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

Licia FINOTTO\(^1\), Alberto BARAUSSE\(^2\) and Carlotta MAZZOLDI\(^1\)*

\(^1\)Department of Biology, University of Padova, Via U. Bassi 58/B, 35131 Padova, Italy

\(^2\)Environmental Systems Analysis Laboratory (LASA), Department of Industrial Engineering, University of Padova, Via Marzolo 9, 35153 Padova, Italy

*Corresponding author, e-mail: carlotta.mazzoldi@unipd.it

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 km². 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 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 ($r_s=0.52; p=0.034; N=$
Finotto et al.: In search of prey: the occurrence of Alopias vulpinus (Bonnaterre, 1788) in the northern Adriatic.

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; Cloidia 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 (Verhoven 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 Barausse & 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 $r_S = +0.54$; $p_{adj} > 0.12$ 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).

An average minimum number of $14 \pm 6$ 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 ($p = 2 \times 10^{-7}$), 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, $p = 9 \times 10^{-6}$), 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
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.

**ACKNOWLEDGEMENTS**

We wish to thank Gabriele BALDIN of the fish market of Chioggia for his help and willingness during data collection, Fulvio GARIBALDI and two reviewers for their comments and suggestions to the manuscript. The study was supported by the CLODIA project, funded by the Veneto Region (Italy) Law 15/2007 (DGR n. 4069), and the Athenaeum Project (CPDA110183), funded by the University of Padova and special thanks to Carlotta MAZZOLDI.
REFERENCES


COLL, M., C. PIRODDI, J. STEENBEEK, K. KASCHNER, F. BEN RAIS LASRAM, J. AGUZZI, E. BAL-


FERRETTI, F., B. WORM, G.L. BRITTEN, M.R. HEITHAUS & H.K. LOTZE. 2010. Patterns and ecosys-


PRETI, A., S.E. SMITH & D.A. RAMON. 2001. Feeding habits of the common thresher shark Alopias vulpinus) sampled from the California-based...
RONDININI, C., A. BATTISTONI, V. PERONACE & C. TEOFILI. 2013. Lista Rossa IUCN dei Vertebrati Italiani. Comitato Italiano IUCN e Ministero dell’Ambiente e della Tutela del territorio e del Mare, 56 pp.

Received: 1 October 2015
Accepted: 31 May 2016
U potrazi za plijenom: pojava psine lisice, *Alopias vulpinus* (Bonnaterre, 1788) u sjevernom Jadranu i njegove interakcije s ribarstvom

Licia FINOTTO, Alberto BARAUSSE i Carlotta MAZZOLDI*

*Kontakt adresa, e-mail: carlotta.mazzoldi@unipd.it

**SAŽETAK**


**Ključne riječi:** psina lisica, ribarstvo, upravljanje, interakcije hranidbenog lanca, srđela