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Temporal dynamics of demersal chondrichthyan species in the central western Mediterranean Sea: The case study in Sardinia Island

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ABSTRACT

Occurrence, abundance and size trends of 25 demersal Chondrichthyes (10 Sharks: 3 Carcharhiniformes, 2 Hexanchiformes, 5 Squaliformes; 14 Batoids: 3 Myliobatiformes, 8 Rajiformes, 3 Torpediniformes and 1 Holocephalan: 1 Chimaeriformes) collected from 22 years (1994–2015) of Mediterranean International Trawl Surveys (MEDITS) around Sardinian seas, were given. Data relative to two strata, the continental shelf (10–200 m), the slope (201–800 m), and the overall (10–800 m), were analyzed in order to identify the general species distribution of their habitat preference. From the gathered data it appeared that the shelf was mostly inhabited by batoids while the slope by sharks. Only the small-spotted catshark *Scyliorhinus canicula* and the thornback skate *Raja clavata* were equally distributed with high values of occurrence and abundance both in the shelf and in the slope. All the other species showed a preferential distribution only in one stratum (shelf or slope). In general, temporal trends of abundance indexes were stable or increasing in all strata. GAM analysis also confirmed a stable trend. Almost all species displayed stable in size structure analysis, apart from *R. brachyura* and *Dipturus oxyrinchus* that showed a statistically increasing trend. Although the investigated chondrichthyan species seemed to display a not alarming status of conservation in Sardinian seas, more investigation should be done to assure a proper management of this threatened resource.

1. Introduction

The rapid expansion of fisheries and globalized trade are emerging as the principal drivers of coastal and ocean threat (McClenachan et al., 2012). Overfishing and habitat degradation have profoundly altered marine animal populations (Polidoro et al., 2012), especially sharks and rays (Ferretti et al., 2010). Chondrichthyes appear to be particularly vulnerable to overexploitation because of their K-selected life-history strategy (e.g., slow growth, late attainment of sexual maturity, long life spans, low fecundity) (Stevens et al., 2000). Moreover, most of chondrichthyan landings are by-catch from fisheries targeting other species, or are registered in countries without adequate fisheries information-gathering systems with a resulting un-recording of the catches (Stevens et al., 2000). Despite their important role as predators at the top of the food chain in marine ecosystems and the dramatic declines in abundance reported from many parts of the world's seas (Ward-Paige et al., 2012), data on their stock status remains still poor or non-existent (Polidoro et al., 2008; Worm et al., 2013).

Chondrichthyan fisheries have expanded globally in response to the growing demand (particularly for valuable parts such as shark fins), expanding the fishing effort to new areas (i.e., open ocean, deep-sea bottom), and involving more technically equipped fishing vessels (Casey and Myers, 1998; Clarke et al., 2007; Polidoro et al., 2008; Worm et al., 2013). These developments, together with the decline in several elasmobranch stocks, have led to a call towards a specific improvement in international actions for the Chondrichthyes management, in order to ensure sustainable fisheries (FAO, 2000; Lucifora et al., 2011; Bradai et al., 2012).

The Mediterranean Sea represents a hotspot of marine biodiversity exposed to multiple threats, including fishing pressure, habitat loss and degradation, pollution, eutrophication and, more recently, climate change and invasion by alien species (Coll et al., 2010). More than half of chondrichthyan species assessed by the IUCN in this basin (39 of 73 species) are threatened. 31 are most imperiled: among these species 20 are classified as Critically Endangered and 11 as Endangered. The level of threat may be worse because uncertainty in species status remains moderately high in the Mediterranean Sea; of the 73 assessed species, 13 remain Data Deficient. (Dulvy et al., 2016). At least, half of

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the batoids (50%, 16 of 32 species) in the Mediterranean Sea faces an elevated risk of extinction, as well as 54% of sharks (22 of 41), whereas the only chimaerid species (*Chimaera monstrosa*) is considered Least Concern (Dulvy et al., 2016).

Italy is characterized by a strong multispecies fishery, which does not allow to correctly define the state of exploitation of single or groups of stocks (Cataudella and Spagnolo, 2011). In addition, strategies based on management plans, according to fishery area and fishing system for cartilaginous fish have not been adopted yet.

Although artisanal fisheries are prevalent in Sardinia, large trawlers operating in areas far from the coast, represent a fishing segment relevant in the region (Follesa et al., 2011a,b). Moreover, even if sharks and other chondrichthyans are not targets of Sardinian fisheries, they are often caught as by-catch or they are discarded.

Fishery-independent surveys provide valuable measures of relative abundance, rates of population change, sex and size composition for a wide range of species including those not targeted by commercial fishing. As these measures are obtained from scientific sampling or within an experimental design, they are less subject to the unknown and often confounding factors that complicate the interpretation of fishery-dependent indices of stock status. Specifically, scientific trawl surveys have as advantages the design assumptions easier to satisfy a multispecies perspective (Rago, 2005).

In this regard, the aim of this work is to assess the status of demersal Chondrichthyes in Sardinian waters, examining temporal changes throughout data obtained from a scientific trawl survey, the Mediterranean International Trawl Survey (MEDITS, Bertrand et al., 2002). This goal will be achieved (i) analyzing time series (1994–2015) trends of abundance (density and biomass) and (ii) assessing the current composition of cartilaginous catches in terms of species and size.

2. Material and methods

2.1. Study area

The investigated area (Fig. 1) extends for 23.700 km^2 and includes all the seas surrounding the island of Sardinia (central western Mediterranean; Geographical Sub-Area, GSA 11).

This region is part of the FAO statistical sub-area 37.1.3 (i.e., Sardinia), which is characterized by 1.846 km of non-homogenous coasts, with different extension, oceanographic, geomorphological and bionomical features (Cau et al., 1994; Addis et al., 1998). From an oceanographical point of view, this area belongs to two different basins: the Algerian-Provençal and the Tyrrhenian ones, which are connected by the Sardinian Channel. For what concerns the bathy-morphological features, four main zones can be described: i) the western coast, characterized by a wide extension of the continental shelf; ii) the northern portion of the island, characterized by a moderate extension of the continental shelf and a narrow and steep slope; iii) the eastern coast, characterized by little and steep fishing grounds and iv) the southern coast, characterized by a wide shelf area (Palomba and Ulzega, 1984). The bathymetric division of the GSA 11 bottoms points out that the great part of them (about 67%) are found below a depth of 100 m.

2.2. Surveys and statistical analyses

Data were collected during the MEDITS scientific bottom trawl survey project (Bertrand et al., 2002) conducted annually in late spring-early summer (from May to July) during daylight (between 30 min after sunrise and 30 min before sunset). The examined time series covered 22 years, from 1994 to 2015. A total of 2339 positive hauls (1414 within 200 m, and 925 between 200 and 800 m) were performed according to the MEDITS protocol (MEDITS Handbook, 2016). This survey is carried out according to a stratified random sampling design based on five depth strata: 10–50 m, 51–100 m, 101–200 m, 201–500 m, 501–800 m, where the number of hauls is proportional to the area of each stratum. The duration of hauls is fixed at 30 min on shallower depths than 200 m and 60 min for deeper sites.

All specimens were counted, weighted (grams), and measured as total length (TL, in cm) (MEDITS Handbook, 2016). The total frequency of occurrence (f% = N positive hauls/total hauls *100) and also the Abundance Indexes (Biomass Index BI, kg/km^2 and the Density Index DI, N/km^2) were calculated for each taxonomic order and by each species considering the continental shelf (10–200 m), the slope (201–800 m), and the overall (10–800 m) depth strata for all the entire examined period. The existence of monothonic temporal trend in abundance was investigated by the Spearman correlation test (Zar, 1999).

Due to the taxonomic misclassification issues dealing with the longnose spurdog *Squalus blainville*, data on frequencies and Abundance Indexes were calculated starting from 2005 when specific morphologic analysis of this species was conducted.

Temporal trends of the Abundance Indexes were also tested by means of General Additive Modelling (GAM). The modelling routines were performed with R software, 'mgcv' package (Wood, 2000). The aim was to test for significant variations in the relation of the response variable (i.e., density and biomass) with depth (included as a smoother term), over the 22 years of investigation. The swept area was included as offset, a measure of the effort for which we could standardize the recorded indexes of abundance and biomass. Since data exploration revealed outliers in most density and biomass datasets (i.e., N of individuals and total weight per trawl), Log-transformation was performed prior to analysis. Model selection was accomplished using the lowest Akaike Information Criterion (AIC; Akaike, 1974) value and model validation was carried out by visual examination of plots of the normalized residuals versus the fitted values from each of the models. Models were ran for the total abundance and biomass of: i) the entire amount of Chondrichthyes; ii) the two major Chondrichthyes groups (i.e., Batoids and Sharks) and iii) the most abundant species of Sharks and Batoids (*G. melastomus*, *R. clavata*, *R. miraletus* and *S. canicula*) in Sardinian seas. All metrics were modelled using the Gaussian distribution with an identity link function.

According to the MEDITS protocol, the TL has been taken since 1994 only for *R. clavata* and *S. canicula*; the other species became targets in the following years (*G. melastomus* from 1999; the other batoids and sharks starting from 2005). Temporal trends in size were calculated considering the overall depth stratum. Statistical analysis of the temporal size trends were tested with the Spearman test (Zar, 1999). The Kolmogorov-Smirnov (KS) two-sampled test was used to test for significant differences in the size composition of those species that were distributed in both bathymetric strata (shelf and slope).

3. Results

A total of 25 demersal Chondrichthyes species belonging to 7 orders and 13 families were detected (Table 1). The frequency distributions and abundances of chondrichthyan subdivided per Order were very skewed (Fig. 2), with Carcharhiniformes and Rajiformes dominant. Chimaeriformes, Myliobatiformes, Torpediniformes and Hexanchiformes occurred only sporadically (Fig. 2).

3.1. Chimaeras

3.1.1. Order Chimaeriformes

Sardinian waters host the only species belonging to this order and living in the Mediterranean: *C. monstrosa* (Table 1). Surveys indicated its exclusive occurrence in the bathyal zone (321–682 m) with low frequencies (f% = 7.28 ± 4.00, mean ± S.D., Table 2) and abundance (DI = 1.74 ± 1.62, BI = 0.12 ± 0.1, mean ± S.D., Table 3) values. Size distribution ranged between 16.6 and 56 cm TL (31.7 ± 10.7 cm TL, mean ± S.D.). The paucity of captures did not