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In search of prey: the occurrence of *Alopias vulpinus* (Bonnaterre, 1788) in the northern Adriatic Sea and its interactions with fishery

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The common thresher shark, Alopias vulpinus*, has shown a marked decline in abundance in the Mediterranean Sea. Through the analysis of long-term fishery time series (1966–2013), this study highlights that an important driver of the presence of* A. vulpinus *in the northern Adriatic Sea, one of the most exploited basins of the Mediterranean, is the abundance of its prey, the sardine* Sardina pilchardus*. From 1997-2013, an annual average of 14 thresher sharks was landed at Chioggia (Italy), the main fish market in the area, mainly from July to October. More than 75% of the landed thresher sharks were sexually immature, with some specimens weighing less than 10 kg, indicating that a high proportion of the catch was composed of small young and newborn individuals. These results support the occurrence of a nursery area in the northern Adriatic Sea, highlighting the need for proper management of* A. vulpinus *catch in this area.*

Key words: Common thresher shark, fishery, management, food web interactions, sardine

INTRODUCTION

The populations of large predatory sharks have declined worldwide (MYERS & WORM, 2003). Large size, late sexual maturity and slow reproductive rate make elasmobranchs in general and larger species in particular, highly vulnerable to overexploitation by fisheries (MYERS & WORM, 2005). The ecological effects of the loss of predatory species, and specifically elasmobranchs, through trophic cascades have been highlighted only in some marine ecosystems (HEITHAUS *et al.*, 2009; FERRETTI *et al.*, 2010). In many seas, indeed, the decline of apex predators dates back to the nineteenth century or even earlier (PINNEGAR & ENGELHARD, 2008), so that the impacts of their decrease in abundance on marine ecosystems are difficult to study and are, therefore, often unknown.

The Mediterranean Sea has a long history of exploitation and habitat degradation (LOTZE *et al.*, 2006; COLL *et al.,* 2010), and human impacts have driven changes in marine resource abundance since the Roman period (LOTZE *et al.*, 2011). The Adriatic basin, particularly its northern part, is one of the most exploited areas of the entire Mediterranean Sea (BARAUSSE *et al.*, 2009; BARAUSSE & PALMERI, 2014). Shallow waters, high intra- and inter-annual variability in temperature and salinity, large nutrient inputs from river catchments, and high but variable primary production (GIANI *et al*., 2012) characterize

the northern Adriatic, covering approximately 32000 km^2. Historically, the northern Adriatic Sea has been inhabited by a wide diversity of elasmobranchs (FORTIBUONI *et al.*, 2010), which have shown a marked decline in abundance, particularly in the case of top predators (FERRETTI *et al.*, 2008; BARAUSSE *et al.*, 2014; DULVY *et al.*, 2014), that started even before the commencement of industrial fishery (FORTIBUONI *et al.*, 2010). In this basin and in the whole Mediterranean, the management of large pelagic shark species is under the jurisdiction of the International Commission for the Conservation of Atlantic Tunas (ICCAT), an inter-governmental fishery organization responsible for the conservation of tunas and tuna-like species in the Atlantic Ocean and its adjacent seas. So far, there has been no stock assessment of large pelagic sharks in the Mediterranean Sea, even for the most common species, the blue shark, mainly due to the lack of data sets suitable for a complete stock assessment procedure. Large sized elasmobranch top predators are represented in the northern Adriatic mainly by two species: the common thresher shark, *Alopias vulpinus*, and the blue shark, *Prionace glauca* (SOLDO, 2006). The common thresher shark is a highly migratory species and is included in Annex I of the 1982 Convention on the Law of the Sea (FAO, 1994) and in the IUCN Red List as "Vulnerable" (GOLDMAN *et al.*, 2013). In Italian Mediterranean waters, *A. vulpinus* has markedly declined in abundance (FERRETTI *et al.*, 2008) and is considered "Critically endangered" (RONDININI *et al.*, 2013), indicating the need for management actions. While it is not permitted to be the direct target of commercial or recreational fisheries in the Atlantic and Mediterranean Sea (EU, 2014), this species is caught as by-catch in the commercial fishery. Estimating the occurrence and exploitation of this species and determining the main drivers of its presence in the different Mediterranean basins is crucial for developing effective conservation strategies.

This paper aims to: a) evaluate the occurrence and b) assess the exploitation of the common thresher shark in the northern Adriatic Sea; c) investigate the relationship between its occurrence, prey abundance and seawater temperature, based on the analysis of long-term landing time series and recent detailed records of the presence of this elasmobranch at the fish market of Chioggia, where the major fishing fleet of the Adriatic operates.

MATERIAL AND METHODS

Long-term time series of official landings at the fish market of Chioggia, a major fishing harbor in the northern Adriatic Sea (BARAUSSE *et al.*, 2011), were used to assess the occurrence of the common thresher shark. The fleet of Chioggia operates with different fishing gears, including bottom and mid-water trawling, hydraulic dredge, and artisanal fishery equipment. Currently, pelagic species represent more than half of the total landings of the fleet (BARAUSSE *et al.*, 2011; CLODIA DATABASE, 2014).

The official landing data of thresher sharks at the fish market are available, expressed as kilograms of eviscerated fish, on a monthly and yearly basis from 1945 to the present (MAZZOLDI *et al.*, 2014). Daily landing data since 1997 are also available. Common thresher sharks were registered at the fish market, mainly as bycatch of mid-water trawls, regularly only from 1966–1978 and then from 1997 to present (for details on landing data, see BARAUSSE *et al.*, 2014; MAZZOLDI *et al.*, 2014); aside from these two periods, they were registered only in 1953 and 1961. Because it was not possible to assess whether the absence of records decades ago represents missing data, the grouping of thresher shark landing with the landing of other sharks, or no landing, only data from 1966–1978 and from 1997–2013 were used. Daily data from 1997-2013 include records of each sell that took place on a given day expressed as eviscerated weight. Since specimens were never divided into parts for selling, these data allow an estimate of the minimum number of landed common thresher sharks, assuming that each record represents at least one specimen.

Considering that the annual biomass (total eviscerated weight) of landed common thresher sharks was positively correlated with their annual computed number (r_S= 0.52; p = 0.034; N =

17), the longest time series (biomass data from 1966-1978 and 1997-2013) were used to put the landings of the common thresher shark in relation to two types of predictors: the landings of its main prey (according to studies carried out in other areas, given the absence of diet analyses for Adriatic or Mediterranean specimens; PRETI *et al.*, 2012; ROGERS *et al.* 2012), i.e. the two main small pelagic fish occurring in the area (European anchovy, *Engraulis encrasicolus*, and European sardine, *Sardina pilchardus*; BARAUSSE *et al.*, 2011), and the sea surface temperature in the Gulf of Trieste on the northern Adriatic Sea coast, available from 1966–2011 (see BARAUSSE *et al.*, 2014 for details). It was not possible to include in our analyses other pelagic species, the possible prey of *A. vulpinus*, due to the lack of appropriate time series for these species. Landings of common thresher shark, anchovy, and sardine were divided by the fishing capacity in Chioggia to obtain a catch-per-unit-effort index of relative abundance (biomass cpue; BARAUSSE *et al.,* 2014). Two-time series of fishing capacity, expressed as gross tonnage (GT), were available in Chioggia: the annual total fishing capacity from 1966–2013 (BARAUSSE *et al.*, 2014) and the annual fishing capacity of pelagic trawlers, which account for the majority of the catches of *A. vulpinus* and small pelagics (BARAUSSE *et al.*, 2011, 2014), from 1997–2013 (also available on a monthly basis; CLODIA DATABASE, 2014). Since both time series have advantages (the former is longer, the latter is more representative of the gears capturing *A. vulpinus*), both were used to compute alternative formulations of the Catch Per Unit Effort (CPUE) to test whether results depended on the chosen measure of fishing capacity. Correlations between time series were tested through Spearman's rank correlation coefficient and the Benjamini-Hochberg FDR procedure (VERHOEVEN *et al.*, 2005) was used to correct for multiple tests.

Daily data (1997-2013) were used to 1) estimate the minimum number of landed common thresher sharks; 2) evaluate seasonality in the landings of thresher sharks; 3) evaluate seasonality in size, using individual eviscerated weights as a proxy; and 4) assess the percentage of immature specimens, based on an estimate of a threshold value for eviscerated weight at maturity. Individual weight was conservatively calculated by assuming that each recorded sell represented one specimen. The total length at which 50% of individuals were sexually mature estimated for *A. vulpinus* in the western North Atlantic Ocean (202 cm, average between male and female values) was converted to a weight of 123.88 kg using the weight-length relationship in GERVELIS & NATANSON (2013). Daily landing data are provided as eviscerated weight; therefore, to estimate the eviscerated weight at which 50% of individuals are mature the total weight was corrected subtracting available weights of digestive and reproductive apparatuses. In details, since no data on the weight of the entire digestive apparatus are available, only liver weight was subtracted, using the hepatosomatic index (5.35%, mean of male and female values for the congeneric species *Alopias superciliosus*, from JAYASINGHE *et al.*, 2003). Ovary weight (maximum value of 1.26 kg, from NATANSON & GERVELIS, 2013) was used as a proxy for reproductive apparatus weight. A threshold-eviscerated weight at maturity of 116 kg was therefore estimated, and all individuals weighting equal to or less than this value were considered immature.

Seasonality in the landings was assessed by analyzing the monthly time series of the ratio of the number of landed common thresher sharks to the fishing capacity of pelagic trawlers (abundance CPUE, Jan 1997–Dec 2013) through the Lomb normalized periodogram (PRESS *et al.,* 1992; the significance of periodicities in the time series was tested against the null hypothesis of white noise). The records from August were excluded from the analysis because trawling has been banned for one month per year, usually in August, beginning in 1988. The analysis was also performed for monthly biomass CPUE (monthly landings divided by the monthly fishing capacity of pelagic trawlers) of small pelagic fish for 1997–2013.

RESULTS

The time series of predictors (CPUE of anchovy and sardine, seawater temperature) were not correlated with each other (Spearman's coefficient r_S, all $p_{adj} > 0.12$ when using CPUEs calculated with total fishing capacity; the results did not change with the fishing capacity of pelagic trawlers). The annual biomass CPUE of the common thresher shark was positively correlated with that of sardine ($r_S = + 0.54$; $p_{adj} = 0.006$; N = 30; Fig. 1) but not with the CPUE of anchovy ($r_S = + 0.04$; $p_{adj} = 0.827$; N = 30) or with seawater temperature ($r_S = - 0.09$; $p_{adj} = 0.827$; N = 28) from 1966 - 2013. The results did not change when using biomass CPUE based on the fishing capacity of pelagic trawlers (1997-2013).

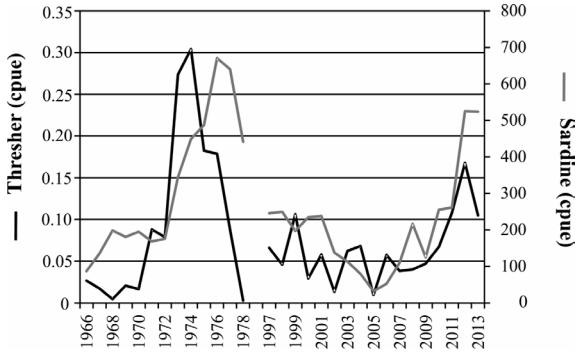

Fig. 1. Annual catch-per-unit-effort (cpue, kg/GT, where kg are kilograms of fish landed and GT is the gross tonnage of the fishing fleet) of the common thresher shark and European sardine (1966-1978; 1997-2013), with reference to the fishery of Chioggia, Italy. Notice that the horizontal axis representing time jumps from 1978 to 1997, the year when the data gap ends

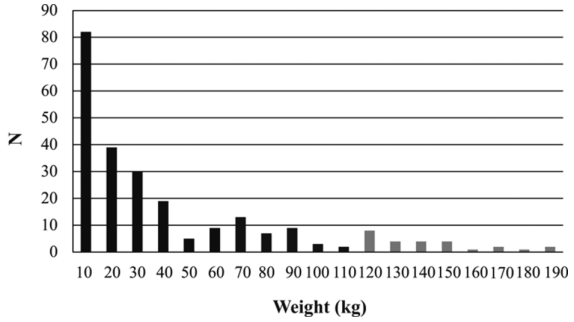

Fig. 3. Frequency distribution of the eviscerated weight of landed common thresher sharks (1997-2013) in Chioggia. Black bars represent immature specimens; gray bars represent mature specimens

An average minimum number of 14 ± 6 common thresher sharks per year (range: 5-23 specimens/year) were landed at the fish market. When analyzing monthly landing (abundance CPUE), common thresher sharks displayed a clear, significant periodicity of 12 months ($p = 2\times10^{-7}$), with higher numbers of landed specimens from July to October (Fig. 2A). A similar periodicity was found for the landing of the European sardine (biomass CPUE, $p = 9\times10^{-6}$), which was more abundant at the fish market from May to October-November. The average weight of the landed thresher sharks was significantly different among months, with smaller individuals landed in July, September and October (Kruskal Wallis: $H_{11} = 46.84$; $p < 0.0001$; N = 244; Fig. 2B). The estimated percentage of immature specimens landed at the fish market was 90.6% and more than 30% were smaller

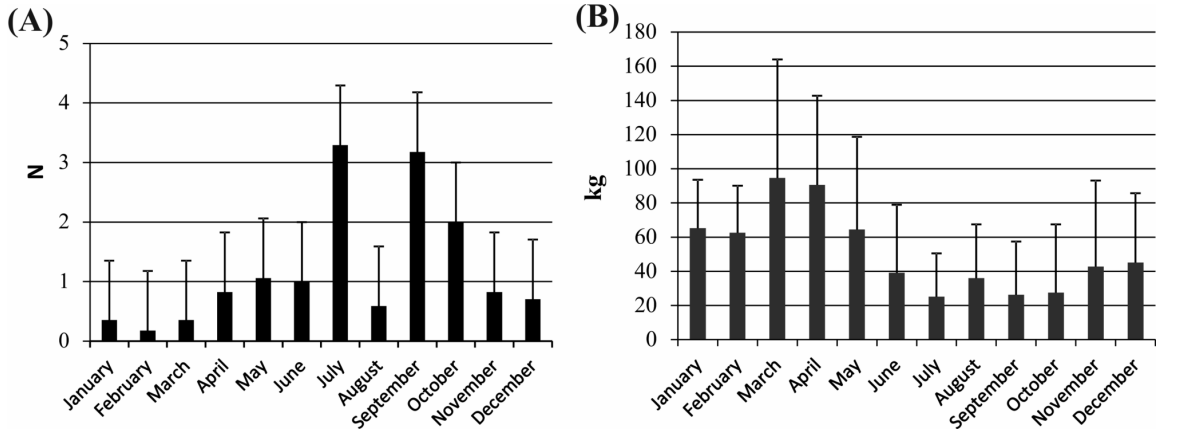

Fig. 2. Monthly landings of the common thresher shark (data from 1997-2013) at the fish market of Chioggia. A) Estimated minimum number of individuals. B) Average eviscerated weight of individuals. Bars represent standard deviations

than 10 kg (Fig. 3). This finding is conservative, because the individual weight of the landed sharks is possibly overestimated, having been computed by assuming that the weight recorded in each sale is referred to only one specimen, and the threshold eviscerated weight at maturity is potentially underestimated, having being calculated by subtracting a maximum reported weight for the reproductive apparatus from total body weight.

DISCUSSION

This study sheds light on three main aspects of the biology and fishery of the common thresher shark in the northern Adriatic Sea: 1) despite the extensive sampling effort performed by the commercial fishery of Chioggia, only a few specimens were caught in the basin, reflecting the drastic decline in abundance (-80.82%) documented by FERRETTI *et al.* (2008) based on the recreational fishery; 2) despite the low number of records, the occurrence of this species in the northern Adriatic Sea is clearly, positively correlated with the abundance of one of its prey species, the European sardine, both on long-term and seasonal scales; and 3) the fishery catches primarily small, immature shark specimens.

The common thresher shark is often found in association with schools of small fish on which it feeds close to the water surface (PRETI *et al.*, 2001). In the study area, common thresher sharks are caught principally as by-catch of mid-water trawling (BARAUSSE *et al.*, 2014) that targets small pelagic fish, mainly anchovy and sardine, the two most abundant species in the basin (BARAUSSE *et al.*, 2011). The annual landings of *A. vulpinus* are correlated with only one of these two species, a result that seems to exclude that the strong relationship between the common thresher shark and the sardine is simply due to changes in the fishing effort targeting both species simultaneously. In this case, we would have expected to find an additional correlation with anchovy. Thus, the detected correlation suggests that food availability is a strong driver of the occurrence of *A. vulpinus* in the Northern Adriatic Sea. Indeed, the diet of the common thresher shark is represented mainly by small pelagic teleosts (anchovy and sardine) in eastern Pacific and Australian waters (PRETI *et al.*, 2001, 2004, 2012; ROGERS *et al.*, 2012), with a predominance of anchovy in both areas. Although the diet of *A. vulpinus* has never been evaluated in the northern Adriatic Sea, the relationship with only one of the two main Clupeiformes in the basin suggests a feeding preference for sardine with respect to anchovy. Anchovy has, indeed, about 66% the energetic value per unit weight of sardine (ARCOS & ORO, 2002). This coupled with the fact that the majority of thresher shark catch is composed by juvenile specimens, which have a high demand for energy during their growth, could clarify the dietary preference towards sardine that our analysis suggests. An alternative explanation for the suggested dietary preference by *A. vulpinus* is that sardine is larger than anchovy in the Adriatic Sea (MORELLO & ARNERI, 2009) and therefore it could be more easily spotted and/or captured by large predators. We believe that the positive relationship between common thresher shark and sardine likely reflects movements of *A. vulpinus* in and out from the northern Adriatic Sea following its prey, rather than variations in shark stock biomass due to food availability, which would take years to take place given the slow growth characterizing large shark species. Of course, our analysis does not exclude that other small pelagic fish species in addition to sardine are important preys of the thresher shark (e.g. anchovy, sprat, horse mackerel, mackerel, etc.): further studies on dietary preferences, e.g. based on stomach content analysis, could clarify this issue.

Fishery data have well-known limitations when they are used to assess the status of fish stocks, and this holds true for the northern Adriatic Sea: landing data are not collected in a standardized manner, often report elasmobranchs aggregated into multispecies categories and suffer from an unreported quota of landings. However, such data can still provide an informative picture of the abundance and distribution of elasmobranch populations, given that commercial fisheries trawl large areas on a frequent basis, thus leading to a high "sampling effort"

both in space and time (BARAUSSE *et al*., 2014). For this reason, landings are often used to estimate trends in population abundance (MORGAN & BURGESS, 2005). *A. vulpinus* represents bycatch of the Chioggia fleet and all the sharks caught are landed due to their large size; therefore the low number of individuals landed (only 13 out of the 10765 specimens of shark species sampled in scientific surveys performed at the fish market of Chioggia during 2006 – 2012 were thresher sharks, BARAUSSE *et al.*, 2014) supports the idea that the abundance of this species is low in the study area (FERRETTI *et al.*, 2008).

Most of the landed specimens were sexually immature, with several of them exhibiting low weight (less than 10 kg), indicating the occurrence of individuals with size close to the size at birth (MORENO *et al.*, 1989). These findings support the hypothesis that the shallow productive waters of the northern Adriatic Sea should be considered as a nursery area (SOLDO, 2006). The use of highly productive coastal or continental shelf areas as nurseries by the thresher shark has been highlighted also in the eastern Pacific (CARTAMIL *et al.*, 2010) and eastern Atlantic, where temporal match between the seasonality of *A. vulpinus*, particularly smaller individuals, and small pelagic fish in coastal areas has also been highlighted (MORENO *et al.*, 1989).

This study highlights some relevant issues for the conservation of *A. vulpinus*, which deserves consideration because its occurrence has declined greatly in the Mediterranean Sea (FERRETTI *et al.*, 2008). Data from the recreational fishery in the northern Adriatic Sea also indicate a marked decline of *A. vulpinus* from 1995–2006 (FERRETTI *et al.*, 2008). Although fishery data from the fish market of Chioggia do not show a decreasing trend from 1997 to the present (BARAUSSE *et al.*, 2014), it is possible that a decline in population abundance took place in the previous decades, similarly to what happened to other large fish in the northern Adriatic (FORTIBUONI *et al.*, 2010; BARAUSSE *et al*., 2011, 2014). Reported catch of immature and even newborn specimens raises concerns about the sustainability of this fishery. The identification of nursery areas is fundamental to plan conservation actions (KINNEY & SIMPFENDORFER, 2009; CARTAMIL *et al.*, 2010), and the likely occurrence of a nursery area in one of the most exploited areas of the entire Mediterranean Sea (CADDY *et al.*, 1995; BARAUSSE *et al.*, 2009) highlights the urgent need to establish management strategies and measures for the common thresher shark. This species is caught as by-catch, therefore a management strategy based on the release of immature and particularly newborn specimens should be developed. Currently, no data on the post-release survival of small common thresher sharks caught with mid-water trawls are available. Data from the longline fishery in the Mediterranean Sea indicate high survival rates for *A. vulpinus* (MEGALOFONOU *et al.*, 2005), however, species performing obligate ram-ventilation, such as the common thresher shark, generally show mortality rates higher than stationary-respiring sharks (DAPP *et al.*, 2015). Therefore, to promote a management strategy for *A. vulpinus*, its survival rate after trawl capture needs to be evaluated. Alternatively, by-catch reduction devices, specifically developed for such large sized animals, could be tested on mid-water trawlers.

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U potrazi za plijenom: pojava psine lisice, *Alopias vulpinus* (Bonnaterre, 1788) u sjevernom Jadranu i njegove interakcije s ribarstvom

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SAŽETAK

Zabilježen je značajan pad zastupljenosti psa lisice, *Alopias vulpinus*, u Sredozemnom moru. Analizom dugoročnog vremenskog niza podataka u ribarstvu (1966-2013), ovo istraživanje pokazuje da je važan pokretač prisutnosti *A. vulpinus*, u sjevernom Jadranu kao jednom od najiskorištenijih bazena na Sredozemlju, obilje njegova plijena srdele, *Sardina pilchardus*. U razdoblju 1997.-2013. godišnji prosjek ulova psine lisice je iznosio 14 primjeraka donesenih na glavnu ribarnicu u mjestu Chioggia (Italija) i to poglavito od srpnja do listopada. Više od 75% primjeraka ulovljenog psa lisice bili su spolno nezreli, od kojih su neki primjerci imali manje od 10 kg, što ukazuje da je visok udio ulova bio sastavljen od malih nedoraslih jedniki i mlađi. Ovi rezultati podupiru pojavu rastilišta u sjevernom Jadranu, ujedno naglašavajući potrebu pravilnog upravljanja ulovom *A. vulpinus* u ovom području.

Ključne riječi: psina lisica, ribarstvo, upravljanje, interakcije hranidbenog lanca, srdela