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Ontogenetic distribution of deep elasmobranch species in Western Mediterranean, commitments to their conservation

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Abstract

The IUCN has taken an important step in protection of elasmobranchs through the development Important Shark and Ray Areas (ISRAs), which have the potential to be managed for conservation purposes. This study aimed to georeference the ontogenetic groups of several elasmobranch species (*Raja asterias, R. montagui, Etmopterus spinax, Dalatias licha, Scyliorhinus canicula, Galeus melastomus* and *G. atlanticus*) recorded in the southeast coast of Spain and propose the area as an ISRA in 2023. Biomass and abundance data were collected from the MEDITS surveys (1994–2023), and the length-weight equation was used to estimate the size of the individuals. The results showed that the proposed ISRA is a nursery area for several species, supporting the recent designation of the ISRA Murcia Pockmarks. Furthermore, this area is not only crucial for elasmobranchs but also a geologically complex zone with significant biological diversity in both pelagic and benthic communities, including sponges (Demospongiae), Pennatulaceas, gorgonians, corals (Isididae sp.) and others.

Introduction

In 2021, the Shark Specialist Group (SSG) completed the IUCN Red List of Threatened Species assessment for all sharks, rays, and chimaeras, revealing that 37% of species are now threatened with extinction driven by overfishing (IUCN SSC Shark Specialist Group's Annual Report 2021). Threat levels are highest in coastal habitats, where 75% of threatened species are found (IUCN SSC Shark Specialist Group n.d.). This makes sharks one of the most threatened taxonomic groups in the marine environment (IPBES 2019).

Large elasmobranchs are especially vulnerable to increased mortality rates due to their slow growth, late maturity, and low reproductive rates (Myers and Worm 2005). Given their biological characteristics, most shark and ray populations can only withstand modest levels of fishing without becoming depleted or collapsing (Camhi 1998; Musick 1999a). There are well-documented cases of shark fishery collapses, such as the porbeagle (*Lamna nasus*) in the North Atlantic and Mediterranean (Campana et al. 2015; Ferretti et al. 2008), and the tope (*Galeorhinus galeus*) in California, Australia, and the Mediterranean (Ripley 1946; Olsen 1959; McCully 2016), among others. Therefore, understanding life history traits and defining the growth parameters of each species is considered crucial for risk assessment and marine fishery management (Musick 1999a, b; Musick et al. 2000).

Large sharks are often found at the top of food chains, playing an important role in the structure and functioning of marine ecosystems (Stevens et al. 2000). Consequently, the decline of large sharks can have significant ecological consequences (Ferretti et al. 2008). In the Mediterranean Sea, at least 20 species can be considered top predators in coastal and pelagic ecosystems (Serena 2005).

In response to these issues, the IUCN Species Survival Commission (SSC) Shark Specialist Group, with support from the IUCN Ocean Team and the IUCN Marine Mammal Protected Areas Task Force, developed the Important Shark and Ray Areas (henceforth ISRA) initiative. These areas are defined as specific zones important for one or more species of sharks, rays, or chimaeras, with high conservation

management potential (Hyde et al. 2022). They are based on a set of standardized criteria that reflect ecological, biological, and conservation significance. Key considerations include the presence of critical life-history stages (e.g., breeding, nursery, feeding, or aggregation sites), areas of high species richness or endemism, habitats essential for threatened or declining species, regions supporting ecological connectivity across populations, and sites of exceptional functional or evolutionary importance. These criteria ensure that ISRAs represent spatially explicit areas where conservation efforts can most effectively contribute to the persistence of sharks, rays, and their ecosystems (IUCN Species Survival Commission Shark Specialist Group 2024).

This study, building on the results of the 2019 CAMONMAR3 project funded by the Biodiversity Foundation, which assessed the occurrence of shark and ray species in the region, aimed to demonstrate that, beyond its elasmobranch diversity, the area also functions as a reproductive habitat. Based on these findings, an ISRA proposal was developed in 2023 for the deep-sea waters of southeastern Spain, between Alicante and Murcia, which was subsequently approved.

Material and methods

Study area

The ISRA Murcia Pockmarks is located in a transition zone between the Alborán Sea and the Algerian-Balearic basin off the coast of southeastern Iberian Peninsula in Spain (western Mediterranean Sea) (Fig. 1). Oceanographically, the area represents a connectivity zone between the Alborán and Balearic Seas, where Atlantic and Mediterranean waters converge, forming an anticyclonic eddy through the Cabo de Palos-Cabo Ténés oceanographic front (Ojeda et al. 2022). The ISRA covers an area of 682.6 km^2 that includes the seamount of Seco de Palos – located between 300 and 800 m deep –, the knolls Planazo and Plis-Plas, and a muddy field of pockmarks created by the expulsion of gas and water (Arroyo et al. 2020, 2021; IUCN SSC Shark Specialist Group 2023).

Data

The data come from the MEDITS surveys (MEDIterranean Trawl Surveys; Bertrand et al. 2002) conducted from 1994 to 2022. Based on abundance data (number of individuals) and biomass captured (kg), the size of the individuals was estimated from the total weight of different species present in the ISRA and in adjacent areas. For hauls where more than one individual was caught, the total biomass was divided by the abundance to obtain the average weight per individual. Then, the length–weight relationship was applied using the following equation (Froese et al. 2014):

$W = aL^b$ where *W* is the fish's weight (g), *L* is the fish's total length (cm), *a* is the form factor or proportionality constant, and *b* is the allometric growth exponent indicating the relationship between weight and length. The parameters *a* and *b* for each species were obtained from the FishBase database.

Several maps were created using QGIS software (QGIS Development Team 2016) for each species present in the ISRA. On one hand, a heat map was generated by weighting the abundance captured of each species. Given that the swept area for each haul was unknown, a ratio of 2.8 km was applied to shallower hauls (< 200 m, 30 min), whereas for deeper hauls (> 200 m, 60 min) the ratio was doubled. On the other hand, another map was created based on the life cycle stages (neonate, juvenile or inmature, and adult or mature) of each species according to the calculated sizes. Bathymetric data were obtained from EMODnet (European Marine Observation and Data Network). Shapefiles for the Spanish Network of Marine Protected Areas (RAMPE) and the delimited ISRA were retrieved from the Ministry for the Ecological Transition and the Demographic Challenge, and from the ISRA e-atlas (IUCN SSC Shark Specialist Group 2022).

Results

At least 10 species of elasmobranchs (sharks, rays, and torpedoes) are known to be present in the deep Murcia Pockmarks ISRA (Arroyo et al. 2020, 2021). These species are: *Scyliorhinus canicula*, *Galeus melastomus*, *G. atlanticus*, *Etmopterus spinax*, *Dalatias licha*, *Raja asterias*, *R. montagui*, *Heptranchias perlo*, *Hexanchus griseus*, and *Tetronarce nobiliana*. However, no size or weight data were available for the last three species.

Scyliorhinus canicula

The small-spotted catshark is the most common shark species found in the area, with a distribution encompassing the entire continental shelf and slope from depths of 41 to 543 m. It was captured every year except for 2020. Between 1994 and 2022, a total of 12446 specimens were captured, of which 15.3% were caught within the ISRA. Regarding biomass, a total of 1683.4 kg was recorded, with 20.1% of this biomass captured inside the ISRA. Figure 2 shows a hotspot of abundance near the boundary of the ISRA, where 32.1% of the abundance and 14.8% of the total biomass were caught.

Only one neonate specimen of *S. canicula* with a length under 10 cm (Marano et al. 2000; Serena 2005; Ebert and Stehmann 2013) was captured within the ISRA (Fig. 3). According to Soares and de Carvalho (2019), in the Mediterranean, males reach maturity between 37 and 40 cm, while the maturity range for females extends up to 47 cm. Using the length of 37 cm as the threshold between immature and mature specimens, 47.9% of the individuals captured within the ISRA would fall below this size, whereas 52% would exceed it. Regarding the total number of specimens captured, 12% of the immature and 20.3% of the mature individuals were caught within the ISRA.

The smallest and largest specimens inside the ISRA measured 9.51 and 49.67 cm, respectively, and were captured at similar depths (399 and 414 m). In adjacent areas, the smallest measured 19.29 and the largest 50.89 cm, caught at depths of 254 and 91.5 m, respectively. However, the average size inside the ISRA is slightly higher, at 39.96 cm (Fig. 4).

Galeus melastomus

G. melastomus is the second most abundant shark species in the area (Arroyo et al. 2020). Its distribution is primarily concentrated within the ISRA and adjacent areas, with a secondary hotspot of high abundance off Águilas (Fig. 2). This shark was captured every year except in 1997 and 2020, with a total of 4622 specimens and a biomass of 232 kg. Of the total specimens captured, 83.1% were recorded within the ISRA, while of the remaining 16.9% caught outside the ISRA, 11% were located in areas close to its boundary and 5.9% off Águilas. Regarding biomass, 86% was captured within the ISRA. However, although there is a higher abundance of *G. melastomus* near the ISRA boundary compared to the Águilas area, only 5.4% of the total biomass was caught in this zone, while 8.6% was caught off Águilas.

According to Costa et al. (2005), the size of neonates ranges between 9 and 12 cm; therefore, no neonate *G. melastomus* were captured, as the smallest recorded specimen measured 16.26 cm (Figs. 4 and 5). Males reach sexual maturity between 34 and 45 cm, while females do so between 38 and 51 cm (Tursi et al. 1993; Ungaro et al. 1994; Rey et al. 2002). Assuming all specimens were male, 94.4% could be immature and the remaining 5.6% mature. Conversely, if they were female, the proportion of mature specimens could decrease to 3.5% due to their later maturation. Of the total immature specimens, 83.3% were captured within the ISRA, as were 80.5% of the mature specimens.

As a deep-water shark, it was recorded at depths ranging from 254 to 543 m. Within the ISRA, the smallest specimen measured 16.66 cm (521 m), the largest 43.17 cm (393 m), and the average size was 25.92 cm (Fig. 4). In contrast, in adjacent areas outside the ISRA boundaries, the minimum captured size was 16.26 cm (372 m), the maximum 21.93 cm (509 m), and the average 18.40 cm.

Galeus atlanticus

Throughout the entire study period, only one specimen of *G. atlanticus* was captured (Arroyo et al. 2020, 2021). Although this species is very common in the Alboran Sea and in the vicinity of the island (Rey et al. 2006), it is rare along the eastern coast of Spain. The specimen was captured within the ISRA at a depth of nearly 400 m in 2016 (Arroyo et al. 2020). This individual weighed 0.055 kg (Arroyo et al. 2020) and had an estimated length of 26.34 cm; thus, it is considered an immature specimen (Figs. 4 and 6). Rey et al. (2006) established the minimum maturity size at 33 cm for males and 37 cm for females. In contrast, Bauchot (1987) and Compagno et al. (2005) report later maturity sizes, ranging between 38 and 42 cm for males and 39.8 to 45 cm for females, which further supports the conclusion that the captured specimen is immature.

Etmopterus spinax

Between 1994 and 2022, with the exception of the years 2008 and 2020, the velvet belly lanternshark was consistently recorded in deep water habitats between 391 and 543 m depth (Arroyo et al. 2020)

(Fig. 2). Over this period, a total of 359 individuals were captured, with a combined biomass of 15.5 kg. Within the ISRA area, 258 of the specimens were caught, totalling 7.5 kg in biomass.

Seventy percent of the neonates, whose size ranges between 8 and 14 cm (Marano et al. 2000; Ebert and Stehmann 2013), are mainly distributed within the ISRA; likewise, 72.3% of the immature individuals up to 33 cm, according to the size established in FishBase, are also found there (Fig. 7). All potentially mature individuals (4 specimens), with sizes between 33 and 36 cm according to FishBase, are located off Águilas. However, according to Capapé et al. (2001) and Cecchi et al. (2004), males reach maturity at 35 cm and females between 38 and 40 cm, which would reduce the number of mature specimens to one male.

The maximum estimated size of this shark in adjacent areas is 37.32 cm (452 m), the minimum is 10.85 cm (474 m), and the average is 22.51 cm. Considering only the specimens captured within the ISRA, the largest size is 29.44 cm (494 m), the smallest is 13.15 cm (398), and the average is 17.56 cm (Fig. 4).

Dalatias licha

The kitefin shark was captured in six different, non-consecutive years (1994, 1997, 2000, 2001, 2009, and 2013) within the ISRA, between 407 and 543 m deep (Fig. 2). A total of six specimens were recorded—one per year—with weights ranging from 0.176 kg to 0.373 kg (Arroyo et al. 2020). Their estimated sizes, which range between 31.51 and 40.08 cm (Fig. 8), fall within the neonate size range, which varies between 30 and 40 or 42 cm (Cox and Francis 1997; Finucci et al. 2018).

Raja asterias

The starry skate is an endemic species of the Mediterranean (Serena 2005). Its capture began in 2002 and continued until 2022, with the exception of the years 2004 and 2020 (Arroyo et al. 2020). In total, 141 specimens were captured, weighing a combined total of 79 kg (Fig. 2). Within the ISRA, only two specimens were recorded, with a total weight of 2.1 kg. Ninety-eight point six percent (98.6%) of the abundance and 97.3% of the biomass captured originated from areas outside the ISRA. In areas adjacent to the ISRA, at depths ranging from 158 to 269 m, 59.6% of the abundance and 31.3% of the biomass were captured. Conversely, in areas closer to the coast, at depths between 43 and 115 m, 39% of the abundance and 66% of the biomass were obtained.

The smallest specimen, measuring 12.82 cm, was captured within the ISRA at a depth of approximately 403 m—close to the reported birth length of 8 cm (Serena et al. 2016) (Figs. 4 and 9). The other specimen captured inside the ISRA measured 66.48 cm (89 m). The considerable difference in size between these two individuals accounts for the high standard error.

In adjacent areas, the largest specimen measured 77.73 cm and was recorded at a depth of 114 m. It was followed by two individuals measuring 73.75 cm, both captured at nearly 41 m deep. If all were males, they would exceed the maximum reported size of 72 cm (Serena and Abella 1999; Bono et al.

2005). Conversely, if they were females, the largest one would surpass the maximum reported sizes of 75 cm (Barría et al. 2015) and 76 cm (Serena and Abella 1999; Bono et al. 2005).

According to Coll et al. (2013), males reach maturity between 45 and 51 cm in the Catalan Sea. In this context, immature specimens captured represent 59.6% of the total abundance, with 88.1% of these specimens caught primarily between 161 and 261 m deep. Furthermore, 70.1% of the biomass corresponds to immature specimens (Fig. 9). Conversely, mature specimens, assuming they are males, constitute 40.4% of the total abundance; of these, 80.7% were captured at depths less than 115 m, representing 77.5% of the total biomass of mature specimens.

Considering females, which reach maturity at 48.1 cm (Coll et al. 2013), the total abundance of mature specimens would decrease to 29.1%. In this case, 78% of the females were captured in coastal areas, accounting for 73.6% of the total biomass of mature females.

Raja montagui

The spotted skate has a more coastal distribution (Fig. 2). Over thirteen different years (1994, 2001, 2004–2006, 2008, 2010, 2014, 2015, 2018, 2019, 2021, and 2022), a total of 74 specimens were captured, with a cumulative weight of 42.3 kg (Arroyo et al. 2020). Only one specimen was recorded within the ISRA, weighing 0.013 kg, at a depth of 402 m. In the abundance hotspot near the boundary of the ISRA, 21 specimens were captured, with a combined weight of 3.7 kg. The remainder of the captures were primarily made off the coast of the Mar Menor.

Eighty-five percent of the specimens captured were immature, while the remaining 14.9% were mature, based on the male maturity size (L50) of 50.3 cm; in contrast, the female maturity size is 64 cm (McCully et al. 2012) (Fig. 10). The largest specimen captured reached a length of 60.97 cm, indicating that no mature females were recorded. The only specimen captured within the boundaries of the ISRA was the smallest, measuring 14.09 cm, very close to the birth size, which ranges between 11 and 12 cm (Muus and Nielsen 1999; Serena 2005). Regarding the remaining immature specimens, 65.1% were found at depths of less than 114 m, and 33.3% at depths between 200 and 300 m. Meanwhile, the 11 mature specimens were captured at depths ranging from 41 to 109 m.

If the size of the smallest mature male, which is 40 cm according to McCully et al. (2012), is considered, the percentage of immature specimens would decrease to 29.7%, while that of mature specimens would increase to 70.3%. With regard to females, if the size of the smallest mature female (49 cm) according to McCully et al. (2012) is taken into account, it can be estimated that 23% of the specimens captured were mature females.

Conclusions

The species mentioned above, especially *S. canicula, G. melastomus*, *E. spinax*, and *R. asterias*, are frequently captured by trawling (Bertrand et al. 2000; Carbonell et al. 2003; Tugores et al. 2019). Although this method is not the most suitable for their study, it allowed the collection of a large amount of data on these and other species (Arroyo et al. 2020, 2021), which led to the proposal of this area as an Important Shark and Ray Area (ISRA). This ISRA was designated on the basis of the occurrence of the deep-sea shark *E. spinax* (Linnaeus, 1758), classified as Vulnerable (Finucci et al., 2021) and for which the area functions as a nursery ground, as well as the starry ray *R. asterias* (Delaroche, 1809), a species endemic to the Mediterranean." (IUCN SSC Shark Specialist Group 2023). However, it was also shown that this area serves as a nursery ground for other species such as *D. licha* (IUCN SSC Shark Specialist Group 2023). Nevertheless, during the final stage of the designation process, *D. licha* was excluded because it did not meet one of the strict IUCN criteria—its presence had only been recorded in six years, whereas prolonged temporal occurrence is required for consideration.

The ecological significance of this ISRA extends beyond elasmobranchs, as it ranges from depths of 300 to 800 m and includes various geological formations such as seamounts (Seco de Palos, Planazo, and Plis-Plas), submarine canyons, and a muddy field of pockmarks—formations created by the expulsion of gas and/or water (Arroyo et al. 2021). Recent research on seamounts has determined that their unique topography, hydrodynamics, light penetration, and other conditions give rise to areas of high biological diversity in both benthic communities and the surrounding pelagic ecosystems (Pitcher et al. 2007; Bo et al. 2011).

Furthermore, this area is characterized by hosting vulnerable marine ecosystems, including large sponges (Demospongiae; e.g., *Pachastrella* spp., *Phakellia* spp., *Poecillastra* spp.), gorgonian assemblages (*Bebryce* spp., *Swiftia* spp., *Nicella* spp., *Paramuricea* spp., *Acanthogorgia* spp., *Placogorgia* spp.), cold-water white corals (genera *Desmophyllum* and *Madrepora*), and Yellow Coral (*Dendrophyllia cornigera*) on hard substrates, and sea-pen fields and bamboo coral gardens (*Isidella elongata*) on muddy substrates (Rossi et al. 2014; Cobo-Viveros et al. 2022; Ramos et al. 2022).

Therefore, the need for integrated management implementing conservation measures is evident, considering the reproductive dynamics and migration patterns of the various species commonly found in this area.

Declarations

Author Contribution

E.A.M: wrote the main manuscript text, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, VisualizationI.A.A: Conceptualization, Investigation, Review the manuscript, Funding acquisitionA.E.: Resources, Review the manuscript, Project administration, Funding acquisitionA.A.R.E.: Conceptualization, Methodology, Validation, Investigation, Resources, Review the manuscript,

Supervision, Project administration, Funding acquisitionF.G.C.: Conceptualization, Methodology, Validation, Investigation, Review the manuscript, Supervision, Funding acquisition

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Data Availability

The data will be available under request.

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Figures

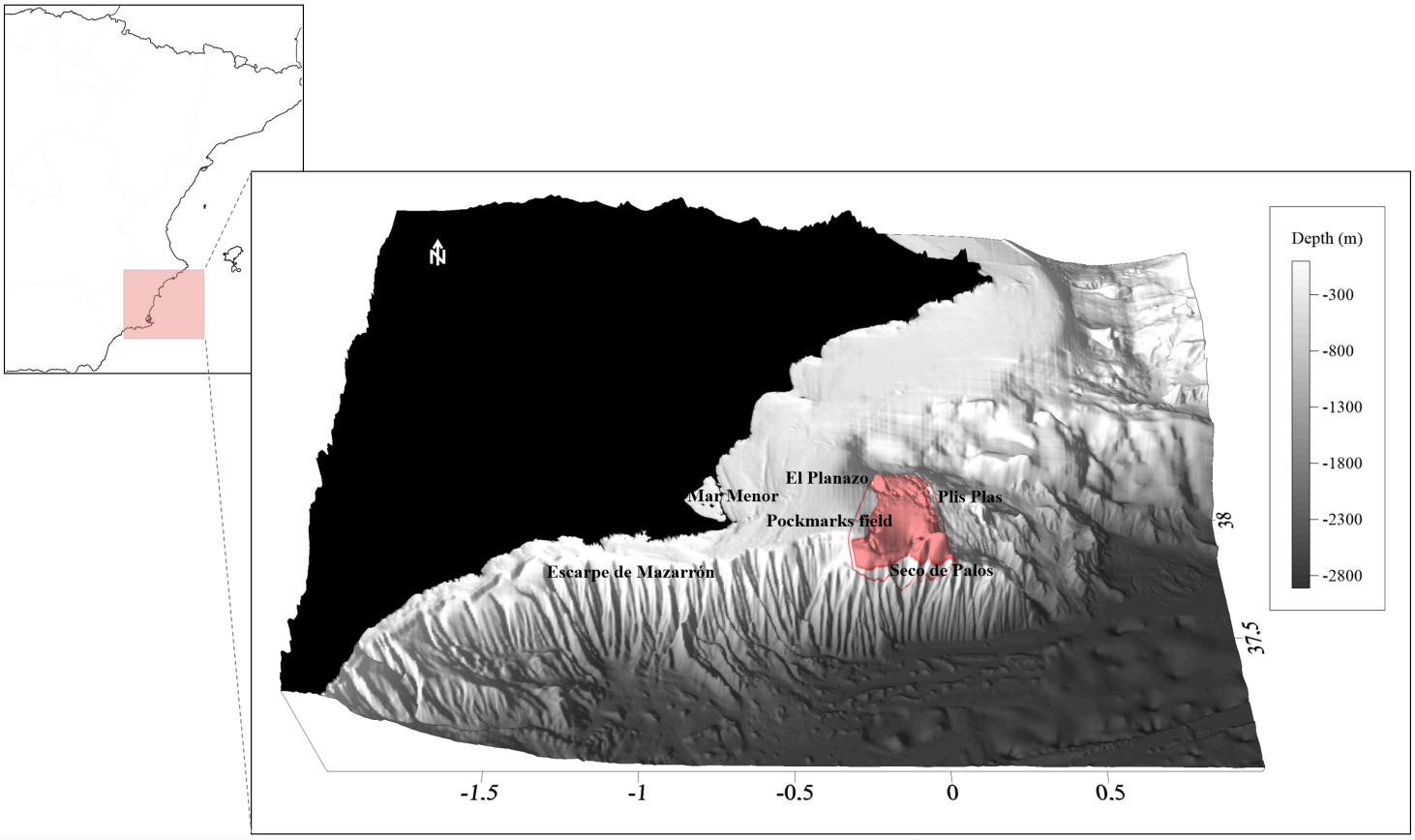


Figure 1

3D map of the seafloor of Alicante and Murcia (Spain). In red, the area designated as ISRA. (Source: author's own elaboration).

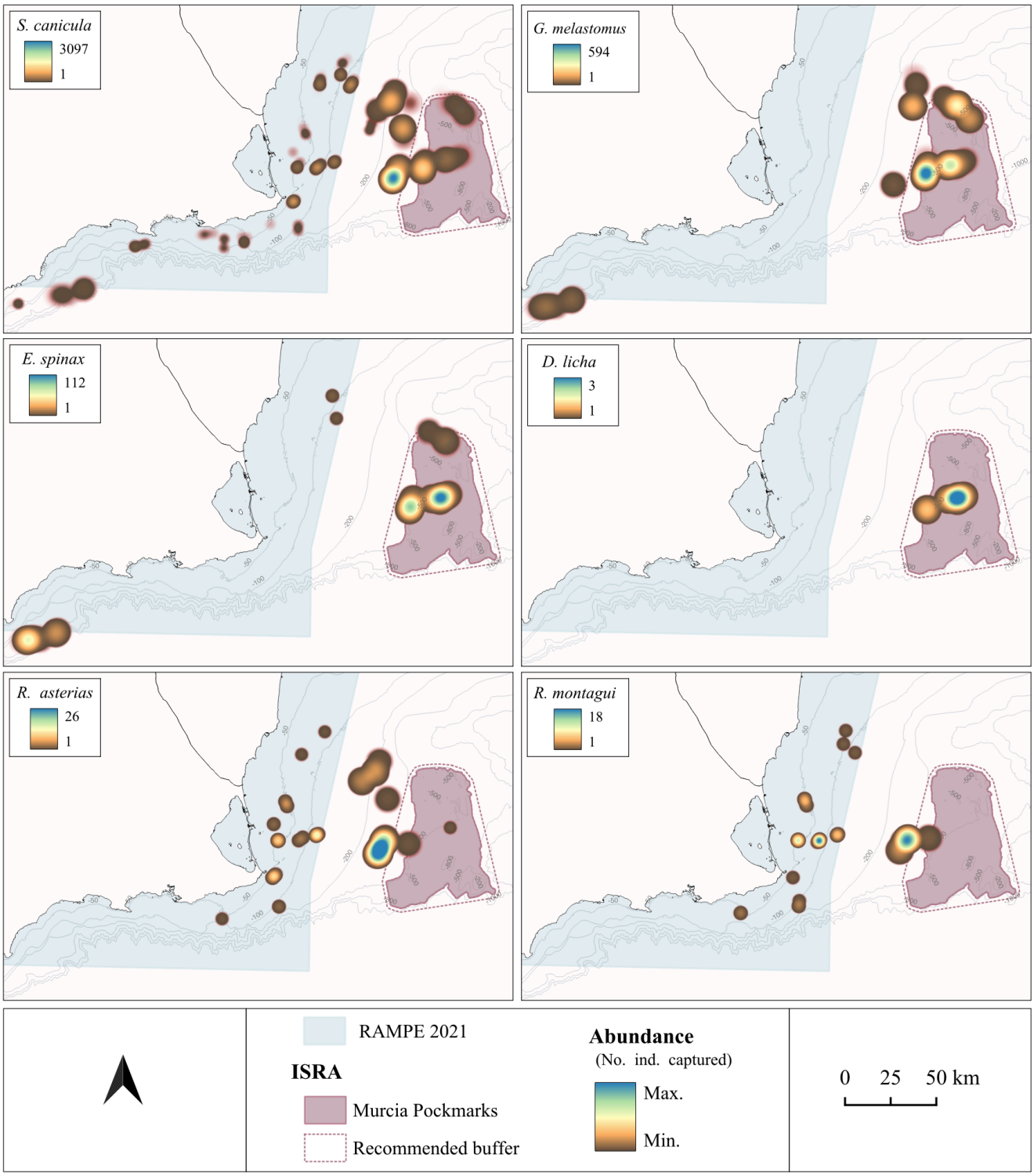


Figure 2

Heat map showing the abundance of individuals captured for each species during the MEDITS surveys. (Source: author's own elaboration).

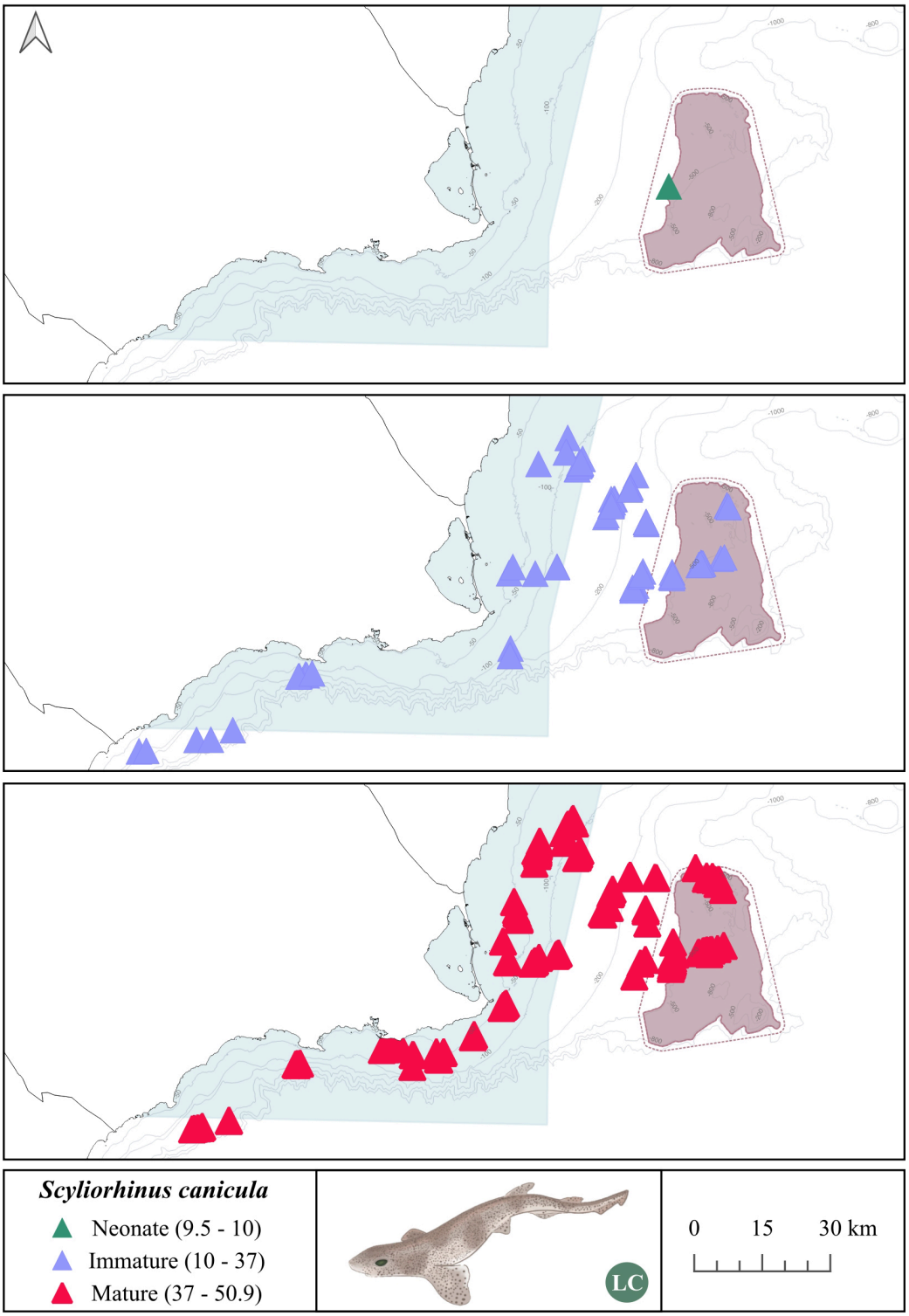


Figure 3

Ontogenetic distribution of *S. canicula*in the ISRA and adjacent areas. Listed as Least Concern (LC) by the IUCN. (Source: author's own elaboration).

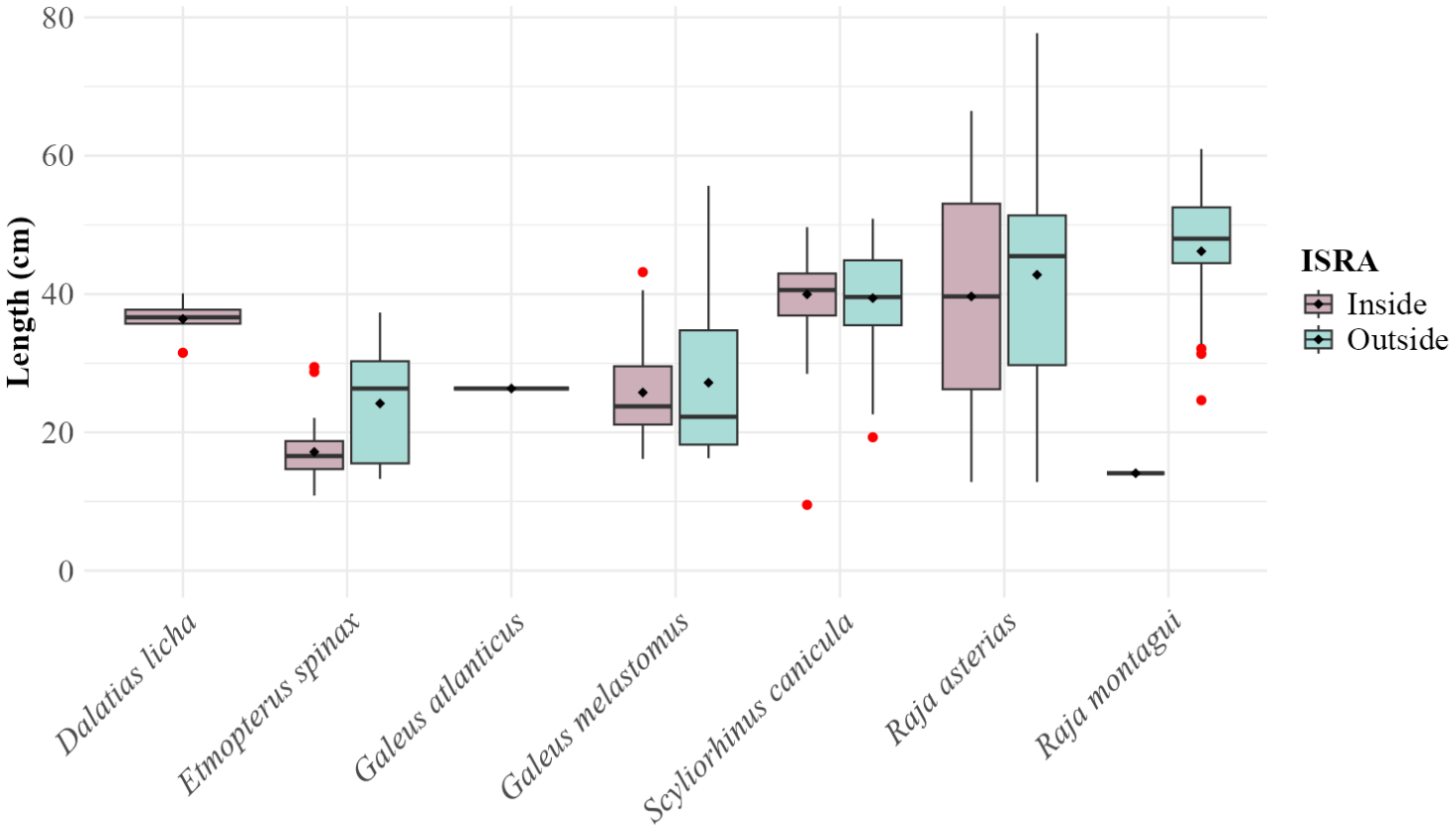


Figure 4

Sizes (cm; Min., Max., Avg. ± SE) calculated from parameters a and b (Froese et al. 2014) for each species inside and outside the ISRA.

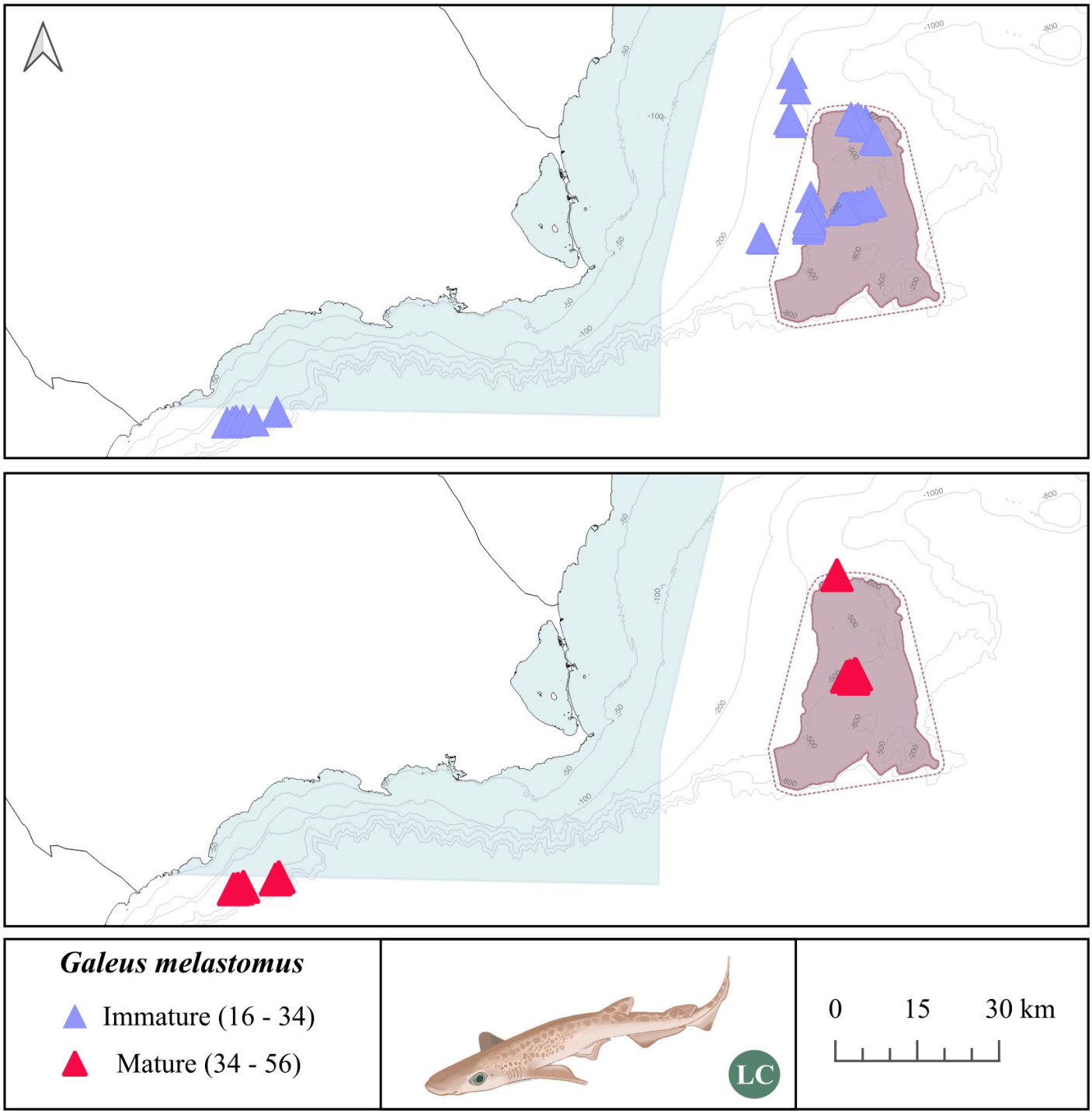


Figure 5

Ontogenetic distribution of *G. melastomus*in the ISRA and adjacent areas. Listed as Least Concern (LC) by the IUCN. (Source: author's own elaboration).

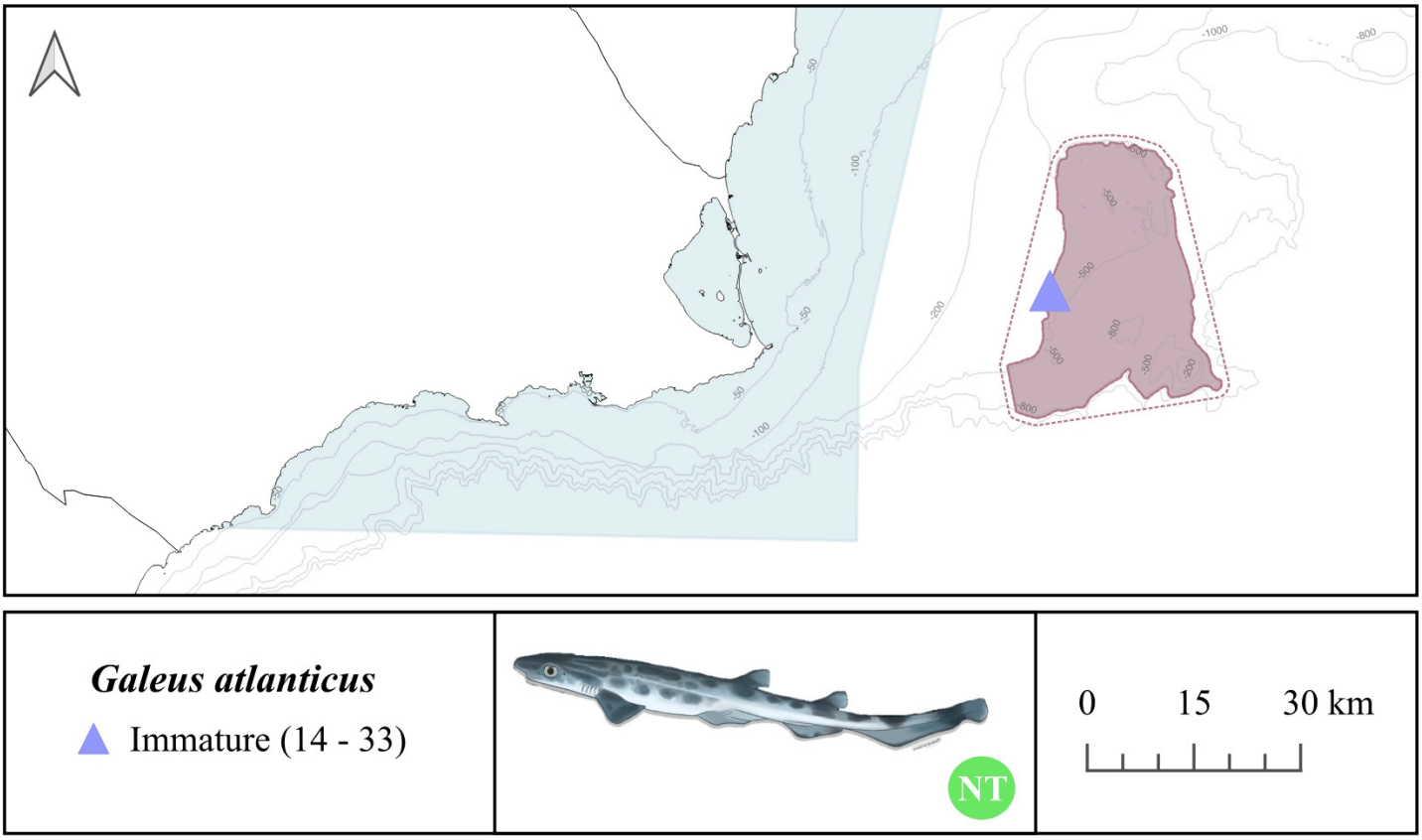


Figure 6

Ontogenetic distribution of *G. atlanticus*in the ISRA and adjacent areas. Listed as Least Concern (LC) by the IUCN. (Source: author's own elaboration).

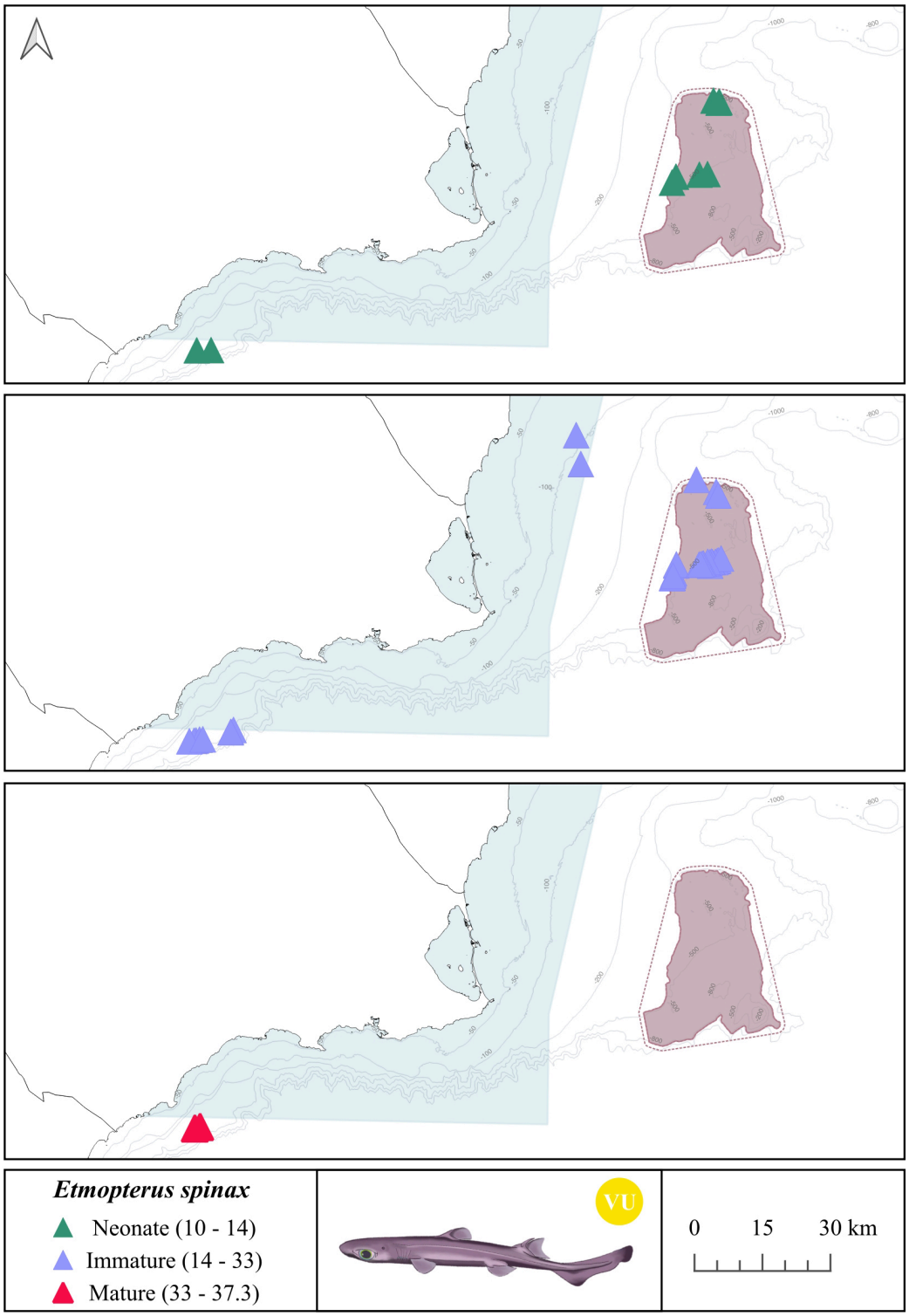


Figure 7

Ontogenetic distribution of *E. spinax*in the ISRA and adjacent areas. Listed as Vulnerable (VU) by the IUCN. (Source: author's own elaboration).

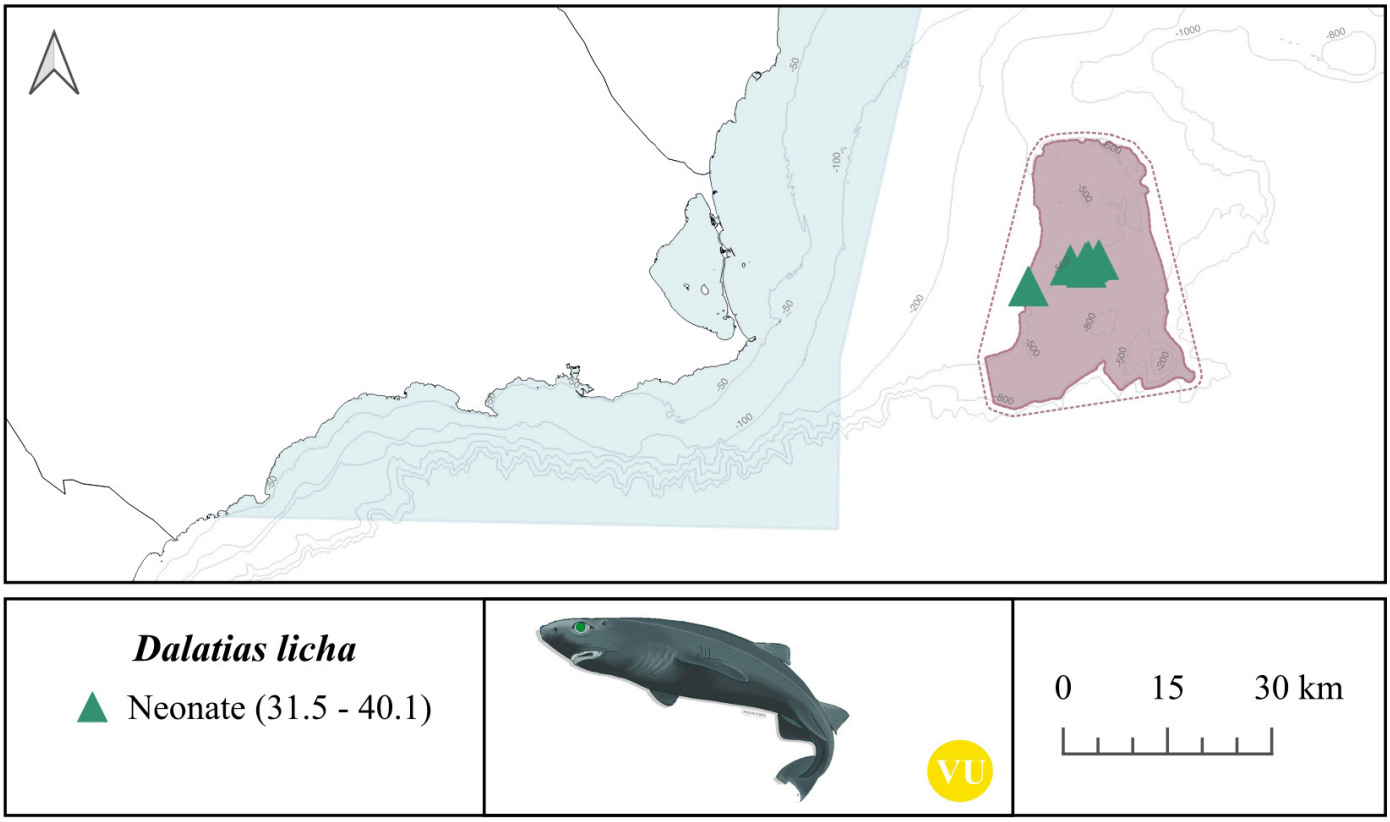


Figure 8

Ontogenetic distribution of *D. licha*in the ISRA and adjacent areas. Listed as Vulnerable (VU) by the IUCN. (Source: author's own elaboration).

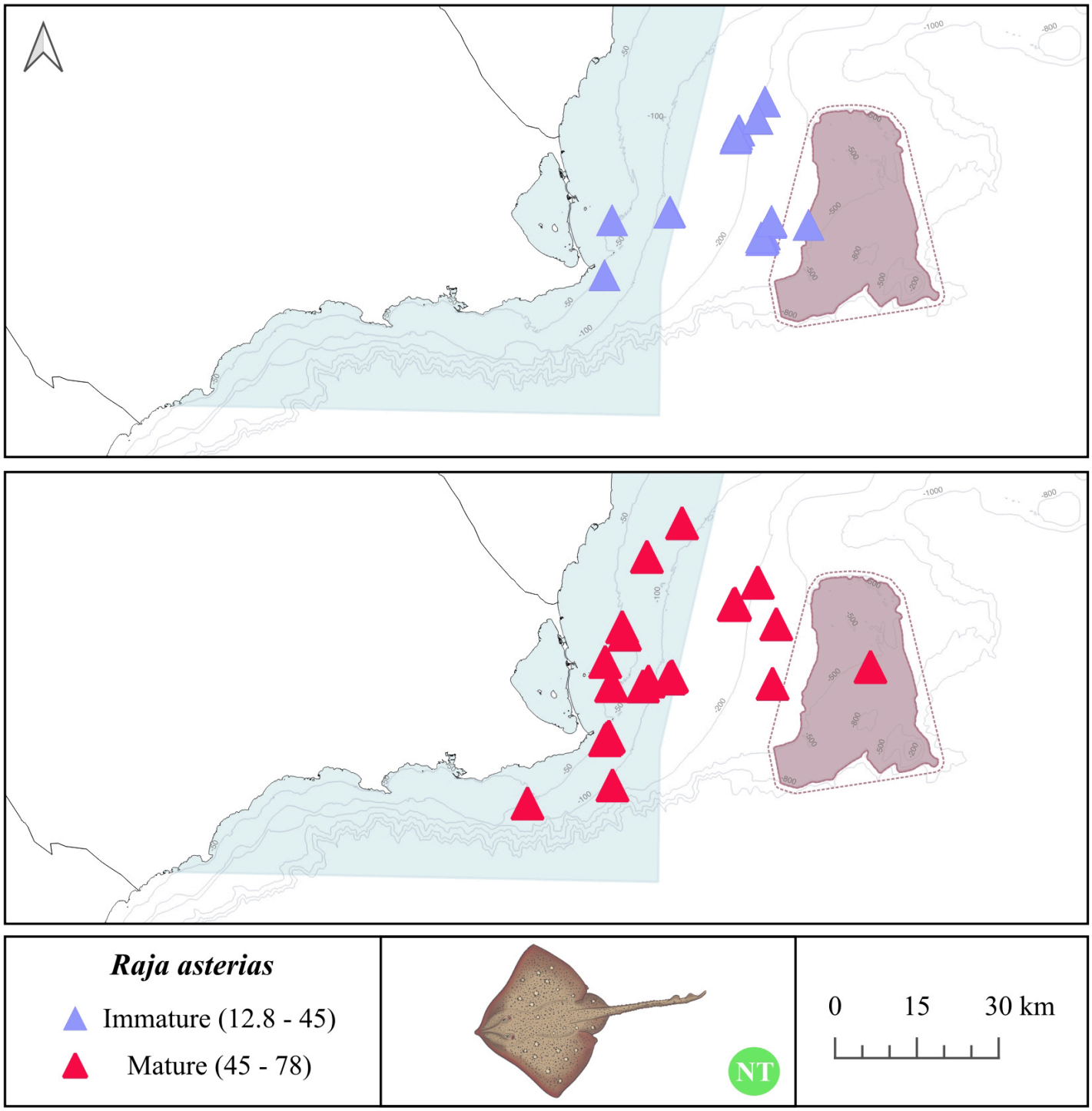


Figure 9

Ontogenetic distribution of *R. asterias*in the ISRA and adjacent areas. Listed as Near Threatened (NT) by the IUCN. (Source: author's own elaboration).

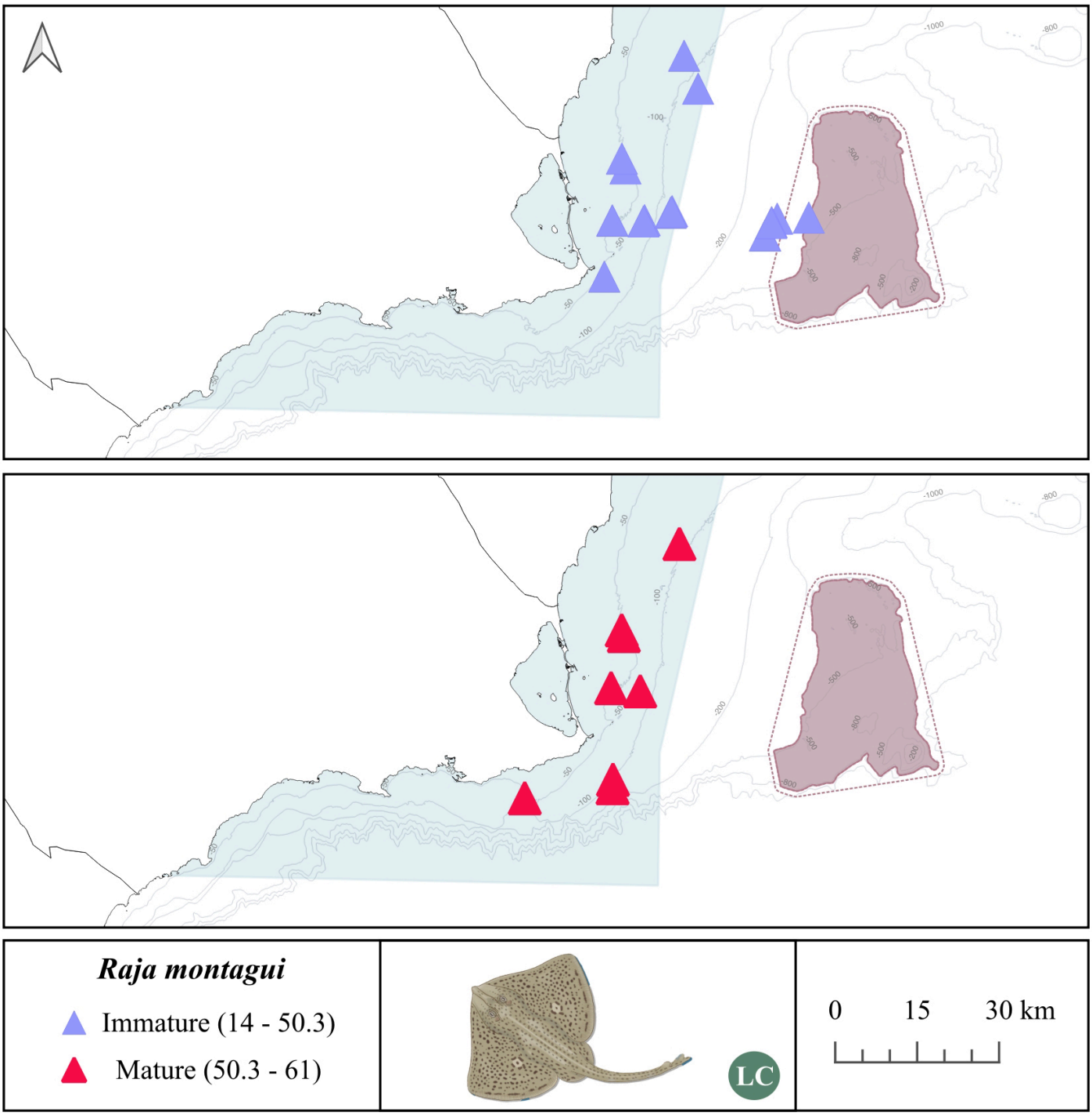


Figure 10

Ontogenetic distribution of *R. montagui*in the ISRA and adjacent areas. Listed as Near Threatened (NT) by the IUCN. (Source: author's own elaboration).