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***Raja asterias* population assessment in FAO GFCM GSA17 area  
Abundance, distribution and demographic composition of the Mediterranean starry ray,  
*Raja asterias* (Chondrichthyes: Rajidae), in the Northern and Central Adriatic Sea**

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## Abstract

Population structure and distribution of the starry ray, *Raja asterias*, were described based on data collected during yearly rapido trawl surveys (SoleMon), between 2005 and 2014 in the Northern and Central Adriatic Sea. A total of 306 individuals was caught, sex ratio was 1.04:1 in favor of males and length-weight relationships were obtained for the complete sample. Following the MEDITS scale, maturity was estimated, detecting a higher number of immature individuals. Relative abundance significantly increased during the last five years with the highest values recorded at 5-30 m depths. Such increase could be related to the response of *R. asterias* to climatic change or to the decrease in fishing pressure in the area. Clear spatial segregation of individuals depending upon their life stage was observed, with immature individuals inhabiting the coastal areas and adults being more abundant at depths greater than 40 m. Comparison of the results of the present study with MEDITS survey outcomes in terms of distribution patterns, persistence areas of adults and juveniles, and abundances indices, indicates that the SoleMon survey seems to be more suitable in defining such features of the stock, likely due to the greater catchability of the rapido trawl in respect to the MEDITS trawl net. However, further investigations are needed to identify factors affecting the increasing abundance of this species, and develop an action plan for spatial management of fishing activities.

**Keywords:** abundance, Adriatic Sea, distribution, persistence, *Raja asterias*, sexual maturity, shark fisheries.

## Introduction

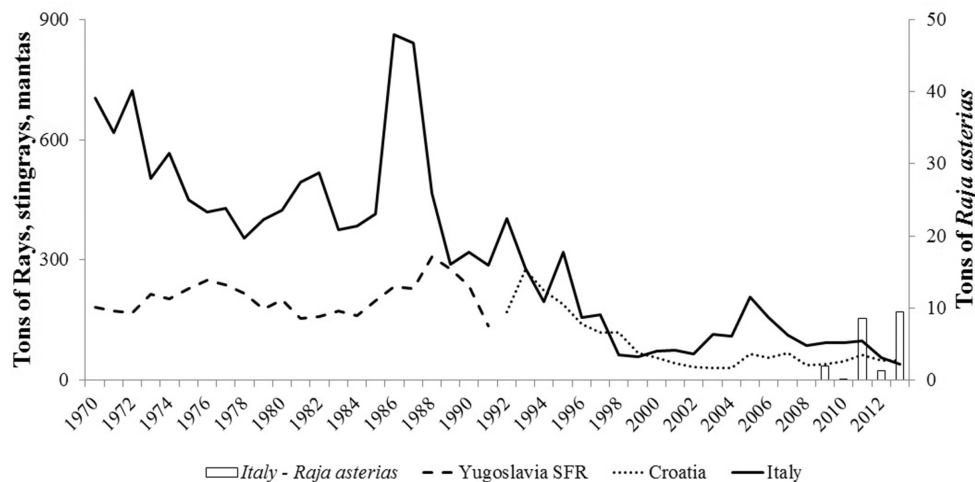
The Mediterranean starry ray, *Raja asterias* Delaroche, 1809 (Chondrichthyes: Rajidae), is an endemic medium-sized skate inhabiting the Mediterranean Sea and nearby areas of the western Atlantic (Fischer *et al.*, 1973; Serena, 2005; Serena *et al.*, 2010). This species is widely distributed in the central Mediterranean, less in the eastern part and probably absent in the Black Sea (Serena, 2006; Barone *et al.*, 2007; Serena *et al.*, 2010), while some observations have been made in the Moroccan coasts (Barone *et al.*, 2007; Tai *et al.*, 2010). This ray inhabits demersal inshore waters on muddy or sandy bottoms and, although it may occur from 2 to 200 m, is mostly present at depths between 20 and 50 m (in Catalan Sea, NW Mediterranean Sea, Navarro *et al.*, 2013). Because of its spatial distribution, adults are commonly caught by bottom trawlers (Barone *et al.*, 2007; Fortuna *et al.*, 2010) and juveniles are often caught by trammel nets (Serena, 2005).

*Raja asterias* is an oviparous species that mates in spring and fall at depths of approximately 25 m (Serena *et al.*, 2010). According to Romanelli *et al.* (2007), the estimated average spawn production in the Tyrrhenian Sea is approximately 40-60 egg capsules twice a year and takes place mainly in summer and fall (Serena *et al.*, 2010). Similar outcomes regarding the spawning period for the

Tunisian coasts were observed by Capapé (1977). Embryonic development lasts 5-6 months and therefore hatching happens from March to July. In winter, when juveniles are nearly 80-90 cm of Total length (TL), recruitment to set gears occurs by trammel net in shallower waters between 2 to 15 m (Serena, 2005; Barone *et al.*, 2007).

The analysis of available long-term data series in different areas of the Mediterranean Sea has revealed a reduction in species numbers and abundance of elasmobranchs, most from the continental shelf, which seems to be primarily related to trawl fisheries (Jukić-Peladić *et al.*, 2001; Massutí & Moranta, 2003; Dell'Apa *et al.*, 2012). In particular, specific studies on the ecology and exploitation status of ray populations in the Mediterranean Sea have been developed, stemming from a long-standing scientific concern for skate stocks (Abella *et al.*, 2008; STECF, 2012; Coll *et al.*, 2013). Likewise, in the Adriatic Sea, a declining trend in landing of rays and skates has been observed (Fig. 1) according to the FAO-FISHSTAT database, especially since the beginning of the nineties. Landings of *R. asterias*, reported solely for Italy, show a fluctuation over the years without demonstrating a clear trend.

According to Ferretti *et al.* (2005), species that are spatially constrained to depths have a higher probability of being exploited, similar to those having biological characteristics common to most of chondrichthyans, such as slow



**Fig. 1:** Landings data of rays and skates in the Adriatic Sea by the Yugoslavian, Croatian and Italian fleets (first y-axis) and *R. asterias* landings in Italy (second y-axis).

growth, low fecundity, large body sizes, and late maturation. The Mediterranean starry ray exhibits similar features (Krstulović-Šifner *et al.*, 2009; Coll *et al.*, 2013) and, although some studies on biological aspects have been carried out in different areas of the Mediterranean Sea (Barone *et al.*, 2007; Coll *et al.*, 2013; Navarro *et al.*, 2013), in the Adriatic Sea the only information available is provided by Ungaro *et al.* (2005) and then only for the southern part of the basin.

In the present study, our aim is to explore the spatial patterns of the Mediterranean starry ray juveniles and adults in the Northern and Central Adriatic Sea. The specific objectives are: 1) to study the trends in abundance of *R. asterias* (all specimens, juveniles, and adults) sampled during experimental trawl surveys carried out in the Northern and Central Adriatic Sea; 2) to establish the spatial distribution of juveniles and adults in the stock and explore the trends in their spatial distributions; and 3) to provide information on the biology of the species.

The importance of this study lies in the origin of our data as they originate from a fishery-independent source (SoleMon survey; Grati *et al.*, 2013) that provides an historical data series of ten years. The SoleMon survey is designed to sample flatfish and benthic resources and has been carried out in a 36.742 km<sup>2</sup> area of the Northern and Central Adriatic Sea up to 100 m depth, from the Italian coast to 12 and 6 nautical miles from the Croatian and Slovenian coasts respectively. Due to the high efficiency of the fishing gear in catching flatfish, the wide area sampled, and the duration of the survey, the data set collected can be considered as optimal for this study.

## Material and Methods

As reported above, data were collected during trawl surveys (SoleMon) carried out in the Northern and Central Adriatic Sea, corresponding to the FAO GFCM Geographical Sub-Area 17, conducted in fall from 2005 to

2014 by the Italian National Research Council (CNR-ISMAR, Italy) in cooperation with the National Institute for Environmental Protection and Research (ISPRA, Italy), the Institute of Oceanography and Fisheries (IOF, Croatia), and the Fisheries Research Institute of Slovenia (FRIS, Slovenia) (Fig. 2).

The gear used is called rapido which is a modified beam-trawl with a rigid mouth and iron teeth along the lower part with an attached net similar to a trawl net (Grati *et al.*, 2013). This gear is commonly used by professional fishermen in the Northern and Central Adriatic Sea for catching flatfishes (*Solea solea* Linnaeus, 1758 and *Scophthalmus maximus* Linnaeus, 1758) and other commercial benthic species as the common cuttlefish (*Sepia officinalis* Linnaeus, 1758) or the caramote prawn (*Penaeus kerathurus* Forskål, 1775).

Rapido trawls used during the SoleMon survey had a width of 3.69 m, weight of nearly 200 kg, and a cod end stretched mesh size of 40 mm (gear described in Hall-Spencer *et al.*, 1999). The sampling methodology as well as the spatial distribution of the stations from 2005 to 2011 is available in Grati *et al.* (2013). For the years 2012, 2013, and 2014 the same sampling design utilized in 2011 was employed; number of hauls per year and depth strata are reported in Table 1.

All rays in catches were identified, sexed, weighed (wet weight in grams) and measured (total length in centimeters). Maturity was estimated following the MEDITS scale for skates defined by Relini *et al.* (2008). In the present study, stages 1 (immature/virgin) and 2 (maturing) were grouped as immature individuals, while stage 3 (mature), and 4 (resting) were grouped as mature individuals. Relative abundance indices for immature and mature individuals, as well as the average catch rate of *R. asterias* for each year were calculated to identify a possible significant trend in the population, using a weighted least squares regression (Reddy, 2011).

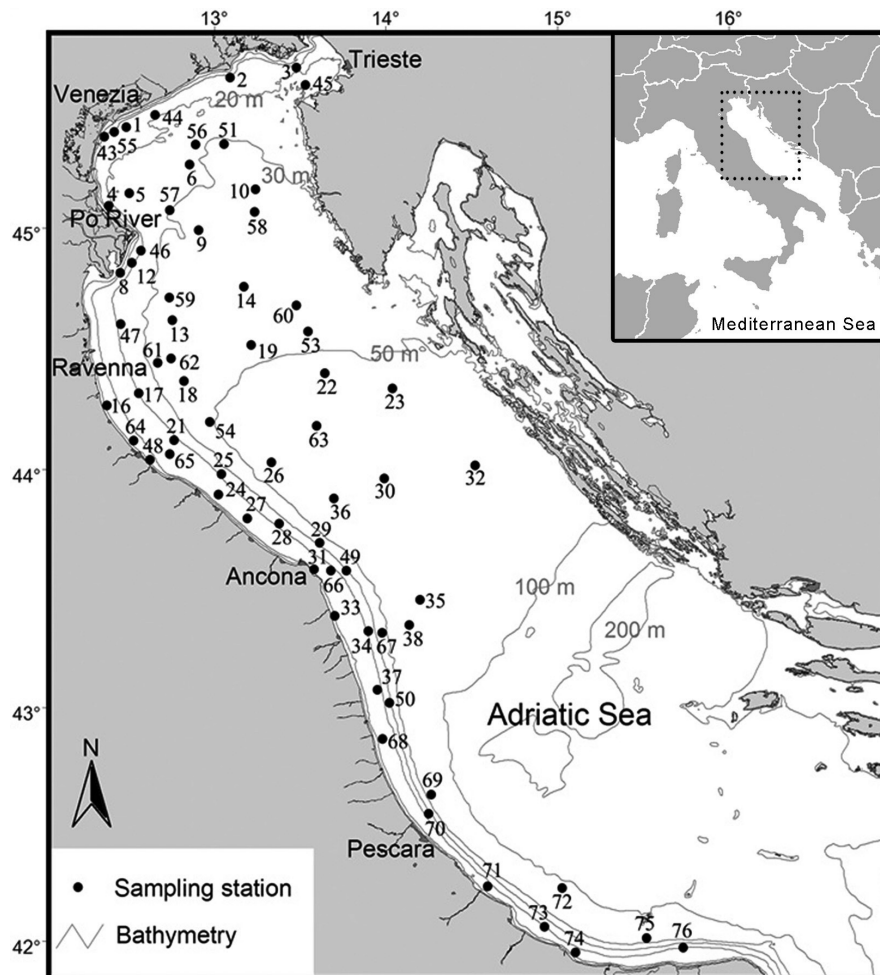


Fig. 2: Map of stations sampled during SoleMon survey from 2007 to 2014.

The exponential relationship between length and weight provided by Ricker (1980) was applied to estimate the weight-length relationship of *R. asterias*:

$$W = aTL^b$$

where *W* is the total weight (g); *TL* the total length (cm); *a* the proportionality constant; and *b* the growth rate that reflects the allometric relationship. This relationship was calculated for the whole population.

Maps of the abundance of immature and mature individuals were generated. Taking into account the large amount of zero observations in the hauls, a specific statistical model was employed to obtain persistency maps of juveniles and adults. The Zero Inflated Generalized Ad-

ditive Model (ZIGAM) assumes that the response variable, in our case the abundance of juveniles and adults of starry ray, follows a probabilistic mixture distribution of a zero atom and a continuous distribution belonging to the exponential family (Hall, 2000).

Data were modeled in two steps. Firstly the probability (*P*) of observing a density greater than 0 was modeled with a GAM where the dependent variable has a binomial distribution and the link function is the logit (logarithmic of the probability of observing a positive catch on the probability of observing a zero):

$$\text{logit}(p(v,t)) = \beta_0 + \sum_{j=1}^p s(x_j(v,t))$$

Table 1. Number of hauls per year and depth stratum in GSA 17, 2005-2014.

Depth strata (m)	Fall 2005	Fall 2006	Fall 2007	Fall 2008	Fall 2009	Fall 2010	Fall 2011	Fall 2012	Fall 2013	Fall 2014	Total
0-30	30	35	32	39	39	39	39	36	38	39	366
30-50	12	20	19	17	17	17	17	17	17	17	170
50-100	15	8	11	11	11	11	11	10	10	11	109
Total	57	63	62	67	67	67	67	63	65	67	645

Then a GAM model was estimated only on the positive hauls using a Gaussian family model, where the identity link function and  $\log(y(v,t))$  work as dependent variable.

$$E(\log(y(v,t))) = \beta_0 + \sum_{j=1}^p s(x_j(v,t))$$

Log-transformed data were assumed to be independent and thus the outcomes of both models were crossed in order to obtain abundance predictions using as covariates:

1. Year (as factor);
2. Latitude and longitude;
3. Grain size (fi) (obtained from Jenkins (2008)).

The spatial autocorrelation in the residuals has been checked. However, in the ZIGAM analyses presented here there was no need of kriging approaches to interpolate residual variation to be incorporated into the model as random effects. As a subsequent step, the annual abundance density hotspots were identified for adults and juveniles of *R. asterias*. The Getis' G statistic (Getis & Ord 1992),

with a radius of 2.5 km and a 0.95 level of significance, was selected among the local methods for spatial hotspot identification. This approach allowed to test if high density clusters of group of species are significantly different.

Finally, the Index of Persistence ( $I_i$ ) measuring the relative persistence of the cell  $i$  as an annual hotspot (Fiorentino *et al.*, 2003; Colloca *et al.*, 2009) was calculated in each 1 km<sup>2</sup> cell considering  $\delta_{ij} = 1$  if the grid cell  $i$  was included as hotspot of juveniles and adults of *R. asteria* in the annual survey  $j$ , and  $\delta_{ij} = 0$  otherwise:

$$I_i = \frac{1}{n} \sum_{j=1}^n d_{ij}$$

where  $n$  is the number of annual surveys considered. The index  $I_i$  ranges between 0 (cell  $i$  never included in an annual hotspot) and 1 (cell  $i$  always included in an annual hotspot) for each cell in the study area. Results were plotted in the persistence maps reporting the classes 0.1-20%, 20.1-40%, 40.1-60%, 60.1-80%, and 80.1-100%.

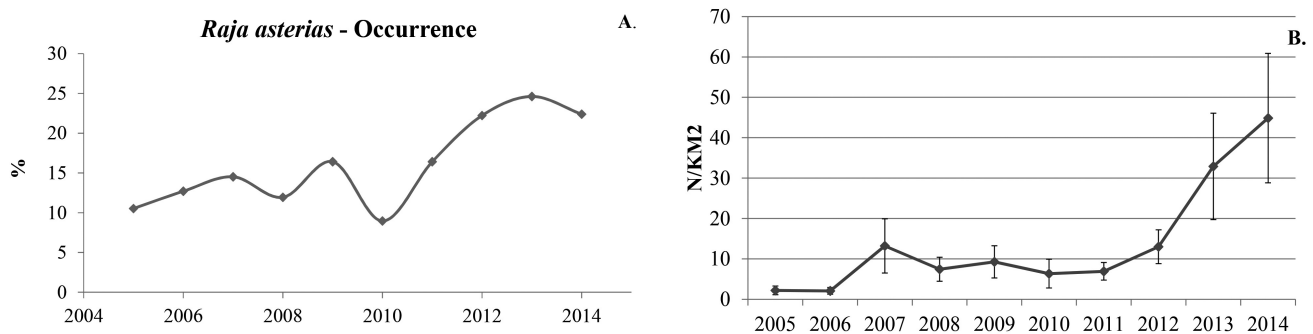


Fig. 3: Frequency of occurrence (A) and abundance (B) of *R. asterias* recorded during SoleMon survey from 2005 to 2014.

Table 2. Frequency of occurrence of *Raja asterias* in SoleMon survey (2005-2014).

Year	Total hauls	Positive hauls	Frequency of occurrence
2005	57	6	10.5%
2006	63	8	12.7%
2007	62	9	14.5%
2008	67	8	11.9%
2009	67	11	16.4%
2010	67	6	9.0%
2011	67	11	16.4%
2012	63	14	22.2%
2013	65	16	24.6%
2014	67	15	22.4%

Table 3. ANOVA results of the weighted regression analysis of the captures N/km<sup>2</sup> per year.

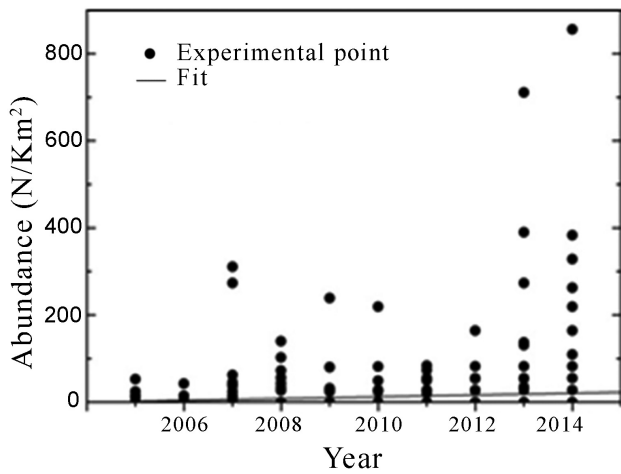
	DF	SS	MS	F-Statistic	P-Value
X	1	1044.28	1044.28	20.5543	6.9139*10 <sup>-6</sup>
Error	643	32668.3	50.8061		
Total	644	33712.6			

Analysis were developed with R software that provided a shape file for each year, which were subsequently treated with the geostatistical software Manifold for the return of results over a spatially georeferenced map.

## Results

Frequency of occurrence in catches was always low with a mean value  $16.1 \pm 1.71\%$  (s.e.); however, annual values varied considerably from this mean and the tendency appeared to increase in the last years (Table 2) (Fig. 3A). In 2013 *R. asterias* was present in 24.6% of hauls, being the maximum recorded during the overall survey period, while the minimum of 9% was recorded in 2010.

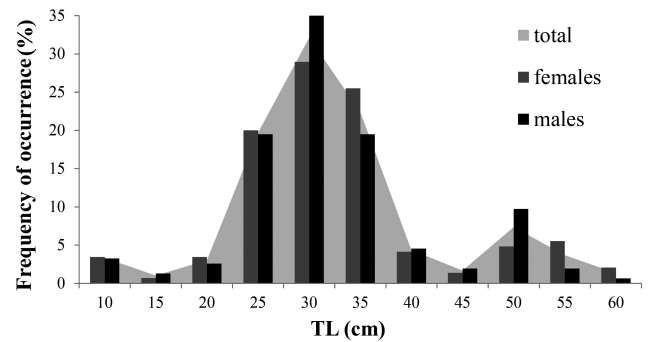
Starry ray relative abundance showed an increasing trend during the latter years (Fig. 3B) with a minimum in 2006 (2.10 N/km<sup>2</sup>) and a maximum in 2014 (44.86 N/km<sup>2</sup>). ANOVA results (Table 3) indicate that the regression model was statistically significant, with a positive slope (Fig. 4).



**Fig. 4:** Relative abundance indices and linear regressions during the years of *R. asterias* sampled during SoleMon survey (2005-2014).

During the ten-year survey period, a total of 306 starry rays was caught, 156 males and 150 females, corresponding to a sex ratio of 1.04:1 in favor of males (Table 4). A high number of immature individuals was observed, accounting for a total 87% of males and 89% of females (Tables 4 & 5). No resting individuals were found for both sexes.

The parameters of length-weight relationships for the entire sample as well as the minimum and maximum



**Fig. 5:** Length frequency distribution of *R. asterias* recorded in Northern and Central Adriatic Sea during SoleMon (2005-2014).

the depth stratum 5-30 m. Immature individuals were mainly found within the top 30 m depth (90.87%) (Fig. 6A), while mature individuals were only found at depths deeper than 45 m (Fig. 6B).

The maps illustrated in Figure 7 show that *R. asterias* young are concentrated near the coast (Fig. 7A) and the mature individuals are located further offshore (Fig. 7B).

Persistency of *R. asterias* showed a consistent spatial distribution across the survey years which corresponds almost entirely to the area of hotspots that is characterized by a persistency ranging between 80.1 and 100% (Fig. 8). Rays are aggregated in three areas: two along

**Table 4.** Number of *R. asterias* in catches subdivided by sex and life stage in the ten-year survey.

Year	Total	Mature		Immature			
		Males	Females	Total	Males	Females	Total
2005	7	2	2	4	1	2	3
2006	10	1	1	2	3	5	8
2007	24	2	1	3	9	12	21
2008	18	3	1	4	7	7	14
2009	19	1	1	2	10	7	17
2010	16	2	1	3	5	8	13
2011	18	2	2	4	7	7	14
2012	28	2	2	4	11	13	24
2013	78	3	2	5	47	26	73
2014	88	2	3	5	36	47	83
Total	306	20	16	36	136	134	270

values for length and weight for males, females and the entire sample are shown in Table 6.

Females ranged from 8.5 cm TL (3 g) to 55.9 cm TL (1298 g), while males fell into the length range 9.0 cm (4 g) to 56 cm (1250 g).

The length-frequency distributions of males and females were characterized by the presence of three cohorts; however, most of individuals fell in the size range between 25 and 35 cm for both sexes (Fig. 5). The smallest male and female mature individuals measured were 44.2 cm and 50.5 cm TL respectively.

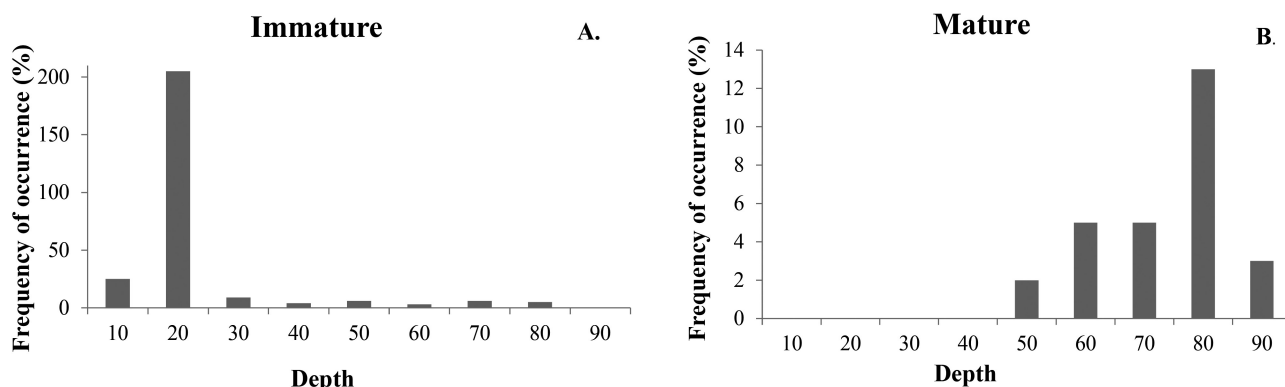
Specimens were fished at depths ranging between 8 m and 89 m, with the highest occurrence (82.13%) in

**Table 5.** Relative abundance (N/km<sup>2</sup>) of immature and mature *R. asterias* individuals in the ten-year survey.

Year	Immature individuals	Mature individuals
2005	0.98	0.55
2006	2.12	0.16
2007	3.63	1.01
2008	9.62	3.19
2009	5.29	3.04
2010	5.51	1.36
2011	7.85	5.23
2012	10.06	5.1
2013	26.37	4.8
2014	20.23	7.27

**Table 6.** Length/weight relationship parameters of *R. asterias*.

	n	Length (cm)		Weight (g)		a	b	R <sup>2</sup>
		min	max	min	max			
Males	156	9.0	56.0	4.0	1250			
Females	150	8.5	55.9	3.0	1298			
Combined sexes	306	8.5	56.0	3.0	1298	0.0032	3.1808	0.9848



**Fig. 6:** Frequency of occurrence of immature (A) and mature (B) specimens of *R. asterias* at different depths.

the Italian coast of the Adriatic Sea that are separated by a strip and another area in the Gulf of Trieste. The two inshore spots consist of immature individuals, while the offshore one hosts primarily mature individuals.

### Discussion

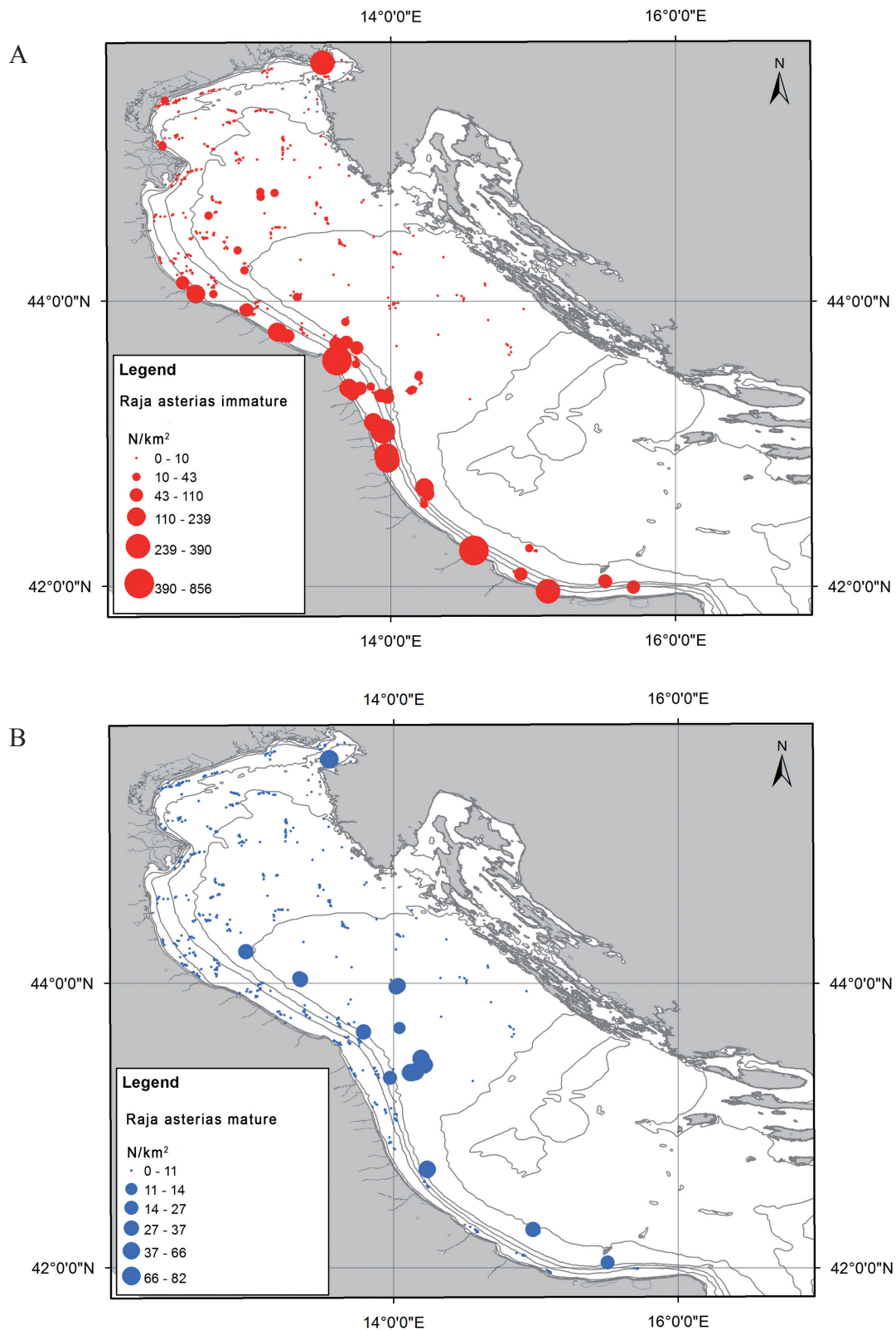
In the Mediterranean Sea relevant policies are currently in place for managing and protecting vulnerable chondrichthyans, such as the EU Action Plan on sharks (EC, 2009) and the GFCM Recommendation GFCM/36/2012/3 (FAO-GFCM, 2012) on conservation of sharks and rays. Both are mainly advising to expand knowledge on elasmobranch species and their role in the ecosystem. Thus, the paper provides new insights in the framework of such initiatives by providing new information about the spatial distribution, biology, and abundance of *R. asterias* in the Northern and Central Adriatic Sea based on fishery-independent data.

Due to the gear design and sampling strategy, it is possible to conclude that the inter-annual variability in starry ray catches will likely reflect variations in abundance (Bertrand *et al.*, 2002). Our results show well-defined persistence areas for this species which shows wider distribution patterns in respect to what observed from the MEDITS survey (Piccinetti *et al.*, 2012). The different outcomes of the two surveys in terms of spatial distribution are likely due to the greater efficiency of rapido trawl in catching flat fish such as rays, compared to the trawl net used in the MEDITS survey (Abella & Serena, 2005; Piccinetti *et al.*, 2012).

The significant increase in the relative abundance observed during the SoleMon surveys could be a response of *R. asterias* to climate change, fact that has been already demonstrated for other species in the Mediterranean Sea (Cartes *et al.*, 2009; Albouy *et al.*, 2013). Another explanation of such trend could be related to the changes in fishing pressures in certain areas that can cause a re-colonization of fishes from less heavily exploited regions (Last *et al.*, 2011). Finally, the enforcement of the Mediterranean regulation EC 1967/2006, with specific spatial management measures for bottom otter trawl (e.g., prohibition of towed gear inside the 3 nautical mile zone from the coast) and the decrease of the Italian trawlers fishing effort as reported in STECF, 2016, could be considered as possible explanations of the positive trend observed in the SoleMon survey.

Previous studies on the biology of this species showed moderately stable values of L50, varying from 50 to 52 cm TL for males and from 56 to 57 cm TL for females depending on the areas (Serena, 2005; Barone *et al.*, 2007; Romanelli *et al.*, 2007). In the present study the smallest mature male and female were 44.2 cm and 50.5 cm TL respectively, which are sizes smaller than those found in the previous studies, indicating that the length at first maturity in the Northern and Central Adriatic Sea could be smaller. However, the observed data are in general agreement with the sizes reported by Ungaro *et al.* (2005) for the southern Adriatic Sea.

The lower values of L50 (mean length at which 50% of the population become mature for the first time) observed for the Adriatic Sea could be related to unfavorable conditions, like higher fishing pressure, as detected in other areas for the same species (Coll *et al.*, 2013) and



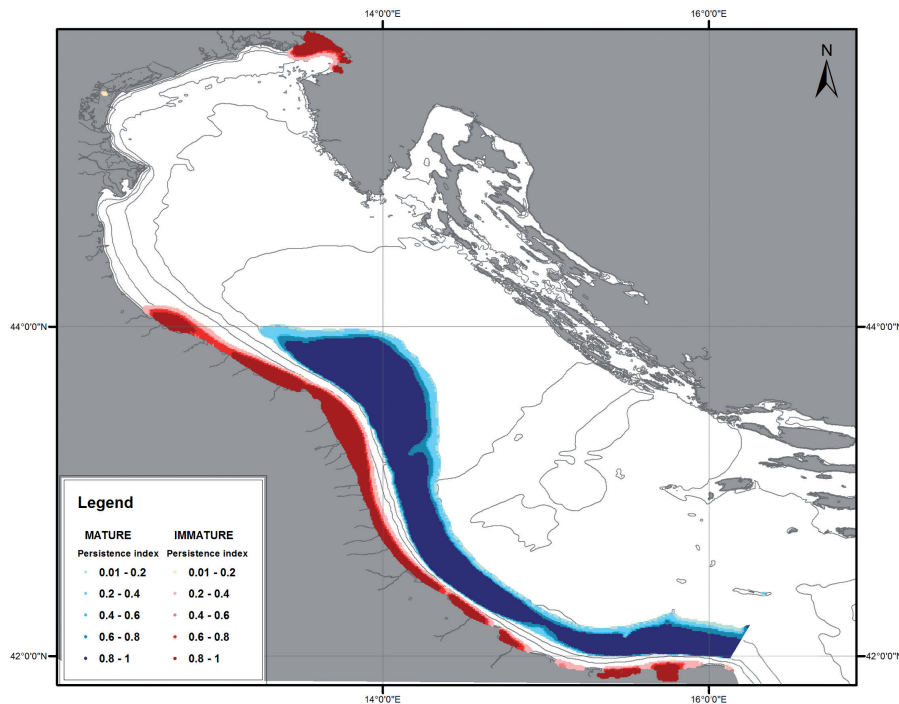
**Fig. 7:** Spatial distribution of (A) immature individuals and (B) mature individuals of *R. asterias*.

for other species in the Adriatic Sea (Krstulović-Šifner *et al.*, 2009).

According to the results presented here, there is a clear segregation of *R. asterias* depending on life stage, with immature individuals inhabiting the coastal areas up to 30 m

depth and adults at depths greater than 40 m, which has been also observed in other areas (Serena *et al.*, 2010). Immature individuals mostly concentrate along the Italian coast in shallow waters, being absent in the northern part of this coast except for the Gulf of Trieste. The spatial





**Fig. 8:** Persistency map of *R. asterias* during the period 2005–2014. Blue spots correspond with mature individuals and red spots with immature individuals.

distribution of this species could be the result of a combination of factors such as prey availability, predation risk, temperature, salinity, oxygen shortage, local hydrodynamics, substrate type, and water depth (Gibson, 1994).

The assessment of juveniles and adults areas of aggregation for *R. asterias* in the Northern and Central Adriatic Sea represents the most important result of the present study, thus forming a knowledge-base for the development of a spatial planning approach to the management of fishing activities. In fact, although abundance of the starry ray seems to increase in the basin, as similarly observed by Coll *et al.* (2013) in Spanish waters, and more generally, the status of the species change from “least concern” to “nearly threatened” in the IUCN Red list (IUCN, 2015), it is necessary to provide information on the spatial distribution of the juveniles in order to protect them in the view of a sustainable management of the resource.

The monitoring of potentially vulnerable chondrichthyan species is extremely important also in view of annual evaluations of the stock status applying *ad-hoc* analytical methodologies tuned with fishery-independent time series of abundance data.

Furthermore, taking into account the importance of *R. asterias* for the local fisheries and the limited available information on its biology, further investigations on this aspect are strongly needed; the outcomes of the study cannot be extrapolated to the eastern Adriatic due to lack of sampling in coastal Croatia area, so a similar investigation should be extended also in the eastern side of the basin, as already advised in the GFCM framework (FAO-GFCM, 2016).

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