent	4
Heptranchias perlo (Bonnaterre, 1788)	*Eptanchus cinereus*	less frequent	3
Hexanchus griseus (Bonnaterre, 1788)	*Notidanus griseus*	less frequent	3
Squalus acanthias (Linnaeus, 1758)	*Acanthias vulgaris*	less frequent	3
Squalus blainville (Risso, 1827)	*Acanthias blainvilli*	less frequent	3
Oxynotus centrina (Linnaeus, 1758)	*Cantrina salviani*	less frequent	3
Scyliorhinus stellaris (Linnaeus, 1758)	*Scyllium stellare*	less frequent	3
Galeorhinus galeus (Linnaeus, 1758)	*Galeus canis*	less frequent	3
Mustelus mustelus (Linnaeus, 1758)	*Mustelus equestris*	less frequent	3
Torpedo marmorata (Risso, 1810)	*Torpedo galvanii*	less frequent	3
Leucoraja circularis (Couch, 1838)	*Raja falsavela*	less frequent	3
Leucoraja fullonica (Linnaeus, 1758)	*Dasybatis fullonica*	less frequent	3
Raja clavata (Linnaeus, 1758)	*Dasybatis clavata*	less frequent	3
Myliobatis aquila (Linnaeus, 1758)	*Myliobatis aquila*	less frequent	3
Raja asterias (Delaroche, 1809)	*Dasybatis asterias/R. punctata*	less frequent/infrequent	2
Torpedo torpedo (Linnaeus, 1758)	*Torpedo narce*	infrequent	2
Leucoraja naevus (Müller & Henle, 1841)	*Raja naevus*	infrequent	2
Raja miraletus (Linnaeus, 1758)	*Raja miraletus/ R. quadrimaculata*	infrequent	2
Raja undulata (Lacepède, 1802)	*Raja undulata*	infrequent	2
Rostroraja alba (Lacepède, 1803)	*Leviraya bramante/ R. marginata*	infrequent	2
Dasyatis pastinaca (Linnaeus, 1758)	*Trygon pastinaca*	infrequent	2
Chimaera monstrosa (Linnaeus, 1758)	*Chimaera monstruosa*	infrequent	2
Raja radula (Delaroche, 1809)	*Batis radula/R. atra*	less frequent/very rare	1
Echinorhinus brucus (Bonnaterre, 1788)	*Echinorinus spinosus*	Rare	1

Etmopterus spinax (Linnaeus, 1758)	*Spinax niger*	Rare	1
Dalatias licha (Bonnaterre, 1788)	*Scymnus lichia*	Rare	1
Rhinobatos rhinobatos (Linnaeus, 1758)	*Rhinobatus columnae*	Rare	1
Tetronarce nobiliana (Bonaparte, 1835)	*Torpedo nobiliana*	Rare	1
Gymnura altavela (Linnaeus, 1758)	*Pteroplatea altavela*	Rare	1
Trygon violacea (Bonaparte, 1832)	*Pteroplatytrygon violacea*	Rare	1
Pristis pristis (Linnaeus, 1758)	*Pristis antiquorum*	very rare	1
Bathytoshia lata (Garman, 1880)	*Trygon thalassia*	very rare	1
Somniosus rostratus (Risso, 1827)	*Laemargus rostratus*	occasional	1

The Medits data

Considering that cartilaginous fishes do not represent a target species for commercial bottom trawl and that the landing data are scattered and biased (Cashion et al., 2019), to perform the preliminary assessment of these species, data gathered through bottom trawl survey were used. In particular, occurrence data by species were collected from 1994 to 2018 by the MEDITS that has been carrying out in the GSA16 every year mainly in spring/summer since 1994 (Bertrand et al., 2002; Spedicato et al., 2019). The bottom trawl surveys covered an area of about 31,400 km^2 within the 10-800 m water depth range, and a total of 1,589 hauls were sampled (1994-2020) (GSA 16, Fig. 1). The survey follows a stratified random sampling with the allocation of hauls proportional to strata extension (depth strata: 10-50 m, 51-100 m, 101-200 m, 201-500 m, 501-800 m). Hauls were carried out by a standard bottom trawl net (GOC 73) with a 20 mm opening mesh size in the cod-end (Fiorentini et al., 1999). Hauls of 30- and 60-minute daylight were performed on the shelf (10–200 m) and slope (201–800 m) grounds, respectively. The swept area in each haul was calculated according to the formula proposed by Fiorentini et al. (1999). The elasmobranch occurrences were recoded for each haul of the considered period.

Data analyses

Occurrence data from the entire MEDITS time series (1994-2018) in the GSA 16, were aggregated by species to determine the total occurrence over the whole period. These species occurrence was then ranked from the most frequent to the rarest. Specifically, the presence data were categorized into 5 ranks: the first rank corresponded to the species currently not present accordingly to the Döderlein's handbook, while the remaining ranks were identified by quartile (2nd rank= first quartile= *rare/infrequent*; 3rd rank = second quartile= *less frequent*; 4th =third quartile= *frequent*; 5th =fourth quartile= *very frequent*). This approach facilitated a semi quantitative comparison between current information on relative occurrence of elasmobranch species derived from MEDITS and the data reported by Döderlein (Table 1). To evaluate differences in species composition and frequency of occurrence between our data in GSA16 and those reported in GSA10, GSA19, and GSA16 by Follesa et al. (2019), which represent the potential fishing grounds of interest to fleets from the ports where Döderlein collected information on chondrichthyan species, we correlated our frequency of occurrence data from 1994 to 2018 with the averaged frequency of occurrence of the three GSAs reported by Follesa et al. (2019) during 2012-2015. The data were log(x+1) transformed, and the Pearson correlation showed a coefficient (rho) of 0.87 (p-value < 0.001), indicating a strong correlation. This support us to proceed with subsequent analyses, using the composition of GSA16 as a proxy for the diversity and occurrence of chondrichthyan species in the entire area (Fig. 2).

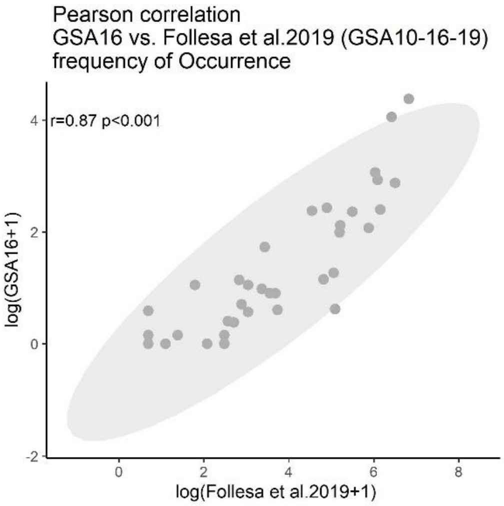

Figure 2. Correlation between the log-transformed frequency of occurrence data from MEDITS in GSA16 and the average frequency of occurrence of GSA10, GSA16, and GSA19 as reported by Follesa et al. (2019).

Table 2. The number of hauls of occurrence and the associated rank for the species caught by Medits trawl surveys from 1995 to 2018 in the GSA 16 (south Sicily) for the 37 demersal chondrichthyan species.

Species	Number of hauls	Medits Rank
Galeus melastomus	918	4th quartile
Scyliorhinus canicula	665	
Etmopterus spinax	612	
Raja clavata	468	
Chimaera monstrosa	439	
Raja miraletus	416	
Squalus blainville	356	
Dipturus oxyrinchus	243	
Mustelus mustelus	182	
Torpedo marmorata	179	3rd quartile
Centrophorus uyato	161	
Raja melitensis	156	
Dalatias licha	133	
Raja montagui	123	
Raja asterias	93	

Heptranchias perlo	41	
Tetronarce nobiliana	39	
Rostroraja alba	34	
Dasyatis pastinaca	30	2nd quartile
Mustelus punctulatus	28	
Oxynotus centrina	20	
Myliobatis aquila	20	
Leucoraja circularis	17	
Torpedo torpedo	16	
Raja polystigma	14	
Raja brachyura	12	
Hexanchus griseus	11	1st quartile
Scyliorhinus stellaris	11	
Mustelus asterias	7	
Aetomylaeus bovinus	5	
Raja radula	3	
Squalus acanthias	2	
Leucoraja naevus	2	
Dipturus batis	1	
Galeorhinus galeus	1	
Leucoraja fullonica	1	
Pteroplatytrygon violacea	1	

Statistical approaches

To evaluate the variation of the present relative occurrence of the chondrichthyan community compared to historical information we employed a randomization-based procedure. Our null hypothesis assumed no differences between the two periods. Thus, if there were no differences between Döderlein's and present data, categorizing the data in two groups - *i.e.* '*past*' and 'present'- would be meaningless. Therefore, we randomly assigned (n=1,000) the categories 'past' and 'present' to the recorded rank of abundance. Subsequently, we calculated the differences as means and the 95^{th} confidence intervals representing the distribution of our null hypothesis. We then compared the observed differences in ranks between the two periods with the null distribution and assessed how unlikely these values differed from the null hypothesis's expectation. To assess differences by rank, the randomization-based procedure was repeated for each of the categories of Döderlein records.

Results

The list published by Döderlein comprised 63 Chondrichthyes species, with 41 of them recognized as valid demersal species according to Serena et al. (2021a) (table 1). In particular, this list included 22 sharks, 18 batoids and one chimaera. Conversely, the species caught during the MEDITS surveys amounted to 37 species, consisting of 15 sharks, 21 batoids and one chimaera. When comparing the composition of demersal Chondrichthyan assemblage between the two periods (fig.2), the species classified as abundant and rare by Döderlein experienced the most significant decline. Specifically, out of the 13 categorized as 'frequent', five transitioned to rare and four to 'not very frequent'. Additionally, out of the 10 species classified as 'rare', six are currently not collected by MEDITS surveys. It worth noting that four species categorized as 'not very frequent' in Döderlein's catalog are currently classified as frequent and two as very frequent (Fig 3). Displaying the difference between current and Döderlein ranks in a synthetic plot (Fig. 3), it can be observed how the categories indicating before a low frequency occurrence are now distributed in higher ranks. Meanwhile, for species that were more frequent, the occurrence category tends to decrease (Fig 2b).

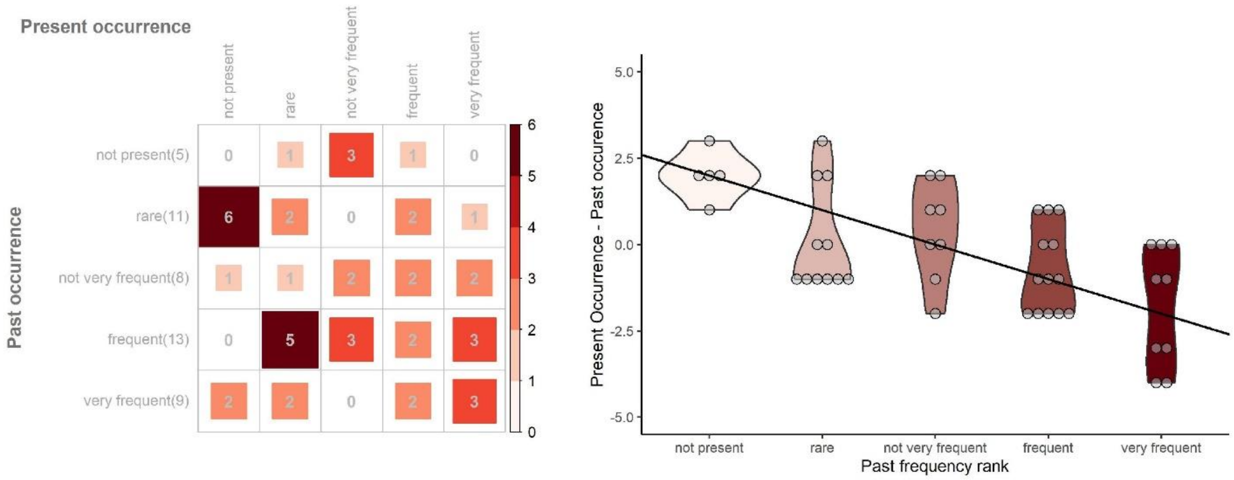

Figure 3. Left panel: Comparison of the composition of chondrichthyan assemblage in the second half of XIX century with that obtained between the last decade of the XX century and the first decades of XXI one. The differences are expressed in terms of number of times a given rank in the past changes to another rank in the present. Right panel: Violin plot, showing the relationship between the difference from Present and actual ranks as a function of the past rank.

The randomization procedure revealed that three of the occurrence categories, on average, underwent significant changes between the two periods (Fig. 4). Specifically, the 'rare' species exhibited a positive change, while the 'frequent' and 'very frequent' categories decreased between the two periods. When examining individual species separately, without considering the average changes from one category in the past to the one recorded in present period, 19 species decreased their rank, 16 species increased, and eight species have maintained the same rank attributed in the past. It is worth noting the absence in Medits data of the sharks belonging to the genus *Squatina*, once very frequent off the Sicilian coast as reported in the Doderlein handbook. Additionally, five species – *L. melitensis*, *R. polistygma, R. brachiura, A. bovinus,* and *M. punctulatus* – were not reported by Döderlein.

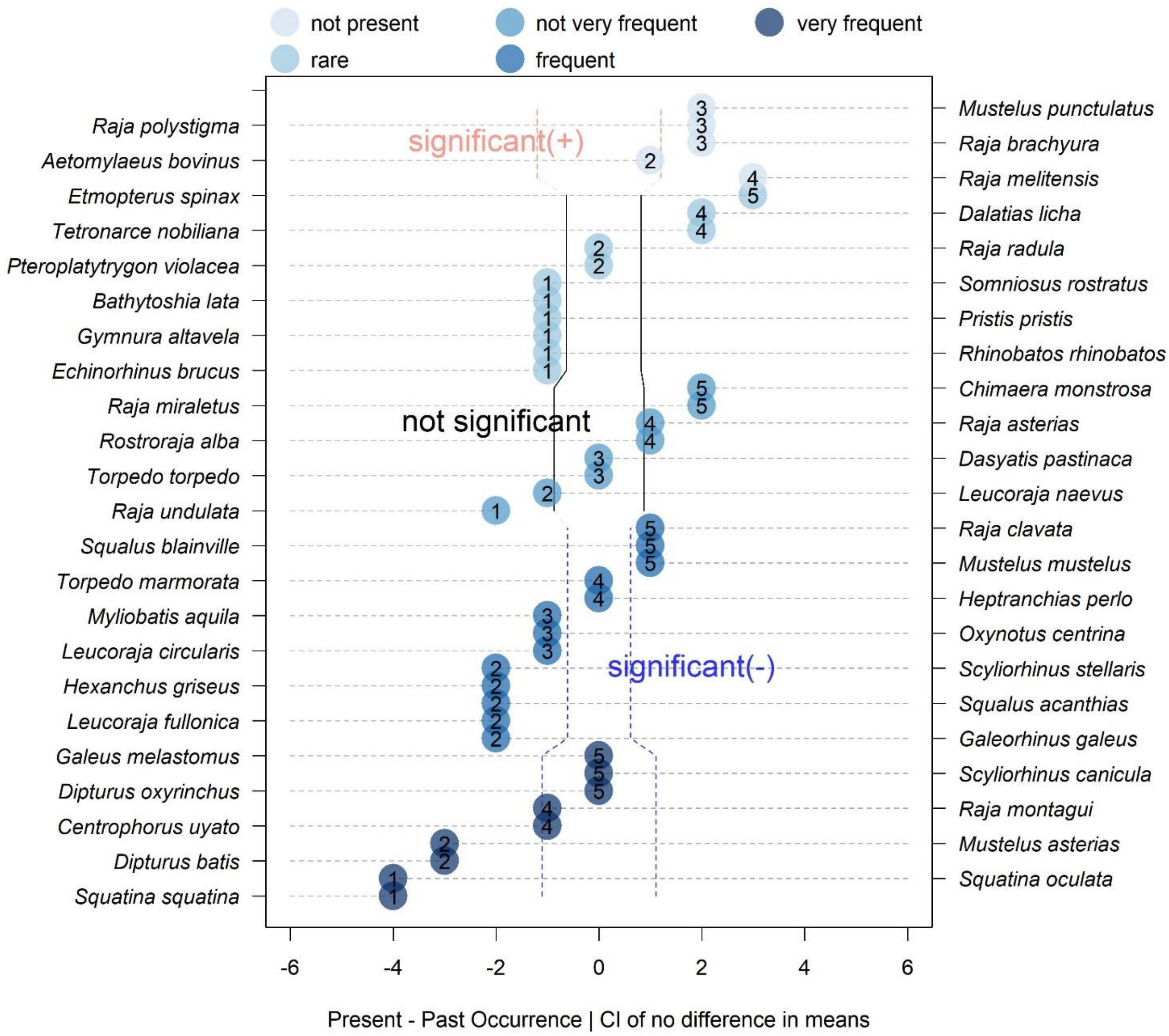

Figure 4. Variation in relation to past abundance measured by the difference between present and past ranks. A positive difference indicates an increase in the present rank compared to the past, while a negative difference the opposite. Vertical dashed lines represent confidence intervals for significant overall differences, while vertical solid lines indicate no significant changes between present and past ranks. The numbers within the dots represent the actual abundance rank, while colors represent the past ranks.

Discussion

Historical baselines are needed to reconstruct long-term changes in marine animal populations and enhance our ability to give management advice (Fortibuoni et al., 2016). Knowledge of the past state of marine animal populations can provide reference point for defining sustainable exploitation of marine living resources, understand the functioning and natural variability of marine environments, and plan activities of human communities depending on these resources (Elegerlhard et al., 2016). Indeed, short term time series often fail in explaining important features of resource dynamics, such as biomass fluctuations and recovery properties, suggesting biased reference points and perceptions of stock status (Schijns & Pauly, 2022). Information here analysed showed a reduction of both number of species and frequency of occurrence of sharks and rays species in the investigated area during the last 150 years. This reduction was primarily driven by those species occurring frequently and very frequently during the 19th century and now are locally rare (e.g *D. batis, S. acanthias, G.galeus*) and not present (genus *Squatina*). It is important to highlight that when examining the occurrence of *D. batis* in the Mediterranean, a particular aspect warrants attention. While the species has been historically reported in the Mediterranean basin, particularly in the Adriatic, these records lack supporting comparative images. This gap also extends to the faunal lists of MEDITS research programme. Presently, specimens of *D. batis* can only be found in museums. For instance, a large specimen reported as *Raja batis* is housed in the Döderlein's collection at the Palermo Museum. Conducting a DNA analysis on this specimen would be extremely valuable in confirming its species identity. Additionally, Döderlein (1879) himself regarded the presence of *R. batis* in the Mediterranean as uncertain. Similarly, Clark (1926) and Norman (1935) expressed reservations about the existence of *R. batis* in this sea, contradicting Risso (1810), who initially described *R. batis* based on specimens from the Mediterranean region. Lastly, Last et al. (2016) omitted this species from the list of Mediterranean skates. Differently, regarding *P. pristis,* whose presence in the Mediterranean has been questioned several times, and Doderlein reported as very rare, nowadays it resulted locally not present accordingly to some authors considering this species as absent from the entire basin (Ferretti et al, 2015; Serena et al., 2020).

Regardless these taxonomic aspects, the disappearance or the strong reduction in the presence of several chondrichthyans are consistent with the peculiar and vulnerable life-history traits of these fish, which are highly threatened by fishing activities (Dulvy et al., 2021; Pacoureau et al., 2021). According to the more recent IUCN assessment, out of the 88 species of chondrichthyans in the Mediterranean Sea, 53.4% are classified as threatened with more than one-third categorized as Data Deficient or Not Evaluated due to insufficient data. At least half of the rays and 56% of sharks in the Mediterranean Sea face an elevated risk of extinction. In general, 74% of the families in the area have at least one species listed as threatened, while approximately 52% have all species listed as threatened (Dulvy et al., 2016). Despite the congruence of our results with the assessments of the current status of populations described by the IUCN, it should be considered that our results could also be influenced by differences in the information collected by Döderlein compared to the data derived from contemporary trawl surveys conducted in the SoS. The former also included observations made in the main Sicilian markets, such as those of Palermo, Messina and Catania along the Tyrrhenian and Ionian coasts. Despite this potential issue, we have verified that the frequency of occurrence data for GSA16 can be used as a proxy for the chondrichthyan community in the potential areas exploited in the past from these ports. This was achieved by correlating our data with that from the three GSAs around Sicily obtained from the publication by Follesa et al. (2019). The correlation showed a high and significant level, with only one species not occurring in the dataset we used, namely *Alopias vulpinus*. This pelagic species was found in only 0.3% of the hauls, exclusively in GSA19, based on the average frequency of occurrence (GSA10-16 and GSA19) reported by Follesa et al. (2019). Nevertheless, given that the SoS is recognised as one of the main areas with the highest richness and abundance of chondrichthyans in the Mediterranean (Colloca et al., 2017; Bradai et al., 2018), our results could be more optimistic than the actual situation of these fishes around the whole Sicily.

It should also be remembered that fisheries in Döderlein's time were not equipped to operate in deep sea. While this suggests that offshore species, such as *C. monstrosa* or *E. spinax*, previously reported as rare in the past, may have become more common today due to improved fishing techniques, it does not justify the rarity or disappearance of easily fished coastal species that were previously abundant. Finally, uncertainties in the taxonomic attribution of the specimens collected by Döderlein, which lead to the exclusion of some non-valid species from comparative list, may help to mitigate the observed decline in abundance.

Although with the limitations mentioned above, the significant reduction of past frequent and very frequent species evidenced, is consistent with the findings of authors who focused on the population dynamics of elasmobranchs within the SoS (e.g., Garofalo 2003; Geraci et al. 2021). Our long-term comparisons not only accord with the general decrease observed by these studies during the last 20 years but also highlight divergences from this general pattern in some species, such as for batoids *R. clavata* and *R. miraletus* and for sharks *S. canicula* and *G. melastomus*. These species appear to be quite resilient to fishing pressure (Cavanagh and Gibson 2007; Follesa et al. 2019) and stable over time, as suggested also by the IUCN Red List, which does not currently classify them as Endangered in the Mediterranean Sea. On the other hand, our results also reveal an increased risk of local extinction for both species of the genus *Squatina*, consistent with local ecological knowledge findings reported by Colloca et al. (2020), and an alarming reduction of *M. asterias* compared to Doderlein's observations. This decline accords with the concerning 70-80% reduction documented in the entire Mediterranean Sea over the last 70 years, as evidenced by multiple bibliographic records (Colloca et al., 2017). A decreasing trend was also highlighted for *H. griseus*, consistent with recent results aimed at understanding the status of this species in the Mediterranean Sea through analysing stakeholders' perceptions, thereby strengthening their conclusions regarding a re-evaluation of the IUCN category assigned to this species (Nuez et al., 2023).

The general decline of chondrichthyans, fishes very vulnerable to high fishing effort, observed in many areas of the Mediterranean between the middle of the XX and the beginning of the XXI century (Aldebert, 1997; Maynou et al., 2011; Ferretti et al., 2013; Fortibuoni et al., 2017) corresponds to the increase in the size and fishing power of Mediterranean fishing fleets and the consequent increased exploitation of fishery resources (Maynou, 2020).

However, it should be remembered that, with few exceptions, such as the smooth-hound sharks in the SoS or in northern Adriatic (Colloca et al. 2017), the demersal chondrichthyans on the Mediterranean are primarily caught as bycatch of trammel net and bottom trawling targeting other species (Bradai et al.,2018; Serena in Carpentieri et al., 2021b). When not commercialized in local market, they are discarded at sea and the fraction of chondrichthyans landed varies according to the different gastronomic traditions of the areas. The discard ratio of main demersal sharks in the Mediterranean bottom trawling ranges between 35% and 90% in the case of *S. canicula*, while is 100% of catch in the case of *E. spinax* (Tsagarakis et al., 2017). Additionally, only a small fraction (about 2%) of *R. radula* caught by trammel net fishery targeting cuttlefish in the south-eastern Ionian coast of Sicily were landed, whereas all *D. pastinaca, T. marmorata,* and *T. torpedo* were discarded (Tiralongo et al. 2018).

The fact that most of the chondrichthyans fished in the Mediterranean are commercial or discarded by-catch could be a positive factor for the adoption of the necessary conservation measures. In view of the challenges of implementing comprehensive assessment and management measures for all species, these measures should focus on protecting those species that have experienced the most significant decline in abundance at sea over time.

In this context, it is crucial that the EU and GFCM adopt an effective mitigation strategy that also prioritises discard practices, based on a combination of technical, legislative and social instruments (Ferretti and Myers, 2006).This strategy should be based mainly on three synergic pillars: i) improving selectivity in bottom trawl net by adopting gears allowing chondrichthyans to escape while retaining target species (see Brčić et al., 2015); ii) prohibiting fisheries in area where adults aggregate to reproduce (mating and spawning areas) (see Jorgensen et al., 2022), and iii) involving fishers in the implementation of chondrichthyan and, more in general, biodiversity conservation measures to ensure productive and healthy ecosystems (see Baum et al., 2003; Iwane et al., 2021)

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