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# Biology, distribution and diversity of cartilaginous fish species along the Lebanese coast, eastern Mediterranean

Myriam Lteif

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# THÈSE

Pour obtenir le grade de  
Docteur

Délivré par  
**UNIVERSITE DE PERPIGNAN VIA DOMITIA**

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CEntre de Formation et de Recherche sur les  
Environnements Méditerranéens (CEFREM)  
UMR 5110 CNRS UPVD

Spécialité : Océanologie

Présentée par **Myriam LTEIF**

**BIOLOGY, DISTRIBUTION AND DIVERSITY  
OF CARTILAGINOUS FISH SPECIES ALONG  
THE LEBANESE COAST, EASTERN  
MEDITERRANEAN**

Soutenue le 22 Septembre 2015 devant le jury composé de

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*To my parents, Imane and Issam*

*To my sister, Stephanie*

*To the love of my life, Salim*

*You all mean the world to me...*

In loving memory of Hanna Kattoura

Two roads diverged in a wood, and I—  
I took the one less traveled by,  
And that has made all the difference.

Robert Frost

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## **Abstract**

Facing the intensive fishing of marine species occupying high trophic levels, the establishment of appropriate management measures is needed. The aim of this study is to contribute to a better knowledge of cartilaginous fish in the Lebanese coastal waters, Eastern Mediterranean.

After a general introduction (Chapter I) presenting the context and objectives of the study, an overview of the study site and diverse methods (Chapter II) (data collection, biological measurements, statistical analyses etc.) are displayed. Data was collected from an experimental survey in the framework of the CIHEAM PESCA-Libano project and periodic observation of fisheries and catches of hired fishermen.

Chapter III presented a literature review on the biology, ecology and geographic range of cartilaginous fish from the Eastern Mediterranean.

In the first part of Chapter IV, emphasis was placed on various aspects of spatial and seasonal distribution, diversity, biology and ecology of these species. In this study, a total of 315 specimens of cartilaginous fish were sampled. These specimens constituted of 25 cartilaginous fish species, including 11 shark species and 14 batoid species. No chimaeras were recorded. The majority of the sharks sampled were *Centrophorus granulosus*, *Galeus melastomus*, *Squalus blainville* and *Mustelus mustelus*. The majority of the batoids sampled were *Rhinobatos rhinobatos*, *Rhinobatos cemiculus*, *Torpedo marmorata*, *Torpedo nobiliana*, *Raja miraletus* and *Raja clavata*. These cartilaginous fish specimens were caught at depths ranging from 10 to 600 m majorly using longlines, then trammel nets and the least were caught using gillnets. The Catch Per Unit Effort was used as an index of abundance and its spatial and seasonal variations were analyzed. The spatio-temporal diversity was also estimated and the highest values were observed in the southern region and during spring and winter. In the second part, different length-weight relationships have been established for species with exhibiting 10 or more individuals (3 sharks and 5 batoids).

Furthermore, a focus was placed on the biology and ecology of two commercially significant and exploited species. The population biology of the batoid *Rhinobatos rhinobatos* (Chapter V) and the shark *Centrophorus granulosus* (Chapter VI) were evaluated separately using individuals from the two data sources combined (scientific and commercial). Finally, the last chapter (Chapter VII) is devoted to the general discussion and perspectives of this study.

**Keywords:** Chondrichthyans; conservation; distribution; life history; Lebanon; Levantine basin

## Résumé

Face à la pêche intensive des espèces marines de haut niveau trophique, l'instauration de mesures de gestion appropriées s'avère nécessaire. L'objectif de cette étude est de contribuer à une meilleure connaissance des poissons cartilagineux dans les eaux côtières libanaises de la Méditerranée orientale.

Après une introduction générale (chapitre I) introduisant le contexte et les objectifs de l'étude, vient la présentation du site d'étude et des diverses méthodes employées (collectes des données, mesures biologiques, analyses statistiques etc.) (chapitre II). Les données ont été collectées à partir de captures expérimentales dans le cadre du projet scientifique "CIHEAM PESCA-Libano" et d'observations périodiques des poissons capturés par les pêcheurs et présents dans les poissonneries.

Le chapitre III est dédié à une synthèse bibliographique sur la biologie, l'écologie et la répartition géographique des poissons cartilagineux de la Méditerranée orientale.

Dans une première partie du chapitre IV, l'accent a été mis sur les différents aspects de la distribution spatiale et saisonnière, la diversité, la biologie et l'écologie de ces espèces. Au total, 314 spécimens de poissons cartilagineux ont été échantillonnés appartenant à 25 espèces, dont 11 espèces de requins et 14 espèces de batoïdes. Aucune chimère n'a été enregistrée. Les requins échantillonnés étaient constitués majoritairement des espèces: *Centrophorus granulosus*, *Galeus melastomus*, *Squalus blainville* et *Mustelus mustelus*. La majorité des batoïdes était constituée de *Rhinobatos rhinobatos*, *Rhinobatos cemiculus*, *Torpedo marmorata*, *Torpedo nobiliana*, *Raja miraletus* et *Raja clavata*. Les différents spécimens de poissons cartilagineux ont été pêchés à des profondeurs allant de 10 à 600 m, en majorité à l'aide de palangres, suivis des trémails puis des filets maillants. La Capture par Unité d'Effort a été employée en tant qu'indice d'abondance et ses variations spatiales et saisonnières ont été analysées. La diversité spatio-temporelle a aussi été estimée et les plus fortes valeurs ont été observées dans la région du sud et durant le printemps et l'hiver. Dans une seconde partie, différentes relations longueur-poids ont été établies pour les espèces majoritaires présentant un nombre d'individus supérieur à 10 (3 requins et 5 batoïdes).

Enfin, un focus a été porté sur la biologie et l'écologie de deux espèces commercialement importantes et bien exploitées dans les eaux côtières libanaises. La biologie des populations du batoïde *Rhinobatos rhinobatos* (chapitre V) et du requin *Centrophorus granulosus* (chapitre VI) a été

évaluée séparément à partir d'individus issus des deux sources de données combinées (scientifiques et commerciales). Pour finir, le dernier chapitre (chapitre VII) est consacré à la discussion générale et aux perspectives de cette étude.

**Mots clés:** Chondrichthyens; conservation; distribution; traits d'histoire de vie; Liban; Bassin Levantin

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# **Chapter I**

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## **General Introduction**

## **Chapter I: General Introduction**

### **1. Overview**

Over the past millennia, humans have deeply altered biodiversity on Earth and especially those of vertebrates (Schipper *et al.*, 2008; Hoffmann *et al.*, 2010). The largest habitats with the longest evolutionary history are found in Earth's oceans. There is a great worry for marine biodiversity (functional, specific, genetic, taxonomic, ecosystems diversity) due to increase of human impact (Jackson, 2010). Overfishing, habitat degradation and pollution have profoundly altered populations of marine animals (Hutchings, 2000; Lotze *et al.*, 2006; Polidoro *et al.*, 2012). For example, the population of humpback whale, *Megaptera novaeangliae* (Borowski, 1781), was reduced to five percent of its previous level between 1920 and 1986 (Butman *et al.*, 1995). Overfishing can affect biological diversity as the species is no longer able to maintain their role as prey, predator, or competitor in the ecosystem when their populations are extremely declined, which can lead to ecological and functional extinction (Lee and Safina, 1995). Cartilaginous fish species have also undergone alterations in populations and are under several threats due to increase of fishing pressure and habitat loss (Stevens *et al.*, 2000; Simpfendorfer *et al.*, 2002; Dudley and Simpfendorfer, 2006; Ferretti *et al.*, 2010). Similar to most marine ecosystems worldwide, the Mediterranean Sea is highly impacted by various threats (Coll *et al.*, 2010) including commercial, artisanal and recreational overfishing, aquaculture, overpopulation along the coasts, and many forms of pollution (Mouillot *et al.*, 2011). Climatic changes and species invasion are two additional threats this last century. Twenty percent of the Mediterranean chondrichthyans are considered threatened (Dulvy *et al.*, 2014). Therefore, light must be shed on this region in order to protect, manage and conserve the species of this fish class.

### **2. The Mediterranean Sea: Biodiversity, threats and fisheries**

#### **2.1. Geographical overview**

The Mediterranean is the largest and deepest enclosed sea on Earth. It has narrow continental shelves and a large area of open water. It covers approximately 2,500,000 km<sup>2</sup> (excluding the

Black Sea), representing around 0.2% of oceans volume, with an average depth of 1460 m and a maximum of 5267 m (Cuttelod *et al.*, 2008) (Figure 1). It connects the three continents: Africa, Europe, and Asia. It is connected to the Atlantic Ocean in the west through the Strait of Gibraltar and to the Sea of Marmara and the Black Sea in the east through the Dardanelles. The Mediterranean has been artificially connected to the Red Sea and Indo-Pacific region through the building of the Suez Canal in 1869.



Figure 1: Map of the Mediterranean Sea and surrounding countries (Cuttelod *et al.*, 2008).

The climate in the region is characterized by hot, dry summers and cool, humid winters. The annual mean sea surface temperature shows a high seasonality and important gradients from west to east and north to south (Hopkins, 1985). The strong environmental gradients in the basin makes the eastern part more oligotrophic than the western one (Azov, 1991). The increase in temperature and salinity from north to south and from west to east causes the decrease in biological production in a likewise direction (Danovaro *et al.*, 2008).

## 2.2. Biodiversity

The recent marine biota in the Mediterranean Sea is primarily derived from the Atlantic Ocean, but the wide range of climate and hydrology has contributed to the co-occurrence and survival of both temperate and subtropical organisms (Bianchi and Morri, 2000). It is known for the diversity and high endemism of marine species (crabs and crayfish, mammals, and cartilaginous

fish) (Cuttelod *et al.*, 2008). Up to 18% of the world's macroscopic marine species (out of which 25 to 30% are endemic) are found in the Mediterranean basin although it makes less than 1% of the global ocean surface, confirming an incredibly rich biodiversity for such a small area (Bianchi and Morri, 2000). Currently, the Mediterranean Sea holds 17,000 (7%) of all known marine species (Coll *et al.*, 2010). The level of endemism is especially high on the islands of the Mediterranean, where species have evolved to survive in very specific habitats (Blondel and Aronson, 1999). Around 23 of the world's cetacean species are found in the Mediterranean, consisting of 9 known year-round residents (Reeves and Notarbartolo di Sciara G., 2006). This sea is also home to the most endangered pinniped: the Mediterranean Monk Seal *Monachus monachus* and it holds around 80 cartilaginous fish species, 40% of which are threatened (Cavanagh and Gibson, 2007; Cuttelod *et al.*, 2008; Bradai *et al.*, 2012). However, Mediterranean biodiversity has been and will be continuously altered and shaped by natural and anthropogenic factors in the past and the coming future (Coll *et al.*, 2010).

### **2.3. Threats**

The effects of human activities are relatively stronger in the Mediterranean than in any other sea of the world (Blondel and Aronson, 2005). Its coasts are highly inhabited and the region strictly participates in the global economy and trade welcoming approximately 200 million tourists yearly (Bradai *et al.*, 2012). Its coastal ecosystems have been particularly affected by the past and recent human activities and economic development (Cuttelod *et al.*, 2008; Papadopoulou *et al.*, 2011). The knowledge about processes, ecological species distribution, the condition of its ecosystems and the drivers for biodiversity loss is still vague, even more than most of the basin is unmanaged and exposed to threats (Notarbartolo di Sciara and Agardy, 2009). Many of the ecological characteristics in the Mediterranean Sea are under threat with areas of potential high cumulative threats overcoming the western and eastern basins and fewer in the southeastern region (Coll *et al.*, 2012). The most important causes of current and future threats for the Mediterranean species are habitat loss and degradation, pollution, overexploitation (unsustainable aquaculture and fishing), eutrophication, maritime traffic, invasive alien species, human disturbance, climate change and bycatch (Cuttelod *et al.*, 2008; Coll *et al.*, 2010) (Figure 2). Moreover, temporal patterns indicate that overexploitation and habitat loss are the main human drivers of historical changes (Lotze *et al.*, 2011). The marine ecosystems and species in

the Mediterranean Sea are affected by several of these threats. For instance, some cetaceans are severely affected by noise pollution (due to marine traffic) that impairs their ability to find prey, while others are affected by chemical pollutants such as polychlorinated biphenyls (PCBs) which affect the immune system, increasing sensitivity to illness, and causing increased mortality and reduced reproduction (Cuttelod *et al.*, 2008).

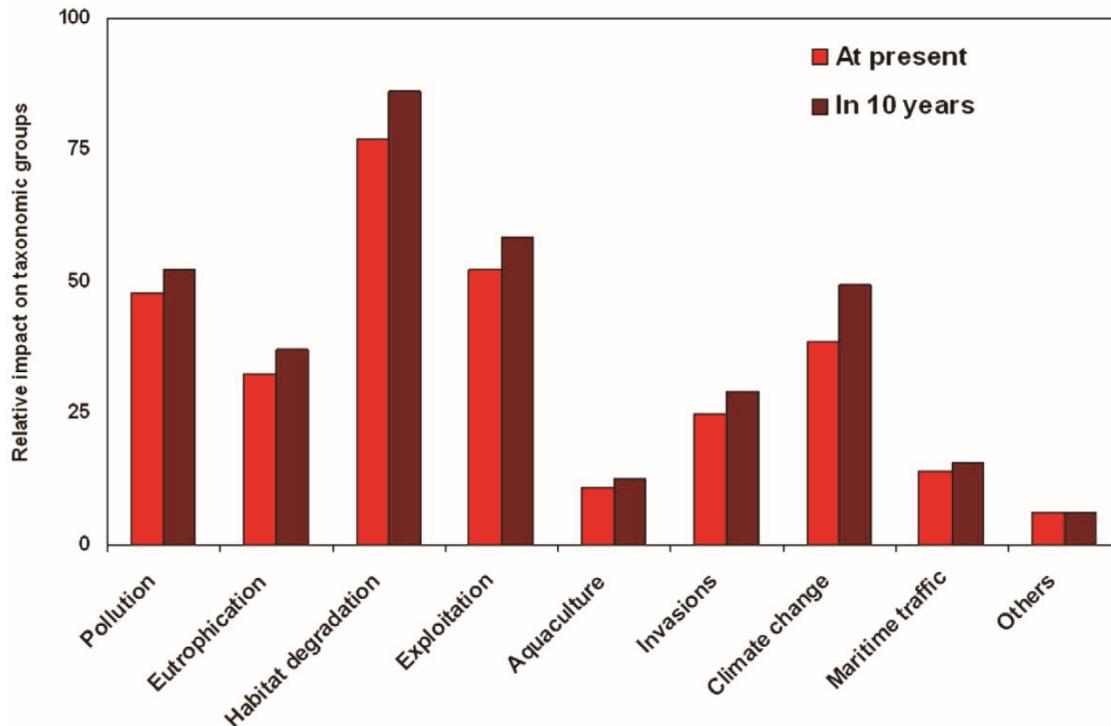


Figure 2: The current and future threats for marine biodiversity in the Mediterranean (Coll *et al.*, 2010).

Furthermore, the southeastern region of the Mediterranean is also influenced by the introduction of Lessepsian (Indo-Pacific) species (Coll *et al.*, 2010). In total, the number of Lessepsian species has reached more than 790 in the Mediterranean Sea, with some of the invaders through the Suez Canal having been very successful colonizers of Mediterranean marine ecosystems (Galil and Zenetos, 2002; Zenetos *et al.*, 2005; Golani *et al.*, 2007; Golani, 2010; Oral, 2010). One example is the silver-cheeked toadfish, *Lagocephalus sceleratus* which is causing several problems in the surrounding ecosystem and fisheries sector (Zenetos *et al.*, 2005; Peristeraki *et al.*, 2006; Streftaris and Zenetos, 2006). A study done in Lebanon concerned the population structure and the sexual maturity of this fish in the Lebanese and Syrian waters in order to shed light on the severity of this problem (Khalaf *et al.*, 2014) (ANNEX I). In addition, the Mediterranean is also influenced by species introduced from the Atlantic Sea through the Strait

of Gibraltar and have reached the Adriatic Sea and even the eastern basin. Some of these Atlantic species are invasive and showed continuous distribution, such as, *Parablennius pilicornis* (Pastor and Francour, 2010), *Pomadasys incisus* (Bodilis *et al.*, 2013), and *Lampris guttatus* (Francour *et al.*, 2010); others showed patchy distributions, such as, *Kyphosus sectatrix* (Francour and Mouine, 2008) and *Pisodonophis semicinctus* (Bodilis *et al.*, 2012). Regarding both distributions, the number of individuals of all Atlantic species has increased during the last decade. Their increasing numbers have an impact on native populations and may lead to a reduction in the abundance of endemic species (Otero *et al.*, 2013).

The creation of a new Suez canal parallel to the current channel (inaugurated on August 6, 2015) is expected to double the capacity of the Canal. This expansion is sure to quickly affect the Levantine Basin unfolding a diverse range of effects, at local and regional scales, on both the biological diversity and the ecosystems (Galil *et al.*, 2014) that will subsequently spread to the rest of the Mediterranean.

Moreover, overexploitation (especially fishing) and bycatch are serious problems for Mediterranean species affecting many threatened marine species, such as, bony and cartilaginous fish, dolphins and marine turtles (Cuttelod *et al.*, 2008). In addition, the overexploitation of large predators, with change in biomass and composition, could possibly have a greater impact on the stability of an ecosystem, especially the marine one, than removing species farther down the food chain (Larkin, 1979; Watson and Pauly, 2001). Bycatch, as well, can lead to the loss of biological resources along with its biological and ecological impact (Hall *et al.*, 2000).

## **2.4. Fisheries**

The Mediterranean is one of the oldest and most intensively exploited marine system. Its fisheries target different resources mostly pelagic stocks (Abella *et al.*, 2002). More than one percent of world landings come from Mediterranean fisheries (Coll *et al.*, 2010). This fishery is typically characterized by small fishing vessels and multispecies landings. important industrial fisheries mainly target small pelagics (mainly sardines and anchovies) which are principally caught using purse seines and pelagic trawls. Artisanal, as well as industrial fleets, exploit a large number of benthic and demersal species distributed over the generally narrow continental shelves characterizing the Mediterranean Sea. These stocks usually remain within national waters, except

in some areas characterized by a wider continental shelf (Caddy, 1993). Catch assessments are difficult in the Mediterranean because of the multi-specific and multi-gear characteristics of most of its fisheries, the dispersed landing sites and the small fraction of the catch that generally passes through organized fish markets. Sometimes the same stocks are exploited by diverse fleets as their geographical distribution often exceeds the national waters of a single country (Abella *et al.*, 2002). Furthermore, juveniles and commercially important species or untargeted species constitute the unknown quantity of bycatch, with some species often discarded dead at sea. Invertebrates constitute a minor fishery sector for most countries in the concerned area, partly due to cultural purposes (Bariche, 2012).

The Mediterranean Sea and Black Sea make up together FAO Fishing Area 37 (FAO, 2004). It is divided into four subareas, each of which has its own divisions: Western Mediterranean (Subarea 37.1), Central Mediterranean (Subarea 37.2), Eastern Mediterranean (Subarea 37.3), and Black Sea (Subarea 37.4) (Table 1) (Figure 3).

Table 1: The subareas of Fishing Area 37 and its divisions (FAO, 2004)

Subarea	Western Mediterranean			Central Mediterranean		Eastern Mediterranean		Black Sea		
	Balearic	Gulf of Lions	Sardinia	Adriatic	Ionian	Aegean	Levant	Marmara Sea	Black Sea	Azov Sea
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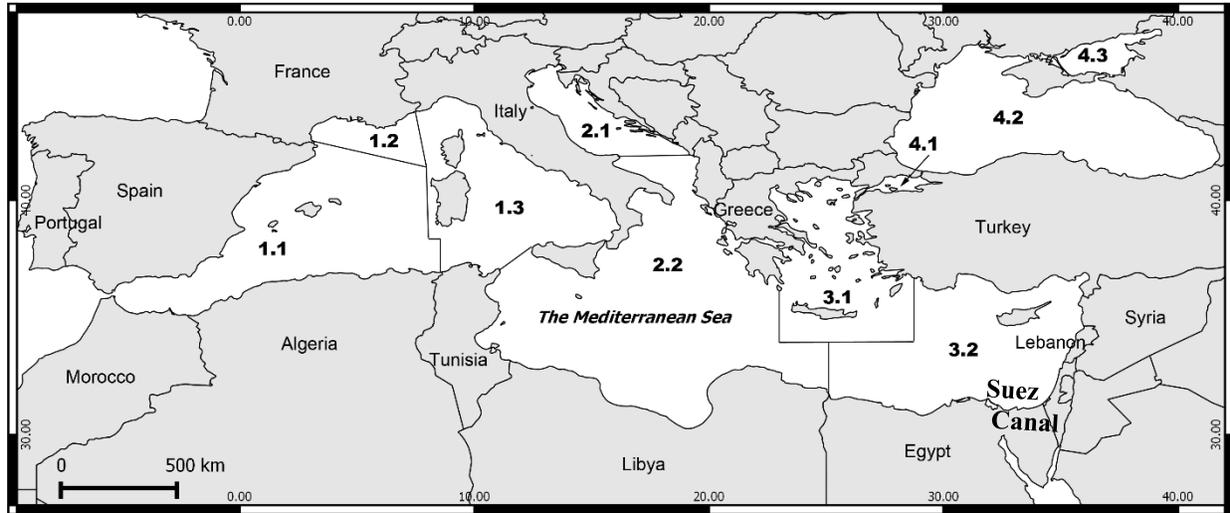


Figure 3: FAO Fishing Area 37: The borders of its subareas and divisions.

The Food and Agriculture Organization (FAO) has three main goals: the eradication of hunger, food insecurity and malnutrition; the elimination of poverty and the driving forward of economic and social progress for all; and, the sustainable management and utilization of natural resources, including land, water, air, climate and genetic resources for the benefit of present and future generations (FAO, 2015a).

FAO Fisheries and Aquaculture is one department of FAO. It contributes significantly to improving the well-being of poor and disadvantaged communities in developing countries and to achievement of several of the Millennium Development Goals, especially those related to poverty reduction and food and nutrition security, environmental protection and biodiversity. Its main mission is to strengthen global governance and the managerial and technical capacities of members and to lead consensus-building towards improved conservation and utilization of aquatic resources. In this context, the fisheries divisions of this department are employed in this study (FAO, 2015b).

### 3. Chondrichthyan: Status, fisheries and threats

#### 3.1. Worldwide overview

Chondrichthyan make up one of the oldest and most ecologically diverse vertebrate families: sharks and their relatives, the batoids (including skates, rays, guitarfishes and sawfishes) and chimaeras are all chondrichthyan, or cartilaginous fishes (Fowler, 2005). Their classification

according to Nelson (2006) comprises 14 orders and 54 families (ANNEX II). The class constitutes a conservative evolutionary group of around 1200 species which arose more than 400 million years ago and rapidly became top predators in aquatic food webs (Compagno, 1990; Kriwet *et al.*, 2008). Most chondrichthyans are marine creatures, although many utilize estuaries, particularly as nurseries. Some even enter or are endemic to fresh water. Chondrichthyans can be present in immediate subtidal zone offshore to coastal, bathyal (200–2000m) and even abyssal habitats (>2000m). Most of them are predators, although some species may specialize on small benthic infaunal animals, such as polychaetes or amphipods. Other species, particularly the myliobatids, may consume hard-shelled bivalve molluscs. Most sharks consume fish and crustaceans, although white sharks prefer marine mammals, and basking sharks and whale sharks filter zooplankton from the sea (Fowler, 2005).

Cartilaginous fish are characterized by their conservative life-history traits. They have the latest maturity and the slowest reproduction of all vertebrates; they display long gestation periods and some of the highest levels of maternal investments in the animal kingdom (Cortés, 2000). These life history traits have been leading to low population growth rates and less compensation in juvenile survival, making them intensively vulnerable to elevated fishing exploitation and mortality (Musick, 1999b; Cortés, 2002; García *et al.*, 2008; Dulvy and Forrest, 2010).

Elasmobranchs are essential to the balance of marine ecosystems. They have a key role, since they clean oceans of injured or sick prey, and thus contribute to maintain healthy populations. Furthermore, these top-predators regulate certain populations of carnivorous fish. The consequence of an over-exploitation of elasmobranchs would be an increase of forage fish, which would ultimately lead to algal and jellyfish blooms in oceans. Therefore, their decrease can lead to fishing down the food web and can disrupt ecosystem. For humans, it would mean an increase of the importance of organisms with less commercial significance and eating fish, shellfish and seafood would become scarcer.

The center of greatest chondrichthyan biodiversity lies in the Indo-West Pacific Region (Fowler, 2005) (Figure 4). Dulvy *et al.* (2014) identified three main hotspots where the biodiversity of sharks and rays was particularly seriously threatened - the Indo-Pacific Biodiversity Triangle, Red Sea, and the Mediterranean Sea - and claim that national and international action is required to protect them from overfishing.

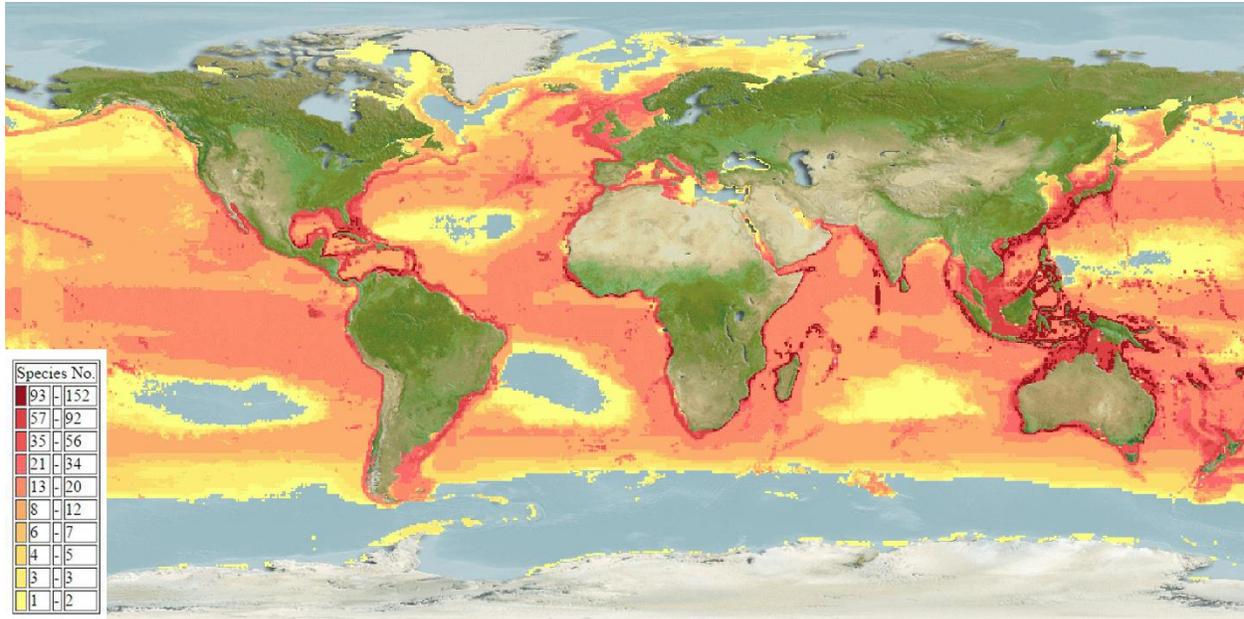


Figure 4: The worldwide representation of the Elasmobranchii species richness (AquaMaps, 2013).

Chondrichthyans are often caught incidentally; however, they are mainly regarded as valuable bycatch of fisheries that focus on more productive teleost fish species, such as tunas or groundfishes (Stevens *et al.*, 2005). They are mainly exploited for their meat, fins, livers and gill rakers carry high value; therefore, fishing pressure on chondrichthyans is increasing (Fowler *et al.*, 2002; Clarke *et al.*, 2006b; Clarke *et al.*, 2007; Lack and Sant, 2009). The globalized trade to meet Asian demand for shark fin soup (traditional and expensive Chinese dish) is the main cause for shark fishing. This profitable trade also affects shark-like rays such as wedgefishes and sawfishes. It is mainly unregulated across the 86 countries and territories that exported large amounts of fins to Hong Kong (a major fin trade hub) in 2010 (Dulvy *et al.*, 2014) (Figure 5). However, bans on ‘finning’ (the removal of a shark’s fins and discarding the carcass at sea) is currently one of the regional and international management measures for sharks and rays through most Regional Fisheries Management Organizations (RFMOs) (Fowler and Séret, 2010).

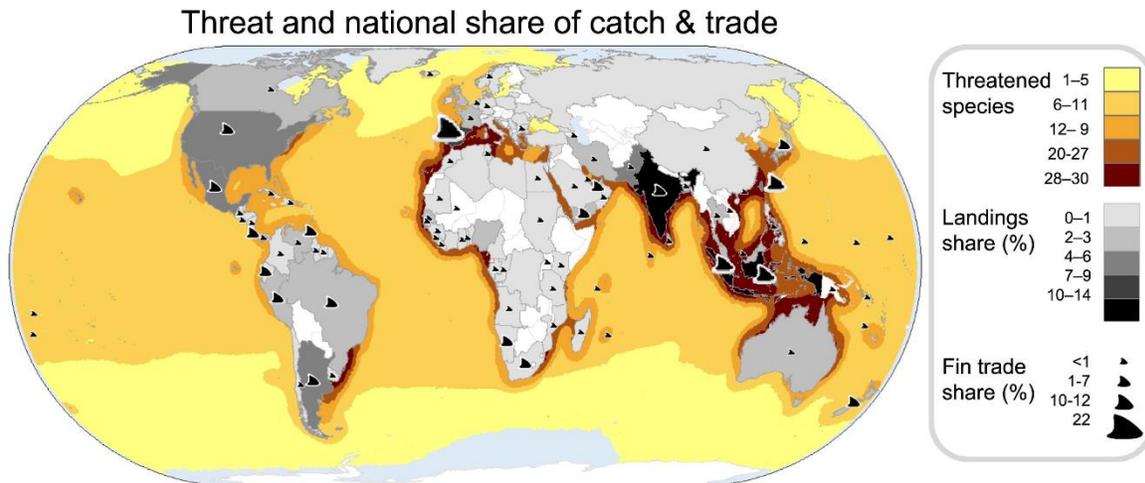


Figure 5: The main shark and ray fishing nations are gray-shaded according to their percent share of the total average annual chondrichthyan landings reported to FAO from 1999 to 2009. The relative share of shark and ray fin trade exports to Hong Kong in 2010 are represented by fin size (Dulvy *et al.*, 2014).

According to the Food and Agricultural Organization of the United Nations (FAO, 2011), elasmobranch landings have increased progressively to peak in 2003 and then showed a decline since then (Figure 6a); and rays have shown to dominate the landings in the past four decades (Figure 6b). Elasmobranch fisheries worldwide have expanded due to growing demand (particularly for highly valuable parts such as shark fins), the availability of new areas (i.e. open ocean, deep-sea bottom), and the use of highly technically equipped fishing vessels (Casey and Myers, 1998; Clarke *et al.*, 2007; Worm *et al.*, 2013). Moreover, most chondrichthyan catches are unregulated and often misidentified, unrecorded, aggregated, or discarded at sea, resulting in a lack of species-specific landings information, and the true catch is estimated 3 or 4 times greater than that reported (Barker and Schluessel, 2005; Clarke *et al.*, 2006b; Ferretti *et al.*, 2008; Iglésias *et al.*, 2010; Bornatowski *et al.*, 2013; Worm *et al.*, 2013).

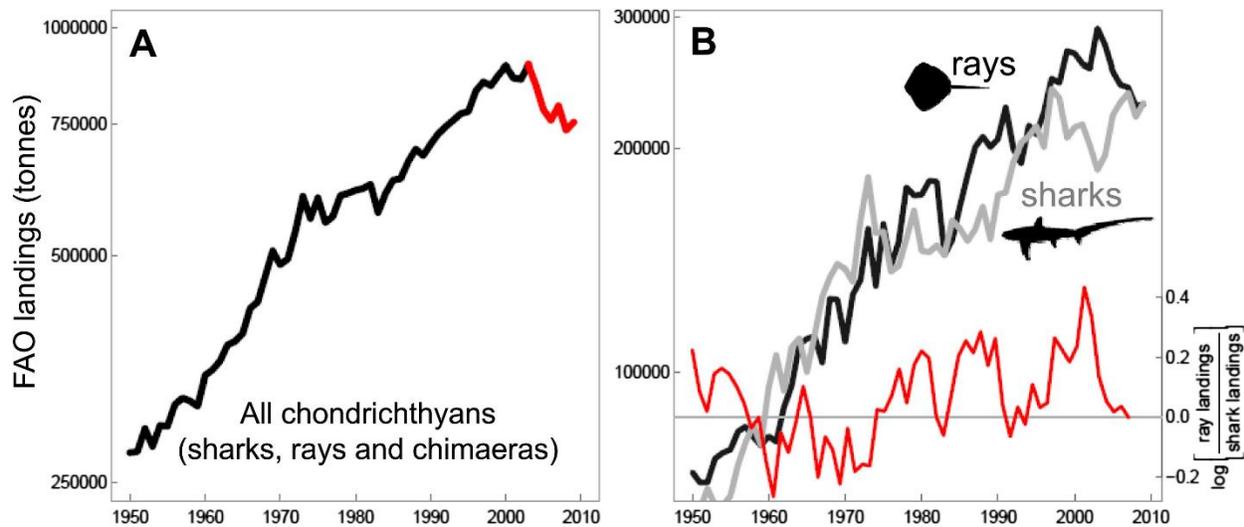


Figure 6: The temporal pattern of chondrichthyan fisheries catch landings. (A) The landed catch of chondrichthyans reported to the Food and Agriculture Organization of the United Nations from 1950 to 2009 up to the peak in 2003 (black) and subsequent decline (red). (B) The rising contribution of rays to the taxonomically-differentiated global reported landed catch: shark landings (light gray), ray landings (black), log ratio [rays/sharks], (red) (FAO, 2011; Dulvy et al., 2014).

### 3.2. Chondrichthyan life history traits

Life history traits are molded by the energy available in the environment for the distribution among different biological processes and by the interactions that influence distribution decisions. The energy available for distribution depends ultimately on the primary productivity of the ecosystem (Arendt and Reznick, 2005), while the strength of biological interactions depends on many ecosystem characteristics, including physical structure (Gotceitas and Colgan, 1989; Almany, 2004) and diversity (Sinclair *et al.*, 2003; Duffy and Stachowicz, 2006). Studies on life history parameters such as age and growth, along with basic information on distribution, abundance, movements, feeding, reproduction and genetics, are essential for biologists to understand and predict how populations will grow and how they will respond to fishing pressure. Species, especially chondrichthyans, exhibiting conservative life histories such as late age-at-maturity, large size, slow growth and low rate of potential population increase appeared more vulnerable to exploitation and decreased more in abundance than others (Jennings *et al.*, 1998; Jennings *et al.*, 1999). These fishes are less productive and fundamentally more vulnerable to extinction than bony fishes (Myers and Worm, 2005). Their reproductive strategies along with the relatively close relationship between parent stock and subsequent recruitment from their live-

borne or egg-borne early development, opposes those employed by all but a few examples of the teleosts, which support most fisheries. The vulnerability of species of this fish class has been linked to the combination of large maximum body size, slow growth, late maturation (at a large size), and long lifespan (Walker and Hislop, 1998; Dulvy *et al.*, 2000; Stevens *et al.*, 2000; Frisk *et al.*, 2001). Life histories are constrained by compromises; slow-growing species tend to be large bodied, mature later in life and have lower annual reproductive output (Charnov, 1993; Reynolds *et al.*, 2001; Frisk *et al.*, 2002; Roff, 2002), as the case of chondrichthyans. Accordingly, studies on life history traits are indispensable for the protection, conservation and fishery management of these top predators that have an important role in the ecosystem.

### 3.3. Mediterranean chondrichthyans

The Mediterranean Sea is identified as one of the three main hotspots where the diversity of sharks and rays is particularly seriously threatened (Dulvy *et al.*, 2014). It holds 80 chondrichthyan species comprising 45 shark species from 17 families and 34 batoid species from 9 families and one chimaera species (almost 7% of total living chondrichthyans in the world) (Compagno, 2001; Compagno *et al.*, 2005; Serena, 2005a; Cavanagh and Gibson, 2007). Out of these, 71 were assessed by the International Union for the Conservation of Nature (IUCN), where 42.25 percent are Vulnerable and Endangered to Critically Endangered, 18.31 percent are Near Threatened and 25.35 percent are Data Deficient (Cavanagh and Gibson, 2007) (Table 2).

Table 2: The number of chondrichthyan species in each IUCN Red List category (Cavanagh and Gibson, 2007).

IUCN Red List categories	Number of species
Critically endangered (CE)	13
Endangered (E)	08
Vulnerable (VU)	09
Near Threatened (NT)	13
Least Concern (LC)	10
Data Deficient (DD)	18
Not Evaluated (NE)	0
Total number of species	71

Bradai *et al.* (2012) took into account new published data on the systematic of elasmobranchs and critically analyzed literature data to consider the presence of a total of 86 species of elasmobranchs in the Mediterranean Sea. According to these authors, these species consisted of 49 shark species from 17 families and 37 batoids species from 9 families.

Only 4 batoid species (*Leucoraja melitensis*, *Raja polystigma*, *Raja radula* and *Mobula mobular*) could be considered endemic (Serena, 2005a) with *Leucoraja melitensis* considered endemic threatened (Dulvy *et al.*, 2014).

The highest concentration of elasmobranchs are observed in the coastal waters of the western Mediterranean, especially along the northwestern coast (Figure 7) (Coll *et al.*, 2010), probably owing it to the highly oligotrophic nature of the eastern basin (Azov, 1991). This confirms the lack of homogeneity in the distribution of elasmobranchs in this area (Serena, 2005a).

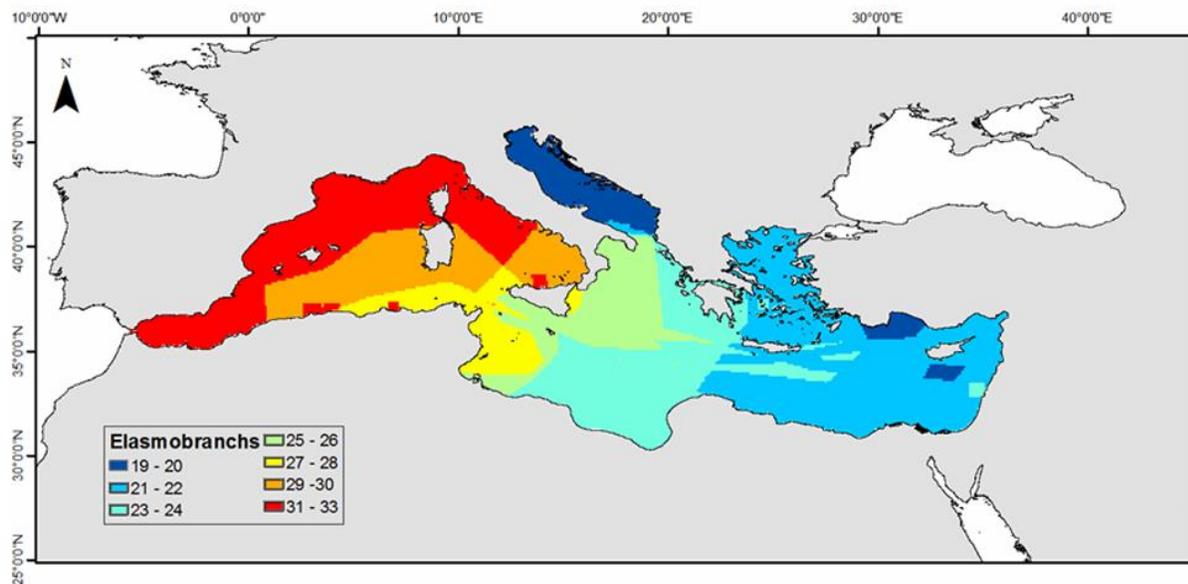


Figure 7: Spatial patterns of elasmobranchs richness in the Mediterranean Sea (Coll *et al.*, 2010).

Furthermore, various species exhibit different distribution patterns. For instance, the small tooth sand tiger shark *Odontaspis ferox* seems to inhabit a particular area of Lebanon (Cavanagh and Gibson, 2007). The rather rare Basking Shark *Cetorhinus maximus* is constantly present in the eastern Adriatic, where its occurrence highly increased between 2000 and 2002. In addition, aggregations of this latter shark have been observed in the northern Balearic, the northern Adriatic, and the Tyrrhenian Sea (Walker *et al.*, 2005; Soldo *et al.*, 2008). Finally, the Great

White Shark, *Carcharodon carcharias*, the Sandbar shark *Carcharhinus plumbeus*, and probably many other species have nursery areas in Tunisian waters (Saidi, 2008; Enajjar, 2009).

### **3.4. Mediterranean chondrichthyan fisheries and threats**

The state of cartilaginous fish (chondrichthyans) in the Mediterranean Sea is much more devastating than it is worldwide: 42% of the shark species are threatened in the region in comparison with 17% globally, hence, describing the Mediterranean as the most dangerous sea in the world for cartilaginous fishes (Cavanagh and Gibson, 2007).

Elasmobranchs fish catches represent only 1.1 percent of the total landings in the Mediterranean Sea (Serena, 2005a). According to the Food and Agricultural Organization (FAO), chondrichthyan fish landings in the Mediterranean increased from 10000 to 25000 tons between 1970 and 1985; however, declines were then reported to 1000 tons by 2004 (SGRST, 2003; FAO, 2006). Moreover, large and smaller commercially significant species have marked a decline in different areas of the Mediterranean (Ferretti *et al.*, 2008; Dell'Apa *et al.*, 2012; Ferretti *et al.*, 2013; Ligas *et al.*, 2013). The major chondrichthyan fishing countries within the Mediterranean are Turkey, Tunisia, Greece, Italy and Spain and the species most commonly taken in coastal fisheries are: smoothhounds *Mustelus* spp., skates *Rajids*, catsharks *Scyliorhinus* spp., dogfish *Squalus* spp., eagle rays *Myliobatids* and whiptail stingrays *Dasyatids* (Walker *et al.*, 2005).

Bycatch and intensive fishing activities are severe threats for cartilaginous fish species (Cuttelod *et al.*, 2008) (Figure 8). Bycatch that is returned to sea is not reported and the number of sharks caught as bycatch cannot be exactly estimated (Camhi *et al.*, 1998; Walker *et al.*, 2005).



Figure 8: A Shortfin Mako, *Isurus oxyrinchus*, caught as bycatch in Lebanon, Levantine Basin of the Mediterranean Sea.

Although the Mediterranean lacks pelagic fisheries targeting migratory oceanic sharks, longline fisheries targeting valuable teleost (swordfish and tunas) strictly threaten chondrichthyans taken as bycatch in this fishery (ICCAT, 2001). Mortality in mixed species fisheries and bycatch fisheries also pose very significant threats to chondrichthyans (Musick and Bonfil, 2005; Stevens *et al.*, 2005). Furthermore, benthic trawls and increased fishing intensities due to the advancement of fishing gear have resulted in a decline for many chondrichthyan species especially in the northwestern Mediterranean (Walker *et al.*, 2005). For instance, large coastal shark species are more seriously affected by bycatch because they are more exposed to intensive fishing (Cavanagh and Gibson, 2007). In addition, chondrichthyans are also targeted by recreational sport fisheries that have increased especially off the Italian, Spanish and French coasts targeting species such as the Thresher Sharks *Alopias* spp. and the Blue Shark *Prionace glauca* (Cavanagh and Gibson, 2007).

The increase in human population also has adverse effects on the chondrichthyans of the Mediterranean. Critical coastal habitats of elasmobranchs have been degraded due to booming urban and industrial development (Camhi *et al.*, 1998; Stevens *et al.*, 2005). Furthermore,

pollution also negatively affects chondrichthyans in the Mediterranean by contaminating food resources (UNEP-MAP and RAC/SPA, 2003). Trace metals have been found in the organs of several elasmobranchs, such as the Gulper Shark *Centrophorus granulosus* (Hornung *et al.*, 1993).

In addition, a total of eight alien chondrichthyans were recorded in the Mediterranean from Atlantic or Indo-Pacific origins (Table 3). *Himantura uarnak* and *Torpedo (Torpedo) Sinuspersici* were observed in the Eastern Mediterranean (Ali and Saad, 2003; Saad *et al.*, 2004; Ali *et al.*, 2010). There are almost no records regarding the potential competition of these species with local ones (for habitat or food). Until now and up to the general knowledge, these species haven't constituted any threats for cartilaginous fish populations in the area.

Table 3: The alien chondrichthyans of the Mediterranean Sea.

<b>Chondrichthyan alien species</b>	<b>Probable origin</b>	<b>Reference</b>
<b>Bignose Shark <i>Carcharhinus altimus</i> (Springer, 1950)</b>	Tropical Atlantic	Golani (1996) Moreno and Hoyos (1983) Hemida and Labidi (2002)
<b>Silky Shark <i>Carcharhinus falciformis</i> (Müller and Henle, 1839)</b>	Tropical Atlantic	Moreno (1987) Hemida and Labidi (2002) Bradai <i>et al.</i> (2002) Bradai <i>et al.</i> (2004)
<b>Tiger Shark <i>Galeocerdo cuvier</i> (Péron and Lesueur, 1822)</b>	Tropical Atlantic	Pinto De La Rosa (1994) Celona (2000)
<b>Milk Shark <i>Rhizoprionodon acutus</i> (Rüppell, 1837)</b>	Tropical Atlantic	Pastore and Tortonese (1984)
<b>Squat-headed Hammerhead Shark <i>Sphyrna mokarran</i> (Rüppell, 1837)</b>	Atlantic	Boero and Carli (1979)
<b>Reticulate Whipray <i>Himantura uarnak</i> (Gmelin, 1789)</b>	Indo-Pacific	Ben-Tuvia (1955) Ben-Tuvia (1966) Mouneimne (1977) El Sayed (1994),

		Basusta <i>et al.</i> (1998)
<b>Halavi Guitarfish</b> <i>Glaucostegus halavi</i> (Forsskäl, 1775)	-	Souissi <i>et al.</i> (2007)
<b>Marbled Electric Ray</b> <i>Torpedo (Torpedo) sinuspersici</i> (Olfers, 1831)	Indo-Pacific	Saad <i>et al.</i> (2004)

Finally, climate change can have a potential effect on fish, especially chondrichthyans. The increase in temperature of marine domains and changes in other environmental variables can lead to declines in fish populations and biomasses due to climate changes. Increased temperatures are expected to change the phenology of fish life cycles and change the forage resources of fishes differentially thus likely leading to very difficult-to-predict community changes relating to mis-matches of co-evolved predator-prey relationships (Hobday *et al.*, 2006). Climate change induces effects at the global level, with effects in the Mediterranean too (Lejeune *et al.*, 2010). Mediterranean ecosystems may be among the most impacted by global change drivers (Sala *et al.*, 2000). Lyne *et al.* (2003) conservatively projected that the expected increases in Australian ocean temperatures would cause a 35% overall economic decline of Australian fisheries by 2070, and that temperate Australian fisheries will be more vulnerable than tropical ones. Moreover, regarding cartilaginous fish species, Chin *et al.* (2010) showed that for the Great Barrier Reef in Australia, freshwater/estuarine and reef associated sharks and rays are most vulnerable to climate change, and that vulnerability is driven by case-specific interactions of multiple factors and species attributes. Changes in temperature, freshwater input and ocean circulation will have the most widespread effects on these species.

### 3.5. Various management tools for coastal ecosystems

Currently, at national and international levels, political, scientific and managing parties have an important set of tools for ecosystem management coastlines.

A number of measures targets particularly professional fishing and concerns limitation measures. For instance, governments have quotas to reduce fishing effort. These measures consist to establish quotas on total catches, to reduce the number and power of vessels, fishing time, number of fishing gear on board, etc.

The decrease in fishing effort can also result from introducing mesh regulations, and fishing periods depending on the species. Such measures are generally not well received by professional fishermen because of their restrictive character. Moreover, these measures are considered little effective currently, mainly because policies find it difficult to enforce on the field these management measures (Pauly and Watson, 2003). Another measure that seems more accepted by professional fishermen is setting fishing areas. This tool consist to establish no-fishing zones for all or part of species, over a predefined period (months to years) and area. But today, two other management tools are put forward by politicians and managers for their protective power of marine resources and of restoration of biodiversity: Marine Protected Areas (MPA) and Artificial Reefs (AR) (Claudet and Pelletier, 2004). The positive effects of MPA have been widely shown internationally, and they benefit from over 30 years of experience (Mosquera *et al.*, 2000; Claudet and Pelletier, 2004). At a longer term, one of the benefits of MPAs for fisheries is the “spillover effect” (area around the no-take zone will benefit fishermen due to the overproduction of fish) (Goñi *et al.*, 2008; Forcada *et al.*, 2009).

However, the MPA are often regarded by professionals and recreational fishers as areas where all human activities are prohibited and therefore negatively perceived by those users. Unlike MPA, ARs do not suffer from this negative view. Thus, this management tool is experiencing a real boom in many countries for 20 years (Baine, 2001; Tessier *et al.*, 2015).

Moreover, in the last three decades, several important conventions have highlighted the need for shark conservation and management globally and regionally:

- Convention on the Conservation of European Wildlife and Natural Habitats, Bern 1979
- Convention on Migratory Species, Bonn, November 1983
- Protocol for Specially Protected Areas and Biological Diversity in the Mediterranean (SPA-BD), the Barcelona Convention, June 1995
- United Nations Food and Agriculture Organisation, International Plan of Action for the Conservation and Management of Sharks, 1999 (FAO/IPOA-Sharks)
- Convention on International Trade in Endangered Species (CITES) November 2002

- United Nations Environment Programme, Mediterranean Action Plan for the Conservation of Cartilaginous Fishes, November 2003

Several reports were established reflecting the status and conservation of chondrichthyans. Séret and Serena (2002), Abdulla (2004), UNEP-MAP and RAC/SPA (2007), Cavanagh and Gibson (2007) gave a reflection on the conservation of cartilaginous fish in the Mediterranean highlighting the threatened status of several sharks and rays including the impacts of overfishing, shark finning, bycatch, pollution and habitat loss on this fish class.

In 2003, the Regional Activity Centre for Specially Protected Areas (RAC/SPA), in the framework of the United Nations Environment Programme (UNEP), created an action plan for the conservation of cartilaginous fishes (Chondrichthyans) in the Mediterranean Sea containing important objectives and implementation measures (UNEP-MAP and RAC/SPA, 2003). This action plan aimed to promote the conservation of cartilaginous fish populations, the protection of selected species (endangered), the protection and restoration of critical habitats, the improvement of scientific knowledge, the recovery of depleted stocks, and the induction of public awareness about the conservation of this fish class.

### **3.6. Eastern Mediterranean chondrichthyans**

The Eastern Mediterranean as shown previously consists of the Aegean (3.1) and Levant (3.2) subareas of Fishing Area 37 according to FAO. It is characterized by being more oligotrophic and having a lower species diversity than the Western Mediterranean (Azov, 1991).

The presence of chondrichthyans is described in several areas of the Eastern Mediterranean through several studies performed in the region. In its northeastern region, chondrichthyans were majorly reflected in studies concerning the Aegean Sea and the southern coast of Turkey (Kaya, 1993; Papaconstantinou *et al.*, 1994; Kabasakal, 2001; Kabasakal and Kabasakal, 2002; Filiz and Bilge, 2004; Kabasakal and Kabasakal, 2004; Kabasakal and Kabasakal, 2013; Kapiris *et al.*, 2014; Yapici and Filiz, 2014; Yigin and Ismen, 2014). A few were carried out in Syria (Ali and Saad, 2003; Ali *et al.*, 2010; Ali *et al.*, 2012; 2013). On the other hand, chondrichthyans in the southeastern part of the Eastern Mediterranean were reflected through studies carried from the northern coast of Egypt to the coast of Israel (Ben-Tuvia, 1955; 1966; AbdelAziz, 1986; Golani, 1986; AbdelAziz *et al.*, 1987; Ezzat *et al.*, 1987).

Nonetheless, almost no studies dealing with cartilaginous fish species were performed along the Lebanese coast, the study area, providing no scientific evidence describing these populations or managing their exploitation in that area. Chondrichthyans were only mentioned in several fish inventories (Boulos, 1968; Mouneimne, 1977; 1978; 1979; Azov, 1991; Mouneimne, 2002) and underwater visual census surveys (Harmelin-Vivien *et al.*, 2005) carried along the Lebanese coast.

The Lebanese fishery being artisanal and traditional (Majdalani, 2004; Fowler, 2005) is composed of small scale artisanal vessels. Trawlers are legally forbidden. According to Martin *et al.* (2006), the Lebanese production of elasmobranchs was 60 tons in 2003 accounting for 2% of all groups caught. Some elasmobranch catches are incidental and others target certain commercially important species such as the Common Guitarfish *Rhinobatos rhinobatos* (Linnaeus, 1758) and the Gulper Shark *Centrophorus granulosus* (Bloch and Schneider, 1801) (Figure 9).



Figure 9: Gulper Shark (a) and Common Guitarfish (b) catches in fisheries along the Lebanese coast.

Several manners were issued by the Ministry of Agriculture aiming to protect these species. According to the “General Fisheries Commission for the Mediterranean” recommendation

GFCM/36/2012/3 and the Barcelona Convention, the Ministry of Agriculture issued decree number 1/1045 as of 13/12/2013, which set standards and prohibitions on fishing or selling certain species of sharks and rays such as the guitarfish *Rhinobatos* spp., the hammerheads *Sphyrna* spp., and other commercially targeted species (ANNEX III). Unfortunately, fishing is maintained and the law is not being efficiently implemented. Other elasmobranch species are also targeted by artisanal fishermen. For example, many heavy weighted sharks or rays such as members of the Hexanchidae, Carcharinidae or the Lamnidae for sharks and the Dasyatidae and Myliobatididae families for batoids are often encountered in fisheries in some Lebanese regions northern (Tripoli) and southern (Sidon) of the country. Such fish caught are cleaned and cut into fish filets to be sold to restaurants or walking-by customers with prices ranging from \$4 to \$6 per one kilogram.

#### **4. Objectives of the study**

The beginning of research work on cartilaginous fish species along the Lebanese coast was a necessity. Indeed, this fish class has been progressively exploited along the coast of Lebanon and the ministry decrees are not being executed in an effective manner. Also, there is almost no written knowledge reflecting the presence and the distribution of species of this fish class along the Lebanese coast. Their presence is often documented and presented in various regions of the Mediterranean and its eastern basin; nonetheless, gaps exist all along the Lebanese coast. Therefore, the lack of data, exploitation and lack of management of this fish class is the basic stimulator for this study.

This thesis aims to contribute to a better knowledge of cartilaginous fishes in the Lebanese marine environment. Emphasis was placed on the following axes:

- 1- The establishment of an inventory of chondrichthyans along the Lebanese coast and a bibliographic revue dedicated to cartilaginous fish species in the Eastern Mediterranean.
- 2- The description of spatio-temporal biodiversity and distribution of chondrichthyans along the Lebanese coast.
- 3- A focus on the biology and ecology of two threatened and commercially significant elasmobranch species (one shark and one batoid species).

Some chapters of the thesis are presented under the form of articles. Following the present general introduction, constituting **Chapter I**, the thesis is divided as follows:

**Chapter II** is dedicated to the presentation of the general “Material and Methods” section containing a description of the studied area and the experimental methodologies and statistical tests and analyses employed through the course of this study.

A bibliographic review describing all the studies on cartilaginous fish species in the Eastern Mediterranean is presented in **Chapter III**. It summarizes all published information on inventories, occurrence, distribution, status, conservation, age and growth, length-weight relationships, reproductive aspects, nutrition and feeding habits and other life history aspects of the cartilaginous fish species in the Eastern Mediterranean.

**Chapter IV** is dedicated to the representation of the spatio-temporal biodiversity and distribution of cartilaginous fish species in the study area using two complementary data collection methods: (a) the CIHEAM PESCA-Libano scientific survey carried out with the involvement of the Ministry of Agriculture and the National Center for Marine Sciences – Lebanese National Council for Scientific Research (CNRSL) and (b) fishery and fishermen catch data. In this section, the Catch Per Unit Effort (CPUE) was used to present the spatio-temporal distribution of these species, and several biodiversity indices were calculated to present their spatio-temporal biodiversity. This chapter also consists of a short communication presenting the length-weight relationships of three sharks and five batoids collected through the course of this study.

Then, a study of the biology and ecology of an Endangered batoid, the Common Guitarfish, *Rhinobatos rhinobatos*, which is a commercially significant species in Lebanese fisheries is presented in **Chapter V**. This chapter aims to a better understanding of the population dynamics parameters models of this exploited fish stock in order to ensure the long-term sustainability of this fishery.

**Chapter VI** presents the biology and ecology of the Gulper Shark, *Centrophorus granulosus*, classified as Vulnerable by IUCN, which is also an exploited species either as bycatch or targeted. This chapter also aims to describe the characteristics of life-history traits of this deep-water exploited shark population in order to protect, manage and maintain it.

Finally, the general discussion, conclusion, and perspectives of this work are presented in the last chapter (**Chapter VII**) and several annexes are included at the end of the thesis to complete certain aspects.

# **Chapter II**

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## **Material and Methods**

## Chapter II: Material and Methods

### 1. Characteristics of the study area

#### 1.1. Overview of the region

Lebanon is one of the smallest countries in the world having area of 10452 km<sup>2</sup>. It is located in the Levantine basin of the Mediterranean Sea, bordered by Syria from the north and east and occupied Palestine from the south. In general, Lebanon enjoys a typical Mediterranean climate with two very contrasting seasons: a winter that is cold and heavily wet and a summer that is long, hot and dry and two intermediate seasons (spring and autumn). Along the coast, winters are relatively mild and rainy where the annual temperature is relatively low, around 13 to 15°C (Abboud Abi Saab *et al.*, 2012). In some cases, this temperature can decrease up to 30°C or 4°C especially in December and January. During summer, temperatures are relatively high and can reach 30 to 35°C and even a 38°C temperature was observed in July and August (United Nations Development Program, 1970; Compendium Statistique National, 2006; Abboud Abi Saab *et al.*, 2012). Moreover, according to Abboud Abi Saab *et al.* (2013) the mean monthly variation of sea surface temperature between 2000 and 2012 varied between a minimum of 17.82°C in March and a maximum of 29.71° C in August, and the mean monthly variation of air temperature varied between a minimum of 12.4°C in January and a maximum of 27.59°C in August (Figure 10). The diurnal range remains close to 7°C throughout the year (Abboud Abi Saab, 1985). This study was carried out along the coast of Lebanon, which is situated between the north latitudes of 33°05'45.6'' and 34°38'45.6'' and east longitudes 35°06'10.8'' and 35°58'37.2''.

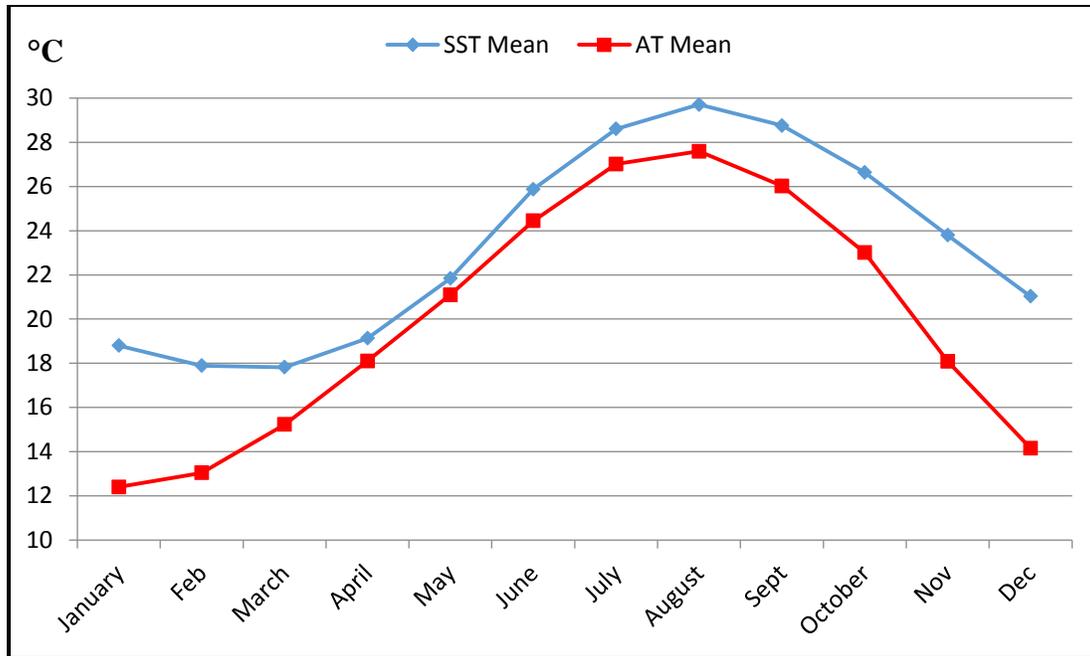


Figure 10: Mean monthly variations for 2000-2012 period of Sea Surface Temperature (SST) and Air Temperature (AT) in Lebanese marine waters (eastern Mediterranean) (Abboud Abi Saab *et al.*, 2013).

## 1.2. The Lebanese coast

The coast of Lebanon is narrow, 3 to 7 km wide. It extends for 220 km from Aarida in the north to Ras Al Naqoura in the south covering 16% (180000 hectares) of Lebanese territory. Land rises sharply from the coast in the north, while forming a narrow coastal plain in the south. The continental shelf is narrow, especially in the south, and the bottoms are majorly rough with wide rocky patches that serve well for standing demersal gear (Majdalani, 2004). The coast is characterized by the presence of a few bays (Bay of Beirut, Bay of Jounieh, Bay of Shekka and Bay of Akkar). Moreover, real cliffs are rare and exceptionally exceed 30 m in height. The Lebanese coast appears almost straight with a slight skew relative to the Palestinian and Syrian coasts. Despite its small area, it is very fertile and considered as the richest region. It has been occupied by urban civilizations since the original “Phoenician” civilization. Nowadays, it is threatened by urban extension as it brings together the main cities. To face some of this threat, two coastal nature reserves/marine protected areas were created by national decrees.

According to the Lebanese Ministry of Environment-IUCN (2012), two marine protected areas are present in Lebanon: the “Palm Islands Nature Reserve” (Decree 121, 09/03/1992) in the north and the “Tyre Coast Nature Reserve” (Decree 708, 05/11/1998) in the south.

#### *Palm Islands Nature Reserve (PINR)*

The PINR is 5.5 km far from the coast of Tripoli. It is formed of 3 islands: Sanani (0.04 km<sup>2</sup>), Ramkine (0.016 km<sup>2</sup>) and Palms (0.2 km<sup>2</sup>). Its area (including 500 m of sea around the islands) is nearly 4.2 km<sup>2</sup>. They are hot stopovers used by sea-crossing migratory birds and the only sites in Lebanon for sea bird breeding. They also comprise a habitat of plants that is no longer found on the eastern Mediterranean littoral, including threatened and endemic species, and important sites for threatened marine turtles and endangered and globally threatened bird species. This reserve, thus, constitutes in general an important area for marine diversity and habitats.

These islands are only open to visitors from July to September. Rangers are always present during the visitation season (July-September) to protect, survey and control visitors and poachers. Recently, the reserve’s rangers were empowered to issue fines to a poacher or anyone breaking the law. Management plans were prepared by the Ministry of the Environment (MoE) in Lebanon through the consultation of experts from various organizations, such as, IUCN, in order to manage the marine and terrestrial parts of the reserve (Lebanese Ministry of Environment-IUCN, 2012).

#### *Tyre Coast Nature Reserve (TCNR)*

The TCNR amounts to an area of 3.8 km<sup>2</sup> divided into three zones; tourism zone, agricultural and archeological zone, and conservation zone. It is an important nesting site for globally endangered Mediterranean Loggerhead and Green sea turtles, a site containing a wide diversity of ecosystems; marine, agriculture, wetland, that have Mediterranean characteristics. The TCNR is also located on major migratory routes where internationally important bird species have been identified. It has also been a Ramsar site (No. 980) since 16/04/1999. Similarly many management plans were prepared by the MoE through the consultation of experts from various organizations aiming for the protection and the conservation of this reserve (Peillen *et al.*, 2012).

### 1.3. Currents and bathymetry

A general surface current from the Atlantic Ocean passes through the Strait of Gibraltar into the Mediterranean. The major part of this current move eastwards parallel to the North African coast but progressively loses force as it approaches eastwards. This current maintains its track southeast passing through the cap of Tunisia, the Libyan and the Egyptian coasts. It then turns and continues along the Palestinian, Lebanese and Syrian coasts. The intensity of this current and the quantity of water reaching the Levantine basin depends on its flow through the Strait of Gibraltar (Nakhle, 2003). Therefore, the general circulation along the coast of Lebanon is dominant northwards during most of the year along with the general counterclockwise current gyre of the Eastern Mediterranean. This current is locally modified by the configuration of the coastline and the topography of the narrow continental shelf. This results in a series of clockwise directed eddies and small gyres associated with bays and headlands as well as with numerous submarine canyons incised in the continental shelf (Goedicke, 1972). Water movements along the coast are also strongly related to surface currents and seasonal meteorological factors.

The bathymetry of the coast is barely investigated. However, ultrasound probe bathymetry results from Pfannenstiel (1960) and Emery *et al.* (1966) show a very narrow continental shelf (3 - 4 km) up till the 200 m isobaths situated 8 to 10 km south and 20 km north. The mean depth of the continental shelf is 20 to 40 m (Goedicke, 1972), and the slope is parallel to the coast, of 1100 to 1400 m depth, and at a distance of 25 to 30 km from the coast before reaching the abyssal plain. The most recent update of bathymetry along the Lebanese coast was performed in fall of 2003 by the Shalimar marine survey. This survey was carried out as part of a French-Lebanese collaborative program to study recent deformation along the Lebanese margin of the Levantine basin. The main objectives were to study the deformation of recent sedimentary layers, map potentially active faults on the seafloor, and identify possible seismic ruptures. During the survey, bathymetric mapping was carried out using a Simrad EM-300 multibeam echo sounder providing high-resolution bathymetric and backscatter data, at a vessel speed of 7.5 to 10 knots over an area of 11,000 km<sup>2</sup> at depths greater than 200 m (Carton *et al.*, 2009) (Figure 11).

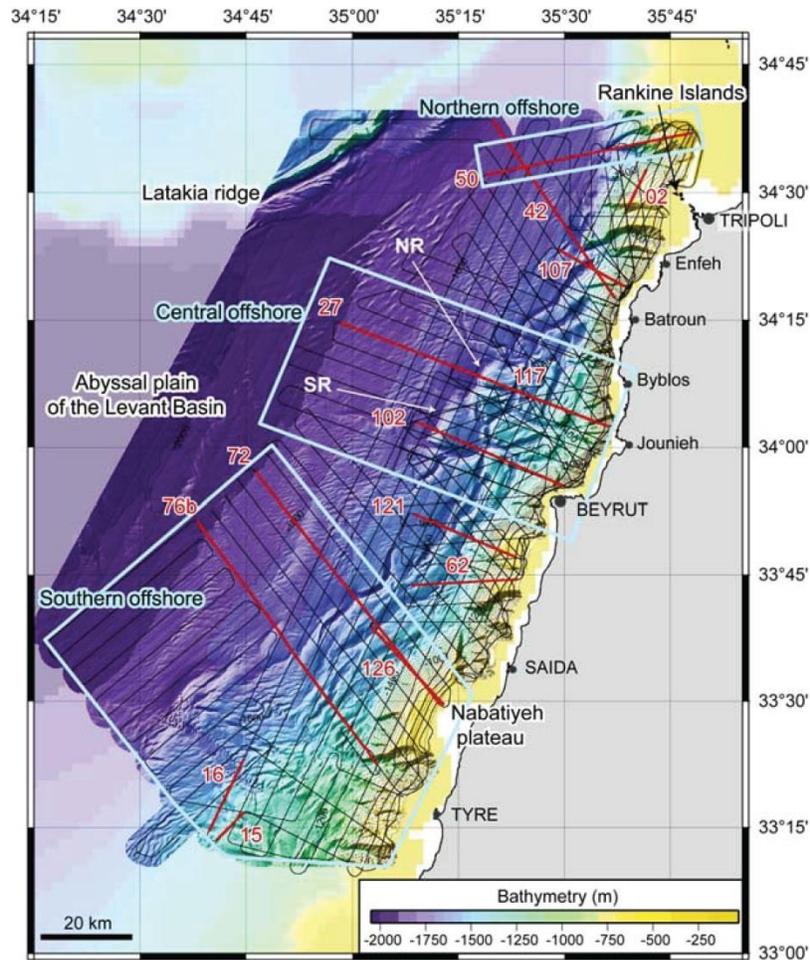


Figure 11: Bathymetric mapping of the Lebanese coast at depths greater than 200 m by the Shalimar cruise in 2003 (Carton *et al.*, 2009).

#### 1.4. The fishery sector

The Lebanese fishery is artisanal and traditional (Majdalani, 2004; Fowler, 2005). The Lebanese fishing fleet is composed of small scale artisanal vessels less than 12 m in length and typical of many Mediterranean countries (Brême, 2004; Majdalani, 2004; Carpentieri and Colloca, 2005; Majdalani, 2005; Lelli *et al.*, 2006; Martin *et al.*, 2006; PescaMed, 2011; Sacchi and Dimech, 2011).

According to the Ministry of Agriculture, a total number of 42 ports are distributed along the Lebanese coast. The majority of these ports do not comply with the technical conditions for the improved development of the fishing sector whether with respect to equipment or management (Majdalani, 2004). The largest fishing ports are distributed according to the governorates as

follows: Abdeh, Tripoli and Batroun ports in the North, Dora Port in Mount Lebanon, Ozaaii Port in Beirut, and Sidon and Tyre Ports in the South (Figure 12).

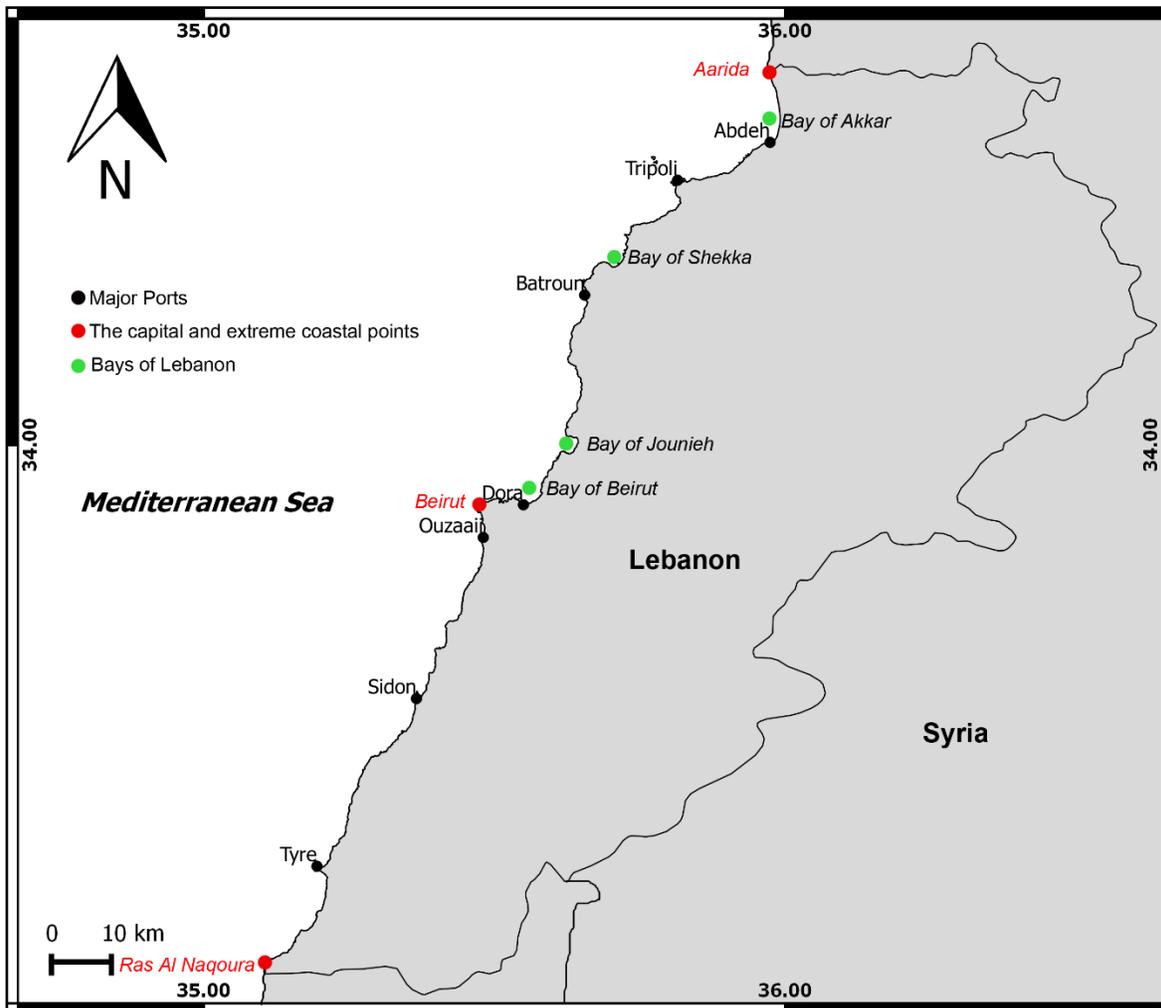


Figure 12: The location of the capital Beirut, the 7 major ports, and the two extreme points along the coast of Lebanon.

According to Pinello and Dimech (2013) the Lebanese fishing fleet consists of 1,460 licensed commercial fishing vessels. Only 24% of the total fleet is operating from Beirut; however, 42% of the fleet capacity is concentrated in Tripoli while only 23% operates in the southern part of the country.

The most common gear used includes trammel nets, longlines, purse seine nets, and lampara nets (Majdalani, 2004; Sacchi and Dimech, 2011). Trawling is legally forbidden although fishing nets with illegal mesh sizes are widely available in the black market (Fowler, 2005). Most of the

gillnets and trammel nets have small mesh sizes and represent more than 50% of the fishing gears used in most part of Lebanese fishing (Pinello and Dimech, 2013). Only few vessels have a Global Positioning System (GPS), while the rest have very limited navigational or safety equipment, and only 20% of the vessels have small electronic fish finders (Majdalani, 2004; Sacchi and Dimech, 2011).

According to Pinello and Dimech (2013), the marine capture fisheries production in Lebanon in the last 10 years was around 3,500 tons per year. The data was derived from the FAO Fisheries and Aquaculture Department. From 2006 onwards the production has remained constant at 3,541 tons due to the fact that Lebanon has stopped sending data to FAO. Therefore, this data does not reflect the status of the Lebanese fisheries production.

## **2. Data collection**

Data collection was carried out from December 2012 to October 2014 in three different manners in order to target a maximum number of cartilaginous species along the Lebanese coast.

### **2.1. CIHEAM PESCA-Libano**

Data collection was aided by the CIHEAM PESCA-Libano project. The CIHEAM PESCA Libano project with the involvement of the Ministry of Agriculture and the National Center for Marine Sciences – Lebanese National Council for Scientific Research (CNRSL) assessed the potentiality of the marine coastal resources in order to support the Lebanese Government in strengthening the management of the marine resources. A survey in the framework of this project was done in 2012 and 2013, where three types of gears were lowered in 62 different sites along the coast of Lebanon and at depths ranging from 10 to 600 m (Figure 13).

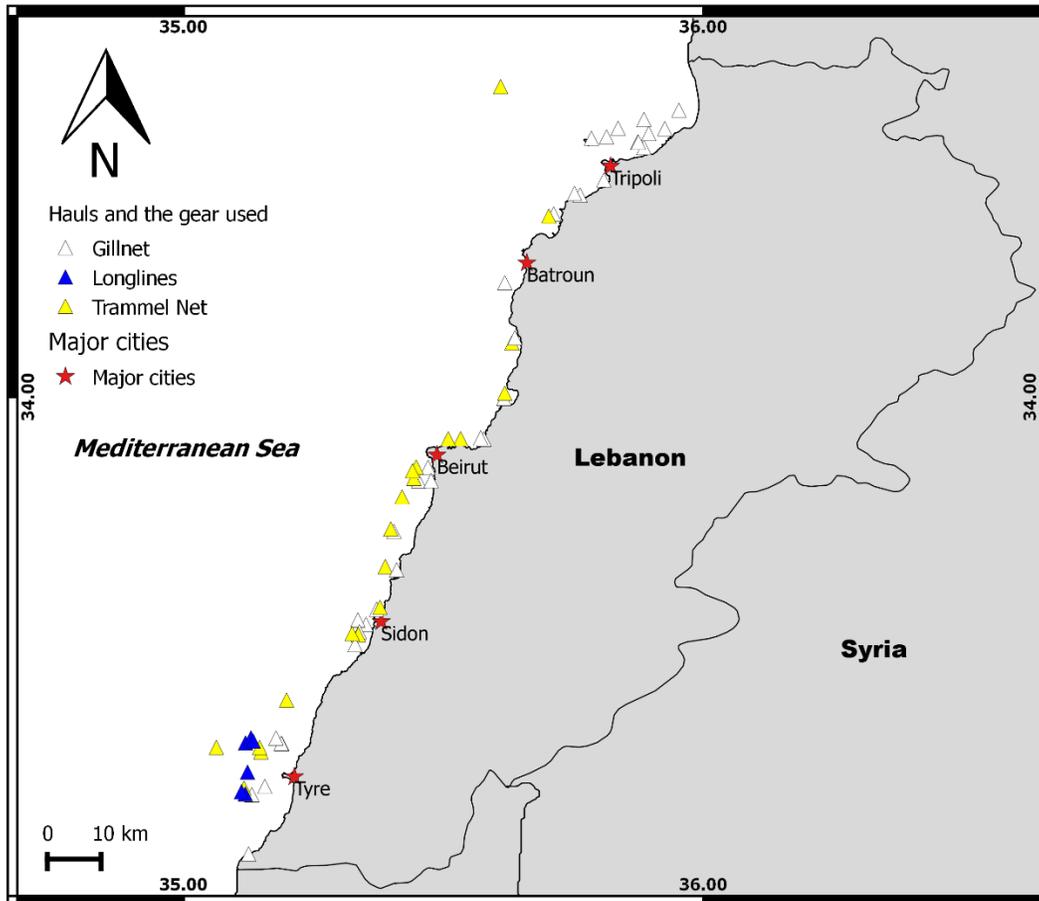


Figure 13: The hauls of the CIHEAM PESCA-Libano survey along with the gear used at each haul.

Gillnets with mesh sizes of 26, 30 and 40 mm (of length 1 km connected together) were lowered at depths less than 100 m; trammel nets with mesh sizes of 22, 24, 26, 28 and 30 mm (of length 1 km connected together) were lowered at depths greater than 100 m. Longlines of size 5 hooks were lowered at specified depths mainly in the south because it was an additional lowering in the survey. Unfortunately, this gear was not lowered in all the region.

Cartilaginous fish data were collected from the CIHEAM PESCA-Libano project along with the type of gear, the coordinates and the depth of each catch.

Six artisanal fishermen from six different ports in Lebanon were hired to lower the gear at the hauls with the specified coordinates. The technical features of the vessels are represented in Table 4.

Table 4: The technical features of the vessels used in the CIHEAM PESCA-Libano survey.

Vessel number	Port	Gross tonnage (t)	Length (m)	Engine power in horse power (hp)
1	Tyre	3.7	10	85
2	Byblos	3	11	85
3	Jounieh	2	8.75	36
4	Ozaaii	5	9	60
5	Sidon	3.5	8.80	24
6	Dora	3	8.75	24

The crew usually included two to four people (with a minimum of one scientific) and a maximum of two hauls were carried out per day depending on the weather conditions and the technical conditions of the vessel. The right point was reached by means of a global positioning system (GPS) instruments and a sonar was used to confirm the depth. The depth of each haul, observed coordinates, and the meshes of the nets used were recorded. Nets were not loaded in baits; however, the hooks of the longlines were always loaded with baits from chopped fish, such as, herrings (*Etrumeus teres*), mackerels (*Scomber scomber*) or tunas (*Euthynnus alletteratus*).

## 2.2. Fishermen

Data collection had also been performed by randomly hiring fishermen throughout the Lebanese coast with the collaboration of the Lebanese National Council for Scientific Research (CNRSL) - National Center for Marine Sciences - to lower longlines at depths ranging from 30 to 600 m aiming to catch cartilaginous species. Most of the Lebanese artisanal fishermen do not have GPS instruments, so the exact position of the data collected by this manner was not recorded; however, the depth was noted as observed by the professional fishermen.

## 2.3. Fisheries

Data collection has also been performed through observation of major fisheries along the Lebanese coast. The main fishery visited was a principal one in Tripoli, where there are constant cartilaginous catches. Fisheries were visited a minimum number of 5 times per month, and data was collected when specimens were available.

### 3. Morphometric measurements

The species were identified according to the Field Identification Guide to the Living Marine Resources of the Eastern and Southern Mediterranean (Bariche, 2012) and Fishes of the Eastern Mediterranean (Golani *et al.*, 2006).

Prior to dissection, the cartilaginous fish samples were examined for external damages and sexed macroscopically by the observation of the male claspers (Figure 14). The presence of claspers in cartilaginous fish indicated a male gender. The external length of the claspers ( $L_C$ ) in male specimens was measured from the tip of the clasper to the base of the pelvic fin using a caliper to the nearest millimeter (mm). The sex ratio (males to females) was calculated for each species of cartilaginous fish observed. A list of all the abbreviations of all parameters and their units of measurement in the Materials and Methods section are presented in ANNEX IV.



Figure 14: A photograph of the claspers in a male *Centrophorus granulosus* (a) and their absence in a female individual (b) of the same species.

The total length ( $L_T$ ) was considered to be the length from the tip of the snout to the posterior tip of the caudal fin along the anterior-posterior axis. It was measured to the nearest centimeter

below the actual length of the fish using a measuring tape. The fork length ( $L_F$ ) was measured from the tip of the snout to the fork of the tail, and the standard length ( $L_S$ ) was measured from the tip of the snout to the origin of the caudal fin also to the nearest centimeter. The total weight ( $W_T$ ) (less than five kilograms) was measured to the nearest gram (g) using an electric balance. A total weight greater than five kilograms was measured using a scale to the nearest 100 g.

#### 4. Biological indices and sexual maturity

Dissection was performed and additional measurements were taken. The liver, digestive tube and gonads were removed along with the expanded uteri in the case of a gravid female (Figure 15). The weight of the liver ( $W_L$ ) and the weight of the gonads ( $W_G$ ) including the weight of the testis in males and oviductal glands, accessory glands, ovary and oviducts in females (Gristina *et al*, 2006) were measured to the nearest gram (g) using an electronic balance. These measurements were used to calculate important biological indices, such as, the hepato-somatic index ( $I_H$ ), the gonado-somatic index ( $I_G$ ) and the condition factor ( $K$ ). After the removal of the digestive and reproductive systems, the eviscerated weight of the fish ( $W_E$ ) was also recorded.

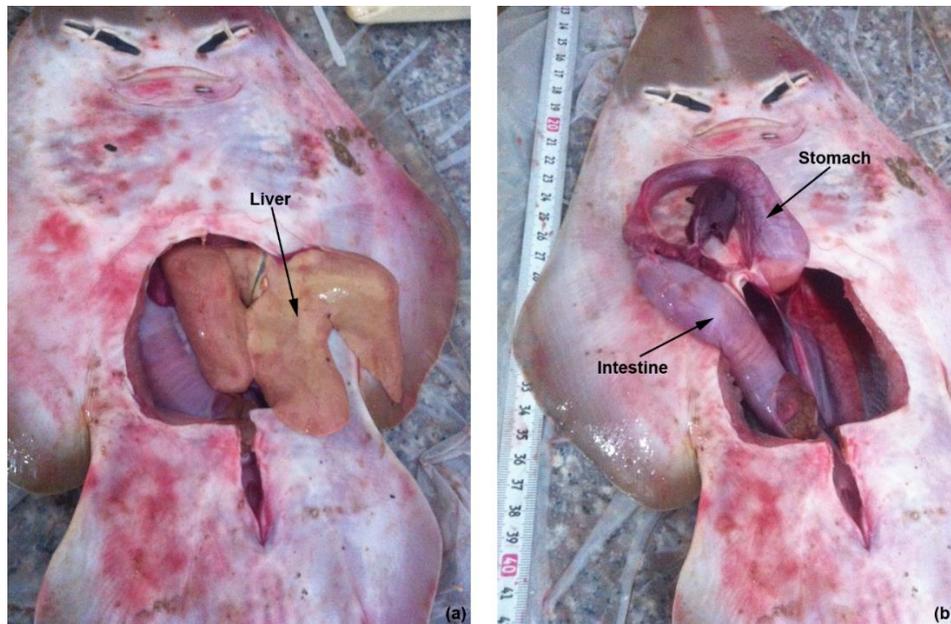


Figure 15: A photograph of a dissected *Rhinobatos rhinobatos* prior to (a) and after (b) liver removal.

#### 4.1. Hepato-somatic index

The knowledge of the hepato-somatic index in fish is very indispensable for the study of its biological functions because the liver is an important energy storage in fish (Halton *et al.*, 2001). The hepato-somatic index ( $I_H$ ) as defined by Bulow *et al.* (1978) and Adams and McLean (1985) was calculated as:

$$I_H = \frac{W_L}{W_T} \times 100$$

Since this biological index provides information about the energy reserves, its variation can imply a change in metabolism during the fish's life. This alteration of metabolism can accompany several phases in the life of an elasmobranch, such as, maturation and pregnancy (Yano, 1995; Demirhan *et al.*, 2010).

#### 4.2. Gonado-somatic index

The change in the ovaries and testes weights of elasmobranchs during the study period was investigated using the gonado-somatic index ( $I_G$ ). This index determines the variations in gonad weight throughout the process of maturation in relation to the weight of the fish. It was defined by Bougis (1952) as:

$$I_G = \frac{W_G}{W_T} \times 100$$

#### 4.3. Condition factor

The condition factor ( $K$ ) of a fish reflects its 'condition', 'fatness', and 'well-being' (Tesch, 1968). It can indicate periods of physiological stress or phenomena, such as, spawning, mating, population density alterations, feeding conditions, and temperature variations (LeCren, 1951; Braga, 1986; Loefer and Sedberry, 2003). It was defined by Fulton (1904) as:

$$K = \frac{W_T}{L_T^3} \times 100$$

#### **4.4. Sexual maturity**

After identification, the type of reproduction (oviparous or ovoviviparous) of the fishery and fishermen data and target species was determined using the information provided in Bariche (2012). All elasmobranchs whose biology was taken into account in this study were ovoviviparous. During dissection, the sexual maturity of each elasmobranch caught was also determined by the observation of the female and male gonads using the gonad aspects for ovoviviparous elasmobranchs as defined in the 'Instruction Manual' of the MEDITS – International bottom trawl survey in the Mediterranean – Version 6 (MEDITS, 2012).

The different reproductive system aspects, sexual maturation states and maturity stages for the ovoviviparous elasmobranchs are represented in Table 5.

Table 5: The different reproductive system aspects, sexual maturation states and maturity stages for the ovoviviparous elasmobranchs according to the MEDITS handbook (MEDITS, 2012).

Sex	Reproductive system aspect	Maturation state	Maturity	Stage
Male	Claspers flexible and shorter than pelvic fins. Testes small (in rays, sometimes with visible lobules). Sperm ducts straight and thread-like.	Immature	Immature	1
Female	Ovaries barely visible or small, whitish; undistinguishable ovarian follicles. Oviductal (nidamental) gland may be slightly visible. Uterus is thread-like and narrow.			
Male	Claspers slightly more robust but still flexible. Claspers as long as or longer than pelvic fins. Testes enlarged; in sharks testes start to segment; in rays lobules clearly visible but do not occupy the whole surface. Sperm ducts developing and beginning to coil (meander).	Developing	Immature	2
Female	Ovaries enlarged with small follicles (oocytes) of different size. Some relatively larger yellow follicles may be present. Ovaries lack atretic follicles. Developing oviductal gland and uterus.			
Male	Claspers fully formed, skeleton hardened, rigid and generally longer than pelvic fins. Testes greatly enlarged; in sharks testes are fully segmented; in rays filled with developed lobules. Sperm ducts tightly coiled and filled with sperm.	Spawning capable	Mature	3a
Female	Large ovaries with enlarged yolk follicles all of about the same size so that they can be easily distinguished. Oviductal gland and uterus developed without yolky matter, embryos and not dilated.	Capable to reproduce		
Male	Description similar to stage 3a, however with clasper glands dilated, often swollen and reddish (occasionally open). Sperm often present in clasper groove or	Actively spawning	Mature	3b

	glans. On pressure sperm is observed flowing out of the cloaca or in the sperm ducts.			
Female	Uteri well filled and rounded with yolk content (usually candle shape). In general segments cannot be distinguished and embryos cannot be observed.	Early pregnancy	Maternal	
Female	Uteri well filled and rounded, often with visible segments. Embryos are always visible, small and with a relatively large yolk sac.	Mid pregnancy	Maternal	3c
Female	Embryos fully formed, yolk sacs reduced or absent. Embryos can be easily measured and sexed.	Late pregnancy	Maternal	3d
Male	Claspers fully formed, similar to stage 3. Testes and spermducts shrunken and flaccid.	Regressing	Mature	4
Female	Ovaries shrunken without follicle development and with atretic (degenerating) follicles. The oviducal glands diameter may be reducing. Uterus appears much enlarged, collapsed, empty and reddish.	Regressing	Mature	4a
Female	Ovary with small follicles in different stages of development with the presence of atretic ones. Uterus enlarged with flaccid walls. Oviductal gland distinguishable.	Regenerating	Mature	4b

## 5. Stomach contents analysis

The stomach content analysis was only undertaken into account in this study for the species *Rhinobatos rhinobatos*. During dissection of this target species, the stomachs were removed and their total weights ( $W_s$ ) were measured. Stomachs containing food were preserved in 4% formaldehyde until identification; empty stomachs were also noted. Upon treatment, full stomachs were rinsed using running water and the contents were separated using a sieve. Each prey was identified to the lowest possible taxon and counted. The total weight of each prey group was measured if possible to the nearest gram (Figure 16).



Figure 16: The separation, identification and weighing of the prey items found in the stomach of a *Rhinobatos rhinobatos* specimen.

Several indices were then calculated to analyse the diet of the target species studied, reflecting its diet composition and feeding strategy.

### 5.1. Diet composition

According to Hyslop (1980), the coefficient of vacuity ( $C_V$ ) that reflects the richness or lack of food in the environment was calculated:

$$C_V = \frac{E_V}{N} \times 100$$

where  $E_V$  is the number of empty stomachs and  $N$  is the total number of stomachs examined.

The percentage of fullness ( $F_I$ ) was also calculated for each stomach:

$$F_I = \frac{W_P}{W_S} \times 100$$

where  $W_P$  is the weight of the prey items in each stomach.

Stomach fullness was classified based on a five-point scale estimated by the percentage of fullness: empty, partially empty (1-25%), slightly full (26-50%), partially full (51-75%), and full (76-100%).

Moreover, three indices were calculated to indicate the importance of the different prey items in the diet of the target species according to Hynes (1950), Hyslop (1980) and Bowen (1983):

1. The frequency of occurrence ( $O_{\%}$ )

$$O_{\%} = \frac{N_P}{M} \times 100$$

where  $N_P$  is the number of stomachs containing a specific prey group and  $M$  is the number of stomachs with prey remains.

2. The coefficient of prey numerical abundance ( $N_{\%}$ )

$$N_{\%} = \frac{n}{n_P} \times 100$$

where  $n$  is the number of prey of each taxonomic group and  $n_P$  is the total number of prey items

3. The percentage of weight ( $W_{\%}$ )

$$W_{\%} = \frac{m}{m_P} \times 100$$

where  $m$  is the mass of prey of each taxonomic group and  $m_P$  is the total mass of prey items.

Using these three indices, a fourth index was estimated to better reflect the importance of each prey item in the stomachs of the target species. This index was defined by Pinkas *et al.* (1971) as the Index of Relative Importance ( $I_{RI}$ ) and modified by Hacunda (1981) to be calculated as:

$$I_{RI} = O_{\%} \times (N_{\%} + W_{\%})$$

Finally, the percent of  $I_{RI}$  ( $I_{\%RI}$ ) for each prey type ( $i$ ) was estimated in order to make comparisons easier among food types (Cortés, 1997) as:

$$I_{\%RIi} = \frac{I_{RIi}}{\sum_{i=1}^n I_{RIi}} \times 100$$

where  $n$  is the total number of prey types.

## 5.2. Feeding strategy

The feeding strategy of the target species was analysed according to the graphical method proposed by Costello (1990). This graph displays the relationship between the frequency of occurrence ( $O_{\%}$ ) (abscissa) and the coefficient of prey numerical abundance ( $N_{\%}$ ) (ordinate). It particularly illustrates the dominance and the rarity of each group of prey in both seasons and the specialized or generalized feeding strategy (Figure 8).

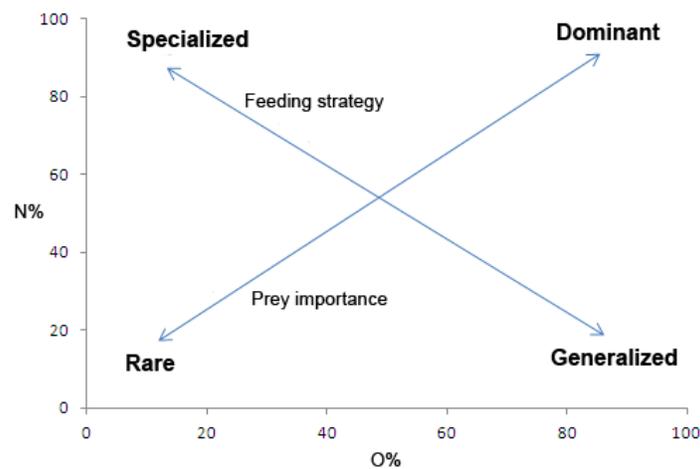


Figure 17: The graph of Costello (1990) and its interpretation concerning feeding strategy and prey importance (with  $O_{\%}$  as the frequency of occurrence and  $N_{\%}$  as the coefficient of prey numerical abundance).

The most dominant prey items in the diet of the target species are situated to the upper right of the graph (high  $N\%$  and  $O\%$ ), whereas the rare prey items are situated to the bottom left (low  $N\%$  and  $O\%$ ).

## 6. Other data collected

Other data was collected from the cartilaginous fish samples of target species and of the fishery and fishermen data. The fork length  $L_F$  and standard length  $L_S$  were measured the tip of the snout to the fork of the tail, and from the tip of the snout to the origin of the caudal fin, respectively. Moreover, spines were collected from the target species *Centrophorus granulosus* for probable age estimation. This data is not used in this study but will probably be included in further studies.

## 7. Catch per unit effort

The catch per unit effort (CPUE) was only calculated for the cartilaginous species caught during the CIHEAM-PESCA Libano survey, during which long liners, trammel nets and gillnets were lowered at specific hauls with predetermined coordinates and depths. The CPUE for the cartilaginous fish caught during the survey was calculated using the statistical software ‘R project’ (R Development Core Team, 2014) in kilogram and in number according to the following:

1. CPUE in kilograms according to each meshed gear (Index  $G$ : gear; Index  $M$ : mesh) for trammel nets, gillnets, and longlines:

$$CPUE_{kg,G,M} = \frac{\sum W_{Ti,G,M} / N_{Ci,G,M}}{E}$$

where  $i$  is the cartilaginous species caught in a specific meshed gear or longline in the predetermined haul,  $N_{Ci,G,M}$  the total number of cartilaginous species  $i$  caught in the same meshed gear or longline also in the predetermined haul, and  $E$  the effort which is considered one because each gear was lowered once with the same effort duration.

2. CPUE in number according to each meshed gear (Index  $G$ : gear; Index  $M$ : mesh) for trammel nets, gillnets, and longlines:

$$CPUE_{number,G,M} = \frac{\sum N_{C_{i,G,M}}}{E}$$

where  $N_{C_{i,G,M}}$  is the total number of the cartilaginous species  $i$  caught in a specific meshed gear or longline in the predetermined haul and  $E$  the effort which is considered one because each gear was lowered once with the same effort duration.

## 8. Biodiversity indices

Seasonal and spatial biodiversity were assessed by calculating several diversity indices considering  $S$  as the total number of species recorded in the sample and  $N$  as the total number of individuals in the same sample (Magurran, 2004). All these indices were calculated using the ‘vegan’ package on the statistical software ‘R project’ (R Development Core Team, 2014).

### 8.1. The Shannon Index

One of the most used of all diversity measures is the Shannon Index. This index assumes that individuals are randomly sampled from an infinitely large community (Pielou, 1975) and that all species are represented in the sample. It accounts for both abundance and evenness of the species present where a higher index value represents higher diversity with a maximum value equivalent to  $\ln S$ . The Shannon Index was calculated using the *diversity* function and choosing “Shannon” for index as:

$$H' = - \sum p_i \ln p_i$$

where  $p_i$  is the proportion of individuals found in the  $i$ th species and calculated as (Pielou, 1969):

$$p_i = \frac{n_i}{N}$$

where  $n_i$  is the total number of individuals in the  $i$ th species.

The Shannon Index takes into account the degree evenness of species abundances; however, no separate value is given. It is thus possible to calculate the Shannon evenness measure separately as (Pielou, 1969; 1975):

$$J' = \frac{H'}{H_{max}}$$

where  $H_{max} = \ln S$  represents the maximum diversity where all species had equal abundances.

## 8.2. Simpson's Index

The Simpson index is one of the most meaningful and robust diversity measures indicating the variance of a species abundance distribution and emphasizing the species richness component of diversity (Magurran, 2004). In fact, the probability of any two individuals picked randomly from an infinitely large community belonging to the same species was defined by Simpson (1949) as:

$$D = \sum p_i^2$$

where  $p_i$  is the proportion of individuals found in the  $i$ th species.

However, the appropriate form for a finite measure was defined as:

$$D = \sum \left( \frac{n_i[n_i - 1]}{N[N - 1]} \right)$$

where  $n_i$  is the total number of individuals in the  $i$ th species.

This form gives an index  $D$  which is inversely proportional to the diversity. As  $D$  increases, the diversity decreases. Therefore, a better expression for Simpson's Index, as recommended by Lande (1996) is:

$$1 - D$$

where the value of this index ranges between 0 and 1, which represents the maximum diversity. It was also calculated using the *diversity* function and choosing the index "Simpson".

Simpson's diversity measures emphasizes dominance, as opposed to the richness component of diversity, and does not purely measure evenness (Magurran, 2004).

### 8.3. Taxonomic diversity

Two or more assemblages can have the same number of species and an equivalence in species abundance, but vary in the diversity of the taxa to which the species belong (Magurran, 2004). Therefore, measures of taxonomic diversity should be used. One development was Clarke and Warwick's taxonomic distinctness measure (Clarke and Warwick, 1998; Warwick and Clarke, 1998). This measure describes the taxonomic distance between two randomly chosen organisms using the phylogeny of all species in an assemblage. It is in two forms:  $\Delta$  or 'taxonomic diversity' and  $\Delta^*$  or 'taxonomic distinctness'.  $\Delta$  considers species abundances as well as taxonomic relatedness and measures the path between two randomly chosen individuals that might belong to the same species.  $\Delta^*$  purely measures taxonomic relatedness considering each individual coming from different species. When such data is used, these measures are reduced to a single measure,  $\Delta^+$ , indicating the average taxonomic distance between two randomly selected species and can be calculated as:

$$\Delta^+ = \frac{[\sum \sum_{i < j} \omega_{ij}]}{[s(s-1)/2]}$$

where  $s$  is the number of species in the study and  $\omega_{ij}$  is the length between species  $i$  and  $j$ .

The taxonomic distances were first calculated using the function *taxa2dist* from a table containing all the species classified up to their class (ANNEX V). The taxonomic diversity was then calculated using the function *taxondive*.

## 9. Statistical analyses and regressions

### 9.1. Statistics

Several statistical analyses were performed in this study using the statistical software 'R project' aiming to aid the analysis of results. Both inferential (tests) and descriptives methods (multivariate analyses such as Principal Component Analysis or Canonical Correspondance Analysis) were employed. The methods performed and application purposes are represented in Table 6.

Table 6: The statistical methods performed in this study as well as their application purposes ( $L_T$ ,  $W_T$ ,  $F_I$ ,  $I_G$ ,  $I_H$ , and  $K$  are total length, total weight, fullness index, gonado-somatic index, hepato-somatic index, and condition factor, respectively. G, L, and T are gillnets, long liners, and trammel nets, respectively. M, F, Imm, and Mat are males, females, immature and mature individuals, respectively).

<b>Statistical test</b>	<b>Description</b>	<b>Application (Chapter)</b>
<b>R function</b>		
<b>Shapiro-Wilk test</b> <i>shapiro.test</i>	Tests that the population is normally distributed.	Tested the normality of the samples in this study. (Chapters V & VI)
<b>Wilcoxon rank sum test</b> <i>wilcox.test</i>	Also called the Mann-Whitney U test. It is nonparametric and tests the difference between two populations. It is efficient for non-normal distributions and when variances are not equal.	Tested the difference in $L_T$ , $W_T$ , and $F_I$ between males and females of a certain species. (Chapters V & VI) Tested the difference in $L_T$ and $W_T$ of species caught between two types of gear used. (Chapter VI)
<b>Kruskal-Wallis rank sum test</b> <i>kruskal.test</i>	A nonparametric test efficient for non-normal distributions and when variances are not equal. It compares two or more independent samples that may have different sizes.	Tested the difference in $L_T$ and $W_T$ of a species according to the sexual maturity stages. (Chapters V & VI) Tested the difference in $I_G$ , $I_H$ , and $K$ of a certain species according to season. (Chapters V & VI)
<b>Pairwise Test for Multiple Comparisons of Mean Rank Sums (Post Hoc; Nemenyi-Tests)</b>  Package: PMCMR <i>posthoc.kruskal.nemenyi.test</i>	Calculates pairwise multiple comparisons between group levels.	Used after significant differences in the Kruskal-Wallis rank sum tests for pairwise multiple comparisons of the ranked data. (Chapter VI)
<b>Pearson's chi-square test (goodness-of-fit or chi-square test for independence)</b>  <i>chisq.test</i>	Tests if there is a significant difference between expected and obtained results in one or more categories.  Tests any association between two categorical variables from a single population.	Tested the difference between the expected and obtained sex ratio. (Chapters V & VI)  Tested the presence of an association between the sex or the sexual maturity of the specimens caught and the depth at which they were caught at. (Chapters VI)

<p><b>Analysis of covariance (ANCOVA)</b></p> <p><i>anova</i></p>	<p>Compares two or more regression lines by testing the effect of a categorical factor on a dependent variable while controlling for the effect of a continuous covariable.</p>	<p>Performed a statistical comparison of length-weight relationships between sexes of the same species. (Chapters IV, V, &amp; VI)</p>
<p><b>Two-way Unbalanced ANOVA</b></p> <p><i>anova.2way.unbalanced</i></p> <p>(Anderson and Legendre, 1999; Legendre and Anderson, 1999)</p>	<p>Two-way crossed-factor multivariate ANOVA (by Redundancy Analysis) for balanced and unbalanced designs, with permutation tests. For unbalanced designs, this function computes type III sums-of-squares.</p>	<p>Performed two-way crossed-factor analysis on the total weight according to several factors.</p> <p>Factors and modalities: Region (North, South); season (cold: spring and winter; hot: summer and autumn); depth ([0,400[; [400,600]); sexual maturity (mature; immature). (Chapter VI)</p>
<p><b>Permutational Multivariate Analysis of Variances (PERMANOVA)</b></p> <p>Package:</p> <p>Vegan</p> <p><i>adonis</i></p>	<p>Analyzes variances using distance matrices using a permutation test with pseudo-<i>F</i> ratios.</p>	<p>Analysed the ‘Catch Per Unit Effort’ in kilograms and number as log (x+1) according to several factors of the different cartilaginous fish species in the scientific survey data.</p> <p>Factors and modalities: Gear (G, L, T); region (North, Central, South); depth ([0-200[, [200,400[, [400,600] in meters); seasons (Spring, Summer, Winter). (Chapter IV)</p> <p>Analysed the total weight as (logx+1) according to several factors of the different cartilaginous fish species in the fisheries and fishermen data.</p> <p>Factors and modalities: Gear (G, L, T); region (North, South); depth ([0-300[, [300, 600] in meters); seasons (Spring, Summer, Autumn, Winter); sex (M, F); sexual maturity (Imm, Mat). (Chapter IV)</p>

<b>Canonical Correspondence Analysis (CCA)</b>  Package: Vegan  <i>cca</i>	An ordination technique in community ecology where chi-square transformed data matrix is subjected to weighted linear regression on constraining variables, and the fitted values are submitted to correspondence analysis performed via singular value decomposition.	Same application, factors, and factor modalities as PERMANOVA; however, this analysis gives further details to how the ordination of species is constrained by their relationships to environmental variables. (Chapter IV)
<b>Principle Component Analysis (PCA)</b>  Packages: FactoMineR and PCAmixdata  <i>PCAmix</i>	A statistical procedure concerned with clarifying the covariance structure of a set of variables. It allows to identify the principal directions in which the data varies.	Analysed the principal directions of the qualitative and quantitative variables in the Gulper Shark dataset.  (Chapter VI)

## 9.2. Linear regressions

The analysis of reproductive organs growth can determine the size or age at maturity. The presence of a relationship between the development of secondary sexual characteristics and reproductive organs and maturity urged the use of clasper length measurements to estimate the size at maturity (Conrath, 2005). Therefore, a linear regression model was used to evaluate the relationship between total length and clasper length. A steeper slope corresponds to the range of lengths at which the elasmobranch is becoming mature. A linear model function in the statistical software ‘R project’(R Development Core Team, 2014), *lm*, was used to fit the linear model and estimate the parameters ‘a’ and ‘b’ of the equation relating clasper length to total length:

$$L_C = a + bL_T$$

The coefficient of determination ( $r^2$ ) was used to evaluate the quality of the model.

### 9.3. Nonlinear regressions

#### 9.3.1. Gonad weight and total length

The most common reproductive measure to plot against length is the clasper length in male elasmobranchs; nevertheless, the weight of other reproductive structures such as the testis and siphon sac are often used in the same manner (Teshima, 1981; Parsons and Grier, 1992; Yano, 1993). However, a power regression is utilized because according to Froese (2006), nonlinear power regressions should be used to represent any regression of weight on length because any weight will scale to the cubic power of length in fish.

A nonlinear least squares function *nls* was used to estimate the parameters ‘a’ and ‘b’ of the nonlinear power equation between gonad weight and total length and was implemented on the statistical software ‘R project’ (R Development Core Team, 2014):

$$W_G = aL_T^b$$

The start values of these parameters were derived from the log transformation of the two variables using the linear model function (*lm*), and the coefficient of determination ( $r^2$ ) was used to evaluate the quality of the model.

#### 9.3.2. Length-weight relationship

Length-weight relationships for fish populations help to a better knowledge of the growth rate, age, and other constituents of population dynamics (Kolher *et al.*, 1995).

A nonlinear least squares function, *nls*, on the statistical software ‘R project’ (R Development Core Team, 2014) was used to estimate of the parameters ‘a’ and ‘b’ of the nonlinear power equation between gonad weight and total length following LeCren (1951):

$$W_T = aL_T^b$$

The start values of these parameters were also derived from the log transformation of the two variables using the linear model function (*lm*) into:

$$\log W_T = a + b \log L_T$$

The coefficient of determination ( $r^2$ ) was also used to evaluate the quality of the model.

The type of growth of the fish studied is determined by parameter 'b'. This parameter is the exponent of the arithmetic form of the weight–length relationship. If  $b = 3$ , growth is isometric and the weight increases at the same rate as the length of the fish, indicating that smaller specimens are in the same condition and form as larger ones. If  $b > 3$ , growth is positively allometric and the weight increases at a faster rate than the length of the fish, indicating that larger specimens have grown in height or width more than in length. If  $b < 3$ , growth is negatively allometric and the length increases at a faster rate than the weight of the fish, indicating that large specimens became more elongated or small specimens were in better nutritional condition at the time of sampling (Froese, 2006).

#### 9.4. Logistic regressions

Size at maturity is also determined by the length at which 50% of the fish sample is mature ( $L_{50}$ ). The proportion of mature elasmobranch specimens in each length group is determined. This data is then fitted in a logistic regression and the length at the point of the curve corresponding to 50% mature ( $P=0.5$ ) indicates the size at which these fish mature. The logistic equation takes the following form:

$$P = \frac{1}{1 + e^{(a+bL_T)}}$$

where  $P$  is the proportion of mature elasmobranch specimens in each determined length class, and 'a' and 'b' are parameters estimated by fitting the data to the logistic curve.

The length at which 50% of the individuals of specific elasmobranch species are mature was estimated for both sexes using a logistic curve from a generalized linear model (GLM) with logit link using the function *glm* in the statistical software 'R project' (R Development Core Team, 2014).

### **9.5. Maps and interpolation**

All maps were created on the Quantum Geographic Information System (qGIS) software (QGIS Development Team, 2012). Interpolations were performed on the same software only for the scientific survey data.

Spatial interpolation is the process of using points with known values to estimate values at other unknown points. Spatial interpolation was performed on the CPUE in kilograms and number and species richness according to haul for the shark, batoid, and combined datasets using the Inverse Distance Weighting (IDW) method and the 'Linear' color interpolation in the software.

The IDW is where the sample points are weighted during interpolation such that the influence of one point relative to another declines with distance from the unknown point to be created. Weighting is given to sample points by a weighting coefficient that controls how the weighting influence will drop off as the distance from new point increases. The greater the weighting coefficient, the less effect the points will have if they are far from the unknown point during the interpolation process. As the coefficient increases, the value of the unknown point approaches that of the nearest observational point.

# **Chapter III**

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**The cartilaginous fishes of the Eastern Mediterranean: A literature review on the biology, ecology and geographic range of these species**

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# **Les poissons cartilagineux de la Méditerranée orientale: revue de la littérature sur la biologie, l'écologie et la distribution géographique de ces espèces**

## **Résumé**

Cette étude est dédiée à une synthèse bibliographique sur la biologie, l'écologie et la répartition géographique des poissons cartilagineux de la Méditerranée orientale. Le but de cette revue est de présenter les diverses études et leurs lacunes et les régions où les espèces de poissons cartilagineux sont peu présentes et étudiées.

Un focus est porté sur les informations concernant les inventaires existants, la présence et la répartition, le statut, la conservation, l'âge et la croissance, les relations longueur-poids, les aspects de la reproduction, les habitudes de nutrition et d'alimentation et d'autres aspects du cycle de vie de ces espèces. Cette synthèse présente également les résultats issus d'un nouvel inventaire des poissons cartilagineux effectué le long de la côte libanaise, où ont été répertoriées 25 espèces (11 requins et 14 batoïdes) appartenant à 15 familles entre 2012 et 2014. La synthèse indique que les captures accidentelles de ces poissons est à l'origine de leur déclin en mer Méditerranée. Cette étude confirme également la présence de lacunes dans les études relatives aux espèces de poissons cartilagineux, avec certaines régions faisant l'objet de nombreuses études alors que peu d'études voire aucune n'existe dans d'autres régions de la Méditerranée orientale, comme la côte libanaise. Cette revue devrait permettre d'aider à une meilleure compréhension, gestion, et protection de cette catégorie de poissons menacés.

**Mot clés :** Traits d'histoire de vie ; structure de population ; répartition spatiale et saisonnière

**Chapter III: The cartilaginous fishes of the Eastern Mediterranean: A literature review on the biology, ecology and geographic range of these species**

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## **Abstract**

This study was dedicated to a literature review on the biology, ecology and geographic distribution of cartilaginous fish from the Eastern Mediterranean. The purpose of this review was to present the various studies and their gaps and the areas where cartilaginous fish species are poorly reflected and studied. A focus was placed on the information on existing inventories, occurrence, distribution, status, conservation, age and growth, length weight- relationships, reproductive aspects, nutrition and feeding habits and other life history aspects of these species.

This review also presents the results for a new inventory of cartilaginous fish along the Lebanese coast, where 25 species (11 sharks and 14 batoids) belonging to 15 families were recorded between 2012 and 2014. It indicates that incidental catches of these fish is one of the cause of their decline in the Mediterranean Sea. This study also confirms the presence of gaps in studies related to cartilaginous fish species, with some regions being studied intensively when few or no studies exist in other areas of the Eastern Mediterranean, such as the Lebanese coast. The review is expected to help understanding, management, and protection of this category of threatened fish class.

**Keywords:** Life history traits; population structure; spatial and seasonal distribution; cartilaginous fish; Eastern Mediterranean

## **1. Introduction**

The Mediterranean basin is known for its high biodiversity and the greatest proportions of species records were within the prokaryotic and eukaryotic microbes (26%), subphylum Crustacea (13.2%) and phyla Mollusca (12.4%), Annelida (6.6%), Platyhelminthes (5.9%), Cnidaria (4.5%), subphylum Vertebrata (4.1%), Porifera (4.0%), Bryozoa (2.3%), subphylum Tunicata (1.3%), and Echinodermata (0.9%), other invertebrate groups (14%), within the Animalia, and Plantae (5%) (Coll *et al.*, 2010). Nearly one third of the Mediterranean fauna is endemic (Cuttelod *et al.*, 2008). Moreover, it is considered as one of the first 25 global biodiversity hotspots (Myers *et al.*, 2000a). The Mediterranean Sea has been inhabited for a long time and ecosystems have changed in many ways. Thus, anthropogenic impacts are stronger in the Mediterranean than in any other sea of the world (Blondel and Aronson, 1999). The loss and damage of habitats through the development of coastal infrastructure, pollution, invasion of exotic species and overexploitation has increased the risk of species extinction in the Mediterranean (Cuttelod *et al.*, 2008). Cartilaginous fishes in the Mediterranean are generally declining in abundance, diversity and range more than cartilaginous fish populations elsewhere in the world (Walker *et al.*, 2005). These decreases can be due to several factors, including the life history characteristics of these fish along with the semi-enclosed nature of the Mediterranean Sea and intense fishing activity throughout its coastal and pelagic waters, effects of habitat loss, environmental degradation and pollution (Stevens, 2005; Walker *et al.*, 2005). Besides, over the last 200 years, the cartilaginous fishes of the Mediterranean have diminished and are in risk of extinction due to fishing pressure (Ferretti *et al.*, 2008).

The Mediterranean Sea is characterized by a quite high diversity of cartilaginous fish with 45 sharks, 34 batoids, and one chimaera found in its waters (Compagno, 2001; Compagno *et al.*, 2005; Serena, 2005a). Dulvy *et al.* (2014) identified three main hotspots where the biodiversity of sharks and rays was particularly seriously threatened - the Indo-Pacific Biodiversity Triangle, Red Sea, and the Mediterranean Sea - and claim that national and international action is required to protect them from overfishing. The center of greatest chondrichthyan biodiversity lies in the Indo-West Pacific Region (Fowler, 2005).

Three endemic species, among which one is endemic threatened are also found in the Mediterranean waters (Dulvy *et al.*, 2014). Bradai *et al.* (2012) stated that elasmobranchs are considered as a significant bycatch of commercial fisheries that target bony fishes and rare are the fisheries targeting sharks. However, the United Nations Food and Agriculture Organization (FAO) suggested that sharks comprise 60% of the catch of cartilaginous fishes in the world (FAO, 1999). Nonetheless, not all the catch is landed and most of the bycatch is discarded dead without any record of the species or capture volume (Stevens *et al.*, 2000).

Among 80 species of cartilaginous fish known in the Mediterranean, 71 were assessed in the frame of the International Union for Conservation of Nature (IUCN) red list. More than 40% are Vulnerable and Endangered to Critically endangered (Cavanagh and Gibson, 2007). Most cartilaginous fish populations can tolerate only modest levels of fishing without reduction and stock collapse (Camhi *et al.*, 1998; Musick, 1999a; Cortés, 2000). Their low fecundity, late maturity and slow growth rates make them vulnerable to fishing (Stevens *et al.*, 2000). Cartilaginous fish, especially elasmobranchs, present a number of reproductive strategies. All elasmobranchs fertilize internally and produce a relatively small number of large eggs. Elasmobranch fecundity generally ranges from one to two offspring produced a year up to a maximum of 300 in the whale shark (Compagno, 1990; Joung *et al.*, 1996). Such characteristics have serious consequences for cartilaginous fish populations; limiting their capacity to withstand fisheries and recover from declines (Camhi *et al.*, 1998; Cailliet *et al.*, 2005).

The Eastern Mediterranean, according to the United Nations Food and Agriculture Organization, consists of all waters from the Aegean Sea (following the coasts of Turkey and Greece) eastward towards the Levantine basin (following the coasts of Turkey and other countries of the Eastern Mediterranean and across the northern entrance to the Suez Canal and along the coast of Egypt) (FAO, 2004) (Figure 18). The Eastern Mediterranean has a lower species diversity and poorer nutrients compared to the Western Mediterranean (Martin *et al.*, 2006). It is the most oligotrophic part of the Mediterranean (Azov, 1991).

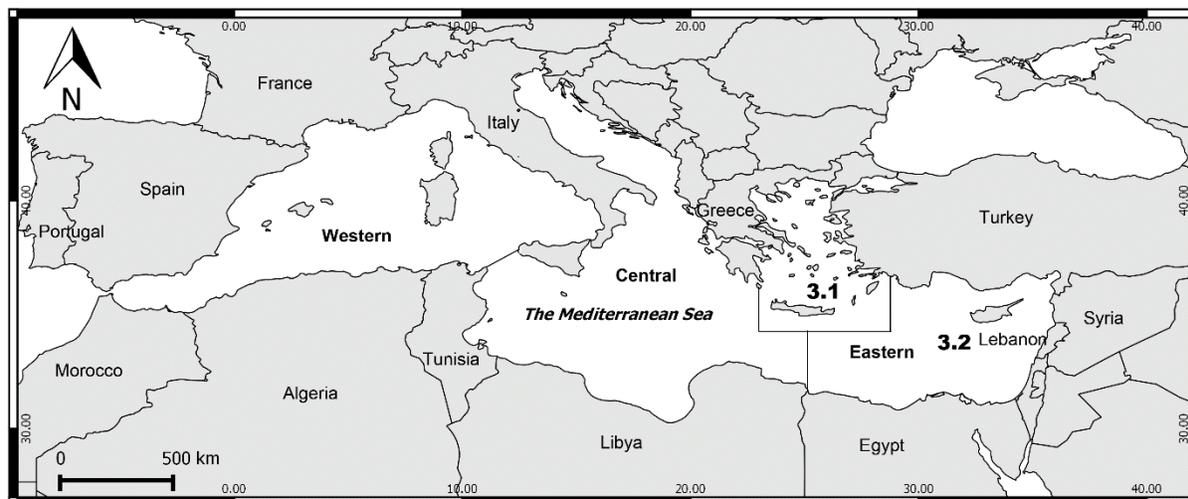


Figure 18: The boundary of the Eastern Mediterranean subarea (37.3) – Aegean (Division 37.3.1) and Levant (Division 37.3.2) – along with the Western and Central basins as adapted from the United Nations Food and Agriculture Organization (FAO, 2004).

Many studies on cartilaginous fishes were performed in the eastern Mediterranean with more than 100 papers ranging from the coasts of Alexandria –Egypt in the South, passing through the coasts of Israel, Lebanon, Syria, Turkey and reaching the Aegean Sea in the North (Bradai *et al.*, 2012).

This study reviews the cartilaginous fishes status in the Eastern Mediterranean based on all the studies published in the latter region summarizing the inventories and studies in order to reflect the presence of this fish class and its life history traits in the eastern region of the Mediterranean.

The following sections describe the various studies that have been carried out on cartilaginous fish species in the Eastern Mediterranean: cartilaginous fish inventories, observations and first records, fishing and conservation, age and growth patterns, length-weight relationships, reproduction and nutrition.

## 2. The cartilaginous fishes of the Levantine Basin and Aegean Sea

Cartilaginous fishes of the Eastern Mediterranean have been mentioned in several field identification guides since 1987 (Fischer *et al.*, 1987; Serena, 2005a; Golani *et al.*, 2006;

Bariche, 2012). However, several inventories on cartilaginous fish species in the Eastern Mediterranean were carried out in studies in several Eastern Mediterranean countries.

An inventory was established in Syria by Ali (2003) and Saad *et al.* (2004) reflecting the presence of 37 cartilaginous fish species along the Syrian coasts, after reporting 22 species in 2003 (Ali and Saad, 2003). Only one work was previously established during the past century (Gruvel *et al.*, 1931) in which the presence of 15 cartilaginous species was reported along the Syrian coast.

The presence of cartilaginous fish species has also been reported in Cyprus. A total number of 28 species of sharks and dogfish and 17 species of skates and rays have been listed in a paper by Hadjichristophorou (2006). The main sources of information, from which the Cypriot inventory was established, were Demetropoulos and Neocleous (1969), Gilat and Gelman (1984), Fischer *et al.* (1987), Compagno (1984a), Compagno (1984b), McEachran and Capapé (1984a) and Serena (2005a).

Fish biodiversity in Lebanon was studied by George *et al.* (1964), George and Athanassiou (1965), George and Athanassiou (1966a), George and Athanassiou (1966b), George and Athanassiou (1967), and George *et al.* (1971), recording a list of 44 cartilaginous fish species and 313 bony fish species. An updated list was established by Boulos (1968). Later, cartilaginous fish species were mentioned by Mouneimne (1977), Mouneimne (1978) and Mouneimne (1979). However, the most recent inventory was established by Mouneimne (2002) who cataloged 22 cartilaginous species along the Lebanese coast by field work performed between 1973 and 1983; and later Harmelin-Vivien *et al.* (2005) mentioned the presence of three species in an underwater visual census survey along the Lebanese coast in 2001.

Cartilaginous fish species found in Israeli waters were also listed in many initial and revised studies (Ben-Tuvia, 1953; Ben-Tuvia, 1971). A general study of marine ichthyofauna in the eastern Levant was then presented by Golani (1996). Later, an updated list was compiled in Golani (2006) stating that the Mediterranean ichthyofauna of Israel includes a total of 57 cartilaginous species: 31 sharks, 25 skates and rays and only a single chimaera species; only one species *Himantura uarnak* (Gmelin, 1789) is a lessepsian migrant of Red Sea.

Turkish ichthyofauna was more strongly studied during the 20th century, where an overall picture was obtained by notable surveys carried Aegean Sea (Geldiay, 1969) and Levantine Sea (Akyuz, 1957). Later, nine cartilaginous fish species were recorded in Edremit Bay (Aegean Sea) during 1996 and 1997 (Torcu and Aka, 2000), three in Saros Bay (North Aegean Sea) during 1999 and 2000 (Torcu-Koc *et al.*, 2004), and 15 in Bozcaada Island (North Aegean Sea) during 2000 and 2001 (Eryilmaz, 2003). Some publications dealing with the fishes of the Aegean Sea are those by Kosswig (1954), Aksiray (1954), Tortonese (1956), Demir (1958), Bini (1967), Tortonese (1970), Aksiray (1987), Papaconstantinou (1988), Papaconstantinou *et al.* (1994), Mater and Meric (1996), Meric *et al.* (1997), Torcu and Mater (2000), and Mater *et al.* (2002). Moreover, a study performed by Kabasakal (2002c), based on field surveys and reviews of available literature, revealed the presence of 69 elasmobranch species representing 21 families along the coasts of Turkey. In fact, Kabasakal and Kabasakal (2004) documented 20 species of sharks representing 11 families and 5 orders in the coasts of the northeastern Aegean Sea; these sharks were caught by commercial fishing vessels, in particular, trawlers. Besides, a prior study conducted in Iskenderun Bay between December 1994 and November 1996 exposed the presence of 19 cartilaginous fish species in that region (Basusta and Erdem, 2000). More recently, a checklist was done by Bilecenoglu (2002) comprising the marine ichthyofauna, including cartilaginous fish species, of the Aegean and Levantine Seas. Later, an updated list was presented by Bilecenoglu *et al.* (2014) reflecting the occurrence of cartilaginous fish species in the Aegean and Levantine Seas of the Eastern Mediterranean.

The species caught or observed in the Eastern Mediterranean are presented in this section and summarized in Table 7.

Table 7: The cartilaginous fish species (Chondrichthyes) caught or observed in the Eastern Mediterranean according to the updated inventories in literature.

Order (Nelson, 2006)	Family (Nelson, 2006)	Cyprus (Hadjichristophorou, 2006)	Along the Lebanese coast between 1973 and 1983 (Mouneimne, 2002)	Along the Syrian coast in 2003 (Ali, 2003; Saad <i>et al.</i> , 2004)	In Turkey, Levantine and Aegean Seas (Bilecenoglu <i>et al.</i> , 2014)	Along the coast of Israel (Golani, 2006)
<b>Lamniformes</b>	Lamnidae	<i>Carcharodon carcharias</i> <i>Isurus oxyrinchus</i> <i>Lamna nasus</i>	<i>Isurus oxyrinchus</i>	<i>Isurus oxyrinchus</i>	<i>Carcharodon carcharias</i> <i>Isurus oxyrinchus</i> <i>Lamna nasus</i>	<i>Carcharodon carcharias</i> <i>Isurus oxyrinchus</i> <i>Lamna nasus</i>
	Cetorhinidae				<i>Cetorhinus maximus</i>	<i>Cetorhinus maximus</i>
	Odontaspidae	<i>Carcharias Taurus</i> <i>Odontaspis ferox</i>	<i>Odontaspis ferox</i>		<i>Carcharias taurus</i> <i>Odontaspis ferox</i>	<i>Carcharias taurus</i> <i>Odontaspis ferox</i>
	Alopiidae	<i>Alopias vulpinus</i>		<i>Alopias superciliosus</i>	<i>Alopias vulpinus</i> <i>Alopias superciliosus</i>	<i>Alopias vulpinus</i> <i>Alopias superciliosus</i>
<b>Hexanchiformes</b>	Hexanchidae	<i>Hexanchus griseus</i> <i>Heptranchias perlo</i>	<i>Hexanchus griseus</i>	<i>Hexanchus griseus</i> <i>Heptranchias perlo</i>	<i>Hexanchus griseus</i> <i>Heptranchias perlo</i>	<i>Hexanchus griseus</i> <i>Heptranchias perlo</i>
<b>Carcharhiniformes</b>	Carcharhinidae	<i>Carcharhinus brevipinna</i> <i>Carcharhinus melanopterus</i> <i>Carcharhinus plumbeus</i> <i>Prionace glauca</i>	<i>Carcharhinus limbatus</i> <i>Prionace glauca</i>	<i>Carcharhinus obscurus</i> <i>Carcharhinus plumbeus</i>	<i>Carcharhinus brevipinna</i> <i>Carcharhinus limbatus</i> <i>Carcharhinus plumbeus</i> <i>Carcharhinus altimus</i> <i>Prionace glauca</i>	<i>Carcharhinus altimus</i> <i>Carcharhinus brevipinna</i> <i>Carcharhinus limbatus</i> <i>Carcharhinus obscurus</i> <i>Carcharhinus plumbeus</i> <i>Prionace glauca</i>
	Triakidae	<i>Galeorhinus galeus</i> <i>Mustelus asterias</i> <i>Mustelus mustelus</i> <i>Mustelus punctulatus</i>	<i>Mustelus mustelus</i>	<i>Mustelus mustelus</i>	<i>Galeorhinus galeus</i> <i>Mustelus asterias</i> <i>Mustelus mustelus</i> <i>Mustelus punctulatus</i>	<i>Mustelus asterias</i> <i>Mustelus mustelus</i>
<b>Carcharhiniformes</b>	Scyliorhinidae	<i>Galeus melastomus</i>	<i>Galeus melastomus</i>	<i>Galeus melastomus</i>	<i>Galeus melastomus</i>	<i>Galeus melastomus</i>

		<i>Scyliorhinus canicula</i> <i>Scyliorhinus stellaris</i>		<i>Scyliorhinus canicula</i>	<i>Scyliorhinus canicula</i> <i>Scyliorhinus stellaris</i>	<i>Scyliorhinus canicula</i>
	Sphyrnidae	<i>Sphyrna zygaena</i> <i>Sphyrna mokarran</i>	<i>Sphyrna zygaena</i>		<i>Sphyrna zygaena</i>	<i>Sphyrna zygaena</i>
<b>Squaliformes</b>	Dalatiidae	<i>Dalatias licha</i>		<i>Dalatias licha</i> <i>Somniosus rostratus</i>	<i>Dalatias licha</i>	<i>Dalatias licha</i>
	Etmopteridae	<i>Etmopterus spinax</i>			<i>Etmopterus spinax</i>	<i>Etmopterus spinax</i>
	Oxynotidae	<i>Oxynotus centrina</i>		<i>Oxynotus centrina</i>	<i>Oxynotus centrina</i>	<i>Oxynotus centrina</i>
	Centrophoridae	<i>Centrophorus granulosus</i>		<i>Centrophorus granulosus</i> <i>Centrophorus acus</i> <i>Centrophorus moluccensis</i> <i>Centrophorus machiquensis</i> <i>Centrophorus uyato</i>	<i>Centrophorus granulosus</i>	<i>Centrophorus granulosus</i>
	Squalidae	<i>Squalus acanthias</i> <i>Squalus blainville</i>	<i>Squalus acanthias</i>	<i>Squalus blainville</i> <i>Squalus megalops</i>	<i>Squalus acanthias</i> <i>Squalus blainville</i>	<i>Squalus acanthias</i> <i>Squalus blainville</i>
<b>Echinorhiniformes</b>	Echinorhinidae				<i>Echinorhinus brucus</i>	
<b>Squatiformes</b>	Squatinae	<i>Squatina squatina</i> <i>Squatina oculata</i>	<i>Squatina squatina</i>	<i>Squatina aculeata</i> <i>Squatina oculata</i> <i>Squatina squatina</i>	<i>Squatina aculeata</i> <i>Squatina oculata</i> <i>Squatina squatina</i>	<i>Squatina aculeata</i> <i>Squatina oculata</i> <i>Squatina squatina</i>
<b>Pristiformes</b>	Pristidae		<i>Pristis pectinate</i>			<i>Pristis pectinata</i>
<b>Torpediniformes</b>	Torpedinidae	<i>Torpedo marmorata</i> <i>Torpedo nobiliana</i> <i>Torpedo torpedo</i>	<i>Torpedo torpedo</i> <i>Torpedo marmorata</i>	<i>Torpedo marmorata</i> <i>Torpedo nobiliana</i> <i>Torpedo sinnuspersici</i>	<i>Torpedo marmorata</i> <i>Torpedo nobiliana</i> <i>Torpedo torpedo</i>	<i>Torpedo marmorata</i> <i>Torpedo nobiliana</i> <i>Torpedo torpedo</i>
<b>Rajiformes</b>	Rhinobatidae	<i>Rhinobatos rhinobatos</i> <i>Rhinobatos cemiculus</i>	<i>Rhinobatos rhinobatos</i> <i>Rhinobatos cemiculus</i>	<i>Rhinobatos rhinobatos</i> <i>Rhinobatos cemiculus</i>	<i>Rhinobatos rhinobatos</i> <i>Rhinobatos cemiculus</i>	<i>Rhinobatos rhinobatos</i> <i>Rhinobatos cemiculus</i>
	Rajidae	<i>Raja clavata</i> <i>Raja miraletus</i> <i>Raja asterias</i> <i>Raja radula</i>	<i>Dipturus oxyrinchus</i> <i>Raja miraletus</i>	<i>Raja clavata</i> <i>Raja miraletus</i> <i>Raja radula</i> <i>Dipturus</i>	<i>Dipturus batis</i> <i>Dipturus oxyrinchus</i> <i>Leucoraja</i>	<i>Dipturus oxyrinchus</i> <i>Raja asterias</i> <i>Raja clavata</i>

		<i>Dipturus oxyrinchus</i>		<i>oxyrinchus</i>	<i>circularis</i> <i>Leucoraja fullonica</i> <i>Leucoraja naevus</i> <i>Raja clavata</i> <i>Raja miraletus</i> <i>Raja asterias</i> <i>Raja radula</i> <i>Raja montagui</i> <i>Raja polystigma</i> <i>Raja undulata</i> <i>Rostroraja alba</i>	<i>Raja miraletus</i> <i>Raja montagui</i> <i>Raja radula</i> <i>Raja undulata</i>
<b>Myliobatiformes</b>	Dasyatidae	<i>Pteroplatytrygon violacea</i> <i>Dasyatis pastinaca</i> <i>Dasyatis centroura</i>	<i>Dasyatis pastinaca</i> <i>Himantura uarnak</i>	<i>Pteroplatytrygon violacea</i> <i>Dasyatis pastinaca</i> <i>Dasyatis tortonesei</i>	<i>Dasyatis centroura</i> <i>Dasyatis marmorata</i> <i>Dasyatis pastinaca</i> <i>Dasyatis tortonesei</i> <i>Himantura uarnak</i> <i>Pteroplatytrygon violacea</i> <i>Taeniura grabata</i>	<i>Dasyatis centroura</i> <i>Dasyatis marmorata</i> <i>Dasyatis pastinaca</i> <i>Dasyatis tortonesei</i> <i>Himantura uarnak</i> <i>Pteroplatytrygon violacea</i> <i>Taeniura grabata</i>
	Gymnuridae	<i>Gymnura altavela</i>	<i>Gymnura altavela</i>	<i>Gymnura altavela</i>	<i>Gymnura altavela</i>	<i>Gymnura altavela</i>
<b>Chimaeriformes</b>	Chimaeridae		<i>Chimaera monstrosa</i>	<i>Chimaera monstrosa</i>	<i>Chimaera monstrosa</i>	<i>Chimaera monstrosa</i>

The most recent inventory in Lebanon was established during the research events of this thesis. A total of 25 cartilaginous fish species were recorded during this study. Table 8 represents the most recent Lebanese inventory along with the native distribution of these species according to FishBase (2015). The native distribution maps for each of the 25 species recorded along the Lebanese coast were downloaded from AquaMaps (2013) and presented in ANNEX VI.

Table 8: The 25 cartilaginous fish species recorded along the Lebanese coast during this study along with their native distribution according to FishBase (2015). When no detailed information was available for the distribution of the sub regions, the cells were merged. No sub regions were specified for the Pacific and Indian Oceans.

Species recorded in Lebanon during this thesis research	Mediterranean Sea			Red Sea	Atlantic Ocean			Pacific Ocean	Indian Ocean
	Eastern	Central	Western		Eastern	Central	Western		
<i>Carcharhinus obscurus</i>	x			x	x		x	x	
<i>Centrophorus granulosus</i>	x					x	x	x	x
<i>Dalatias licha</i>			x		x		x	x	x
<i>Dasyatis marmorata</i>	x				x				
<i>Dasyatis pastinaca</i> *	x				x				
<i>Dasyatis tortonesei</i>	x								
<i>Dipturus oxyrinchus</i> *	x				x				
<i>Galeus melastomus</i> *	x				x				
<i>Gymnura altavela</i> *	x				x		x		
<i>Heptranchias perlo</i>	x				x		x	x	x
<i>Hexanchus griseus</i> *	x				x		x	x	x
<i>Isurus oxyrhynchus</i> *	x			x	x		x	x	
<i>Mustelus mustelus</i> *	x				x		x		
<i>Pteromylaeus bovinus</i> *	x				x				
<i>Pteroplatytrygon violacea</i>	x				x		x	x	
<i>Raja clavata</i>	x				x				
<i>Raja miraletus</i> *	x				x				x
<i>Rhinobatos cemiculus</i> *	x				x				
<i>Rhinobatos rhinobatos</i> *	x				x				
<i>Squalus blainville</i>	x				x		x	x	x
<i>Squatina aculeata</i>			x		x				
<i>Squatina oculata</i>	x				x				
<i>Taeniura grabata</i>	x			x	x				x
<i>Torpedo marmorata</i> *	x				x				
<i>Torpedo nobiliana</i>	x				x		x		

\* The species also recorded in Lebanon between 1973 and 1983 (Mouneimne, 2002)

### 3. Cartilaginous fish observations and first records in the Eastern Mediterranean

Knowledge of the biology, ecology and records of cartilaginous fish along the coast of Lebanon is almost absent. Only the inventories mentioned previously reflect the presence of this fish class in the Lebanese waters.

#### *Syria*

Along the Syrian coast, however, several papers based on cartilaginous fish first records were established. A first record of the Basking Shark, *Cetorhinus maximus* (Gunnerus, 1765) off the coast of Syria was noted in 2012 by Ali *et al.* (2012). The specimen was a pregnant female ( $L_T=690$  cm) containing 34 egg cases. Later in 2013, a Round Fantail Stingray, *Taeniura grabata* (Geoffroy Saint-Hilaire, 1817) off the Syrian coast was first recorded by Ali *et al.* (2013). As for the Red Sea migrant, *Himantura uarnak*, it was first recorded along the Syrian coast in 2010 (Ali *et al.*, 2010). Another Red Sea migrant, *Torpedo sinuspersici* (Olfers, 1831) was recorded along the Syrian coast by Saad *et al.* (2004).

#### *Israel*

The studies on the biology and ecology of cartilaginous fish along the coast of Israel are not so common. There have been a few studies on *Centrophorus granulosus* (Bloch & Schneider, 1801) and other deep-water species (Gilat and Gelman, 1984; Pisanty and Golani, 1995; Golani and Pisanty, 2000) and several taxonomical studies (Baranes, 1973; Goren and Galil, 1997). Moreover, several studies on cartilaginous fish observations and first records were also established. During 1954, Ben-Tuvia (1955) reported the observation of several specimens of the Red Sea migrant, *Himantura uarnak*, along the coast of Israel. Later, Ben-Tuvia (1977) reported large catches of two shark species *Carcharhinus plumbeus* (Nardo, 1827) and *Carcharhinus obscurus* (Lesueur, 1818) outside the openings connecting the Bardawil Lagoon (northern Sinai) to the Mediterranean between 1975 and 1976. Studies on cartilaginous fish observations were then maintained along the coast of Israel, where Golani (1986) recorded the first occurrence of *Somniosus rostratus* (Risso, 1827), authenticated the presence of *Centrophorus granulosus* and *Dalatias licha* (Bonnaterre, 1788) in the region, and noted *Galeus melastomus* (Rafinesque, 1810)

at a depth of 1440 m, which increased its bathymetric range. More recently, two studies noted the first record of *Dasyatis chrysonota* (Smith, 1828) (Golani and Capapé, 2004) and the second record of *Mobula mobular* (Bonnaterre, 1788) (Golani and Levy, 2005) along the Mediterranean coast of Israel.

### *Turkey*

Several studies on cartilaginous fish first records and observations were established in the Mediterranean Turkish and Aegean Seas. In 1996, an accurate recording of five *Etmopterus spinax* (Linnaeus, 1758) specimens was presented by Kabasakal and Unsal (1999) in the Gulf of Saros (Northeastern Aegean Sea). The presence of this species in the seas of Turkey has been recorded by Aksiray (1987) with vague information about depth and locality. Kaya (1993) reported only one specimen of *E. spinax* from the Gulf of Gokova (Southeastern Aegean Sea) at a depth of 730 m. Moreover, a Bigeye Thresher Shark ( $L_T=350$  cm), *Alopias superciliosus* (Lowe, 1841) was recorded for the first time in the latter gulf in May 2005 (Kabasakal and Karhan, 2008). A male Shortfin Mako, *Isurus oxyrinchus* (Rafinesque, 1810) was also recorded in the Gulf of Saros for the first time in 2012 by a commercial fisherman using a hook and a line (Kabasakal and Kabasakal, 2013). Furthermore, a study in 2008 in the Aegean Sea presented the smallest neonate Great White Shark, *Carcharodon carcharias* (Linnaeus, 1758), from the Mediterranean waters to (Kabasakal and Ozgurgedikoglu, 2008). The latter study recorded the capture of a new born Great White Shark by a commercial gill-netter in the coast of Altinoluk (Edremit Bay, North Aegean Sea) prior to the capture of a juvenile by the bottom long liner of the same fisherman. Besides, 12 individuals of *C. carcharias* were either recorded or sighted in Aegean waters from 1957 to 2011 (Kabasakal, 2014). Captures of the Bluntnose Sixgill Shark, *Hexanchus griseus* (Bonnaterre, 1788), from 1967 to 2013 by commercial fisheries in the Mediterranean and Aegean Seas of Turkey were also recorded in Kabasakal (2013). First record studies were maintained in the Turkish Mediterranean seas, especially in the northeastern part. A Red Sea migrant, *Himantura uarnak*, and a Round Fantail Stingray, *Taeniura grabata* were first recorded in May 1997 in Iskenderun Bay at depths of 15 and 20 m respectively (Basusta *et al.*, 1998). Almost during the same period of time, a Speckled Ray, *Raja polystigma* (Regan, 1923) was also recorded for the first time in the Mediterranean seas of Turkey (Kabasakal, 1998). In addition, four accidental captures of *C. maximus* in the coastal waters of Antalya and Mersin

Bays (Eastern Mediterranean) were documented since 1987 (Kideys, 1997; Kabasakal, 2002a). Besides, small groups of this shark have been sighted by Kideys (1997) in Mersin Bay near Edremlı in 1996. On 30 December 2006, *C. maximus* ( $L_T= 300$  cm) was also incidentally caught by a stationary net set in the coastal waters of İskenderun Bay; and on 7 April 2012, a male of the same species has been incidentally caught by a coastal gill-netter just 50 m off Erdemli coast (Bilecenoglu *et al.*, 2013). Furthermore, a Sawback Angelshark *Squatina aculeata* (Cuvier, 1829) was caught in a trawl in May 1997 in İskenderun Bay at about 120-200 m depth and recorded for the first time in the eastern Mediterranean coast of Turkey (Basusta, 2002). Again in İskenderun Bay (Eastern Mediterranean), two gravid Lusitanian Cownose Rays, *Rhinoptera marginata* (Geoffroy Saint-Hilaire, 1817) were captured by a bottom trawl for the first time and documented by Basusta *et al.* (2012b). Furthermore, the occurrence of *Dasyatis marmorata* (Steindachner, 1892) in Turkey was confirmed in Kapiris *et al.* (2014) from samples collected between 2005 and 2011 off İskenderun Bay, Adana, and Mersin (Levantine basin). The latter species was first mentioned by Diamant *et al.* (2010) as *D. chrysonota* in the northeastern Levant without providing any taxonomical information. According to Bradai *et al.* (2012), all previous records given from the Mediterranean Sea under the names *D. pastinaca marmorata* and *D. chrysonota* should be considered as *D. marmorata*, and DNA studies are required to resolve the taxonomical argument. Moreover, the Starry Smooth-hound *Mustelus asterias* (Cloquet, 1819) was also recorded in İskenderun Bay in February 2014 (Kapiris *et al.*, 2014) after 30 years from its capture between 1980 and 1984 by Gucu and Bingel (1994) in the same region. In addition, the smallest individual of *I. oxyrinchus* ( $L_T= 69.8$  cm) was caught by a purse seine boat in March 2010 at a 54 m depth off the Samamdag coast of İskenderun Bay (Bilecenoglu *et al.*, 2013). Finally, during the last 58 years only 12 Angular Rough Sharks, *Oxynotus centrina* (Linnaeus, 1758) have been recorded in Turkish waters; three of these were recorded in the Aegean Sea and one in Levantine waters (Kabasakal, 2010). Recently, a gravid female of *O. centrina* and an adult male were recorded in the northeastern Mediterranean, indicating that there is a nursery area in the region, where mating might probably occur (Basusta *et al.*, 2015).

#### 4. Cartilaginous fishing in the Eastern Mediterranean

Assessing Mediterranean elasmobranch fishing is an important issue and it applies to all its basins. Elasmobranch fish catches constitute 1.1% of the total landings in Mediterranean Sea (Serena, 2005a). About half of the estimated global catch of elasmobranch species is bycatch and not disclosed in official fishery statistics (Bradai *et al.*, 2012). Discards constitute over 40% of the catch (Sánchez *et al.*, 2004). Bycatch can induce imbalances between top predators and prey and consequently affect biodiversity (Hall *et al.*, 2000).

The major elasmobranchs fishing countries within the Mediterranean are Italy, Turkey and Tunisia. There are no fisheries directed to elasmobranchs in the Mediterranean and elasmobranchs are part of the bycatch in most local artisanal fisheries (Bradai *et al.*, 2012). However, Dulvy *et al.* (2014) indicated that there is a low fin trade share in the Mediterranean (i.e. Tunisia).

Juvenile bycatch of commercial species may harmfully affect the future stock and catch levels (Hall *et al.*, 2000). Nevertheless, the bycatch of endangered species such as marine mammals, seabirds, turtles and elasmobranchs can have troublesome ecological consequences. These groups of species are susceptible due to their specific biological characteristics (Musick *et al.*, 2000; Gilman *et al.*, 2008), especially elasmobranchs that are characterized by their slow growth rate, late maturity and low fecundity compared to bony fish.

Trawling is considered responsible for a large amount of elasmobranch bycatches and discards throughout the world (Bonfil, 1997). Trawling is prohibited along the coast of Lebanon, in the Levantine Basin of the Eastern Mediterranean (Fowler, 2005). This method is problematic and leads to juvenile catches, important discards and negative impact on the environment (Sacchi, 2007). There is no fishery targeting elasmobranchs, but all species are mainly caught by this fishing gear; 62 species are listed in the trawl fisheries in Greece, 62 in Catalonia and 74 in Italian waters (Bertrand *et al.*, 2000). Nonetheless, demersal species are the most caught (Baino *et al.*, 2001; Massutí and Moranta, 2003). Trammel nets and gillnets are the most frequently used by small Mediterranean fisheries and there is a little use of gillnets targeting sharks (Bradai *et al.*, 2012).

The impact of all fishing gear used in the Mediterranean on cartilaginous fish species was assessed in several papers. Tudela (2004) described demersal and pelagic fisheries separately giving the different species involved and the corresponding impacting activities. Sacchi (2007) evaluated 11 fishing methods, their impact on cartilaginous fish and solutions for improvement.

Bycatches and discards of sharks in the large pelagic fisheries in the Mediterranean Sea were assessed in a report by Megalofonou *et al.* (2000). More recently, two papers analyzed the composition and abundance of the pelagic shark bycatch and estimated discards from Greek swordfish and tuna fisheries in the eastern Mediterranean Sea during the period from 1998 to 2001 (Megalofonou *et al.*, 2005b; Megalofonou *et al.*, 2005c). These papers showed that shark bycatches were notable in the swordfish fishery, with the most common species being the Blue Shark, *Prionace glauca* (Linnaeus, 1758). Moreover, higher abundance indices were observed in the Levantine Basin and low discards in the Aegean Sea. A later paper by Megalofonou *et al.* (2009b) assessed the environmental, spatial, temporal, and operational effects on blue shark bycatches in the Mediterranean longline fishery by applying generalized linear model approaches.

Shark bycatch and discards were maintained in the Greek waters (Eastern Mediterranean) in a paper dealing with the Greek swordfish fishery (Peristeraki *et al.*, 2008). In this paper, data on bycatches and discards of the Greek fleets targeting swordfish, collected by observers on board from 2004 to 2006 were analyzed. In terms of weight, the landed swordfish represented the 84% of the total catches, and shark bycatch represented 1.9%. Furthermore, regarding the same Greek swordfish fishery in the Eastern Mediterranean, spatio-temporal variations in shark bycatches were examined by Tserpes *et al.* (2006) using Generalized Linear Modeling techniques applied to “presence-absence” data collected from 2000 to 2003. In the latter paper, the presence of sharks had a stable pattern, showing only significant monthly variations.

Finally, Ferretti and Myers (2006) reviewed examples of bycatch mitigation tools available worldwide that would be effective for elasmobranchs particularly in the Mediterranean basin. For instance, the latter mentioned technological methods by modifying the fishing gear, and legislative regulations to decrease wastage productions and protect endangered species, and social approaches by working with fishermen to adapt them to these types of work limits.

## 5. Age and growth

Age determinations based on the examination of hard anatomical parts is indispensable in fisheries research. Precise age information allows quality estimates of growth and other vital rates such as natural mortality and longevity, and is important for successful fisheries management. Fish age and growth also aid to evaluate many other biological (and pathological) processes, such as productivity, yield per recruit, prey availability, habitat suitability and even feeding kinematics (Devries and Frie, 1996; Campana, 2001; Robinson and Motta, 2002). Several studies on cartilaginous fish age and growth were performed in the Eastern Mediterranean. One study dealt with the dying techniques of aging in Iskenderun Bay (Basusta *et al.*, 2010). In the latter study, age determinations were carried out using vertebral sections and alcian blue dying techniques were used to improve the visibility of the band on vertebrae. This study concluded that the alcian blue staining technique can be used successfully for age determination of elasmobranchs vertebrae. Other studies on the biological characteristics of some elasmobranchs mentioned age estimates and ages at first maturity. For example, Megalofonou *et al.* (2005a) and Megalofonou *et al.* (2009a) estimated the age of *P. glauca* from caudal vertebrae to range from 1 to 12 years and estimated the age at 50% maturity as 4.9 years for males and 5.5 years for females using caudal vertebrae. Moreover, the oldest estimated age of a Roughtail Stingray, *Dasyatis centroura* (Mitchill, 1815), was also studied by Basusta and Sulikowski (2012) in Iskenderun Bay. In the latter study, a 24 years of age estimated from the vertebrae section was recorded for a large *D. centroura* from the Mediterranean Sea. The maximum age of the Longnosed Skate, *Dipturus oxyrinchus* (Linnaeus, 1758) was estimated by Yigin and Ismen (2010a) in Saros Bay, North Aegean Sea, to be 8 years for males and 9 years for females. More recently, the maximum age of the Rough Ray, *Raja Radula* (Delaroche, 1809) was estimated by Yigin and Ismen (2014) in to be 6 years for males and 8 years for females in the same region.

Among the several models and variations of models estimating growth parameters in fishes, the Von Bertalanffy (1938) growth model is the most commonly applied. The Von Bertalanffy growth function has been introduced into fisheries by Beverton and Holt (1993) and has been broadly used since then. Although it has been criticized over the years, it is the most widely used growth function in fisheries biology today (Roff, 1982; Haddon, 2001). Modeling growth is based on the principle that the size of an organism depends on the result of anabolism and

catabolism. Furthermore, it is suitable to use and allows easy comparison between populations and several different forms of the model can be fitted to the age-length data. Several studies on elasmobranch age and growth using the Von Bertalanffy growth model were performed in the Eastern Mediterranean. Age and growth data for six cartilaginous fish species of the Eastern Mediterranean are presented in this section and include parameters for the Von Bertalanffy growth model providing estimates of  $L_{\infty}$ , the asymptotic or maximum length (or width for some batoids),  $k$ , the growth coefficient, and  $t_0$ , the age or time when length theoretically equals zero (

Table 9).

Table 9: The Von Bertalanffy growth parameters and age estimation methods for several cartilaginous fish species in different studies in the Eastern Mediterranean ( $L_{\infty}$  = the asymptotic or maximum length (or width for some batoids);  $k$  = the growth coefficient; and  $t_0$ =the age or time when length theoretically equals zero; M = Males; F = Females; N = Number of specimens; SM = Southeastern Mediterranean; NM = Northeastern Mediterranean; NAS = North Aegean Sea).

Species	Region	Method	Von Bertalanffy growth parameters					References
			N	Sex	$L_{\infty}$ (cm)	$K$ (year <sup>-1</sup> )	$t_0$ (years)	
<i>Raja miraletus</i>	Egyptian Mediterranean coast (SM)	Vertebral band count	318	M	87.87	0.19	-0.50	AbdelAziz (1992)
			229	F	91.92	0.17	-0.25	
<i>Dasyatis pastinaca</i>	Iskenderun Bay (NM)	Vertebral band count	256	Both	121.50	0.09	-1.615	Ismen (2003)
<i>Rhinobatos rhinobatos</i>	Iskenderun Bay (NM)	Vertebral band count	225	Both	128.60	0.29	-0.89	Ismen <i>et al.</i> (2007b)
	Iskenderun Bay (NM)		97	Both	137.70	0.16	-2.18	Basusta <i>et al.</i> (2008)
<i>Dipturus oxyrinchus</i>	Saros Bay (NAS)	Vertebral band count	179	Both	256.46	0.04	-1.17	Yigin and Ismen (2010a)
<i>Torpedo marmorata</i>	Iskenderun Bay (NM)	Vertebral band count	117	Both	57.31	0.19	-0.39	Duman and Basusta (2013)
<i>Raja radula</i>	Saros Bay (NAS)	Vertebral band count	114	M	74.70	0.20	-0.22	Yigin and Ismen (2014)
			147	F	82.94	0.16	-0.59	

## 6. Length-weight relationships

Size relationships and conversions (i.e. length-weight relationships) are considered as basic for fish stock assessment. These relationships are significant to understand the rate of growth, age, and other constituents of population dynamics (Kolher *et al.*, 1995). Such relationships aid in deriving the weight estimates of fish from their lengths. They have been estimated for cartilaginous fish species throughout the Mediterranean, with several studies concentrated in its eastern part. They can be used to induce laws to limit the overexploitation of these fishes through direct fishing and bycatch by establishing a minimum catch weight limit and abiding to these weights when the lengths are estimated at sea.

This section presents the length-weight relationships of several cartilaginous fish species mentioned in studies performed in the Eastern Mediterranean (Table 10).

Table 10: The length-weight relationships for cartilaginous fish species in several studies performed in the Eastern Mediterranean ( $W_T$ : total weight;  $L_T$ : total length;  $D_W$ : Disk width; N: number of individuals).

Species	Region	N	Length-weight relationship	Coefficient of determination ( $R^2$ )	Reference
<i>Carcharhinus plumbeus</i>	Antalya Bay	1	Males: $W_T=0.0626 \times L_T^{3.41}$	-	Güven <i>et al.</i> (2012)
<i>Centrophorus granulosus</i>	Antalya Bay	56	$W_T=0.001 \times L_T^{3.41}$	0.98	Güven <i>et al.</i> (2012)
	Off the island of Crete	43	$W_T = 3.46 \times 10^{-7} L_T^{3.40}$	-	Megalofonou and Chatzisprou (2006)
<i>Chimaera monstrosa</i>	North Aegean Sea	17	$W_T=0.0028 \times L_T^{2.82}$	0.98	Filiz and Bilge (2004)
<i>Dalatias licha</i>	Antalya Bay	3	Females: $W_T=0.0117 \times L_T^3$	-	Güven <i>et al.</i> (2012)
<i>Dasyatis pastinaca</i>	Iskenderun Bay	146	Males : $W_T=0.00237 \times L_T^{3.17}$ $W_T=0.02963 \times D_W^{3.31}$	0.95 0.91	Ismen (2003)
		110	Females : $W_T=0.01681 \times L_T^{3.21}$ $W_T=0.00091 \times D_W^{3.44}$	0.94 0.94	
	Iskenderun Bay	417	$W_T = 0.0419 \times L_T^{3.3169}$	0.84	Basusta <i>et al.</i> (2012a)
	North Aegean Sea	71	$W_T = 0.00074 \times L_T^{3.55}$	0.96	Yigin and Ismen (2009b)
	Central Aegean Sea	31	$W_T = 0.0102 \times L_T^{3.37}$	0.98	Ilkyaz <i>et al.</i> (2008)
	Central	16	$W_T = 0.0023 \times L_T^{3.248}$	0.99	Ozaydin <i>et al.</i> (2007)

	Aegean Sea				
	North Aegean Sea	48	$W_T = 0.01259 \times L_T^{3.3024}$	0.99	Ismen <i>et al.</i> (2007a)
	North Aegean Sea	29	$W_T = 0.0149 \times L_T^{2.81}$	0.85	Filiz and Bilge (2004)
	North Aegean Sea	14	$W_T = 0.0085 \times L_T^{2.9379}$	0.97	Filiz and Mater (2002)
	North Aegean Sea	12	$W_T = 0.1168 \times L_T^{2.122}$	0.64	Karakulak <i>et al.</i> (2006)
<i>Dipturus oxyrinchus</i>	North Aegean Sea	179	$W_T = 0.0008 \times L_T^{3.35}$ $W_T = 0.0043 \times D_W^{3.29}$	-	Yigin and Ismen (2010a)
	North Aegean Sea	179	$W_T = 0.00083 \times L_T^{3.35}$	0.99	Yigin and Ismen (2009)
	Central Aegean Sea	12	$W_T = 0.0535 \times L_T^{2.639}$	0.98	Ozaydin <i>et al.</i> (2007)
	North Aegean Sea	118	$W_T = 0.00423 \times L_T^{3.2909}$	0.99	Ismen <i>et al.</i> (2007a)
	North Aegean Sea	8	$W_T = 0.0007 \times L_T^{3.40}$	0.99	Filiz and Bilge (2004)
<i>Etmopterus spinax</i>	Antalya Bay	150	$W_T = 0.0052 \times L_T^{2.94}$	0.97	Guyen <i>et al.</i> (2012)
	North Aegean Sea	11	$W_T = 0.0023 \times L_T^{3.2256}$	0.95	Ismen <i>et al.</i> (2009)
	North Aegean Sea	24	$W_T = 0.00172 \times L_T^{3.2659}$	0.92	Ismen <i>et al.</i> (2007a)
<i>Galeus melastomus</i>	Antalya Bay	544	$W_T = 0.0026 \times L_T^3$	0.98	Guyen <i>et al.</i> (2012)
	North Aegean Sea	303	$W_T = 0.0016 \times L_T^{3.1750}$	0.95	Ismen <i>et al.</i> (2009)
	North Aegean Sea	93	$W_T = 0.00238 \times L_T^{3.0290}$	0.98	Ismen <i>et al.</i> (2007a)
<i>Gymnura altavela</i>	Iskenderun Bay	104	$W_T = 0.017 \times L_T^{2.7948}$	0.73	Basusta <i>et al.</i> (2012a)
	Central Aegean Sea	9	$W_T = 0.0025 \times L_T^{3.27}$	0.97	Ilkyaz <i>et al.</i> (2008)
	Central Aegean Sea	17	$W_T = 0.0449 \times L_T^{2.84}$	0.99	Ozaydin <i>et al.</i> (2007)
	North Aegean Sea	9	$W_T = 0.0268 \times L_T^{2.96}$	0.98	Filiz and Bilge (2004)
<i>Heptranchias perlo</i>	Antalya Bay	11	$W_T = 0.0021 \times L_T^{3.08}$	0.99	Guyen <i>et al.</i> (2012)
	North Aegean Sea	18	$W_T = 0.0047 \times L_T^{2.9043}$	0.96	Ismen <i>et al.</i> (2009)
	North Aegean Sea	14	$W_T = 0.00424 \times L_T^{2.927}$	0.96	Ismen <i>et al.</i> (2007a)
<i>Hexanchus griseus</i>	North Aegean Sea	7	Females: $W_T = 0.0002 \times L_T^{3.6060}$	0.98	Ismen <i>et al.</i> (2009)
	North Aegean Sea	5	$W_T = 0.0008 \times L_T^{3.8222}$	0.91	Ismen <i>et al.</i> (2007a)
<i>Mustelus asterias</i>	North Aegean Sea	7	$W_T = 0.0006 \times L_T^{3.4005}$	0.99	Ismen <i>et al.</i> (2009)
<i>Mustelus mustelus</i>	Antalya Bay	4	Females: $W_T = 0.0974 \times L_T^{2.77}$	0.99	Guyen <i>et al.</i> (2012)
	North Aegean Sea	70	$W_T = 0.0034 \times L_T^{2.9789}$	0.99	Ismen <i>et al.</i> (2009)
	Central Aegean Sea	148	$W_T = 0.0027 \times L_T^{3.05}$	0.98	Ilkyaz <i>et al.</i> (2008)

	Central Aegean Sea	17	$W_T = 0.0044 \times L_T^{2.912}$	0.98	Ozaydin <i>et al.</i> (2007)
	North Aegean Sea	26	$W_T = 0.00131 \times L_T^{3.1895}$	0.99	Ismen <i>et al.</i> (2007a)
	North Aegean Sea	35	$W_T = 0.0011 \times L_T^{3.25}$	0.97	Filiz and Bilge (2004)
	North Aegean Sea	24	$W_T = 0.0008 \times L_T^{3.3259}$	0.97	Filiz and Mater (2002)
<i>Myliobatis aquila</i>	North Aegean Sea	66	$W_T = 0.00027 \times L_T^{3.56}$	0.92	Yigin and Ismen (2009)
	Central Aegean Sea	39	$W_T = 0.0058 \times L_T^{3.28}$	0.99	Ilkyaz <i>et al.</i> (2008)
	North Aegean Sea	14	$W_T = 0.0008 \times L_T^{3.34}$	0.93	Filiz and Bilge (2004)
<i>Oxynotus centrina</i>	Antalya Bay	4	$W_T = 0.0151 \times L_T^3$	-	Guyen <i>et al.</i> (2012)
<i>Pteromylaeus bovinus</i>	Iskenderun Bay	22	$W_T = 0.0194 \times L_T^{2.9034}$	0.90	Basusta <i>et al.</i> (2012a)
<i>Raja clavata</i>	Iskenderun Bay	75	$W_T = 0.023 \times L_T^{2.6421}$	0.76	Basusta <i>et al.</i> (2012a)
	North Aegean Sea	226	$W_T = 0.00163 \times L_T^{3.32}$	0.99	Yigin and Ismen (2009)
	Central Aegean Sea	24	$W_T = 0.0335 \times L_T^{2.89}$	0.96	Ilkyaz <i>et al.</i> (2008)
	North Aegean Sea	112	$W_T = 0.013 \times L_T^{3.1163}$	0.99	Ismen <i>et al.</i> (2007a)
	North Aegean Sea	37	$W_T = 0.0016 \times L_T^{3.30}$	0.94	Filiz and Bilge (2004)
	North Aegean Sea	29	$W_T = 0.0016 \times L_T^{3.2914}$	0.93	Filiz and Mater (2002)
<i>Raja miraletus</i>	South Aegean Sea	62	$W_T = 0.0008 \times L_T^{3.4392}$	0.97	Bilge <i>et al.</i> (2014)
	Iskenderun Bay	22	$W_T = 0.0021 \times L_T^{3.262}$	0.95	Basusta <i>et al.</i> (2012a)
	North Aegean Sea	52	$W_T = 0.00173 \times L_T^{3.27}$	0.95	Yigin and Ismen (2009)
	Central Aegean Sea	10	$W_T = 0.0346 \times L_T^{2.82}$	0.98	Ilkyaz <i>et al.</i> (2008)
	Central Aegean Sea	12	$W_T = 0.0063 \times L_T^{2.948}$	0.97	Ozaydin <i>et al.</i> (2007)
	North Aegean Sea	30	$W_T = 0.00891 \times L_T^{3.2231}$	0.97	Ismen <i>et al.</i> (2007a)
	North Aegean Sea	13	$W_T = 0.0001 \times L_T^{4.15}$	0.93	Filiz and Bilge (2004)
	North Aegean Sea	13	$W_T = 0.0001 \times L_T^{0.173}$	0.92	Filiz and Mater (2002)
<i>Raja polystigma</i>	Central Aegean Sea	18	$W_T = 0.0218 \times L_T^{3.05}$	0.98	Ilkyaz <i>et al.</i> (2008)
<i>Raja radula</i>	North Aegean Sea	113	Males: $W_T = 0.0022 \times L_T^{3.30}$ $W_T = 0.0053 \times D_W^{3.46}$	0.97 0.96	Yigin and Ismen (2014)
		142	Females: $W_T = 0.0019 \times L_T^{3.36}$ $W_T = 0.0092 \times D_W^{3.28}$	0.97 0.97	
	South Aegean	38	$W_T = 0.0068 \times L_T^{2.9718}$	0.99	Bilge <i>et al.</i> (2014)

	Sea				
	North Aegean Sea	204	$W_T = 0.00205 \times L_T^{3.32}$	0.97	Yigin and Ismen (2009)
	North Aegean Sea	49	$W_T = 0.01131 \times L_T^{3.2491}$	0.98	Ismen <i>et al.</i> (2007a)
	North Aegean Sea	25	$W_T = 0.0030 \times L_T^{3.217}$	0.94	Karakulak <i>et al.</i> (2006)
<i>Rhinobatos cemiculus</i>	Iskenderun Bay	262	$W_T = 0.00265 \times L_T^{3.0199}$	0.86	Basusta <i>et al.</i> (2012a)
<i>Rhinobatos rhinobatos</i>	Iskenderun Bay	20	$W_T = 0.0011 \times L_T^{3.1863}$	0.96	Basusta <i>et al.</i> (2012a)
	Iskenderun Bay	115	$W_T = 0.0012 \times L_T^{3.1915}$	0.99	Basusta <i>et al.</i> (2008)
	Iskenderun Bay	129	Males: $W_T = 0.003 \times L_T^{2.98}$	0.99	Ismen <i>et al.</i> (2007b)
		96	Females: $W_T = 0.0043 \times L_T^{2.89}$	0.99	
<i>Rhinoptera marginata</i>	Iskenderun Bay	17	$W_T = 0.01 \times L_T^{2.1347}$	0.75	Basusta <i>et al.</i> (2012a)
<i>Rostroraja alba</i>	Southeastern Aegean Sea	12	$W_T = 0.0021 \times L_T^{3.214}$	0.99	Yapici and Filiz (2014)
	North Aegean Sea	126	$W_T = 0.00194 \times L_T^{3.27}$	0.98	Yigin and Ismen (2009)
	Central Aegean Sea	5	$W_T = 0.0083 \times L_T^{3.13}$	0.99	Ilkyaz <i>et al.</i> (2008)
	North Aegean Sea	43	$W_T = 0.00662 \times L_T^{3.201}$	0.99	Ismen <i>et al.</i> (2007a)
	Central Aegean Sea	11	$W_T = 0.009 \times L_T^{3.478}$	0.99	Ozaydin <i>et al.</i> (2007)
<i>Scyliorhinus canicula</i>	South Aegean Sea	144	$W_T = 0.0012 \times L_T^{3.2999}$	0.92	Bilge <i>et al.</i> (2014)
	Antalya Bay	647	$W_T = 0.0012 \times L_T^{3.27}$	0.96	Guven <i>et al.</i> (2012)
	North Aegean Sea	188 8	$W_T = 0.0017 \times L_T^{3.1735}$	0.98	Ismen <i>et al.</i> (2009)
	North Aegean Sea	112	$W_T = 2 \times 10^{-6} \times L_T^{3.0999}$	0.864	Cakir <i>et al.</i> (2008)
	Central Aegean Sea	744	$W_T = 0.0012 \times L_T^{3.29}$	0.96	Ilkyaz <i>et al.</i> (2008)
	Central Aegean Sea	187	$W_T = 0.0006 \times L_T^{3.437}$	0.95	Ozaydin <i>et al.</i> (2007)
	North Aegean Sea	150 1	$W_T = 0.00169 \times L_T^{3.1709}$	0.99	Ismen <i>et al.</i> (2007a)
	North Aegean Sea	291	$W_T = 6 \times 10^{-7} \times L_T^{2.9276}$	0.83	Cakir <i>et al.</i> (2006)
	North Aegean Sea	637	$W_T = 0.0012 \times L_T^{3.26}$	0.99	Filiz and Bilge (2004)
	North Aegean Sea	110	$W_T = 0.0016 \times L_T^{3.1804}$	0.98	Filiz and Mater (2002)
<i>Scyliorhinus stellaris</i>	South Aegean Sea	128 1	$W_T = 0.0039 \times L_T^{2.9755}$	0.98	Bilge <i>et al.</i> (2014)
	North Aegean Sea	12	$W_T = 0.0009 \times L_T^{3.3653}$	0.99	Ismen <i>et al.</i> (2009)

	Central Aegean Sea	11	$W_T = 0.002 \times L_T^{3.23}$	0.99	Ilkyaz <i>et al.</i> (2008)
	Central Aegean Sea	34	$W_T = 0.0065 \times L_T^{2.817}$	0.98	Ozaydin <i>et al.</i> (2007)
<i>Squalus acanthias</i>	North Aegean Sea	565	$W_T = 0.0037 \times L_T^{3.0477}$	0.97	Ismen <i>et al.</i> (2009)
	North Aegean Sea	32	$W_T = 0.0031 \times L_T^{3.11}$	0.98	Filiz and Bilge (2004)
	North Aegean Sea	32	$W_T = 0.0031 \times L_T^{3.1056}$	0.98	Filiz and Mater (2002)
<i>Squalus blainville</i>	South Aegean Sea	80	$W_T = 0.0052 \times L_T^{2.964}$	0.99	Bilge <i>et al.</i> (2014)
	Antalya Bay	177	$W_T = 0.0033 \times L_T^{3.06}$	0.99	Guyen <i>et al.</i> (2012)
	North Aegean Sea	27	$W_T = 0.003 \times L_T^{3.07}$	0.99	Ismen <i>et al.</i> (2009)
	North Aegean Sea	299	$W_T = 0.00345 \times L_T^{3.0555}$	0.98	Ismen <i>et al.</i> (2007a)
<i>Torpedo marmorata</i>	South Aegean Sea	57	$W_T = 0.0721 \times L_T^{2.5325}$	0.98	Bilge <i>et al.</i> (2014)
	Iskenderun Bay	56	Males: $W_T = 0.0315 \times L_T^{2.8171}$	0.92	Duman and Basusta (2013)
		61	Females: $W_T = 0.017 \times L_T^{3.0396}$	0.92	
	Central Aegean Sea	35	$W_T = 0.0232 \times L_T^{2.98}$	0.99	Ilkyaz <i>et al.</i> (2008)
	Central Aegean Sea	12	$W_T = 0.0535 \times L_T^{2.639}$	0.98	Ozaydin <i>et al.</i> (2007)
	North Aegean Sea	20	$W_T = 0.0592 \times L_T^{2.6433}$	0.99	Ismen <i>et al.</i> (2007a)
	North Aegean Sea	22	$W_T = 0.0139 \times L_T^{3.103}$	0.95	Karakulak <i>et al.</i> (2006)
	North Aegean Sea	37	$W_T = 0.0273 \times L_T^{2.91}$	0.98	Filiz and Bilge (2004)
	North Aegean Sea	20	$W_T = 0.0488 \times L_T^{2.6935}$	0.96	Filiz and Mater (2002)
<i>Torpedo nobiliana</i>	South Aegean Sea	73	$W_T = 0.0519 \times L_T^{2.7154}$	0.99	Bilge <i>et al.</i> (2014)
	Iskenderun Bay	92	$W_T = 0.015 \times L_T^{3.0611}$	0.85	Basusta <i>et al.</i> (2012a)

## 7. Reproductive aspects and biological indices

Assessing the reproductive aspects and biological indices in cartilaginous fish plays a vital role in determining the age at first maturity, mating and parturition time, and probable nursery areas. This information can aid in thoroughly understanding the life history characteristics of elasmobranchs that is essential for their proper management because these fishes are particularly susceptible to anthropogenic threats. Essential life history characteristics needed for proper management include age/size at maturity, gestation length, and reproductive cyclicity (Walker, 2004; 2005). When this information is incorporated into fisheries models and species assessments, insight can be gained into when, where, and how often populations are reproducing, which can ultimately aid in reducing their decrease through the development of management protocols that improve fishery practices (Walker, 2004; 2005). This section presents the numerous studies that mention the reproductive aspects of several species of sharks and batoids in the Eastern Mediterranean.

### 7.1. Sharks

Several studies in the Eastern Mediterranean consisted of the biological and reproduction characteristics of 8 sharks in the region.

- *Scyliorhinus canicula* (Linnaeus, 1758)

Four studies on the biology and reproductive aspects of this shark species were done in the Eastern Mediterranean.

Erdogan *et al.* (2004) analyzed the morphometric characteristics and dentition of 100 *S. canicula* specimens in Edremit Bay (Northern Aegean Sea) in 1998. These authors established that sexual dimorphism exists for this species and males have longer and narrower mouths than females. Moreover, significant differences were recorded in the girth of the head and preoral, prebranchial head and body lengths.

In addition, sexual dimorphism was also recorded for the same species in Izmir Bay (Aegean Sea, Turkey) (Filiz and Taskavak, 2006b). The latter study was performed on 296 specimens of *S. canicula* between September and November 2002. It demonstrated pronounced sexual

dimorphism where males showed to have longer and narrower mouths than females. Head and body measures also significantly differed between sexes.

Moreover, this species was mentioned in a study by Cakir *et al.* (2006) in the northern Aegean Sea. The latter study revealed that the reproduction activities of this species continued in all seasons with a relatively high rate of oogenesis in the summer and mature females spawned successively two eggs in each batch.

Finally, the sexual maturity and fecundity of *S. canicula* in the Aegean Sea were recently studied by Kousteni *et al.* (2010). These authors Kousteni *et al.* (2010) demonstrated the size at 50% maturity of this species to be 396 mm and 399 mm for males and females, respectively. This study also evaluated ovary weight, oocyte diameter and fecundity for female specimens with an ovarian fecundity reaching a maximum of 18 ripe oocytes in the ovary of a 460 mm female. Only one pair of egg cases was found in each one of the 30 adult females examined. It finally showed significant seasonal variations in the gonado-somatic index of females.

- *Centrophorus granulosus* (Bloch and Schneider, 1801)

The reproductive biology of the Gulper Shark, *Centrophorus granulosus*, was evaluated by two studies in the Eastern Mediterranean. Golani and Pisanty (2000) studied this species from September 1982 to November 1992 along the Mediterranean coast of Israel at depths of 200-1400 m. The population studied consisted mainly of females and gravid females had only one embryo or a single large egg. More recently, the reproductive aspects of *C. granulosus* were mentioned in a study by Megalofonou and Chatzisprou (2006) on 43 specimens caught with bottom long lines off the island of Crete between 350-480 m depth. Most of the specimens in the latter study were mature with high gonado-somatic indices (females: 0.1-8.9; males 0.1-2.2). The unique gravid female found had only one large candle ovum in its right uterus.

- *Hexanchus griseus* (Bonnaterre, 1788)

Rare are the studies evaluating the reproductive aspects of the Bluntnose Sixgill Shark, *Hexanchus griseus*, in the Eastern Mediterranean. However, eleven specimens of *H. griseus* were mentioned in a study by Kabasakal (2004) in the Aegean Sea. Biological examinations and available information in this study suggested that *H. griseus* gives birth from October to the end of February in the northern Aegean Sea. Furthermore, a more recent study by Kabasakal (2006) determined the maturity states of the *H. griseus* specimens captured mostly between September and March, with two young specimens captured at depths less than 75 m.

- *Dalatias licha* (Bonnaterre, 1788)

One study mentioning some reproductive aspects of the Kitefin Shark, *Dalatias licha*, was done in the Eastern Mediterranean, specifically in the northern Aegean Sea. This study by Kabasakal and Kabasakal (2002) evaluated biological information on three neonate and two post-neonate *D. licha* specimens captured in October 1999 of the northern coast of Gokgeada (Northeastern Aegean Sea) at a depth of 380 m. This study deduced from the capture of these specimens that this region might be a nursery area for this species.

- *Squalus blainville* (Risso, 1827)

One study was also performed on the reproductive biology and embryonic development of *S. blainville* in the Eastern Mediterranean. This study by Kousteni and Megalofonou (2011) evaluated 526 specimens of *S. blainville* that were sampled from the bottom trawl and bottom longline catches from December 2004 to December 2009. The males in this study reached sexual maturity at smaller sizes than females. The smallest sexually mature female was 523 mm in total length, while the smallest sexually mature male was 425 mm in total length. The length at 50% maturity was estimated to be 564.4 mm for females and 457.7 mm for males. The high gonado-somatic index of the specimens in the sample and the presence of sexually mature specimens of both sexes in every season of the year indicated a continuous reproductive cycle. This study also suggested that females ovulate after parturition because females carrying near-term embryos had large, equally developed ovarian oocytes.

- *Squalus acanthias* (Linnaeus, 1758)

The reproductive biology and embryonic development of the Spiny Dogfish, *Squalus acanthias*, were investigated by Chatzisprou and Megalofonou (2005) in the Aegean Sea, Eastern Mediterranean. In the latter study, 180 specimens of *S. acanthias* were studied; the gonado-somatic index and hepato-somatic index were higher during June and August in females, respectively; in males the gonado-somatic index peaked in July and the hepato-somatic index showed its highest value in April. A total of 39 gravid females were identified out of which 28 were bearing embryos. Ovarian and uterine fecundity ranged between 1 and 6 and the size of the pups varied from 72 to 220 mm total length and their weight ranged between 1.6 and 48.5 g.

- *Oxynotus centrina* (Linnaeus, 1758)

Some embryonic characteristics of the Angular Rough Shark, *Oxynotus centrina* were mentioned by Megalofonou and Damalas (2004) in the Eastern Mediterranean. In this study, the authors recorded a gravid female in the Aegean Sea and characterized its 15 embryos. They all had a distinguishing coloration of darker marks on a light brownish background and were attached to sizeable yolk sacs but showed differences in development. Some had already absorbed a significant part of yolk sac content, while others had not. All embryos had clearly formed external morphological characteristics, similar to the adult stage and their sex was difficult to identify because no sign of clasper formation was observed.

- *Prionace glauca* (Linnaeus, 1758)

The reproductive characteristics of the Blue shark, *Prionace glauca*, were also mentioned in two studies about Blue Sharks sampled from the swordfish and tuna fishery in the Mediterranean Sea during the four-year period from 1998 to 2002 (Megalofonou *et al.*, 2005a; Megalofonou *et al.*, 2009a). The gonad observation of the sharks in the latter studies revealed that females smaller than 120 cm total length had immature ovaries with no mature oocytes, while females larger than 203 cm total length had mature ovaries with visible yolky oocytes. All males smaller than 125 cm were immature while males larger than 187 cm were mature. The length at 50% maturity for the Blue Sharks studied was estimated to be 202.9 cm for males and 214.7 cm for females.

## 7.2. Batoids

The reproductive aspects and biological characteristics of 5 batoid species were also studied in the Eastern Mediterranean. These studies concentrated on the biological observations and reproductive cycles of these species.

- *Rhinobatos rhinobatos* (Linnaeus, 1758)

The reproductive aspects and biology of the Common Guitarfish, *Rhinobatos rhinobatos*, were most commonly studied in the Eastern Mediterranean. Three studies were done in Iskenderun Bay (Northeastern Mediterranean) and one along the coast of Alexandria (Southeastern Mediterranean).

In Iskenderun Bay, the length at 50% maturity of *R. rhinobatos* was mentioned in Ismen *et al.* (2007b) to be 68 cm for males and 69 cm for females. Moreover, parturition was found to be in summer and the mean total length and mean weight of developed fetuses were 25.7 cm and 48.5 g, respectively. In the same region, Cek *et al.* (2009) used histological examinations of the gonads and showed that *R. rhinobatos* exhibits a cystic mode of spermatogenesis and can be used as a model for biomedical and toxicological studies. Eight stages of maturation for females and seven stages of maturation for males were identified. The study also suggested that both sexes are reproductively active at different times of the year and the species exhibit lecithotrophic embryonic development. More recently in Iskenderun Bay, the maturity and reproductive cycle of *R. rhinobatos* was also investigated by Demirhan *et al.* (2010). Lengths at 50% maturity in the latter study were 70 cm and 86 cm for males and females, respectively. In addition, the gonado-somatic index peaked in May for females and in November for males, and the hepato-somatic index was found to fluctuate widely in males and females.

Regarding an older study in the Egyptian Alexandria waters, data on gonado-somatic index, maximum ovum diameter, size frequency of ova, and ovarian and uterine contents for 438 *R. rhinobatos* specimens were analyzed on a monthly basis by Abdel-Aziz *et al.* (1993) and indicated a distinct seasonal reproductive cycle for this species. Lengths at 50% maturity were 87 and 70 cm for females and males, respectively. Ovarian egg size and male gonado-somatic index both peaked in July and August, indicating that mating occurred in summer, and females with

full-term embryos were observed in late August, and parturition was followed immediately by ovulation. Ovarian fecundity ranged from 8 to 27 eggs per fish, whereas uterine fecundity ranged from 8 to 14 eggs or embryos per fish.

- *Torpedo torpedo* (Linnaeus, 1758) and *Torpedo marmorata* (Risso, 1810)

The reproduction and biology of these two batoids were only reflected in a study by AbdelAziz (1994) in the Egyptian Eastern Mediterranean waters (Southeastern Mediterranean). In this study, the sizes at maturity of *T. torpedo* and *T. marmorata* were 18 and 25.5 cm for males, respectively, and 22 and 35.5 cm for females, respectively. *T. torpedo* was shown to have a restricted breeding season whereas *T. marmorata* was shown to have a more extended reproductive cycle (probably breeding every two years). In both species, males were capable of mating every year. Individuals of *T. torpedo* mated between December and February, ovulated in March and April, and underwent parturition in late August and September after five to six months of gestation. Individuals of *T. marmorata* mated between November and January, ovulated between December and February, and underwent parturition the following December after 10 to 12 months of gestation. The embryo sizes ranged from 4.6 to 8.2 cm for *T. torpedo* and from 5.8 to 10.1 cm for *T. marmorata*. Finally, a strong correlation between ovarian and uterine fecundity and the length of the mother in both species was shown from these observations.

- *Raja miraletus* (Linnaeus, 1758)

The sexuality, reproduction and fecundity of the Brown Skate, *Raja miraletus*, were also studied in the Eastern Mediterranean by (AbdelAziz *et al.*, 1987) off the coast of Alexandria. This study showed that the males and females of this species reached sexual maturity at 28 cm and 30 cm total length, respectively. Furthermore, the authors showed that vitellogenic activity started in spring (May) and peaked in summer (June, July, August). The study also suggested that the rate of egg laying and vitellogenic activity was controlled by temperature, and indicated the presence of a linear relationship between size and fecundity.

- *Dasyatis pastinaca* (Linnaeus, 1758)

The reproduction of the Common Stingray, *D. pastinaca*, in the Eastern Mediterranean was only reflected in a study by Ismen (2003) in Iskenderun Bay, Turkey. The latter study revealed that the parturition time of *D. pastinaca* occurred during summer and total length at maturity was 43 cm and 46 cm for males and females, respectively.

## **8. Nutrition and feeding habits**

The analysis of stomach contents has become a standard practice to study the feeding habits of fish (Hyslop, 1980). Stomach content analysis provides significant insight into fish feeding patterns, and the quantitative assessment of food habits is an important aspect of fisheries management. Precise description of fish diets and feeding habits also provide basic comprehension of trophic interactions in aquatic food webs. Diets of fishes represent a combination of many important ecological components that include behavior, condition, habitat use, energy intake and inter/intra specific interactions. A feeding habit study might help determine the most frequently consumed prey, the relative importance of various food items to fish nutrition and quantify the consumption rate of individual prey types. Several studies consisting of stomach content analyses have been performed in the Eastern Mediterranean. These studies, as well as, their general results are detailed in Table 11.

Table 11: The stomach content analysis studies and the general results for several cartilaginous fish species in the Eastern Mediterranean (N: The number of specimens).

Species	Region	N	Prey	Index of Relative Importance (IRI)	References
<b>Sharks</b>					
<i>Centrophorus granulosus</i>	Off the island of Crete	43	- Teleosteans (main) - Cephalopods	-	Megalofonou and Chatzistryrou (2006)
	Mediterranean coast of Israel	-	- Cephalopods (main) - Meso- to bathypelagic fishes	-	Golani and Pisanty (2000)
<i>Dalatias licha</i>	North Aegean Sea	2	- Cephalopods (main) - Teleosteans - Crustaceans (rare)	-	Karachle and Stergiou (2010)
<i>Galeus melastomus</i>	North Aegean Sea	3	- Cephalopods (main) - Teleosteans	-	Karachle and Stergiou (2010)
	North Aegean Sea	-	- Cephalopods	-	Kabasakal (2002b)
<i>Hexanchus griseus</i>	Turkish seas	12	- Teleosteans (main) - Chondrychthyans - Marine mammals - Cephalopods	-	Kabasakal (2006)
	Aegean sea	11	- Teleosteans (main)	-	Kabasakal (2004)
<i>Mustelus mustelus</i>	North Aegean Sea	-	- Cephalopods	-	Kabasakal (2002a)
<i>Scyliorhinus canicula</i>	North Aegean Sea	34	- Cephalopods (main) - Teleosteans - Crustaceans - Polychaetes	-	Karachle and Stergiou (2010)
	Northeastern Aegean Sea	146	- Teleosteans (main) - Crustaceans (main) - Polychaetes (secondary) - Cephalopods (secondary) - Sipunculida (occasional)	%IRI=52.00% %IRI=42.07% %IRI=3.29% %IRI=32.44% %IRI=0.20%	Filiz and Taskavak (2006a)
	North Aegean Sea	-	- Cephalopods	-	Kabasakal (2002a)
	North Aegean Sea	-	- Teleosteans - Crustaceans - Cephalopods - Polychaetes	-	Kabasakal (2001)
	Northeastern Aegean Sea	-	- Crustaceans (main) - Teleosteans (main) - <i>Liocarcinus</i> spp.- <i>Parapenaeus longirostris</i>	IRI=7098.59 IRI=2734.8 IRI=2072.74 IRI=1143.2	Kabasakal (2002d)
<b>Batoids</b>					
<i>Dasyatis pastinaca</i>	North Aegean Sea	1	- Crustaceans (main) - Polychaetes	-	Karachle and Stergiou (2010)
	Iskenderun Bay	256	- Crustaceans (main)	-	Ismen (2003)

<i>Dipturus oxyrinchus</i>	North Aegean Sea	1	- Crustaceans (main)	-	Karachle and Stergiou (2010)
<i>Raja clavata</i>	Sigacik Bay (Aegean Sea)	187	- Mysidacea - <i>Parapenaeus longirostris</i> - <i>Plesionika</i> sp.	-	Eronat and Ozaydin (2014)
	North Aegean Sea	7	- Crustaceans (main) - Teleosteans	-	Karachle and Stergiou (2010)
	Saros Bay (Aegean Sea)	121	- Crustaceans (main) - Teleosteans - Nematodes - Cephalopods - Annelids - Molluscs	% IRI =74.78% % IRI =18.59% % IRI =5.98% % IRI =0.08% % IRI =0.03% % IRI =0.01%	Yigin and Ismen (2010b)
	North Aegean Sea	-	- Cephalopods	-	Kabasakal (2002a)
	Northeastern Aegean Sea	-	- Crustaceans (main) - Teleosteans - Cephalopods	-	Kabasakal (2001)
	Egyptian Mediterranean waters	121	- Crustaceans (main) - Teleosteans - Polychaetes - Cephalopods (rare)	-	AbdelAziz (1986)
	<i>Raja miraletus</i>	North Aegean Sea	3	- Crustaceans (main) - Cephalopods	-
Egyptian Mediterranean waters		381	- Crustaceans (main) - Teleosteans (main) - Molluscs - Annelids	-	Ezzat <i>et al.</i> (1987)
Egyptian Mediterranean waters		320	- Crustaceans (main) - Teleosteans (main) - Polychaetes - Cephalopods (rare)	-	AbdelAziz (1986)
<i>Raja radula</i>	North Aegean Sea	3	- Crustaceans (main) - Teleosteans	-	Karachle and Stergiou (2010)
	Egyptian Mediterranean waters	457	- Crustaceans (main) - Teleosteans - Polychaetes - Bivalves (rare)	-	AbdelAziz (1986)
<i>Rhinobatos rhinobatos</i>	Iskenderun Bay	115	- Unidentified shrimps - Unidentified teleosts - Unidentified crabs - <i>Squilla mantis</i> - <i>Crangon crangon</i>	% IRI=35.89% % IRI=34.51% % IRI=16.91% % IRI=5.11% % IRI=4.69%	Basusta <i>et al.</i> (2007)
	Iskenderun Bay	225	- Squilladae (main) - Penaidea - Crangonidea - Teleostei - Brachyura - Annelidae	-	Ismen <i>et al.</i> (2007b)
	Egyptian	233	- Crustaceans(main)	-	AbdelAziz <i>et al.</i> (1993)

	Mediterranean waters		- Teleosteans - Cephalopods - Annelids		
<i>Torpedo marmorata</i>	North Aegean Sea	118	- Teleosteans - Cephalopods (rare) - Crustaceans (rare)	-	Karachle and Stergiou (2010)
	Egyptian Mediterranean waters	-	- Teleosteans (main) - Cephalopods	-	AbdelAziz (1994)
<i>Torpedo torpedo</i>	Egyptian Mediterranean waters	-	- Teleosteans (main) - Crustaceans	-	AbdelAziz (1994)

## 9. Other studies

Other studies involving diverse aspects in cartilaginous fish research were also performed in the Eastern Mediterranean. These studies included genetics, organ trace metal and muscle fatty acid content, infections, distributions, temporal variation and habitat selection of cartilaginous fish species in the area.

### *Genetics*

Regarding the genetics field, Turan (2008) used mitochondrial 16S ribosomal RNA to clarify the pattern of relationships and systematic status of 4 genera, including 9 species of skates (*Rostroraja alba*, *Leucoraja fullonica*, *Dipturus oxyrinchus*, *D. batis*, *Raja clavata*, *R. montagui*, *R. asterias*, *R. miraletus*, and *R. radula*) in Iskenderun Bay, northeastern Mediterranean. This study revealed 4 main evolutionary lineages; the first lineage included *R. clavata*, *R. montagui*, and *R. miraletus*, the second included *L. fullonica* and *R. asterias*, the third included *D. batis* and *D. oxyrinchus* in a close relationship, which was the sister group to *R. radula*. *R. alba* was clustered separately from all others. More recently, Moftah *et al.* (2011) presented an update on the composition of sharks in the Egyptian Mediterranean waters of Alexandria using DNA barcoding in addition to classical taxonomical methodologies. The latter study confirmed the presence of species *Squalus acanthias*, *Oxynotus centrina*, *Squatina squatina*, *Scyliorhinus canicula*, *Scyliorhinus stellaris*, *Mustelus mustelus*, *Mustelus punctulatus* and *Carcharhinus altimus* in the Egyptian Mediterranean waters.

### *Muscle and organ content*

Concerning muscle and organ content, two studies involving trace metal contents and one involving fatty acid contents were performed on cartilaginous fish in the Eastern Mediterranean. Regarding trace metals, Hornung *et al.* (1993) analyzed trace metals in the muscle and other organs from several species of deep-water sharks (particularly *Centrophorus granulosus* and *Galeus melastomus*) in the Eastern Mediterranean between 1985 and 1991. The latter study revealed a significant correlation between specimen size and the mercury concentration in the muscle as well as in the liver and kidneys, and the overall trace metal content was considerably higher in the specimens from the Eastern Mediterranean compared with the same species from the northeastern Atlantic. More recently, Kousteni *et al.* (2006) studied the total mercury concentrations in edible tissues of *Squalus acanthias* and *Mustelus mustelus* collected around the island of Crete, Eastern Mediterranean. This study revealed that in all muscle samples of *M. mustelus*, except one, the concentrations of total mercury were below the maximum permitted level, whereas mercury concentrations were above this limit in 81% of the *S. acanthias* samples. Regarding the fatty acid contents, total lipid content and fatty acid composition were analyzed by Hornung *et al.* (1994) in muscles of deep water sharks (*Centrophorus granulosus*, *Galeus melastomus*). The study revealed that the fatty acid composition and lipid content of the two shark species were similar, and that there was no correlation between mercury concentration and fatty acid composition or lipid content in the muscle of the sharks.

### *Parasitic infections*

In addition, one study dealt with the parasitic infections of the Common Guitarfish, *Rhinobatos rhinobatos*, in Iskenderun Bay (Genc *et al.*, 2006) by evaluating the seasonal variations of the presence of an anisakid nematode *Hysterothylacium aduncum* (Rudolphi, 1802) in the digestive tract of the latter elasmobranch.

### *Sediment preferences*

Another study, carried out in Babadillimani Bight, northeastern Mediterranean, related sediment structure to the occurrence of skates and rays inhabiting the region by evaluating sediment composition and the distribution of the most common rays and skates in the area (Yeldan and

Avsar, 2006). The study revealed that skates preferred slightly silty bottoms while rays were more densely distributed along the shallower areas and sandy silts.

#### *Habitat selection*

Furthermore, studies of cartilaginous fish habitat selection and spatial and temporal distribution patterns were also carried out in the Eastern Mediterranean. For instance, Keskin and Karakulak (2006) studied 13 stations in the North Aegean Sea through sampling using a bottom trawl at depths ranging from 40 to 500 m. The study revealed that the most abundant cartilaginous fish species was *Scyliorhinus canicula* and it was caught at all depths. *Torpedo marmorata*, *Raja radula* and *Dipturus oxyrinchus* were rarely caught. Moreover, Maravelias *et al.* (2012) and Tserpes *et al.* (2013) analyzed the MEDITS scientific bottom trawl survey data for several cartilaginous fish species in the Aegean Sea covering an 11-year sampling period. Maravelias *et al.* (2012) studied two of the most abundant cartilaginous fish species (*Scyliorhinus canicula*, *Raja clavata*) and revealed a declining trend in the abundance of these two species from the late 1990s until 2004. The latter study also suggested that habitats with the higher probability of finding cartilaginous fish present were those located in intermediate waters (depth: 200–400 m), and depth appeared to be one of the key determining factors for the selection of habitats for all species examined. Besides, Tserpes *et al.* (2013) analyzed the data for the demersal elasmobranchs *Mustelus mustelus*, *Raja asterias*, *Torpedo marmorata* and *Galeus melastomus* and revealed that both depth and geographical coordinates were the key determinants of the presence of all species, while annual abundance fluctuations were found to be either insignificant or without any specific trend. Finally, Yeldan *et al.* (2013) investigated the spatio-temporal changes in Catch Per Unit Effort (CPUE) of *Dasyatis pastinaca*, *Gymnura altavela*, *Rhinobatos rhinobatos*, *Raja radula*, *Myliobatis aquila*, and *Torpedo marmorata* by considering two depth contours (10 and 20 m) in Iskenderun Bay. The latter study revealed highly significant seasonal variations and year–season 2-way interactions for total cartilaginous CPUE values.

#### **General conclusion**

This bibliographic review focuses on all the studies on cartilaginous fish species carried out in the Eastern Mediterranean region. Many studies on cartilaginous fish species are rare or lacking

in some regions of the Eastern Mediterranean, such as, Lebanon, where species of this fish class are targeted by fishermen or constitute part of the bycatch in most local artisanal fisheries and have different degrees of commercial significance. Several species of this fish class are exploited for their fins, skin, jaws, or meat, directly targeted by commercial or recreational fisheries, or incidentally caught as bycatch. Some countries generally report shark statistics without distinction between species or, worse still, the species are not recorded at all, and some even do not report statistics at all probably due to the lack of taxonomists or scientists and officials trained in monitoring and evaluating these species, with insufficient access to basic tools for shark identification (FAO, 2014). Therefore, DNA barcoding studies that are lacking in the region should be used to validate species identification and decrease problems related to misidentification.

Fishing can lead to phenotypic and genetic responses altering age, size at maturity, longevity, fecundity and egg size (Rochet, 1998; Law, 2000; Hutchings, 2002). Hence, studies on life history traits (especially age and histological reproduction) should be enforced in the Eastern Mediterranean as a stimulant to manage the exploitation of these species by artisanal fisheries or commercial fisheries. Works are concentrated mainly in the western Mediterranean and papers on biologic parameters concern few species primarily in the western and central Mediterranean areas (Bradai *et al.*, 2012). In general, this review shows that Eastern Mediterranean studies are concentrated on the biology of these species and their ecology is not well known.

Works on life history traits are mainly concentrated in the Aegean Sea with a few and almost none in some parts of the Levantine basin. Some highly exploited species, such as, *R. rhinobatos* are presented in several studies in the Eastern Mediterranean. The Endangered IUCN status of this species could facilitate the funding for studies related to its conservation. However, other species, such as, *C. granulosus*, having a Vulnerable status are less studied and problems in their identification still exist. In addition, studies related to the overall organization, structure, and complexity of the group/population of sharks are also lacking in the region; however, studies such as that of Mourier (Mourier *et al.*, 2013; Mourier and Planes, 2013) allow to highlight behavioral aspects of sharks. Furthermore, tagging studies also seem to be lacking in the region. Life history parameters, stock status, behavioral and distribution patterns, and migration patterns can be provided by such studies. Tagging constitutes an important tool to fishery managers

because it provides the ability to record the presence of a particular fish or group of fish in time and space by marking (Rounsefell and Everhart, 1953). Behavioral and distribution patterns, as well as migration patterns, can provide insight to the location of nurseries or breeding areas aiming to reduce exploitation of these top predators. In addition, few are the studies relating cartilaginous fish to abiotic factors (i.e. habitat structure, temperature, salinity, dissolved oxygen, tide, photoperiod, barometric pressure, pH etc.) and biotic factors (i.e. marine community distributions, species interactions etc.). Due to a decline in cartilaginous fish species landings and the increase in fishing effort in the Mediterranean (Bradai *et al.*, 2012), such studies are important to be implemented to highlight the importance and enforce the protection of these top predators in the marine ecosystem. Marine ecologists need to recognize that each species of cartilaginous fish occupies a distinct niche within a particular community. Thus, important studies are necessary to properly clarify the role each cartilaginous fish species plays in a given community (Compagno *et al.*, 2008).

Protection is currently granted to cartilaginous fish species under various regional and international conventions, but generally few species are considered. However, more studies performed on these fish should help for a better protection, as well as, fisheries management and stock assessment of this fish class. Finally, the International Union for the Conservation of Nature (IUCN) clearly reveals the vulnerability of this fish group and the lack of data in certain regions of the Mediterranean. Therefore, research projects on systematics, genetics, general biology, and ecology and population dynamics of concerned species should be carried out, and essential and critical cartilaginous fish habitats should be identified. More legislations and control should be implemented on the landing and bycatch of this fish group aiming to reduce its exploitation.

# Chapter IV

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**Part I: Diversity, distribution and abundance of elasmobranchs and the main influential factors along the coast of Lebanon (eastern Mediterranean)**

**Part II: The length-weight relationships of three sharks and five batoids in the Lebanese marine waters, eastern Mediterranean**

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# **I-Diversité, distribution et abondance des élastomobranches le long de la côte libanaise et principaux facteurs influents (Méditerranée orientale)**

## **Résumé**

Cette étude constitue la seule évaluation des ressources, de la distribution et de la diversité des élastomobranches le long de la côte libanaise, en Méditerranée orientale. Les données concernant les poissons cartilagineux sont issues de captures obtenues à partir de deux méthodes de collecte de données complémentaires, issues : (a) du projet scientifique CIHEAM PESCA-Libano réalisé avec la participation du Ministère de l'Agriculture et le Centre national pour les sciences marines - Conseil national libanais pour la recherche scientifique (CNRSL) et (b) des poissonneries et des pêcheurs. Au cours du suivi scientifique, des filets maillants expérimentaux, trémails et palangres ont été déployés à des profondeurs allant jusqu'à 600 m en 2013. Les poissons cartilagineux issus des données commerciales ont été recueillis auprès des principales poissonneries, qui ont été visitées périodiquement le long de la côte libanaise et de captures issues de pêches expérimentales réalisées avec des pêcheurs pendant la même année. La capture par unité d'effort (CPUE) a été utilisée comme un indice de l'abondance des élastomobranches capturés et a montré des variations saisonnières et spatiales de distribution et selon la profondeur. L'utilisation de données scientifiques et commerciales de manière complémentaire a permis de constituer une image plus précise de l'effet de la pêche sur les espèces d'élastomobranches. La diversité spatio-temporelle a également été évaluée et a montré des valeurs plus élevées dans la région sud de la côte et pendant les saisons du printemps et de l'hiver. Cette étude peut servir de base pour évaluer les menaces des opérations de pêche et constituer une base de réflexion pour la mise en place de mesures de conservation possibles pour les espèces de poissons cartilagineux le long de la côte libanaise en vue d'une gestion plus durable des ressources.

**Mots clés:** Chondrichthyens; impact de la pêche; Bassin Levantin; variations spatio-temporelles

I- Diversity, distribution and abundance of elasmobranchs and the main  
influencing factors along the coast of Lebanon (eastern Mediterranean)

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**Abstract**

The study represents the only evaluation of elasmobranch resources, distribution and diversity along the Lebanese coast, Eastern Mediterranean. It uses cartilaginous fish data from two complementary data collection methods: (a) the CIHEAM PESCA-Libano project carried out with the involvement of the Ministry of Agriculture and the National Center for Marine Sciences – Lebanese National Council for Scientific Research (CNRSL) and (b) fishery and fishermen catch data. Regarding the survey, experimental gillnets, trammel nets and long liners were lowered at depths up to 600 m in 2013. Regarding fisheries and fishermen catch data, cartilaginous fish were collected from major fisheries visited periodically along the Lebanese coast and from the catches of randomly hired fishermen during the same year. The Catch Per Unit Effort (CPUE) was used as an indicator of abundance of the elasmobranchs caught and showed variations in depth, seasonal and spatial distributions. The fishery and fishermen catch data complemented the survey catch data and helped to constitute a wider image of the effect of fishing on elasmobranch species. The spatio-temporal diversity was also reflected and showed highest values in the southern region of the coast and during the spring and winter seasons. This study can be considered as a basis for assessing the threats of fishing operations and inducing sustainable management techniques and possible conservation measures of cartilaginous fish species along the coast of Lebanon.

**Keywords:** Chondrichthyans; fishing impact; Levantine basin; spatio-temporal variations

## 1. Introduction

The Mediterranean Sea is the largest and deepest bounded sea on earth. Connecting three continents, it constitutes a hotspot of terrestrial and marine biodiversity (Bianchi and Morri, 2000; Myers *et al.*, 2000b; Coll *et al.*, 2010). Despite constituting a small percentage (0.32%) of the global oceanic volume and surface area (0.82%), the Mediterranean Sea holds 17,000 (7%) of all known marine species and exhibits a high level of endemism (Bianchi and Morri, 2000; Coll *et al.*, 2010). Throughout history, this rich ecosystem has been distorted in many ways, especially by overexploitation and habitat loss which are the main human drivers of historical changes (Lotze *et al.*, 2011). In addition, pressures on these these ecosystems have increased exponentially since the Industrial Revolution with resulting advances in technology and a human population explosion (Coll *et al.*, 2010; Lotze *et al.*, 2011). Currently, habitat loss and degradation, pollution, overexploitation, eutrophication, introduction of invasive species, bycatch, and recently climate change, are the most important threats affecting a greatest number of organisms in the Mediterranean Sea, especially chondrichthyans (Cuttelod *et al.*, 2008; Coll *et al.*, 2010; Costello *et al.*, 2010). The Mediterranean Sea is identified as one of the three main hotspots where the diversity of sharks and rays is particularly seriously threatened (Dulvy *et al.*, 2014). It holds 80 chondrichthyan species (Compagno, 2001; Compagno *et al.*, 2005; Serena, 2005a), out of which 71 were assessed by the IUCN, where three are endemic and one is endemic threatened (Dulvy *et al.*, 2014). Bycatch, intensive fishing activities and pollution are severe threats for these species (Cuttelod *et al.*, 2008). The situation of cartilaginous fish (chondrichthyans) in the Mediterranean Sea is much more miserable than it is worldwide: 42% of the shark species are threatened in the region in comparison with 17% globally, thus, describing the Mediterranean as the most unsafe sea in the world for cartilaginous fishes (Cavanagh and Gibson, 2007).

Lebanon is located in the central part of the Levantine basin, Eastern Mediterranean. The coast is affected by a marked deterioration in the coastal water quality, ecological sites and natural resources due to the influence of competing interests. Urbanization due to demographic change has greatly amplified the demand for coastal resources. Climate change and human impact along the Lebanese coast are leading to the rapid alteration of the local biodiversity. Rare are the protection measures for species or ecosystems, and the increase in Indo-Pacific species is

increasing the competition with native marine flora and fauna (MoE/UNDP/ECODIT, 2011). The fishery in Lebanon is artisanal and trawling is legally forbidden. The most common gear used are trammels, longlines, ‘roundhaul’ nets and beach seines (Majdalani, 2004; Fowler, 2005). Information about the diversity or distribution of cartilaginous fish species along the Lebanese coast is still currently lacking. The presence of these fish species have already been mentioned along the coast (George *et al.*, 1964; Boulos, 1968; Mouneimne, 1977); however, no direct specific studies about the diversity or distribution of these species have been carried out in Lebanon knowing that several species of this fish class are exploited in some regions along the coast. In addition, the eastern Mediterranean area lacks long term fishery monitoring and studies in different regions, especially the Lebanese coast. Few studies mentioning cartilaginous fish habitat selection and spatial and temporal distribution were carried out in the Aegean Sea (Keskin and Karakulak, 2006; Maravelias *et al.*, 2012; Tserpes *et al.*, 2013) and Iskenderun Bay (Yeldan *et al.*, 2013).

Spatial and temporal distribution and diversity of exploited populations can be determined via data from scientific surveys, records of commercial fisheries and fishermen catches. These are two complementary methods each with advantages and disadvantages. Scientific survey data is standardized and controlled with defined georeferenced points; it can provide an important reflection of the spatial distribution of the studied population. However, a survey conducted once a year can contain temporal gaps. Fishery and fishermen data, on the other hand, provide a good temporal (seasonal) coverage but a weak spatial one due to the fact that most of the Lebanese artisanal fishermen do not have GPS instruments. In addition, total catch information for the computation of Catch per Unit Effort (CPUE) can sometimes be lacking. CPUE is commonly calculated from fishery data as an abundance index. Therefore, these two methods can be used in a complementary way to provide a further reflection of the spatial, depth and seasonal distribution and diversity of this exploited fish class.

The present study uses cartilaginous fish data from the scientific CIHEAM PESCA-Libano project carried out with the involvement of the Ministry of Agriculture and the National Center for Marine Sciences – Lebanese National Council for Scientific Research (CNRSL) along with fishery and fishermen data. It aims to assess the depth, spatial and seasonal distribution of cartilaginous fish species by analyzing the variation of CPUE data from the survey and total

weight data from fishery and fishermen catches. Moreover, it reflects the spatial and seasonal diversity of this fish class aiming to highlight their presence along the coast. This could lead to stimulating the protection and management of the exploited cartilaginous fish along the Lebanese coast.

## **2. Materials and Methods**

### **2.1. Description of the scientific survey: CIHEAM PESCA-Libano**

The CIHEAM PESCA-Libano project with the involvement of the Ministry of Agriculture and the National Center for Marine Sciences – Lebanese National Council for Scientific Research (CNRSL) assessed the potentiality of the marine coastal resources in order to support the Lebanese Government in strengthening the management of the marine resources. A survey in the framework of this project was performed from January to August 2013, where hauls have been surveyed by means of experimental gillnets, trammel nets and long liners lowered up to 600 m depth. The project aimed to assess the distribution and abundance of fisheries resources along the Lebanese coasts in order to deliver scientific advice to Ministry of Agriculture for an enhanced fisheries management.

Gillnets with mesh sizes of 26, 30 and 40 mm (of 1 km length connected together) were lowered at depths less than 100 m; trammel nets with mesh sizes of 22, 24, 26, 28 and 30 mm (of 1 km length connected together) were lowered at depths greater than 100 m. Longlines of size 5 hooks were lowered at randomly specified depths.

Six artisanal fishermen from six different ports in Lebanon distributed in the north, south and central regions of the country were hired to lower the gear at the hauls with the specified coordinates (Figure 19). The length of the vessels ranged from 8.75 to 11 m and their gross tonnage ranged from 2 to 3.7 tons. A global positioning system (GPS) was used to reach the right haul and depth was confirmed using a sonar. Nets were not loaded with bait; however, the hooks of the longlines were always loaded with bait from chopped fish, such as, herrings (*Etrumeus teres*), mackerels (*Scomber scomber*) or tunas (*Euthynnus alletteratus*). Cartilaginous fish collected from the survey were identified and date, type of gear, net meshes, coordinates and depth in each catch were noted.

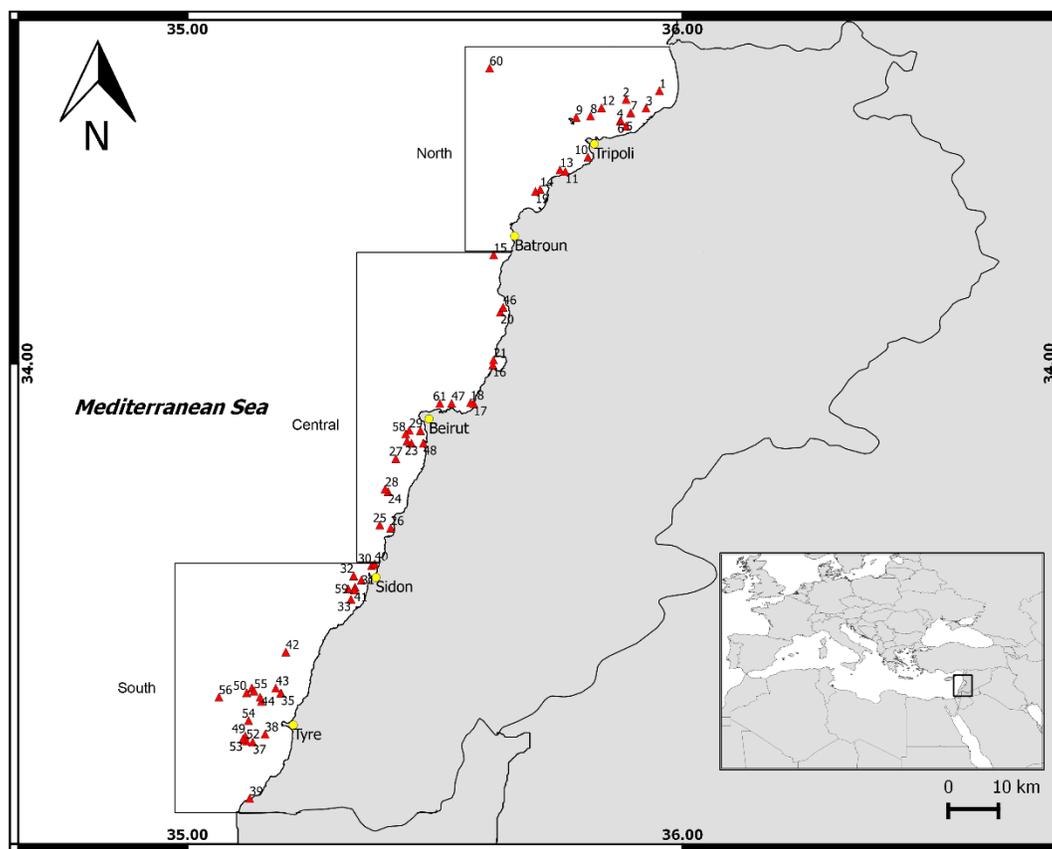


Figure 19: Location of the 62 hauls of the PESCA Libano survey in the north, central and south regions of the Lebanese coast according to the Lebanese administrative divisions.

## 2.2. Description of the fishery and fishermen data collection

The Lebanese fishing fleet is composed of small scale artisanal vessels less than 12 m in length and typical of many Mediterranean countries. Around 42 ports are distributed along the Lebanese coast. The main ones are distributed according to the governorates as follows: Tripoli and Batroun ports in the North, Ozaaii Port in Beirut, and Tyre and Sidon Ports in the South (Figure 19).

Data collection from fisheries and artisanal fishermen had been performed in two manners:

a) Cartilaginous fish were collected from randomly hired fishermen throughout the Lebanese coast with the collaboration of the Lebanese National Council for Scientific Research (CNRSL) - National Center for Marine Sciences - to lower longlines at depths ranging from 30 to 600 m aiming to catch cartilaginous species.

b) Cartilaginous fish were collected from major fisheries visited periodically along the Lebanese coast. Fisheries were visited a minimum number of 5 times per month from December 2012 to October 2014, and data were collected when specimens were available. The main fishery visited was a principal one in Tripoli, where there are constant cartilaginous fish catches and where species of this fish class have a significant commercial value.

Regarding both manners of the latter data collection, the exact position of the data collected was not recorded because most of the Lebanese artisanal fishermen do not have GPS instruments; however, the depth was noted as observed by the professional fishermen.

### **2.3. Measures and biological parameters recorded after collection**

The cartilaginous fish caught were identified according to the Field Identification Guide to the Living Marine Resources of the Eastern and Southern Mediterranean (Bariche, 2012) and Fishes of the Eastern Mediterranean (Golani *et al.*, 2006). Many morphometric and biological measurements were recorded prior to and after dissection; nevertheless, only few were considered in this study.

- *Measurements considered for the scientific survey data*

Total weight ( $W_T$ ) was only used for the analyses of the scientific survey data. A total weight (less than five kilograms) was measured to the nearest gram (g) using an electric balance. A total weight greater than five kilograms was measured using a scale to the nearest 100 g.

- *Measurements considered for fisheries and fishermen data*

Along with total weight, sex of each specimen, and sexual maturity were used for the analyses of the fisheries and fishermen data. The sexual maturity of each specimen caught was determined by observing female and male gonads using gonad aspects as defined in the 'Instruction Manual' of the MEDITS – International bottom trawl survey in the Mediterranean – Version 6 (MEDITS, 2012).

## 2.4. Computation of the abundance index, statistical analyses and cartography

### 2.4.1. Computation of the abundance index

The catch per unit effort (CPUE) was calculated for the cartilaginous species caught only during the CIHEAM-PESCA Libano survey using the statistical software R project (R Development Core Team, 2014) and was expressed in kilograms and in number according to the following:

1. CPUE in kilograms according to each meshed gear (Index  $G$ : gear; Index  $M$ : mesh) for trammel nets, gillnets, and longlines:

$$CPUE_{kg,G,M} = \frac{\sum W_{Ti,G,M} / N_{Ci,G,M}}{E}$$

where  $i$  is the cartilaginous species caught in a specific meshed gear or longline in the predetermined haul,  $N_{Ci,G,M}$  the total number of cartilaginous species  $i$  caught in the same meshed gear or longline also in the predetermined haul, and  $E$  the effort which is considered one because each gear was lowered once with the same effort duration.

2. CPUE in number according to each meshed gear (Index  $G$ : gear; Index  $M$ : mesh) for trammel nets, gillnets, and longlines:

$$CPUE_{number,G,M} = \frac{\sum N_{Ci,G,M}}{E}$$

where  $N_{Ci,G,M}$  is the total number of the cartilaginous species  $i$  caught in a specific meshed gear or longline in the predetermined haul and  $E$  the effort which is considered one because each gear was lowered once with the same effort duration.

### 2.4.2. Factors impacting the abundance index of elasmobranch species

*Permutational Multivariate Analysis of Variance (PERMANOVA)*

PERMANOVA was performed on the matrix of CPUE in kilograms and number separately of the different cartilaginous species caught to test the influence of various factors (gear, region, depth, and season) in the scientific survey using the Euclidean method with 9999 permutations. The considered factors were: gear: Gillnets, Long liners, Trammel nets; region: North, Central,

South; depth: [0-200[, [200-400[, [400-600] in meters and seasons: Spring, Summer, Winter. Regarding the fisheries and fishermen data, PERMANOVA was performed on the total weight of the different cartilaginous species caught according to the available factors for fisheries data (gear, region, depth, season, sex, and sexual maturity) using the same method with the same number of permutations. All factors were considered as fixed. The factor modalities of the PERMANOVA fisheries and fishermen data analysis were for gear: Gillnets, long liners, trammel nets; region: North, South; depth: [0-300[, [300, 600] in meters; seasons: Spring, Summer, Autumn, Winter; sex: Males and females and sexual maturity: Immature and mature individuals.

The data (CPUE in kilograms and number or total weight) were log transformed before the analyses into  $\log(x+1)$  in order to homogenize the variances and normalize the distributions. Both PERMANOVA analyses were performed using the *adonis* function of the ‘vegan’ package on the statistical software ‘R project’(R Development Core Team, 2014) on shark, batoid and combined datasets with interaction of factors.

#### *Canonical Correspondence Analysis (CCA)*

A descriptive statistical method was also carried out to give further details to how the ordination of species is constrained by their relationships to environmental variables. A CCA was performed on the matrix of CPUE in kilograms and number separately of the different cartilaginous species caught according to the scientific survey factors (gear, region, depth, and season). Concerning the fisheries and fishermen data, another CCA was performed on the total weight of the different cartilaginous species caught according to several factors (gear, region, depth, season, sex, and sexual maturity). The data (CPUE in kilograms and number or total weight) were log transformed before the analyses into  $\log(x+1)$  in order to homogenize the variances and normalize the distributions. Both CCA analyses were performed using the *cca* function of the ‘vegan’ package on the statistical software ‘R project’(R Development Core Team, 2014) on shark, batoid and combined datasets. The factor modalities were the same as these used for the PERMANOVA analyses.

#### *Maps and interpolation*

The maps and interpolations were realized and performed on the Quantum Geographic Information System (qGIS) software (QGIS Development Team, 2012) only for the scientific survey data. Spatial interpolation was performed on the CPUE (expressed in kilograms and number) and species richness according to haul for the shark, batoid, and combined datasets using the Inverse Distance Weighting (IDW) method and the 'Linear' color interpolation.

## **2.5. Biodiversity indices**

Seasonal and spatial biodiversity were evaluated for the scientific survey and fishery and fishermen data combined by calculating several diversity indices according to Magurran (2004). The Shannon Index ( $H'$ ), Shannon evenness (Pielou's evenness:  $J'$ ), Simpson Index ( $1-D$ ), and taxonomic distinctness and diversity ( $\Delta^+$ ) were all calculated for the four different seasons (Autumn, Winter, Spring and Summer) and the two main regions (North and South) using the 'vegan' package on the statistical software 'R project' (R Development Core Team, 2014).

## **3. Results**

### **3.1. Scientific survey and fishery/fisherman data analysis**

#### **3.1.1. The scientific survey CPUE analysis: Depth, seasonal and spatial distribution**

The results related to the scientific survey data are firstly presented. A total number of 62 hauls with predetermined depths were distributed along the Lebanese coast (Figure 19). Gillnets were lowered in the majority of these hauls (Gillnets: 36 hauls; Trammel nets: 20 hauls; Long liners: 6 hauls) and nearly most hauls were lowered during the summer season. Furthermore, a large amount of hauls (52) had depths less than 200 m (versus 7 in [200-400] and 3 in [400-600] with a few having greater depths. Moreover, more hauls were performed in the southern region (26 hauls versus 19 for the central and 17 for the northern regions) (Table 12).

Table 12: The sampling effort represented by the number of hauls where gear (G: gillnets; T: trammel nets; L: longlines) was lowered according to every combination of season, region (N: north; C: central; S: south), and depth strata.

Depth (Total)	[0-200[ (52)									[200-400[ (7)									[400-600] (3)									Total			
	G			T			L			G			T			L			G			T			L						
Region	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S	
Winter	13	0	4	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
Spring	0	0	2	0	0	4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	10
Summer	2	8	6	1	7	2	0	0	0	0	1	0	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32
Total	15	8	12	1	7	6	0	0	3	0	1	0	1	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	62

A quantitative representation of the scientific survey total CPUE (expressed in kilograms) according to species, season, region, and depth is presented in Table 2. A total of 15 elasmobranchs (N=131), 4 sharks and 11 batoids, were caught during the scientific survey. Regarding all elasmobranchs, the total CPUE ranged from 0.051 kg/unit effort for *T. marmorata* to 150 kg/unit effort for *H. griseus* according to depth, region and season. The total CPUE varied with depth during all seasons. The general total was highest (198.401 kg/unit effort) in the depth class [0-200[, displayed its minimum (19.669 kg/unit effort) in depth class [200-400[, and showed a value of 21.776 kg/unit effort in the largest depth class ([400-600]). The general total CPUE also varied seasonally displaying the highest value in winter (164.534 kg/unit effort), a lower value in spring (46.954 kg/unit effort), and the lowest in summer (28.358 kg/unit effort) (Table 13).

The CPUE for shark catches also varied according to depth and season. No sharks were captured during the summer season at depths less than 200 m and during the spring season at depths ranging from 200 to 400 m. The highest total CPUE was observed in winter (150 kg/unit effort), a lower one in spring (26.403 kg/unit effort), and the lowest was observed in summer (14.375 kg/unit effort). The CPUE for shark catches ranged from 5.450 kg/unit effort for *C. granulosus* to 150 kg/unit effort for *H. griseus* according to depth, region and season. In addition, regarding depth variation, the highest total CPUE (150 kg/unit effort) was displayed at depth stratum [0-200[ and the lowest was observed at depth stratum [400-600] (Table 13). The CPUE of batoids ranged from 0.051 kg/unit effort for *T. marmorata* to 8 kg/unit effort for *T. grabata*. Batoids were observed in all depth strata; the highest total CPUE (31.473 kg/unit effort) was observed in

depth class [0-200[, a lower one (12.301 kg/unit effort) in depth class [400-600], and the lowest (5.294 kg/unit effort) was observed in depth class [200-400[. Batoids were also observed in all seasons, showing the highest total CPUE in spring (20.551 kg/unit effort), a lower one in winter (14.534 kg/unit effort), and the lowest in summer (13.983 kg/unit effort) (Table 13).

Moreover, *C. granulatus* showed to be a prominent shark in the survey. It was observed in spring and summer in all depth strata with CPUE ranging from 5.450 to 10.328 kg/unit effort. The other sharks, *D. licha*, *H. perlo*, and *H. griseus* were observed in spring, summer and winter, respectively, at the depth strata [0-200[and [200-400[. Regarding batoids, the most prominent in the survey was *R. clavata*, which was observed in all seasons in depth strata [0-200[and [200-400[with CPUE ranging from 0.365 to 2.3 kg/unit effort. Similarly, *T. marmorata* showed the same latter seasonal and depth distribution with CPUE ranging from 0.280 to 1.127 kg/unit effort; however, it was not observed in the winter season. Only *D. oxyrinchus* and *P. violacea* were observed at the largest depth stratum ([400-600]) with CPUE of 5.951 and 6.350 kg/unit effort, respectively. Some batoids were observed each in a single season and depth stratum; for example, *D. pastinaca* (summer; [0-200[), *G. altavela* (summer; [0-200[), *R. rhinobatos* (spring; [0-200[), *T. grabata* (winter; [0-200[), and *T. nobiliana* (spring; [0-200[) (Table 13).

Table 13: List of species (with their total number) caught in the CIHEAM PESCA-Libano survey with CPUE (kg/unit effort) per depth stratum, season and region (N: north; C: central; S: south) of the Lebanese coast. The gear used to catch each species is also represented (T: trammel nets; G: gillnets; L: longlines) along with the International Union for the Conservation of Nature (IUCN) Red List Category for each species caught. No gear was lowered in winter at depth strata [200-400[and [400-600] and in summer at depth stratum [400-600]. The percentages are according to the general total.

Species (IUCN status)	Gear caught with	Region	Depth (m)					
			[0 – 200[			[200 – 400[		[400 – 600]
			Winter	Spring	Summer	Spring	Summer	Spring
<i>Sharks</i>								
<i>Centrophorus granulosus</i> (Vulnerable)	T	N	-	-	-	-	5.450 (29.11%)	-
	T, L	S	-	10.328 (42.62%)	-	-	-	9.475 (43.51%)
<b>N=22</b>			-	<b>10.328 (42.62%)</b>	-	-	<b>5.450 (29.11%)</b>	<b>9.475 (43.51%)</b>
<i>Dalatias licha</i> (Near Threatened)	T	S	-	6.6 (27.24%)	-	-	-	-
<b>N=2</b>			-	<b>6.6 (27.24%)</b>	-	-	-	-
<i>Hepranchias perlo</i> (Near Threatened)	T	C	-	-	-	-	8.925 (47.67%)	-
<b>N=3</b>			-	-	-	-	<b>8.925 (47.67%)</b>	-
<i>Hexanchus griseus</i> (Near Threatened)	L	S	150 (91.17%)	-	-	-	-	-
<b>N=1</b>			<b>150 (91.17%)</b>	-	-	-	-	-
<b>Total (N=28)</b>			<b>150 (91.17%)</b>	<b>16.928 (69.86%)</b>	-	-	<b>14.375 (76.78%)</b>	<b>9.475 (43.51%)</b>

<i>Batoids</i>								
<i>Dasyatis marmorata</i> (Data Deficient)	G, T	C	-	-	2.262 (23.48%)	-	-	-
	L, G	S	4.234 (2.57%)	-	0.518 (5.38%)	-	-	-
<b>N=9</b>			<b>4.234 (2.57%)</b>	-	<b>2.780 (28.86%)</b>	-	-	-
<i>Dasyatis pastinaca</i> (Data Deficient)	T	N	-	-	1.521 (15.79%)	-	-	-
	T	C	-	-	1.45 (15.05%)	-	-	-
<b>N=2</b>			-	-	<b>2.971 (30.84%)</b>	-	-	-
<i>Dipturus oxyrinchus</i> (Near Threatened)	L	S	-	-	-	-	-	5.951 (27.33%)
<b>N=7</b>			-	-	-	-	-	<b>5.951 (27.33%)</b>
<i>Gymnura altavela</i> (Vulnerable)	T	C	-	-	-	-	0.453 (2.43%)	-
<b>N=1</b>			-	-	-	-	<b>0.453 (2.43%)</b>	-
<i>Pteroplatytrygon violacea</i> (Least Concern)	L	S	-	-	-	-	-	6.350 (29.16%)
<b>N=4</b>			-	-	-	-	-	<b>6.350 (29.16%)</b>
<i>Raja clavata</i> (Near Threatened)	T	N	-	-	-	-	0.365 (1.95%)	-
	T	C	-	-	0.853 (8.85%)	-	1.153 (6.16%)	-
	G, T	S	2.3 (1.4%)	1.05 (4.33%)	-	0.366 (38.73%)	0.821 (4.38%)	-
<b>N=19</b>			<b>2.3 (1.4%)</b>	<b>1.05 (4.33%)</b>	<b>0.853 (8.85%)</b>	<b>0.366 (38.73%)</b>	<b>2.339 (12.49%)</b>	-
<i>Raja miraletus</i>	G, T	C	-	-	0.799 (8.29%)	-	0.692 (3.69%)	-

(Least Concern)	T	S	-	0.13 (0.54%)	0.193 (2%)	-	-	-
<b>N=30</b>			-	<b>0.13 (0.54%)</b>	<b>0.992 (10.29%)</b>	-	<b>0.692 (3.69%)</b>	-
<i>Rhinobatos rhinobatos</i> (Endangered)	L	S	-	3.6 (14.86%)	-	-	-	-
<b>N=1</b>			-	<b>3.6 (14.86%)</b>	-	-	-	-
<i>Taeniura grabata</i> (Data Deficient)	L	S	8 (4.86%)	-	-	-	-	-
<b>N=1</b>			<b>8 (4.86%)</b>	-	-	-	-	-
<i>Torpedo marmorata</i> (Data Deficient)	T	N	-	-	0.362 (3.76%)	-	0.051 (0.27%)	-
	G, T	C	-	-	0.830 (8.61%)	-	0.534 (2.85%)	-
	T	S	-	1.127 (4.65%)	0.846 (8.78%)	0.579 (61.27%)	0.280 (1.49%)	-
<b>N=22</b>			-	<b>1.127 (4.65%)</b>	<b>2.038 (21.16%)</b>	<b>0.579 (61.27%)</b>	<b>0.865 (4.61%)</b>	-
<i>Torpedo nobiliana</i> (Data Deficient)	T	S	-	1.398 (5.76%)	-	-	-	-
<b>N=7</b>			-	<b>1.398 (5.76%)</b>	-	-	-	-
<b>Total (N=103)</b>			<b>14.534 (8.83%)</b>	<b>7.305 (30.14%)</b>	<b>9.634 (100%)</b>	<b>0.945 (100%)</b>	<b>4.349 (23.22%)</b>	<b>12.301 (56.49%)</b>
<b>General total of all elasmobranchs (N=131)</b>			<b>164.534 (100%)</b>	<b>24.233 (100%)</b>	<b>9.634 (100%)</b>	<b>0.945 (100%)</b>	<b>18.724 (100%)</b>	<b>21.776 (100%)</b>

The spatial distribution of all survey elasmobranchs and sharks and batoids separately was presented by the map interpolation of CPUE (expressed in kilograms and number) and specific richness. Such interpolation can assign predicted values to all non-sampled locations to provide a wider picture of the distribution in this case.

Biomass distribution of all elasmobranchs combined or separated was presented by the CPUE (expressed in kilograms). The highest values were observed in the southern region of the Lebanese coast for sharks, batoids, and the combined set of elasmobranchs. However, batoids showed to have an important biomass in certain central and northern regions of the coast, but not extending to further points. Furthermore, between shark and batoid data, sharks showed to have a larger biomass in general (Figure 20a).

The distribution in number of all elasmobranchs combined or separated was presented by the CPUE (expressed in number). High values were observed as extended from the central to the southern region for the combined and batoid data sets. Moreover, high values were also observed in the north for both data sets but not extending to further non-sampled points. The shark sample, however, displayed extended high values in the south and high values in confined areas located in the northern and central regions. In addition, between shark and batoid data sets, batoids displayed larger numbers in general (Figure 20b).

The distribution of specific richness demonstrated that more species were caught in the southern and central regions, shown by the extended red region, for the combined and batoid data sets. Sharks, however, showed a high number of species in a confined area in the central and northern regions, but not extended to further points. Finally, between shark and batoid data sets, batoids displayed a higher specific richness in general (Figure 20c).

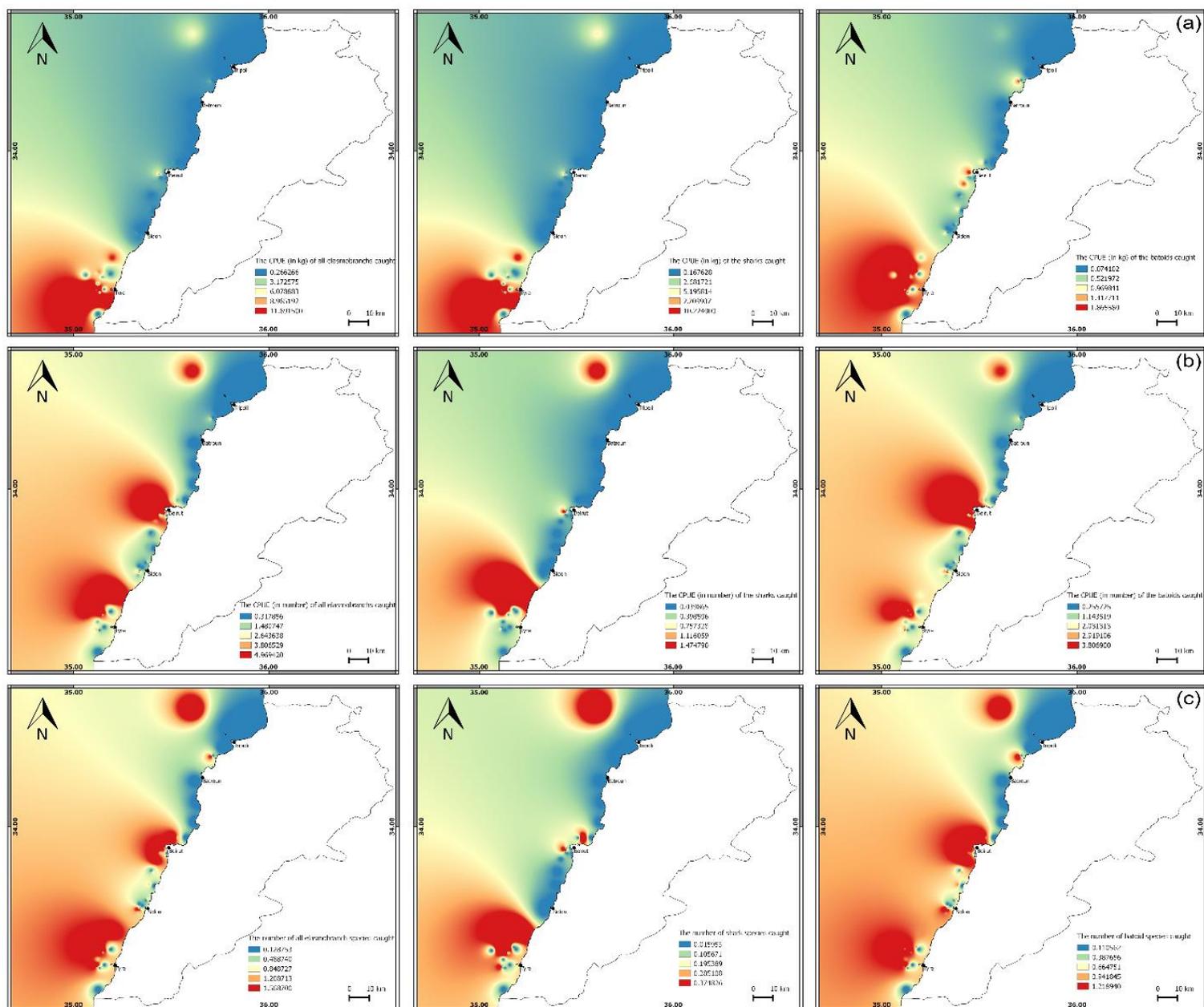


Figure 20: Interpolation maps using the IDW method for the (a) CPUE (expressed in kilograms), (b) CPUE (expressed in number), and (c) specific richness for the combined (left), shark (center), and batoid (right) data sets of the CIHEAM PESCA-Libano survey.

### 3.1.2. Fishery and fishermen data analyses: Seasonal and depth variation

The results related to the fishery and fishermen data are presented in this section. A total number of 17 elasmobranchs (N=184), 8 sharks and 9 batoids, were collected from major fisheries or fishermen catches during winter, autumn, spring and summer at two depth strata ([0-300]; [300,600]). No elasmobranchs were collected from catches in spring at depth stratum [300-600];

moreover, all batoids were collected from catches at the depth stratum [0-300]. Sharks, however, displayed their presence at the two depth strata. In addition, the number of sharks collected ranged from a minimum of one for *I. oxyrinchus* and *H. perlo* to a maximum of 16 for *C. granulatus*. The number of batoids collected ranged from a minimum of one for *D. marmorata* to a maximum of 69 for *R. rhinobatos*. Regarding the region of collection, the majority of shark species were collected from the northern region of the coast, followed by the southern region, and only a few were collected from the central region. On the other hand, no batoids were collected from the central region and the majority were collected from the northern region of the coast (Table 14).

Furthermore, the sharks collected from fisheries and fishermen varied seasonally and by depth. The most prominent shark was *C. granulatus*. It was collected from catches in most seasons (autumn, winter, and summer) only at depths between 300 and 600 m. The least collected shark were *I. oxyrinchus* and *H. perlo*; only one individual of each was caught in spring and winter, respectively, at depths less than 300 m. Other sharks were collected during various seasons at both depth strata, except *M. mustelus* and *S. blainville* which were not observed at depths greater than 300 m (Table 14).

Regarding batoids, none was caught at depth stratum [300-600] as mentioned previously. The most prominent one was *R. rhinobatos* that was observed in all four seasons. The least batoid observed was and *D. marmorata*, of which only one individual was observed in winter at a depth less than 300 m (Table 14).

Table 14: The list of species (and number) collected from fisheries and fishermen catches with their mean total weight ( $W_T$ ) and total length ( $L_T$ ) per depth stratum, season and region (N: north; C: central; S: south) along the Lebanese coast. The gear used to catch each species is also represented (T: trammel nets; G: gillnets; L: longlines) along with the International Union for the Conservation of Nature (IUCN) Red List Category for each species caught. The percentages are according to the general total.

Species (IUCN status) General Total (N=184)	Gear caught with	Region	Depth						
			[0 – 300]				[300 – 600]		
			Autumn Mean $W_T \pm SD$ Mean $L_T \pm SD$	Winter Mean $W_T \pm SD$ Mean $L_T \pm SD$	Spring Mean $W_T \pm SD$ Mean $L_T \pm SD$	Summer Mean $W_T \pm SD$ Mean $L_T \pm SD$	Autumn Mean $W_T \pm SD$ Mean $L_T \pm SD$	Winter Mean $W_T \pm SD$ Mean $L_T \pm SD$	Summer Mean $W_T \pm SD$ Mean $L_T \pm SD$
<i>Sharks (N=61)</i>									
<i>Carcharhinus obscurus</i> (N= 3) (Vulnerable)	L	N	-	<b>2 (1.09%)</b> 55000 ± 15000 g 205 ± 45 cm	-	<b>1 (0.54%)</b> 10000 g 125 cm	-	-	-
<i>Centrophorus granulosus</i> (N= 16) (Vulnerable)	L	N	-	-	-	-	<b>4 (2.17%)</b> 4575 ± 1725.1 g 85.7 ± 8.6 cm	<b>7 (3.80%)</b> 3250 ± 978.5 g 77.8 ± 6.4 cm	-
		S	-	-	-	-	-	-	<b>5 (2.71%)</b> 3063 ± 232.6 g 78.5 ± 2.9 cm
<i>Galeus melastomus</i> (N=14) (Least Concern)	L	N	-	<b>11 (5.98%)</b> 344.1 ± 129 g 48.2 ± 5 cm	-	-	<b>1 (0.54%)</b> 366.4 g 50 cm	<b>2 (1.09%)</b> 450 g 50 ± 0.7 cm	-
<i>Heptranchias perlo</i> (N=1) (Near Threatened)	G	S	-	<b>1 (0.54%)</b> 6000 g 115 cm	-	-	-	-	-
<i>Hexanchus griseus</i> (N=9) (Near Threatened)	L	N	-	-	-	-	-	<b>9 (4.89%)</b> - 201.3 ± 39.4 cm	-
<i>Isurus oxyrinchus</i> (N=1) (-)	G	S	-	-	<b>1 (0.54%)</b> - -	-	-	-	-
<i>Mustelus mustelus</i> (N=6) (Vulnerable)	L, G	N	<b>4 (2.17%)</b> 762.6 ± 228.1 g 64.4 ± 4.5 cm	-	-	-	-	-	-
		C	<b>2 (1.09%)</b> 900 ± 282.8 g	-	-	-	-	-	-

			62.5 ± 4.9 cm						
<i>Squalus blainville</i> (N=11) (Data Deficient)	L, G	N	-	<b>10 (5.43%)</b> 684.3 ± 215.2 g 49.4 ± 5.1 cm	-	<b>1 (0.54%)</b> 599 g 51 cm	-	-	-
<b>Batooids (N=123)</b>									
<i>Dasyatis marmorata</i> (N= 1) (Data Deficient)	L	N	-	<b>1 (0.54%)</b> 1000 g 51 cm	-	-	-	-	-
<i>Dasyatis pastinaca</i> (N=3) (Data Deficient)	L, T	N	<b>2 (1.09%)</b> 1025 ± 106.1 g 49.7 ± 3.2 cm	<b>1 (0.54%)</b> 4100 g -	-	-	-	-	-
<i>Dasyatis tortonesei</i> (N=6) (-)	L, G	N	<b>4 (2.17%)</b> 5750 ± 1738.5 g 90 ± 5 cm	<b>2 (1.09%)</b> 1100 g -	-	-	-	-	-
<i>Gymnura altavela</i> (N=3) (Vulnerable)	L, G	N	<b>1 (0.54%)</b> 2500 g 44 cm	<b>2 (1.09%)</b> - -	-	-	-	-	-
<i>Pteromylaeus bovinus</i> (N=5) (Data Deficient)	L	N	<b>4 (2.17%)</b> 8725 ± 2229.2 g 146.2 ± 9.3 cm	-	-	<b>1 (0.54%)</b> - -	-	-	-
<i>Rhinobatos cemiculus</i> (N=31) (Endangered)	L	N	<b>25 (13.59%)</b> 2136.1 ± 2044.5 g 80.8 ± 16.9 cm	<b>6 (3.26%)</b> 2756.7 ± 1085.5 g 91.7 ± 11.9 cm	-	-	-	-	-
<i>Rhinobatos rhinobatos</i> (N=69) (Endangered)	L, T	N	<b>39 (21.19%)</b> 2121.6 ± 2475.4 g 78.1 ± 23.1 cm	<b>23 (12.5)</b> 1078.5 ± 449.1 g 67.7 ± 9.4 cm	<b>1 (0.54%)</b> 3750 g 104.5 cm	<b>6 (3.26%)</b> 1775 ± 913.1 g 80.4 ± 11.9 cm	-	-	-
<i>Squatina oculata</i> (N=2) (Critically Endangered)	L, G	N	-	<b>1 (0.54%)</b> 2900 g 67 cm	-	-	-	-	-
		S	-	-	<b>1 (0.54%)</b> - -	-	-	-	-
<i>Taeniura grabata</i> (N=3) (Data Deficient)	L, G	N	-	<b>2 (1.09%)</b> 2250 ± 636.4 g 62.7 ± 3.2 cm	-	-	-	-	-
		S	-	-	-	<b>1 (0.54%)</b> 20000 g 200 cm	-	-	-

## 3.2. Statistical analyses of the main factors impacting the abundance index

### 3.2.1. PERMANOVA of the survey and fishery and fishermen data

Concerning survey data, results of PERMANOVA analyses are presented in Table 15. The CPUE (expressed in kilograms) for the combined data and batoids separately varied significantly following season, depth and gear with a significant double interaction between season and gear. The CPUE (kg) for sharks separately varied significantly for season and gear only. On the other hand, the CPUE (expressed in number) varied significantly following season and depth for the combined data and sharks separately, and following depth only for batoids separately. Concerning the fishery and fishermen data, the results of the PERMANOVA showed that the total weight varied significantly following season, region, depth and sexual maturity with double interactions between season and sexual maturity and sex and sexual maturity for the combined data and batoids separately. A triple interaction was only observed between season, sex and sexual maturity for the combined data. The total weight of sharks only varied significantly following season, region and depth with a triple interaction between season, depth and sex (Table 15).

### 3.2.2. CCA of the survey and fishery and fishermen data

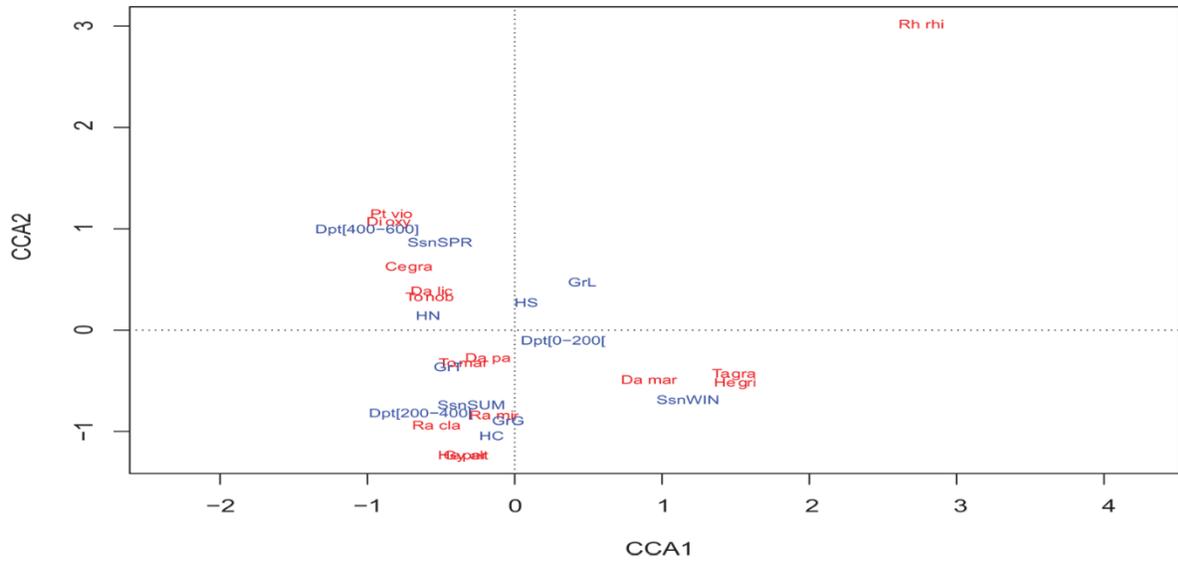
Following PERMANOVA, a CCA was carried out to better visualize the relationships of the species observed with the environmental variables following CPUE (expressed in kilograms and number) for the survey data and the total weight for the fishery and fishermen data. The ordination diagrams with elasmobranch species and environmental variables are presented in Figure 3. Regarding the survey data CCA, sharks showed clear opposition along the two components according to several environmental factors following CPUE (expressed in kilograms and number). Batoids also showed such opposition following both CPUE, especially *P. violacea* and *D. oxyrinchus* that showed a close relationship with the highest depth stratum and an opposition to other depth strata. *R. rhinobatos* also showed clear opposition along the second component to several factors on the positive side of the axis (Figure 21a, b). Regarding the fishery and fishermen data CCA, most sharks showed close relationships to lower depths and the winter season following the total weight. Sex modalities demonstrated clear opposition along the

first component following total weight. The total weight of *M. mustelus* showed to form a close relationship with gillnets as a gear and a clear opposition to other sharks on the positive side of the second component. Batoids were all concentrated in the center of the plot along with most factors. However, *T. grabata* demonstrated a close relationship with gillnets and a clear opposition to the summer season following total weight along the first component (Figure 21c).

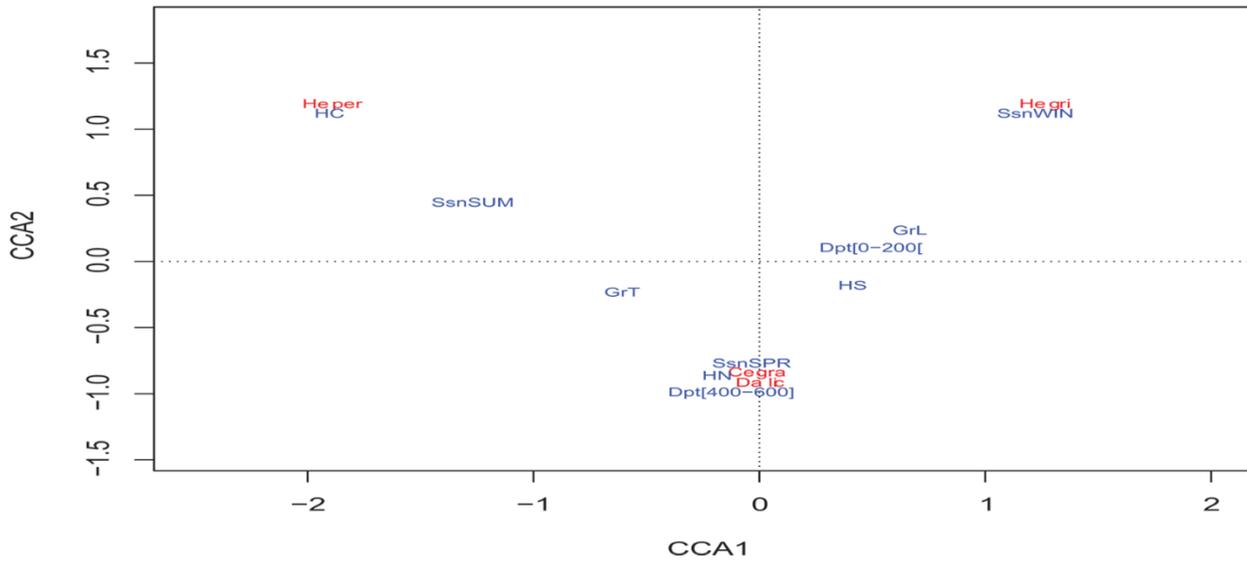
Table 15: A Univariate 4-way PERMANOVA for the community matrix of  $\log(\text{CPUE}(\text{kg}) + 1)$  and  $\log(\text{CPUE}(\text{number}) + 1)$  (A), and a univariate 6-way PERMANOVA for the community matrix of  $\log(W_T + 1)$  (B). All combinations of factors were tested but only significant results are presented (Sex. mat.: sexual maturity; the number in parenthesis is the number of individuals in each sample). The sign  $\times$  means interaction between factors. The considered factors for survey data were: gear, region, depth and season; two additional factors (sex and sexual maturity) were considered for fishery data.

A		All elasmobranchs (15)			Sharks (4)			Batoids (11)		
		Factor	F	P-value	Factor	F	P-value	Factor	F	P-value
Survey data Factors:	CPUE (kg)	Season	3.19	0.0002	Season	3.42	0.002	Season	2.7	0.0006
		Depth	3.35	0.008	Gear	4.19	0.041	Depth	6.04	0.0001
		Gear	4.73	0.007				Gear	5.91	0.0004
		Season $\times$ Gear	3.03	0.049				Season $\times$ Gear	7.57	0.02
	CPUE (number)	Season	2.55	0.001	Season	5.11	0.003	Depth	3.43	0.005
		Depth	3.44	0.002	Depth	3.47	0.042			
B		All elasmobranchs (17)			Sharks (8)			Batoids (9)		
		Factor	F	P-value	Factor	F	P-value	Factor	F	P-value
Fishery/ Fishermen data Factors:	Total weight (kg)	Season	3.96	0.007	Season	6.6	0.0072	Season	3.07	0.017
		Haul	9.23	0.0001	Haul	27.16	0.0001	Haul	3.25	0.026
		Depth	15.02	0.0001	Depth	49.59	0.0001	Depth	3.47	0.02
		Sex. mat	4.21	0.002	Season $\times$ Depth $\times$ Sex	5.3	0.0251	Sex. mat	5	0.002
		Season $\times$ Sex. mat.	2.56	0.023				Season $\times$ Sex. mat.	2.97	0.03
		Sex $\times$ Sex. mat	3.28	0.007				Sex $\times$ Sex. mat.	3.79	0.011
		Season $\times$ Sex $\times$ Sex. mat.	2.34	0.037						

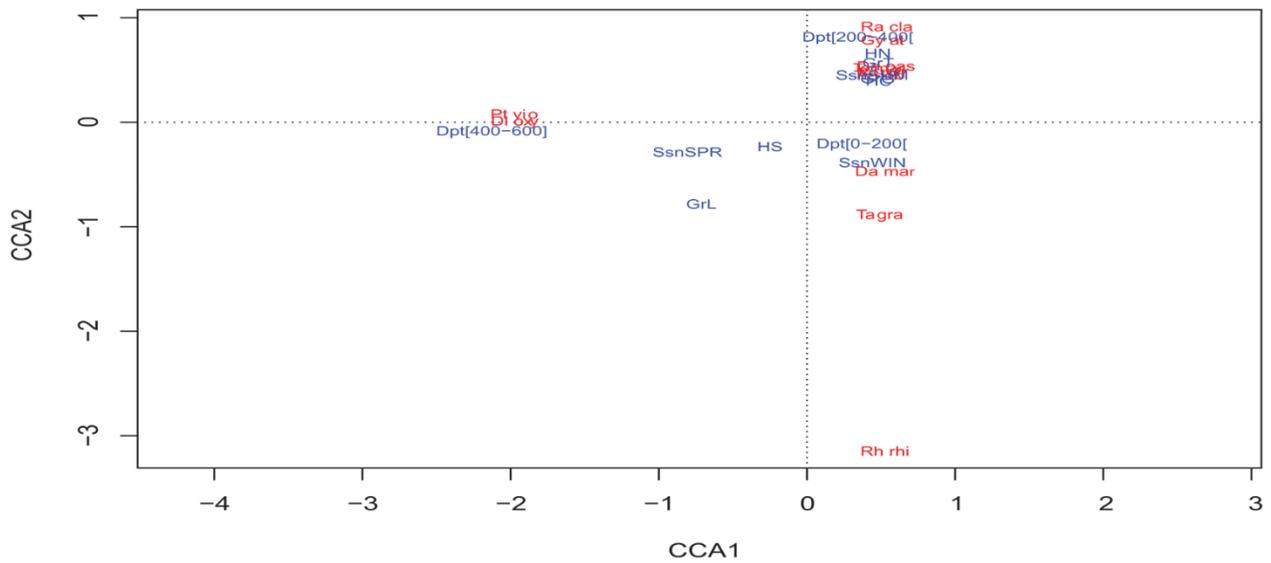
log(CPUE(kg)+1): All elasmobranchs



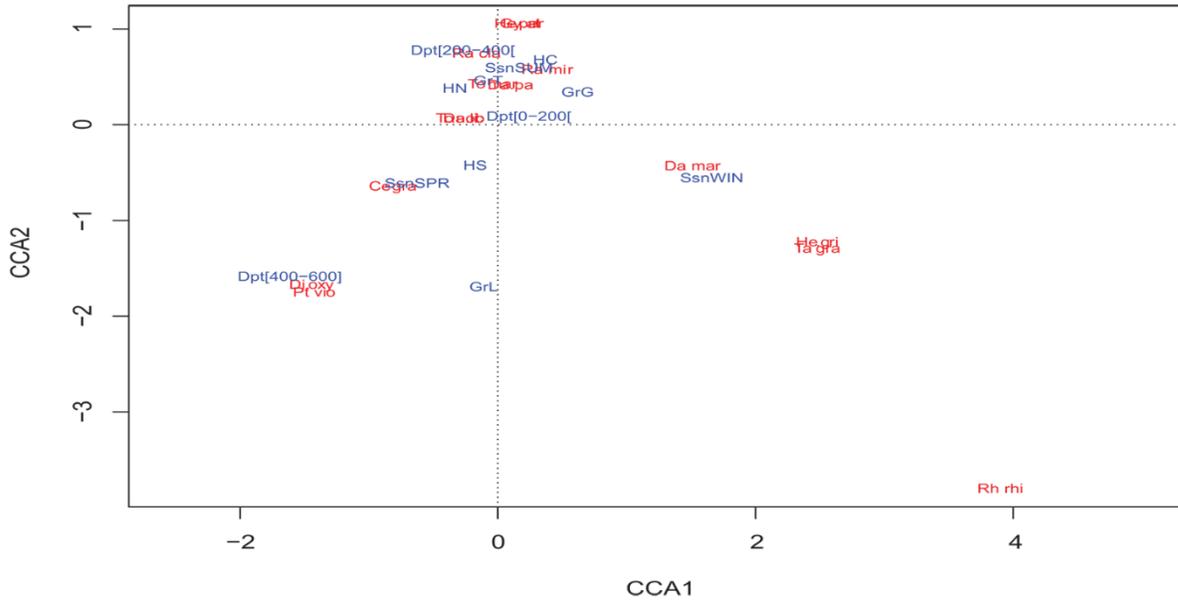
log(CPUE(kg)+1): Sharks



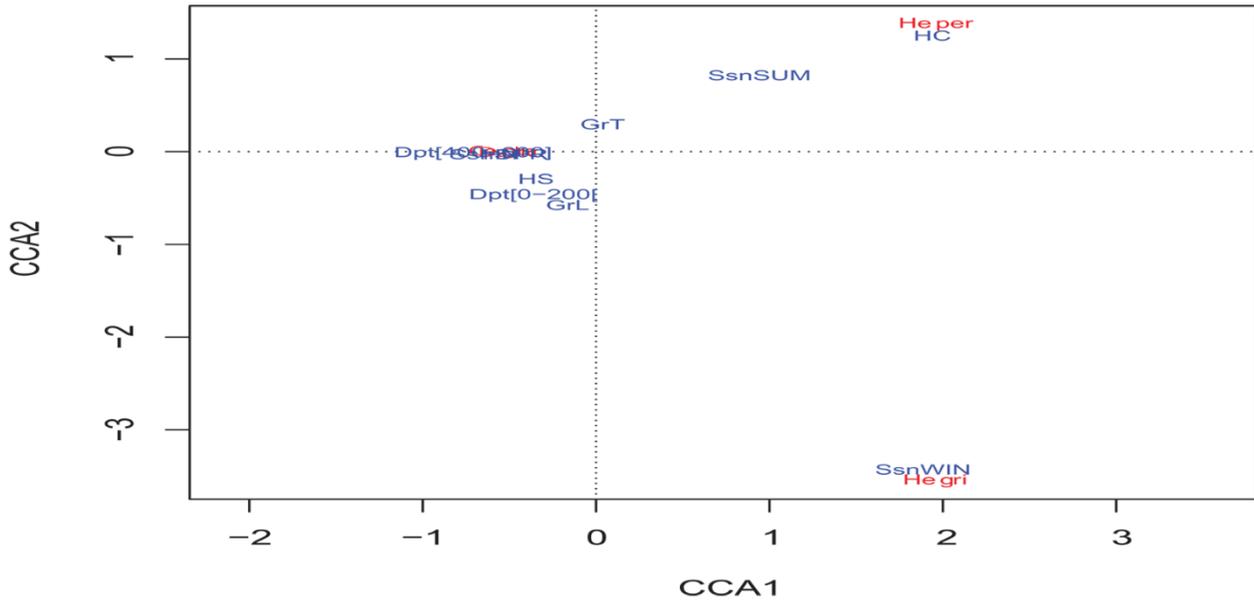
log(CPUE(kg)+1): Batoids



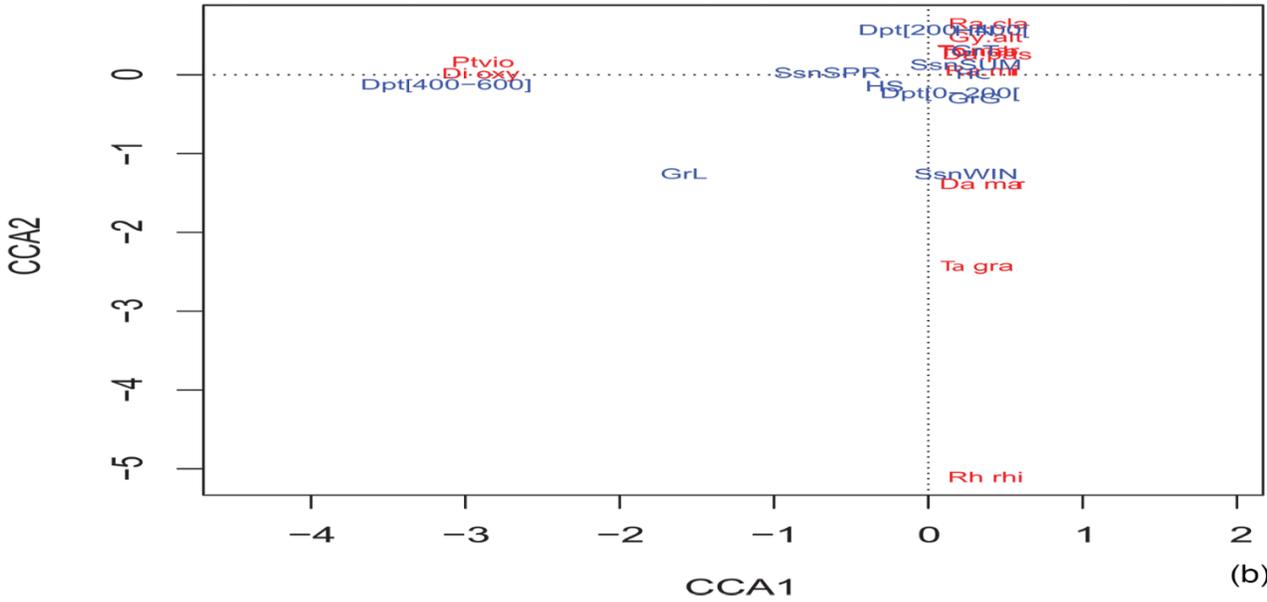
log(CPUE(num)+1): All elasmobranchs



log(CPUE(num)+1): Sharks

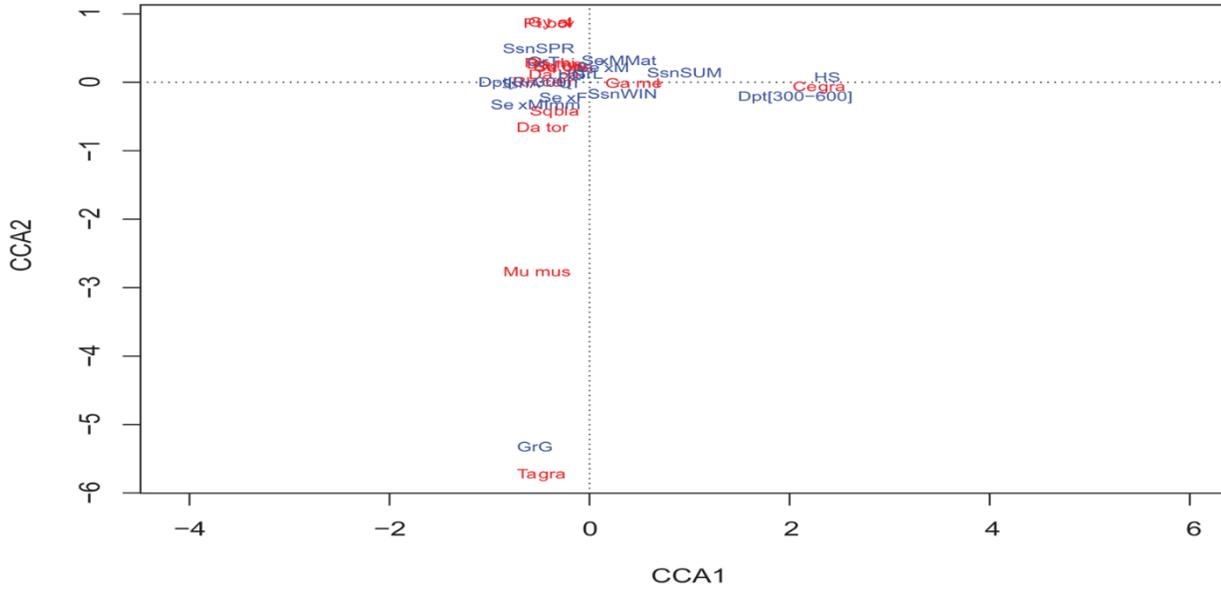


log(CPUE(num)+1): Batoids

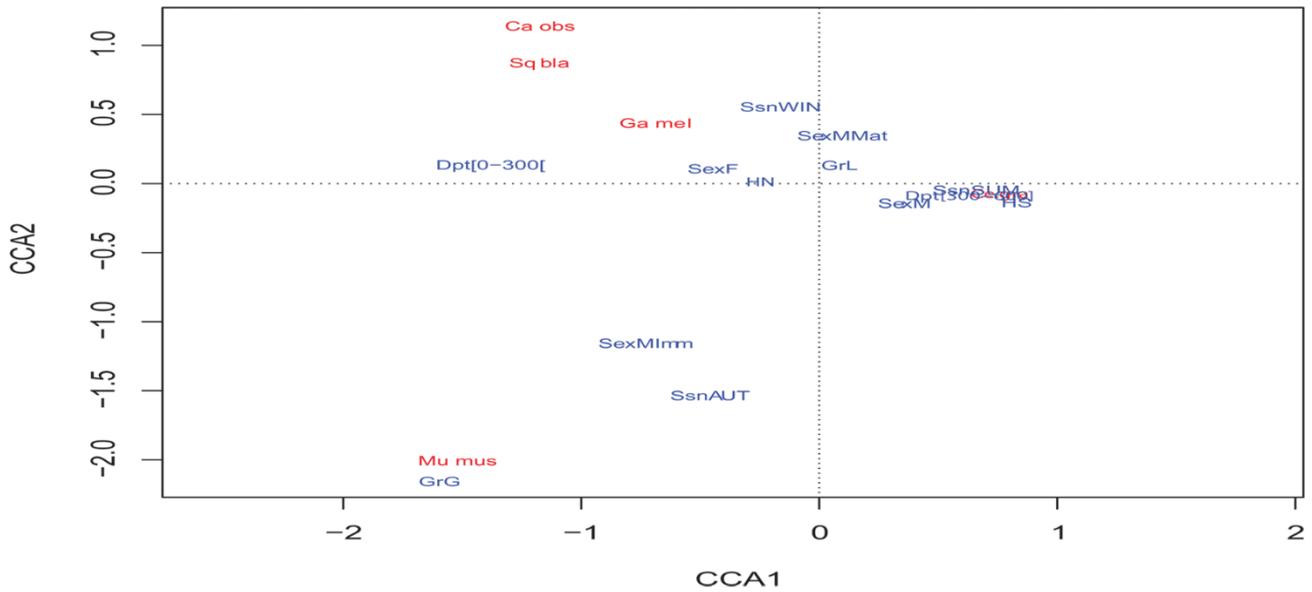


(b)

log(W<sub>T</sub>(kg)+1): All elasmobranchs



log(W<sub>T</sub>(kg)+1): Sharks



log(W<sub>T</sub>(kg)+1): Batoids

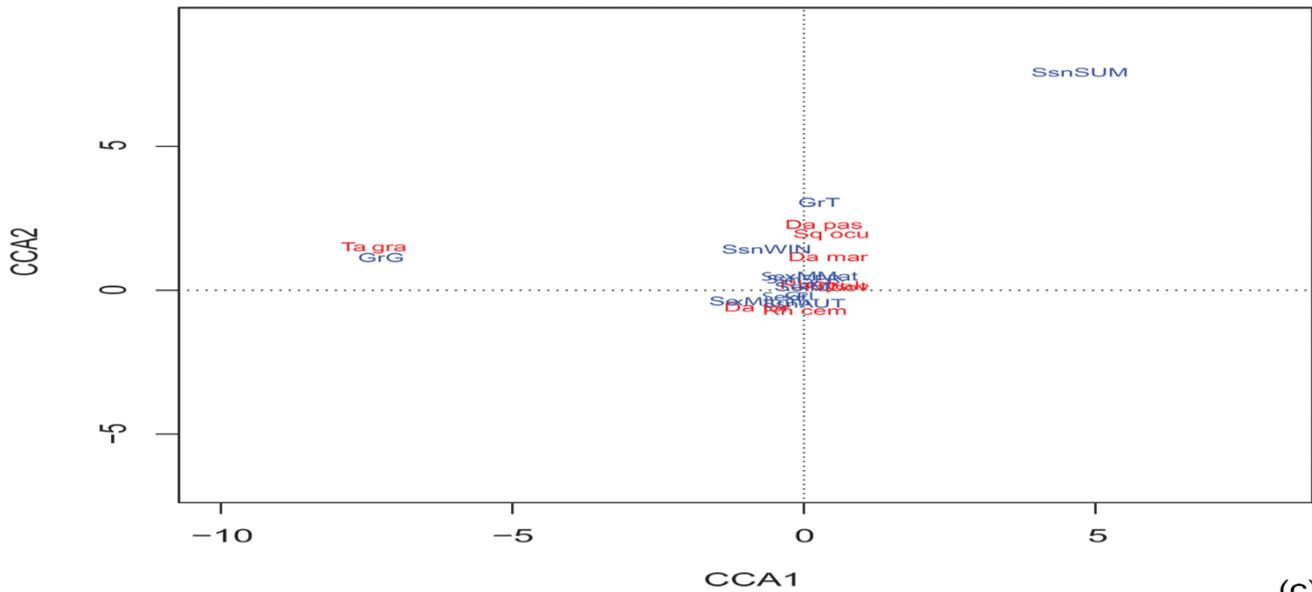


Figure 21: Canonical Correspondence Analysis (CCA) ordination diagrams of species and environmental data following the log transformed CPUE (expressed in kilograms) (a) and CPUE (expressed in number) (b) for survey data, and Total Weight (kg) (c) for fishery and fishermen data for the combined (left), shark (center), and batoid (right) data sets. The shark species are: Ca obs = *Carcharhinus obscurus*, Ce gra = *Centrophorus graulosus*, Da lic = *Dalatias licha*, Ga mel = *Galeus melastomus*, He gri = *Hexanchus griseus*, He per = *Hepttranchias perlo*, Is oxy = *Isurus oxyrinchus*, Mu mus = *Mustelus mustelus*, Sqbla = *Squalus blainville*. The batoid species are Da mar = *Dasyatis marmorata*, Da pas = *Dasyatis pastinaca*, Da tor = *Dasyatis tortonesei*, Di oxy = *Dipturus oxyrinchus*, Gy alt = *Gymnura altavela*, Pt bov = *Pteromylaeus bovinus*, Ra cla = *Raja clavata*, Ra mir = *Raja miraletus*, Rh cem = *Rhinobatos cemiculus*, Rh rhi = *Rhinobatos rhinobatos*, Sqocu = *Squatina oculata*, Ta gra = *Taeniura grabata*, To mar = *Torpedo marmorata*, To nob = *Torpedo nobiliana*. The environmental data consist of region (HN = North, HC = Central, HS = South), depth (Dpt), season (SsnSPR = Spring, SsnSUM = Summer, SsnAUT = Autumn, SsnWIN = Winter), gear (GrL = Longlines, GrT = Trammel nets, GrG = Gillnets).

### 3.3. Spatial and seasonal diversity

The spatial and seasonal diversity was evaluated for the total of 25 species recorded through the course of this study. Regarding the spatial diversity, it was evaluated for two regions (north and south, having the cap of Beirut as a midpoint). More species were recorded in the southern region of the coast showing higher Shannon ( $H'$ ) and Simpson ( $1-D$ ) indices. The latter region also showed higher evenness between species abundances ( $J'$ ) and higher phylogenetic diversity (taxonomic distinctness  $\Delta^+$ ) compared to the northern region (Table 16). In addition, the values of  $\Delta^+$ , presented in Figure 22 (a), fall below the expected average value for the northern region. Regarding seasonal diversity, the highest diversity and even distribution of species abundances were observed during the winter season following  $H'$ ,  $1-D$ , and  $J'$ . However, spring showed to have the highest phylogenetic diversity, followed by summer and winter, with the least phylogenetic diversity in autumn (Table 16).

Table 16: The diversity indices used to evaluate spatial and seasonal diversity ( $S$  is the number of species in each sample;  $H'$ : Shannon Index;  $J'$ : Pielou's evenness;  $1-D$ : Simpson's Index;  $\Delta^+$ : Taxonomic distinctness).

	Spatial diversity		Seasonal diversity			
	North	South	Autumn	Winter	Spring	Summer
$S$	18	19	9	15	12	14
$H'$	2.140280	2.312068	1.5226824	2.2717730	2.0186018	2.0242640
$J'$	0.7404862	0.7852320	0.6930026	0.8388962	0.8123451	0.7670406
$1-D$	0.8061828	0.8674317	0.6976744	0.8651860	0.8239721	0.8078125
$\Delta^+$	90.277	92.188	87.0513	90.1289	92.1480	91.0861

Furthermore, the values of  $\Delta^+$ , presented in Figure 22 (b), fall below the expected average value for the autumn, winter, and summer seasons.

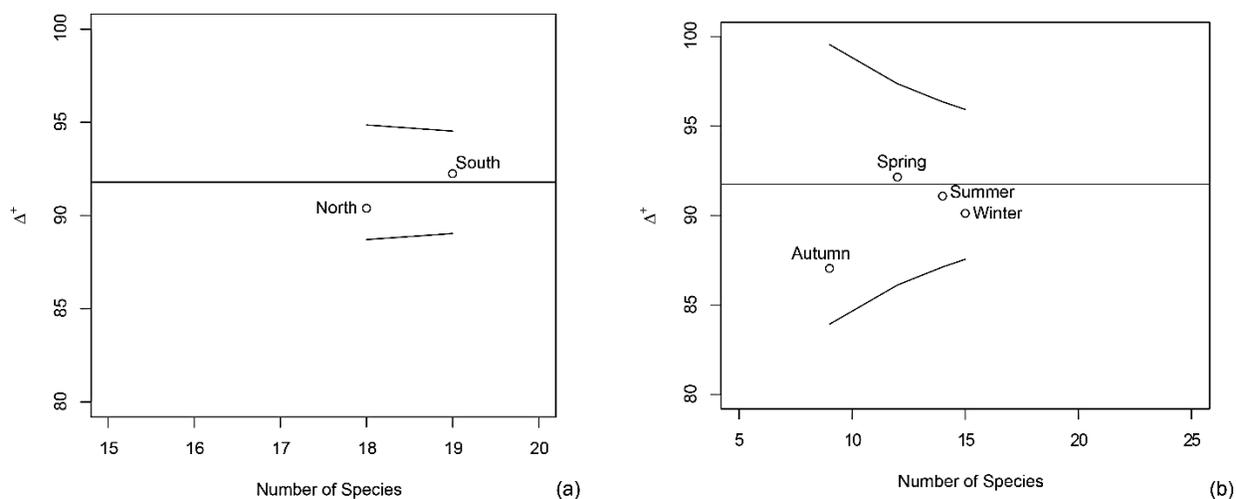


Figure 22: Confidence funnel indicating the taxonomic distinctness of the regions (a) and seasons (b) in relation to the pattern for regions and seasons, respectively. The funnel plot shows the 95% probability limits of  $\Delta^+$  for each value of the number of species. The line indicates average taxonomic distinctness which does not change with  $S$ .

#### 4. Discussion

The study represents the only evaluation of elasmobranch resources, distribution and diversity along the Lebanese coast, Eastern Mediterranean. This study uses two complementary data collection methods (scientific survey catches and fisheries and fishermen catches). Both data

were analyzed separately to constitute the most complete image of the status of this fish class along the Lebanese coast. Almost 30% of the Mediterranean chondrichthyan species belonging to the 15 families (combining the scientific survey and fishery/fishermen data) were recorded along the Lebanese coast and used to assess the spatial and seasonal diversity.

#### **4.1. Variation of abundance index**

##### *Scientific survey data*

The use of scientific survey data allowed to comprehensively represent the seasonal and depth distributions and depict the spatial variation of this fish class. The results indicate that for all elasmobranchs, the CPUE played an important role in explaining spatial and seasonal abundances. Sharks were present in all depth strata. On the contrary, the presence of batoids was dramatically reduced with depth, except for *D. oxyrinchus*, which was recorded at depths between 400 and 600 m and frequently documented to be caught between 200 and 500 m (Baino *et al.*, 2001). Moreover, *P. violacea* was also present at the largest depth stratum (400-600 m); however, this presence contradicts with what has been documented about its pelagic occurrence at depths ranging from 1 to 381 m (Mollet, 2002; Mundy, 2005; Bester *et al.*, 2007). In addition, the results also show that there is higher probability to find cartilaginous fish in shallow and intermediate depths (0-400 m) which comes in accordance with some observations in the Aegean Sea (Damalas *et al.*, 2010; Maravelias *et al.*, 2012), but we have to be careful with these observations because less sampling was performed in higher depths (16% of the hauls were carried out in higher depths). The depth distribution of elasmobranchs can also be influenced by the age of the individuals as bigger or older individuals prefer deeper waters (Gouraguine *et al.*, 2011). Therefore, the presence of elasmobranch species in different depths can indicate differences in the age structure of the populations examined. In this context, this information can enforce the fishing management and protection of these species in their habitats.

The seasonal variation in species CPUE can be attributed to the species seasonal migration or the influence of fishing activities in the shallower zone. Seasonal migration has been reported for several elasmobranchs, such as, *R. clavata* (Hunter *et al.*, 2006), *C. maximus* (Francis and Duffy, 2002), *C. squamosus* (Rodríguez-Cabello and Sánchez, 2014) and *C. carcharias* (Weng *et al.*, 2007). Temperature is also a significant factor in determining the distribution and abundance of

some elasmobranch species (Hopkins and Cech, 2003). Moreover, most elasmobranchs are ectothermic and changes in the environmental temperature can be rapidly transferred to the body of the fish, thus, affecting most physiological processes (Prosser, 1991). This can lead to a variation in depth or region of presence during fluctuations of temperature. Along with seasonal migration as a reason, the significant variations in CPUE (whether in terms of biomass or density) according to season can also be attributed to environmental conditions such as the properties of the water mass as well as predator–prey relationships, daily migrations, breeding and feeding migrations, fishery (Bianchi, 1992; Koslow, 1993; Gordon *et al.*, 1995), or social structure of the population (Mourier *et al.*, 2012).

The largest biomass in the southern region of the Lebanese coast may be attributed to the different gear used and the species caught because bottom longlines were only lowered in the southern region and a 150 kg *H. griseus* was caught in a single haul there, which might have caused this abnormal biomass value. Moreover, it has been documented that bottom longlines incidentally bring several demersal species such as *Mustelus sp.*, *Squalus sp.*, *Torpedo sp.* and especially species of the Rajidae family, which represent 6 to 19 percent of the total catch (Stergiou *et al.*, 2002). Therefore, such biomass distribution may be attributed to longlines (being lowered in the south only). The observed spatial patterns could also be attributed to the specific topographic and bathymetric conditions of the Lebanese coast. For example, the Lebanese coast is characterized by a narrow continental shelf, especially in the south, and mainly rough bottom grounds with intensive rocky patches (Goedicke, 1972; Majdalani, 2004). The distribution of the species richness can also be related to various abiotic and biological factors. Information on currents, temperature, salinity, nutrient concentration and the availability of food are important and should be considered in future studies. Furthermore, many causes can also be taken into account for this observed distributional pattern, such as, fishery and pollution, because the main understanding of the ecology of elasmobranchs is limited and even unknown in the region studied.

#### *Fishery data*

The data from fishery and random fishermen catches was used to complement the information related to the distribution and presence of cartilaginous fish species along the Lebanese coast. Artisanal fishery exploitation can greatly affect the abundance and size composition of long-

lived species, such as elasmobranchs (Pinnegar and Engelhard, 2008). According to Martin *et al.* (2006), the Lebanese marine production of elasmobranchs was 60 tonnes in 2003, accounting for 2% of all groups caught. Similar to the survey data, the observed seasonal and depth distribution for the fishery/fishermen data may be influenced by biological or environmental factors. More elasmobranch species were observed in the fishery and fishermen data rather than the scientific survey data. This might be attributed to the fact that Lebanese artisanal fishermen target and specify the hauls of their catches according to personal experience, and many fishermen sell their various catches in major fisheries providing a higher probability of finding more species in fisheries rather than in a scientific survey. In addition, the survey involves a single gear at a specific georeferenced point with an increased possibility of finding no elasmobranchs. The majority of the elasmobranchs of the fishery/fishermen data, were collected from the northern region in Lebanon, particularly, a major fishery in Tripoli. The highest percentage of navigation licenses and the majority of fishing operations occur in the latter region (Majdalani, 2005). In addition, the presence of some species in the survey data but not in the artisanal fishery/fishermen data or vice versa may indicate marked declines of these populations, differences in the spatial, depth or seasonal distributions of these species, or the depths during fishing activities, which are mostly carried out at depths less than 50 m along the Lebanese coast (Majdalani, 2005).

*Rhinobatos rhinobatos* was the most commonly observed elasmobranch in the fisheries of northern region of Lebanon. This elasmobranch is subject to fishing pressure in several regions especially Iskenderun Bay, northeastern Mediterranean (Cicek, 2006), where it is discarded dead or dying, because of poor commercial value (Ismen *et al.*, 2007b). Some studies declared its extinct status from the northern Mediterranean and its persistent presence in areas of the southern Mediterranean, particularly the Gulf of Gabés (Sciara *et al.*, 2007). However, the results of this study confirm its presence in the eastern Mediterranean with a significant commercial value in the northern region of Lebanon. In this context, there is an urgent need to assess the status of this species, develop and implement management plans in order to facilitate the conservation and sustainable management of this and all chondrichthyan species in the region.

## **4.2. Factors influencing spatial and seasonal diversity**

The variations in spatial and seasonal diversity may be attributed to various environmental and anthropogenic factors. Spatial diversity may vary following the topography or bathymetry of the region as well as the convergence of the currents, all of which can affect species richness and diversity due to various species affinities or ecological requirements. The nature of the bottom and the fact that the continental shelf is narrower in the south (Goedicke, 1972) may also have attributed to the variation of spatial diversity between the north and the south in the study area. In addition, human activity also has an influence on spatial diversity because except for a short stretch (about 22 km) from Tyre to Ras el Naqoura in the south, most of the Lebanese coast (225 km) is greatly influenced by anthropogenic activity (Khater and El-Hajj, 2012). The presence of two legal coastal nature reserves, the “Tyre Coast Nature Reserve” (Decree 708, 05/11/1998) in the south and the “Palm Islands Nature Reserve” (Decree 121, 09/03/1992) in the north may have also positively affected this diversity. Furthermore, intense fishing activities in some regions, especially in the northern region of the study area, can cause reductions observed in species richness (Greenstreet and Hall, 1996; Rice and Gislason, 1996). For example, the long-term decline in abundance of three ray species and other species of large bodied carcharhiniform sharks in Biscay Bay was attributed to the persistent effects of bottom trawling throughout the area (Quero and Cendrero, 1996). Thus, further analysis of time-series changes in the distribution and abundance of elasmobranchs, their life-history characteristics and their patterns of exploitation, are indispensable to confirm the role of fishing effort in the decrease of some of these species and the alteration of their diversity.

Regarding seasonal diversity, its variation can be attributed to the change in temperature, fishing effort that varies according to season, and the depth at which fishing operations took place. Temperature plays an important role in the seasonal migrations of several elasmobranchs species in nearshore waters (Talent, 1985; Wallman and Bennett, 2006; Wiley and Simpfendorfer, 2008). Species diversity decreases with depth especially for the deep water fish fauna that are influenced by the temperature difference throughout their depth range (White, 1987). Moreover, diversity levels can also be influenced by oceanographic factors especially those related to high marine productivity. Large elasmobranchs can be distributed in shallow-water according to plankton biomass, which decreases with depth and varies according to season (Lalli, 1999;

Pough *et al.*, 1999). Some elasmobranchs are found in plankton-rich near surface waters, other species feed on invertebrates and fish in deep water (Pough *et al.*, 1999). Furthermore, the definite prey availability in spring due to the phytoplankton bloom (Lakkis and Novel-Lakkis, 1981) can be a possible explanation of the highest taxonomic diversity observed during this season.

Consequently, the results of this study provide a quantitative description of spatio-temporal distribution and diversity of the cartilaginous fish community along the Lebanese coast to complete and extend the knowledge of the biological and ecological interactions of this fish class. More than 90% of elasmobranch species worldwide inhabit demersal ecosystems on continental shelves and slopes (Compagno, 1990), which makes them vulnerable to fishing activities. Several consequences in the marine ecosystems can result from the declines of these top predators. The information presented here is the first along the Lebanese coast and of significant value. It should be used to evaluate the conservation status of species and define the threats brought upon their populations notably by the artisanal fishing operations in Lebanon. This study also constitutes a starting point for a continuous assessment of the impact of natural and anthropogenic factors on cartilaginous fish species along the coast of Lebanon.

## **Acknowledgements**

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## II- Les relations longueur-poids de trois requins et cinq batoïdes dans les eaux marines libanaises, Méditerranée orientale

### Résumé

Des relations longueur-poids sont présentées pour 8 élastomobranches, 3 requins et 5 batoïdes, dans les eaux marines libanaises, en Méditerranée orientale. Ces élastomobranches ont été collectés à l'aide de palangres, trémails et filets maillants de décembre 2012 à octobre 2014. Des modèles non linéaires ont été employés et les valeurs du paramètre  $b$  des relations longueur-poids  $W = aL^b$  allaient de 1.752 à 3.337. Les relations longueur-poids ne variaient pas selon le sexe, sauf pour le requin *Centrophorus granulosus* (Bloch & Schneider 1801) et le batoïdes *Torpedo marmorata* (Risso 1810). Ces relations ne doivent être appliquées que dans les gammes de longueurs observées.

**Mots clés:** Liban; régression longueur-poids; poissons cartilagineux ; pêche ; elasmobranches

II- The length-weight relationships of three sharks and five batoids in the Lebanese marine waters, eastern Mediterranean

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**Abstract**

Length-weight relationships were estimated for 8 elasmobranches, 3 sharks and 5 batoids, in the Lebanese marine waters, eastern Mediterranean. These elasmobranches were collected using long liners, trammel nets, and gillnets from December 2012 to October 2014. Nonlinear models were used and the values of parameter  $b$  of the length-weight relationship  $W=aL^b$  ranged from 1.752 to 3.337. Sex did not affect the length-weight relationships except for the shark *Centrophorus granulosus* (Bloch & Schneider 1801) and the batoid *Torpedo marmorata* (Risso 1810). These relationships should be applied only to the observed length ranges.

**Keywords:** Lebanon; length-weight; regressions; cartilaginous fish; fishing; elasmobranchs

## 1. Introduction

Elasmobranch catches represent around 1.1% of the total landings in the Mediterranean Sea (Serena, 2005b). The maintenance of fishing pressure on elasmobranchs increases their risk of extinction (Ferretti *et al.*, 2008), especially in the eastern Mediterranean where these fish populations are declining through direct fishing pressure and bycatch (Basusta *et al.*, 2012b). Length-weight relationships for fish populations are important to comprehend the growth rate, age, and other factors influencing of population dynamics (Kolher *et al.*, 1995). They help in predicting weight from length as required in yield assessment (Garcia *et al.*, 1998) and calculation of biomass. Due to the absence of information on length-weight relationships of cartilaginous fish along the Lebanese coast and its scarcity in the eastern Mediterranean, the parameters for 8 elasmobranchs are reported. This study aims to create significant approaches in the population dynamics of these cartilaginous fish inhabiting the Lebanese coastal waters. The results also provide new maximum lengths and weights for these species.

## 2. Materials and Methods

Specimens were collected from December 2012 to October 2014 from the Lebanese marine waters, eastern Mediterranean. Sampling was performed through observation of major fisheries along the coast and through the CIHEAM-PESCA Libano scientific survey, in the framework of the CANA project - “Establishing Monitoring and Sustainable Development of the Lebanese Sea” - of the Lebanese National Council for Scientific Research (CNRS-L) performed during the same time period. These samples were collected using long liners, trammel nets and gillnets through both sampling manners. After collection, the specimens were identified using the two identification guides of Bariche (2012) and Golani *et al.* (2006). Total lengths ( $L$ ) were measured to the nearest centimeter (cm) using a measuring tape. Total weights ( $W$ ) less than five kilograms were measured to the nearest gram (g) using an electronic balance, and weights greater than five kilograms were measured to the nearest 100 g using a scale. The length-weight relationship (LWR:  $W=aL^b$ ) curve parameters,  $a$  and  $b$ , were estimated using a nonlinear least squares function *nls* in the statistical software R (R Development Core Team, 2014). The start values of these parameters were derived from the log transformation of the two variables using the linear model function *lm*. The coefficient of determination ( $r^2$ ) aids in determining the accuracy of the

model prediction skills. Finally, statistical comparison of WLR between sexes was performed by applying an ANCOVA test. When significant differences were observed, WLR was estimated for each sex; when no significant differences were observed, one WLR was estimated for the sexes combined.

### 3. Results and Discussion

A total of 235 elasmobranch individuals comprising of 3 shark species and 5 batoid species were collected in this study. The length and weight characteristics, as well as, the sample size and parameters of the length-weight relationships are represented in Table 17. The sample sizes ranged from a minimum of 11 for *S. blainvillei* to a maximum of 70 for *R. rhinobatos*. Significant differences were only observed between the males and females of *C. granulatus* and *T. marmorata* (ANCOVA;  $P < 0.05$ ). The value of parameter  $b$  ranged from a minimum of 1.752 for the females of *T. marmorata* to a maximum of 3.337 for the combined sample of *R. miraletus*. All estimated relationships showed negative allometry except those for *R. rhinobatos*, *R. clavata* and *R. miraletus* that showed positive allometry with  $b$  values of 3.102, 3.203, and 3.337 respectively. The most accurate model was shown to be that of *R. rhinobatos* ( $r^2 = 0.9873$ ) and the least accurate was that of the females of *C. granulatus* ( $r^2 = 0.6380$ ). This variation in model accuracy can be due to the absence of a complete sample consisting of different size classes. Furthermore, some samples in this study do not consist of small individuals for some species, such as, females of *C. granulatus*. Hence, the relationships presented should only be applied to the observed length ranges (Pettrakis and Stergiou, 1995; Gonçalves *et al.*, 1997).

Table 17: The weight and length characteristics, as well as, the parameters of the LWR ( $W=aL^b$ ) for the 8 elasmobranchs caught in the Lebanese waters. N is the sample size; mean, min, max, and SD are the mean, minimum, maximum, and standard deviation respectively; a and b are the parameters of the weight – length relationship; SE (b) is the standard error of parameter b;  $r^2$  is the coefficient of determination; allometric (-) and allometric (+) is negatively and positively allometric respectively; M, F, and Both are the male, female, and the combined sample respectively.

Species	Sex	N	Weight and length characteristics		Parameters of the LWR				Growth
			L mean $\pm$ SD (Lmin-Lmax) in centimeters (cm)	Wmean $\pm$ SD (Wmin-Wmax) in grams (g)	a	b	SE (b)	$r^2$	
<i>Shark species</i>									
<i>Centrophorus granulosus</i> (Bloch & Schneider, 1801)	M	20	73.95 $\pm$ 9.24 (45 – 83)	2705.75 $\pm$ 616.84 (870 – 3400)	0.3585	2.071	0.2351	0.9419	Allometric (-)
	F	18	88.08 $\pm$ 3.11 (81 – 94)	4997.22 $\pm$ 631.17 (3400 – 6200)	0.02392	2.735	0.5563	0.6380	Allometric (-)
<i>Squalus blainvillei</i> (Risso, 1827)	Both	11	49.59 $\pm$ 4.85 (42 – 57)	676.55 $\pm$ 205.77 (367 – 1050)	0.008192	2.894	0.4969	0.8238	Allometric (-)
<i>Galeus melastomus</i> (Rafinesque, 1810)	Both	14	48.64 $\pm$ 4.48 (41- 55)	360.81 $\pm$ 119.41 (110 – 495)	0.003783	2.946	0.6328	0.6458	Allometric (-)
<i>Batoid species</i>									
<i>Rhinobatos rhinobatos</i> (Linnaeus, 1758)	Both	70	75.60 $\pm$ 19.59 (50 – 143)	1793.53 $\pm$ 1957.87 (410 – 10000)	0.002138	3.102	0.0325	0.9873	Allometric (+)
<i>Rhinobatos cemiculus</i> (Geoffroy Saint-Hilaire, 1817)	Both	31	82.93 $\pm$ 16.49 (57.80 – 150)	2256.19 $\pm$ 1898.02 (650 – 11500)	0.004565	2.941	0.0365	0.9775	Allometric (-)
<i>Raja clavata</i> (Linnaeus, 1758)	Both	19	47.42 $\pm$ 12.28 (25 – 70)	832.68 $\pm$ 680.83 (62 – 2300)	0.002970	3.203	0.3002	0.9765	Allometric (+)
<i>Raja miraletus</i> (Linnaeus, 1758)	Both	30	34.62 $\pm$ 3.86 (25 – 44)	224.23 $\pm$ 92.92 (72 – 490)	0.001563	3.337	0.2321	0.9130	Allometric (+)
<i>Torpedo marmorata</i> (Risso, 1810)	M	16	25 $\pm$ 3.49 (14 – 30)	327.69 $\pm$ 95.74 (51 – 474)	0.3520	2.118	0.3125	0.9487	Allometric (-)
	F	6	25.67 $\pm$ 4.56 (18 – 31)	400.50 $\pm$ 127.38 (222 – 550)	1.3367	1.752	0.4508	0.8994	Allometric (-)

Information related to the length-weight relationships of elasmobranchs are absent along the Lebanese coast, however, showing an important presence in the eastern Mediterranean especially in the Aegean Sea (Filiz and Mater, 2002; Filiz and Bilge, 2004; Ismen *et al.*, 2007a; Ozaydin *et al.*, 2007; Cakir *et al.*, 2008; Ilkyaz *et al.*, 2008; Ismen *et al.*, 2009; Yigin and Ismen, 2009a;

Bilge *et al.*, 2014; Yapici and Filiz, 2014), Iskenderun Bay (Basusta *et al.*, 2012a) and Antalya Bay (Güven *et al.*, 2012). This information helps in deriving the weight estimates of these elasmobranchs from their lengths at sea in order to limit the catches of these fish along the Lebanese coast. This might be a good tool to induce laws to limit the overexploitation of these fishes through direct fishing and bycatch by establishing a minimum catch weight limit and taking into consideration these weights when the lengths are estimated at sea.

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# Chapter V

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**Population biology of an Endangered species:  
the Common Guitarfish *Rhinobatos*  
*rhinobatos* L. 1758 in the Lebanese marine  
waters, eastern Mediterranean**

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# **Biologie des populations d'une espèce en voie de disparition : la guitare de mer commune *Rhinobatos rhinobatos* L. 1758 dans les eaux marines libanaises, Méditerranée orientale**

## **Résumé**

Cette étude est consacrée à la biologie et l'écologie de la population de la Guitare De Mer Commune *Rhinobatos rhinobatos* L. 1758, qui est répertoriée sur la liste rouge par l'Union Internationale pour la Conservation de la Nature (IUCN) comme une espèce de poisson cartilagineux en voie de disparition. Bien que fortement exploitée, jusqu'à maintenant, aucune étude n'a été menée sur cette espèce d'éla-smobran-ches le long de la côte libanaise dans le bassin Levantin en Méditerranée orientale. Un total de 67 spécimens issus de différents ports des eaux marines côtières libanaises a été recueilli par les palangriers de fond à des profondeurs allant de 10 à 110 m entre décembre 2012 et janvier 2014. La longueur totale des spécimens de l'échantillon variait entre 50 et 143 cm avec une moyenne de  $76,21 \pm 19,7$  cm. Les classes de taille les plus courantes se répartissaient entre 60 et 70 cm de longueur totale. Le poids total des échantillons se situait entre 410 et 10000 g avec une valeur moyenne de  $1841,3 \pm 1,987$  g. Le sexe-ratio n'était pas significativement différent de 1:1 avec un nombre total de 34 mâles et 33 femelles. La relation longueur-poids a montré une croissance allométrique positive avec  $b = 3.096$  et  $R^2 = 0,99$ . La longueur à laquelle 50% des individus étaient mûres était de  $84,73 \pm 5,81$  cm pour les femelles et  $78,57 \pm 4,88$  cm pour les mâles. Les indices gonado-somatique et hépato-somatiques ainsi que le facteur de condition ont été représentés, et la parturition semblaient avoir eu lieu en hiver. Les principales proies trouvées dans les estomacs appartenaient à la famille Penaeidae en automne et en hiver. Les résultats de cette étude aideront à paramétrer les modèles de dynamique des populations de ce stock de poisson exploité afin d'assurer la durabilité à long terme de cette pêche.

**Mots-clés:** Chondrichthyens; IUCN; Liban; histoire de vie; surexploitation; biologie reproductive.

**Chapter V: Population biology of an Endangered species: the Common Guitarfish *Rhinobatos rhinobatos* L. 1758 in the Lebanese marine waters, eastern Mediterranean**

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**Abstract**

This study focuses on the population biology of the Common Guitarfish *Rhinobatos rhinobatos* L. 1758, which is listed as an Endangered cartilaginous species on the International Union for the Conservation of Nature (IUCN) Red List. Although heavily exploited, until now, no study has been performed on this elasmobranch species along the Lebanese coast in the Levantine basin, eastern Mediterranean. A total of 67 individuals were collected from the coastal Lebanese marine waters by bottom long liners through different ports at depths ranging from 10 to 110 m between December 2012 and January 2014. The total length of the sample varied between 50 and 143 cm with an average of  $76.21 \pm 19.7$  cm. The most common size classes were between 60 and 70 cm total length. The total weight of the specimens ranged between 410 and 10000 g with an average value of  $1841.3 \pm 1987$  g. The sex ratio was not significantly different from 1:1 with a total number of 34 males and 33 females. The length-weight relationship showed a positive allometric growth with  $b = 3.096$  and  $R^2 = 0.99$ . The length at which 50% of the individuals matured was  $84.73 \pm 5.81$  cm for females and  $78.57 \pm 4.88$  cm for males. The gonado-somatic and hepatosomatic indices along with the condition factor were represented, and parturition seemed to have taken place in winter. The main prey items found in the stomachs belonged to the Penaeidae family in the autumn and winter seasons. The results of this study will help to parameterize the population dynamics models of this exploited fish stock in order to ensure the long-term sustainability of this fishery.

**Keywords:** Chondrichthya; IUCN; Lebanon; life history; overfishing; reproductive biology.

## 1. Introduction

Paleoecological, archaeological, and historical data show that consequent alterations in ecological communities occurred decades to centuries after the start of anthropogenic overfishing (Jackson *et al.*, 2001). More human impact is observed in the Mediterranean Sea than in any other sea (Blondel and Aronson, 2005). Natural and anthropogenic events that have shaped its biodiversity in the past will continue to do so in the future (Coll *et al.*, 2010). In the Mediterranean, cartilaginous fish are characterized by their diversity with a total estimate of 80 species (45 sharks, 34 batoids, and one chimaera) found in its waters (Compagno, 2001; Compagno *et al.*, 2005; Serena, 2005b). These fishes are an important bycatch of commercial fisheries targeting bony fishes (Bradai *et al.*, 2012). Moreover, it has been shown that sharks in the Mediterranean Sea, such as, the hammerhead (*Sphyrna spp.*), blue (*Prionace glauca*), mackerel (*Isurus oxyrinchus* and *Lamna nasus*), and thresher sharks (*Alopias vulpinus*), have declined by more than 97% in number and “catch weight” over the last two centuries and are in a risk of extinction if current fishing pressure continues (Ferretti *et al.*, 2008). In addition, the Mediterranean Sea is considered one of the seven Chondrichthyan biodiversity hotspots and one of the three main hotspots where the biodiversity of sharks and rays was seriously threatened (Dulvy *et al.*, 2014). Among the 80 species of cartilaginous fish known in the Mediterranean, 71 were assessed in the frame of the International Union for Conservation of Nature (IUCN) red list, and more than 40% (34 species) are threatened and face an elevated risk of extinction (Cavanagh and Gibson, 2007).

The Common Guitarfish *Rhinobatos rhinobatos* L. 1758 is an elasmobranch of the Rhinobatidae family that is classified as Endangered by the IUCN (Sciara *et al.*, 2007). It is an ovoviviparous species with a nine months gestation period and an average number of eight to 14 embryos per pregnancy (Abdel-Aziz *et al.*, 1993). This increases the concern of its Endangered status as most elasmobranchs have a slow growth rate, late maturity and low fecundity compared to bony fish; this results in low reproductive potential and low capacity for population increase (Stevens *et al.*, 2000). Furthermore, Dulvy *et al.* (2014) linked depth and body size to extinction risk, where larger species occupying shallow waters are at a greater risk and the majority of the threatened families are rays.

It is a demersal species found in the Eastern Atlantic and the Mediterranean (Bauchot *et al.*, 1987). Its presence in the latter region is more prevalent in the southern and eastern regions (Whitehead *et al.*, 1984; Capapé, 1989), especially around the Gulf of Gabès, on the eastern coast of Tunisia (Quignard and Capapé, 1971). The Common Guitarfish species was documented to be extinct in the northern regions of the Mediterranean (Relini and Piccinetti, 1991; Baino *et al.*, 2001).

In the eastern Mediterranean, the study area, the Common Guitarfish is commonly found in Turkish waters and discarded dead or dying because of poor commercial value (Ismen *et al.*, 2007b). Nonetheless, it is commonly found in Lebanese fisheries presenting a significant commercial value, where its meat is consumed as fish filets with a value ranging from four to six US dollars per one kilogram. It is targeted by Lebanese fishermen using longlines and sometimes caught as bycatch with entangling nets, provided that the Lebanese fleet is artisanal and the number of licensed vessels in 2011 was 1460 (Pinello and Dimech, 2013). The lack of management measures (particularly specific to elasmobranchs) and commercial fishing has created the need to manage the stocks of such elasmobranch species in this region.

Basic biological information needed for stock assessment is lacking for many of these eastern Mediterranean cartilaginous species, including minimum, maximum, and average sizes, as well as length-to-weight relationships. However, these data are essential to understand the growth rate, age structure, and other aspects of population dynamics. Size conversions also have a practical value in fisheries. One measure currently in practice is the establishment of minimum size limits and usually a minimum weight. Since sizes must be estimated at sea, means for converting lengths to weights are essential to fishermen.

Rare are the studies performed on the Common Guitarfish in the eastern Mediterranean, and none in the Lebanese coastal waters. Most studies, dealing with biological and aging aspects, were performed in the Egyptian Alexandria waters (southeastern Mediterranean) (Abdel-Aziz *et al.*, 1993), the Turkish Iskenderun Bay (northeastern Mediterranean) (Basusta *et al.*, 2007; Ismen *et al.*, 2007b; Basusta *et al.*, 2008; Cek *et al.*, 2009; Demirhan *et al.*, 2010), and the Tunisian coasts (south-central Mediterranean) (Capapé *et al.*, 1975; Capapé and Zaouali, 1981; Capapé *et al.*, 1997).

This study, being the first for the Lebanese coastal waters, essentially reflects the biological aspects of the Common Guitarfish population. In response to the immediate needs for management initiatives, it aims to contribute to a better knowledge of the growth, sexual maturity, reproduction and nutritional strategy of the Common Guitarfish population in the Lebanese marine waters. Length and weight data, sex ratio, length-weight relationships, length at which 50% of the individuals matured, gonadosomatic and hepatosomatic indices, condition factor as well as the main prey items found in the stomachs of this species are presented and compared to available data from other areas. This study provides a first evaluation of the population health condition and aims, at a longer term, to stimulate the implementation of regulations to control the fishing of this endangered cartilaginous species.

## **2. Materials and Methods**

### **2.1. Sampling and study area**

A total of 67 specimens of Common Guitarfish were collected by bottom long liners through four different ports along the Lebanese coastal waters located in the Levantine basin, eastern Mediterranean, at depths ranging from 10 to 110 m between December 2012 and January 2014. These were collected through observation of catches of the fisheries along the Lebanese coast, with the majority collected in the Tripoli port (Figure 23). The exact position of the fishery catches is not available because the majority of Lebanese fishermen have no Global Positioning System (GPS) instruments; however, the depth is provided.

The specimens were identified according to the two field identification guides of Bariche (2012) and Golani *et al.* (2006). They were either dissected on the site of collection, whether on a port or in a fishery, or preserved in ice and later frozen at -20°C to be eventually treated in the laboratories of the Lebanese National Council for Scientific Research-National Center for Marine Sciences in Batroun.

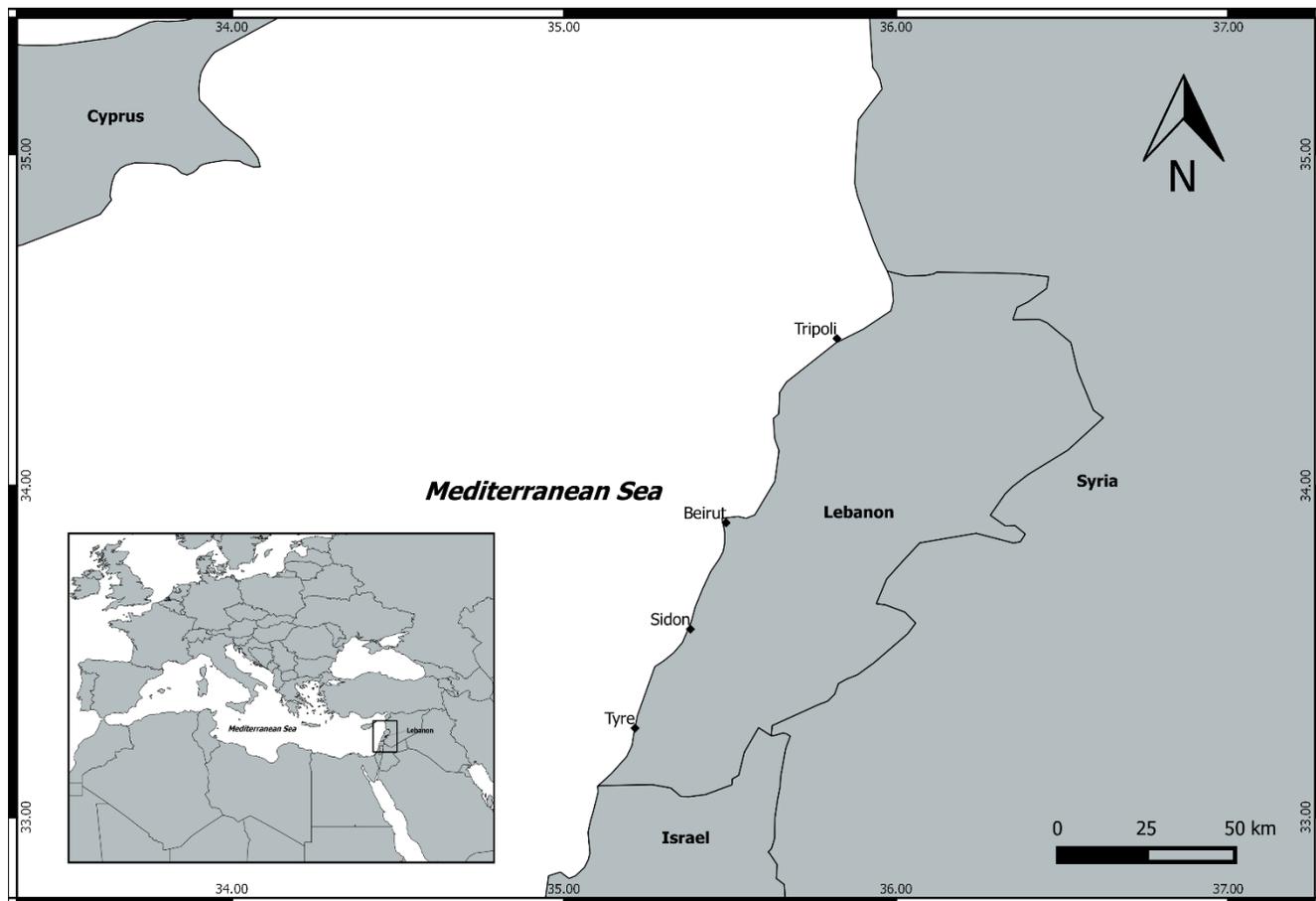


Figure 23: Location of the major ports along the Lebanese coast.

## 2.2. Biological measures

Upon treatment, the specimens were observed for external damages and males were macroscopically sexed by examining the claspers. The external length of the clasper ( $L_C$ ) in males was measured from the tip of the clasper to the base of the pelvic fin all using a calliper to the nearest millimetre (mm). In the rest of the paper, all lengths and weights (less than five kilograms) were measured to the nearest centimetre (cm) and nearest gram (g), respectively, using an electronic balance and a measuring tape. Weights greater than five kilograms were measured using a scale to the nearest 100 g.

Morphometric measurements were performed for each Common Guitarfish specimen. The total weight ( $W_T$ ) and total length ( $L_T$ ) were measured prior to dissection. The liver and gonads were removed along with the expanded uteri in the case of a gravid female.

The weight of the liver ( $W_L$ ) was measured and used for the computation of the hepato-somatic index ( $I_H$ ) (Bulow *et al.*, 1978; Adams and McLean, 1985) where:

$$I_H = W_L \times W_T^{-1} \times 100$$

The  $I_H$  gives useful indication of energy reserves because the liver is an important energy storage in fish (Halton *et al.*, 2001).

The weight of the gonads ( $W_G$ ) including the weight of the testes in males, and oviductal glands, accessory glands, ovary and oviducts in females (Gristina *et al.*, 2006) were also measured for the computation of the gonado-somatic index ( $I_G$ ) (Bougis, 1952) where:

$$I_G = W_G \times W_T^{-1} \times 100$$

The  $I_G$  allows to investigate the changes in gonad weight in relation to the weight of fish.

Sexual maturity was determined using the Instruction Manual for the MEDITS Survey – Version 6 (MEDITS, 2012), where the ovoviviparous elasmobranch females were classified among eight maturity stages (1: Immature; 2: Developing; 3a: Capable to reproduce; 3b: Early pregnancy; 3c: Mid pregnancy; 3d: Late pregnancy; 4a: Regressing; 4b: Regenerating), and the males among five maturity stages (1: Immature; 2: Developing; 3a: Spawning capable; 3b: Actively spawning; 4: Regressing).

Finally, the condition factor ( $K$ ) (Fulton, 1904) was also computed using total weight ( $W_T$ ) and total length ( $L_T$ ), where:

$$K = W_T \times L_T^{-3} \times 100$$

The  $K$  is used for comparing the ‘condition’, ‘fatness’, or ‘well-being’ of fish, based on the assumption that heavier fish of a given length are in better condition (Froese, 2006).

### 2.3. Stomach content analysis

The total weight of the stomach ( $W_S$ ) was measured. Stomachs with food contents were preserved in 4% formaldehyde until identification. The stomach contents were then rinsed under tap water. Their weight was measured if possible to the nearest gram, counted and identified to the lowest possible taxon (Megalofonou and Chatzisprou, 2006).

According to Hyslop (1980), two indices were calculated. The coefficient of vacuity ( $C_V$ ) was calculated to reflect the richness or lack of food in the environment:

$$C_V = E_V \times N^{-1} \times 100$$

where  $E_V$  is the number of empty stomachs and  $N$  is the total number of stomachs examined.

The percentage of fullness ( $F_I$ ) was also calculated for each stomach:

$$F_I = W_P \times W_S^{-1} \times 100$$

where  $W_P$  is the weight of the prey items in each stomach.

Stomach fullness was classed based on a five-point scale estimated by the percentage of fullness: empty, partially empty (1-25%), slightly full (26-50%), partially full (51-75%), and full (76-100%).

Moreover, three indices were used to show the significance of different prey items. The frequency of occurrence ( $O_{\%}$ ), the coefficient of prey numerical abundance ( $N_{\%}$ ), and the percentage of weight ( $W_{\%}$ ) (Hynes, 1950; Hyslop, 1980; Bowen, 1983):

$$O_{\%} = N_P \times M^{-1} \times 100$$

$$N_{\%} = n \times n_P^{-1} \times 100$$

$$W_{\%} = m \times m_P^{-1} \times 100$$

where  $N_P$  is the number of stomachs containing a specific prey group,  $M$  is the number of stomachs with prey remains,  $n$  is the number of prey of each taxonomic group,  $n_P$  is the total number of prey items,  $m$  is the mass of prey of each taxonomic group, and  $m_P$  is the total mass of prey items.

Out of these indices, the importance of each food item in the diet was obtained by the Index of Relative Importance ( $I_{RI}$ ) (Pinkas *et al.*, 1971) that was modified by Hacunda (1981):

$$I_{RI} = O_{\%} \times (N_{\%} + W_{\%})$$

Finally, the percent of IRI ( $I_{\%RI}$ ) for each prey type was estimated in order to make comparisons easier among food types (Cortés, 1997).

## 2.4. Regressions and statistical analyses

All regressions and statistical analyses were performed using the statistical software ‘R project’ (R Development Core Team, 2014). A linear regression model was used to examine the relationship between total length and clasper length ( $L_C = a + bL_T$ ) using the *lm* function. The coefficient of determination ( $R^2$ ) was used to evaluate the quality of the model.

The total length and total weight were used to produce the length-weight relationship in a nonlinear power regression ( $W_T = aL_T^b$ ) (LeCren, 1951) where ‘a’ and ‘b’ are the parameters to estimate using the *nls* function. A nonlinear power regression was also used to produce the relationship between the gonad weight and total length of male specimens ( $W_G = aL_T^b$ ). Nonlinear regressions were used to represent any regression of weight on length because any weights will scale to the cubic power of length (Froese, 2006). In addition, the length at which 50% of the fish are mature ( $L_{50}$ ) was estimated for all length classes using a logistic curve from a generalized linear model (GLM) with logit link using the *glm* function. Furthermore, statistical comparison of weight-length relationships between sexes was performed by applying an ANCOVA test using the *anova* function. A Shapiro-Wilk normality test was used to test for the normality of the sample using the *shapiro.test* function, and the Wilcoxon rank sum test was used to test for differences in lengths, weights and percentages of fullness between males and females using the *wilcox.test* function. Moreover, a Kruskal-Wallis rank sum test was used to examine the differences between total length and total weight according to sexual maturity and between the biological indices ( $I_G$ ,  $I_H$  and  $K$ ) according to season using the *kruskal.test* function. The sex ratio was calculated for the whole sample and compared to the 1:1 proportion by a chi-squared test (Zar, 2010) using the *chisq.test* function.

Moreover, in order to determine the feeding strategy of both species, feeding strategy graphs were plotted following the Costello (1990) method. The feeding strategy graphs particularly illustrate the dominance and the rarity of each group of prey in both seasons and the specialized or generalized feeding strategy.

### 3. Results

#### 3.1. Sex ratio and length frequency distribution

A total of 67 (33 females and 34 males) of Common Guitarfish were reported to be collected at depths ranging from 15 to 110 m, with 91% (61 individuals) of the specimens collected at depths less than 50 m. The sex ratio of males to females was found to be 1.03. No significant differences between the number of males and females were observed and the sex ratio was not significantly different from 1:1 ( $\chi^2$  test,  $\chi^2 = 0.0149$ , d.f. = 1,  $P > 0.05$ ). The length and weight measurements for each sex are represented in Table 18.

Table 18: The mean, minimum (min) and maximum (max) lengths and weights of the females and males of the Common Guitarfish sample (S.D.: Standard deviation)

	Number of individuals	Length (cm)			Weight (g)		
		Mean and S.D.	Min	Max	Mean and S.D.	Min	Max
<b>Females</b>	33	81.79 ± 23.07	58	143	2360.21 ± 2563.00	628	10000
<b>Males</b>	34	70.78 ± 14.09	50	114	1337.65 ± 997.88	410	5500

The length–frequency distribution for each and both sexes shows that 56.7% (38 individuals) of the sampled Common Guitarfish were in the 60 and 70 cm length class. No individuals were observed in the length class of 120 cm. The majority of the females, 33.3% (11 individuals) and 21.2% (seven individuals) occupied the length classes of 60 and 70 cm respectively. In addition, the majority of the males, 32.3% (11 individuals) and 26.5% (nine individuals) occupied the length classes 70 and 60 cm respectively. The length classes of 130 and 140 cm were only occupied by females (Figure 24).

Males and females showed significant difference in length distributions, however, no significant differences in weight distributions (for  $L_T$ : Wilcoxon test,  $W = 402$ ,  $P < 0.05$ ; for  $W_T$ : Wilcoxon test,  $W = 407.5$ ,  $P > 0.05$ ).

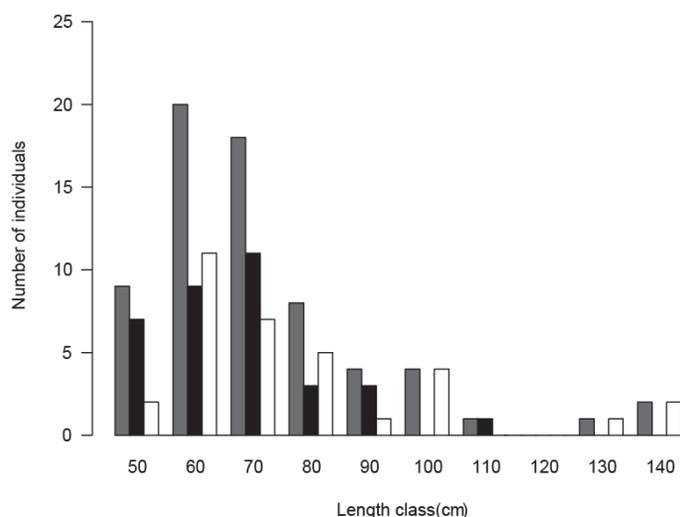


Figure 24: The length frequency distribution of the Common Guitarfish sample during the study period for males ( ■ ), females ( □ ) and both sexes ( ■ ).

### 3.2. Length-weight relationship

The weight ( $W_T$ ) – length ( $L_T$ ) relationship was estimated using a nonlinear power regression analysis (Males:  $W_T = 0.0012 L_T^{3.241}$ ,  $R^2 = 0.98$ ,  $n = 34$ ; Females:  $W_T = 0.0023 L_T^{3.089}$ ,  $R^2 = 0.99$ ,  $n = 33$ ). No significant differences were obtained from the statistical comparison of weight–length relationships between males and females (ANCOVA,  $F = 0.2381$ ,  $P > 0.05$ ); therefore, the sexes were combined. The calculated parameters of  $W_T - L_T$  relationship for sexes combined demonstrated a scaling coefficient greater than three ( $b = 3.096$ ) with a determination coefficient equal to 0.99 (Figure 25).

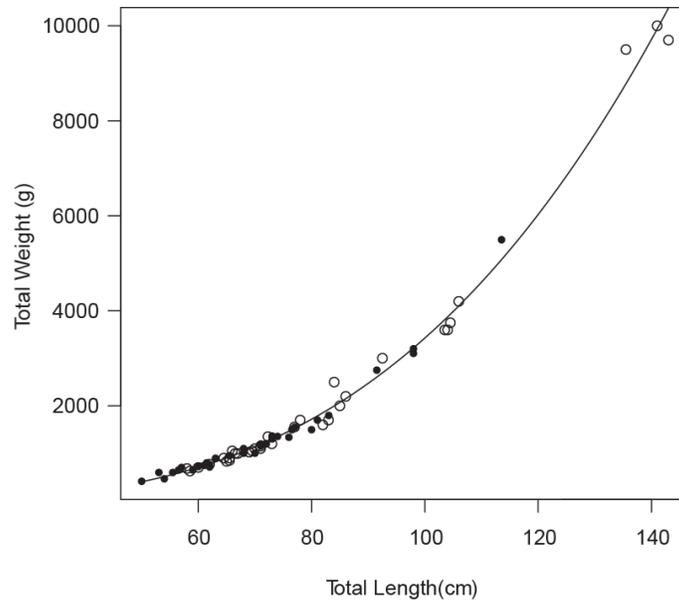


Figure 25: The weight – length relationship of the Common Guitarfish sample during the study

### 3.3. Sexual maturity and biological indices

All maturity stages were encountered among the specimens observed during the study period except the ‘regressing’ stage (stage: 4) for males and the ‘mid pregnancy’ (stage: 3c), ‘regressing’ (stage: 4a) and ‘regenerating’ (stage: 4b) stages for females. The males and females were equally distributed among all the encountered stages except stage 3d which is solely for female maturity classification (Figure 26).

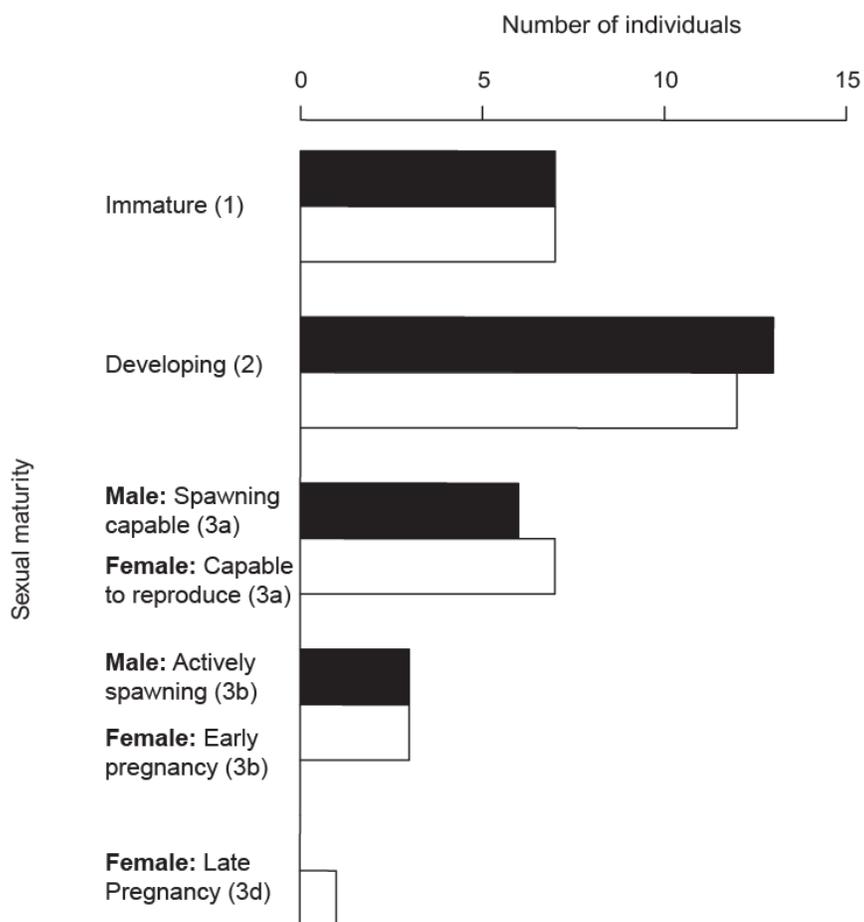


Figure 26: The number of Common Guitarfish individuals according to the maturity stages and sexes (Males: ■ ; Females: □ ) (MEDITS, 2012).

In addition, significant differences were observed between the weights and the lengths of the specimens according to each maturity stage, whether taking the sample as a whole or taking the male or female specimens separately (Total weight of the whole sample according to maturity stage: Kruskal-Wallis test, Kruskal-Wallis = 32.5134, d.f. = 4,  $P < 0.05$ ; males: Kruskal-Wallis test, Kruskal-Wallis = 16.2315, d.f. = 3,  $P < 0.05$ ; females: Kruskal-Wallis test, Kruskal-Wallis = 18.5535, d.f. = 4,  $P < 0.05$ . Total length of whole sample according to maturity stage: Kruskal-Wallis test, Kruskal-Wallis = 31.537, d.f. = 4,  $P < 0.05$ ; males: Kruskal-Wallis test, Kruskal-Wallis = 15.7701, d.f. = 3,  $P < 0.05$ ; females: Kruskal-Wallis test, Kruskal-Wallis = 15.7701, d.f. = 3,  $P < 0.05$ ).

Examination of the male and female maturity stages according to length classes in a logistic regression indicated that the length at 50% maturity ( $L_{50}$ ) was  $78.57 \pm 4.88$  cm for males and  $84.73 \pm 5.81$  cm for females (Figure 27).

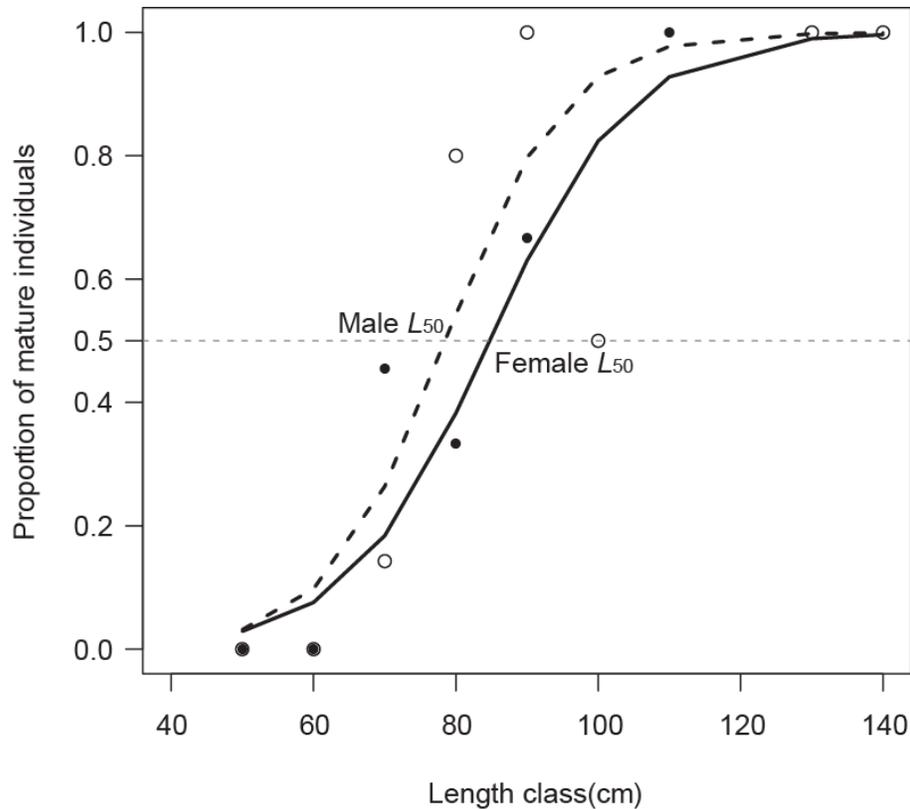


Figure 27: The proportion of mature Common Guitarfish according to length class to estimate the length at 50% maturity ( $L_{50}$ ) in logistic regressions (Logistic curves: Males = - - - - ; females = ———) during the study period for males (●) and females (○).

The weight of the gonads along with clasper length was the indicator of maturity in males. An increase in clasper length (Figure 28a) with respect to total length was observed in males following a linear regression ( $L_C = 0.2304L_T - 8.375$ ). Moreover, the nonlinear relationship between gonad weight and total length (Figure 28b) is given by the following equation  $W_G = 0.00017 L_T^{2.489}$ . No relationship was found between the gonad weight of the females and the total length. The only late pregnant female of  $L_T = 92.5$  cm was caught in December 2013 bearing six embryos of  $W_T$  ranging from 51 to 55.8 g (mean  $W_T = 53.3$  g) and  $L_T$  ranging from 23 to 24 cm (mean  $L_T = 23.6$  cm). Thus, parturition would have taken place at a later date.

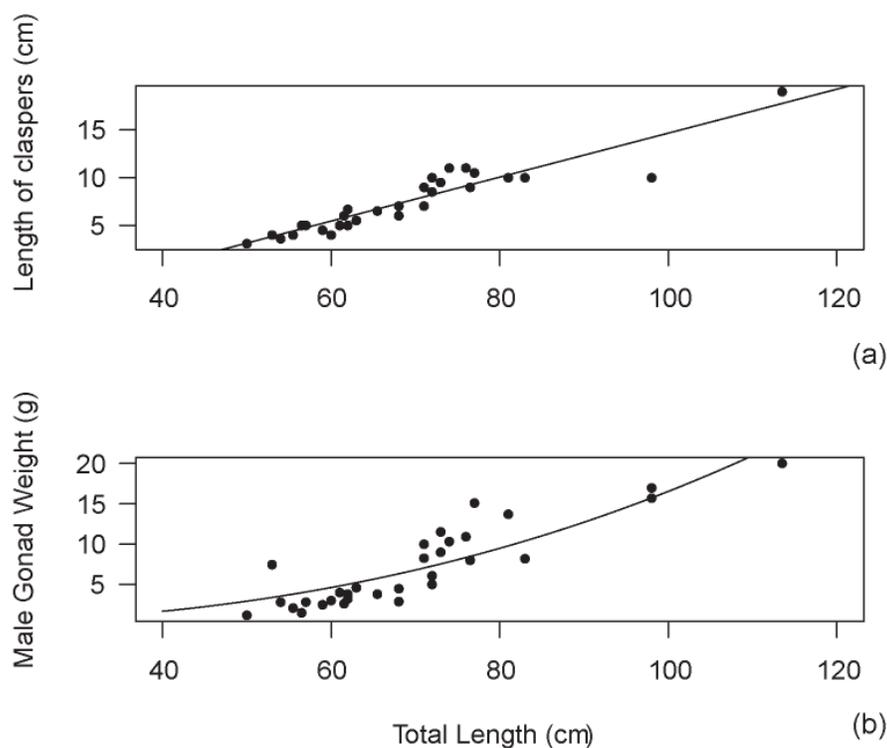


Figure 28: A linear and a nonlinear regression plot showing the relationship between the length of the claspers ((a):  $L_C=0.2304L_T - 8.375$ ) and the weight of the male gonads ((b):  $W_G = 0.00017 L_T^{2.489}$ ) and the total length of the individual Common Guitarfish, respectively.

The  $I_H$  values of the Common Guitarfish specimens peaked in summer (Figure 29a) and the  $I_G$  peaked in autumn (Figure 29b). The  $I_H$  values fluctuated throughout the year with a relative decrease in winter and autumn when the  $I_G$  increased (Figure 29a, b). The condition factor ( $K$ ) showed almost constant values in all seasons and the highest value in autumn with the increase in  $I_G$  (Figure 29c). Finally, there were significant differences between the  $I_H$  according to seasons (Kruskal-Wallis test, Kruskal-Wallis = 17.8115, d.f. = 3,  $P < 0.05$ ), whereas no significant differences were observed in the other biological indices during the same period (For  $I_G$ : Kruskal-Wallis test, Kruskal-Wallis = 1.2335, d.f. = 3,  $P > 0.05$ ; for  $K$ : Kruskal-Wallis test, Kruskal-Wallis = 4.7639, d.f. = 3,  $P > 0.05$ ).

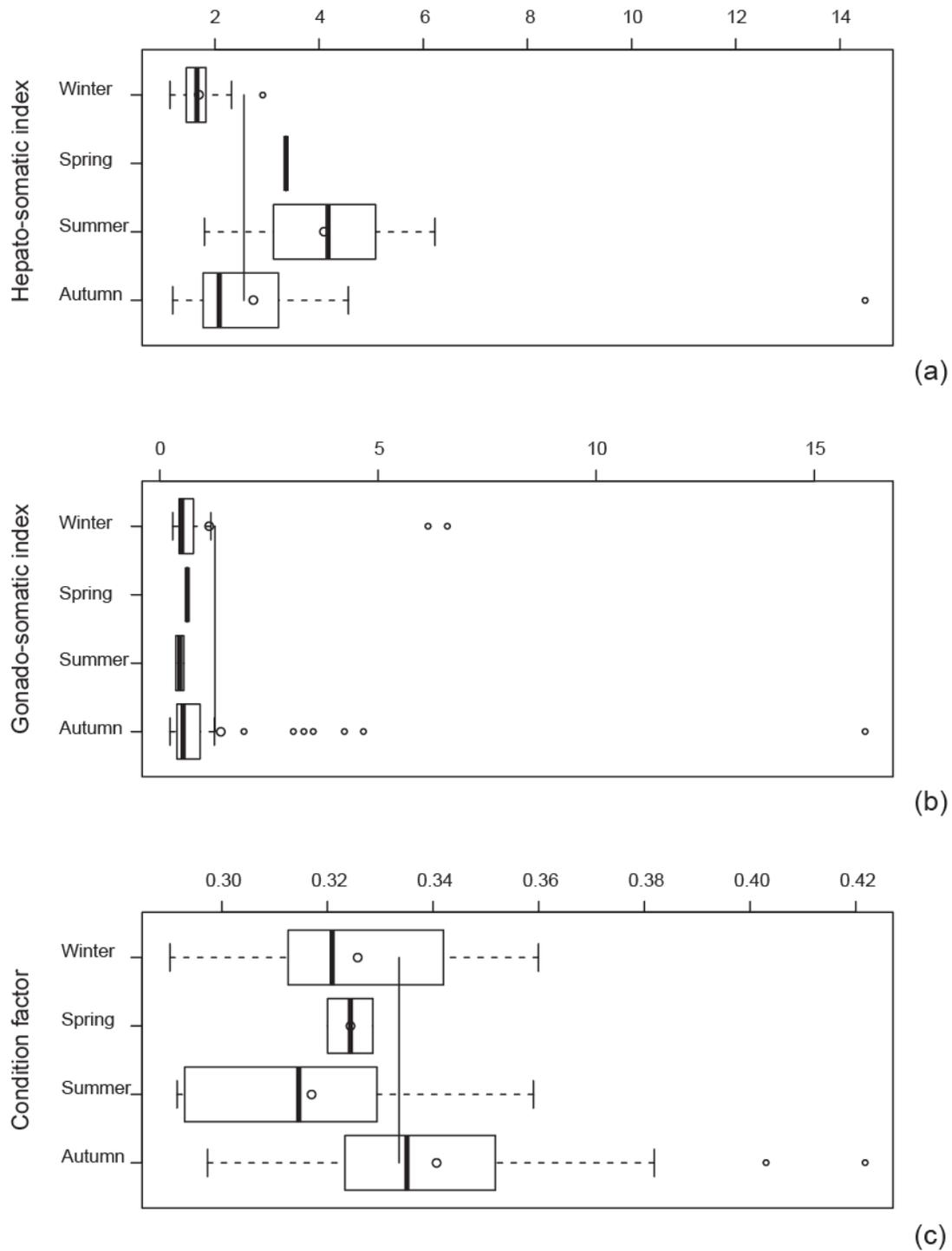


Figure 29: Boxplots representing the hepato-somatic Index (a), gonado-somatic Index (b), and condition factor (c) of the Common Guitarfish specimens according to seasons (during the study period (black line in box: median; line outside box: general mean between seasons; points in box: mean in each season; points outside box: outliers)).

### 3.4. Stomach content analysis

A total of 67 stomachs were examined out of which 56 stomachs were found to be proper for analysis, and 34 (16 males and 18 females) of the 56 stomachs were found to contain identifiable food items. The coefficient of vacuity was estimated to be 39.29% for all the specimens, 44.83%, and 33.33% for male and female specimens respectively. The majority of the full stomachs (61.76%) belonged to individuals having a length less than 80 cm applying to both males (41.38%) and females (33.33%) (Figure 30a, b).

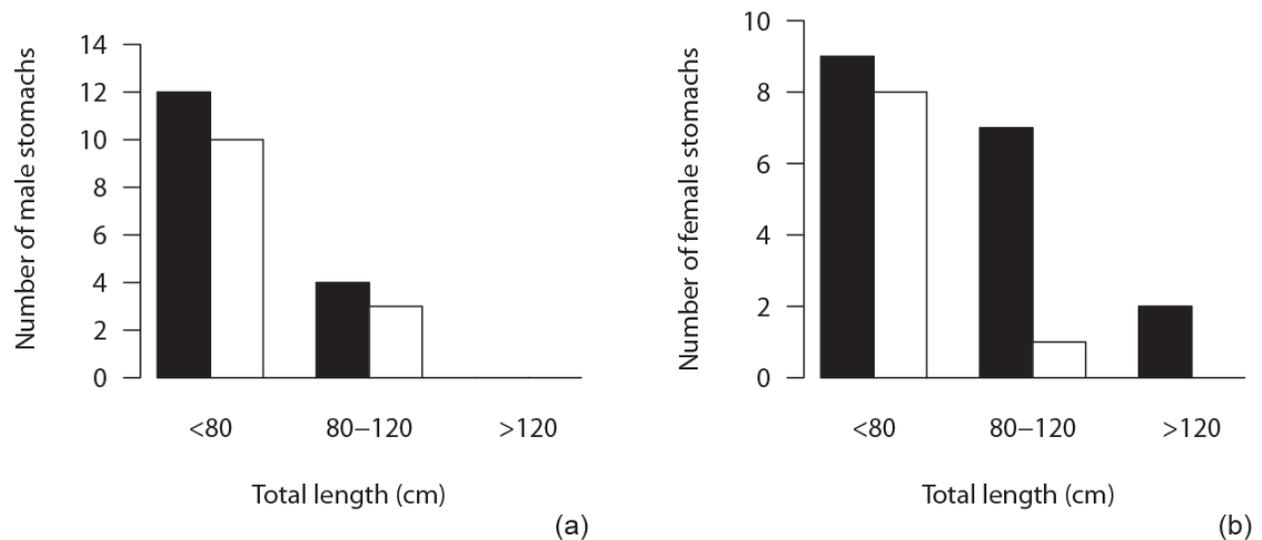


Figure 30: The number of full (■) and empty (□) Common Guitarfish stomachs according to total length for males (a) and females (b).

Out of the 34 stomachs examined, 20 were partially empty (1-25%) and 14 were slightly full (26-50%) according to the five-point scale estimated by the percentage of fullness. The percentage of fullness ( $F_1$ ) ranged between a minimum value of 6.36% for a 73 cm male and a maximum value of 47.27% for a 72 cm male (Figure 31a). The largest female with a full stomach ( $L_T = 143$  cm) had a  $F_1 = 27.16\%$  (Figure 31b). No significant differences were observed between the  $F_1$  of males and females (Wilcoxon test,  $W = 153$ ,  $P > 0.05$ ).

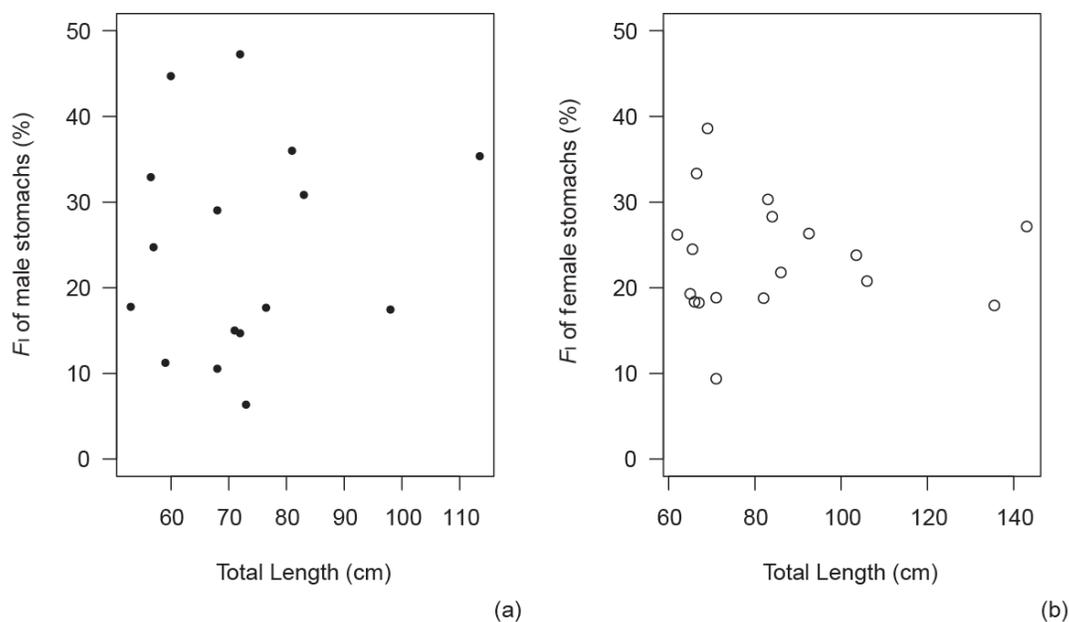


Figure 31: The percentage of fullness ( $F_1$ ) for the full stomachs examined according to total length for the male (a) and female (b) specimens.

The Common Guitarfish was found to prey upon six categories of prey constituted of crustaceans (Penaeidae, Brachyura, Squilladae, and Juvenile Nephropidae), fish (Teleostei) and cephalopods (Octopodidae) in the autumn and winter seasons. Overall, crustaceans were the most abundant prey in the stomachs of the specimens in the autumn (93.46%) and winter (78.23%) seasons. Moreover, the most abundant prey group in both seasons was the Penaeidae group with  $I_{\%RI}$  of 44.2 and 57.01% in the autumn and winter seasons respectively. Juveniles of the Nephropidae family constituted the secondary prey ( $I_{\%RI}=32.89\%$ ) in the autumn season, however, showed to be absent in the winter season, during which the Teleostei group represented the secondary prey with  $I_{\%RI}=21.77\%$ . No items of the Octopodidae family were observed in the winter season after constituting the third prey item ( $I_{\%RI}=4.06\%$ ) in autumn. Brachyurans were considerably found in the stomachs of the specimens in winter ( $I_{\%RI}=20.57\%$ ) but not in autumn ( $I_{\%RI}=2.88\%$ ). This observation was contradicted by the Squilladae family which had an important presence in the stomachs of the specimens in autumn with  $I_{\%RI}=13.49\%$ , however, showing the least importance in winter ( $I_{\%RI}=0.75\%$ ) (Table 19).

Table 19: Variation in the diet of Common Guitarfish in terms of the frequency of occurrence ( $O\%$ ), coefficient of prey numerical abundance ( $N\%$ ), percentage of weight ( $W\%$ ), and percentage of the Index of Relative Importance ( $I\%_{RI}$ ) during the autumn and winter season.

Prey group	Autumn				Winter			
	$O\%$	$N\%$	$W\%$	$I\%_{RI}$	$O\%$	$N\%$	$W\%$	$I\%_{RI}$
<b>Penaeidae</b>	64	33.33	26.20	44.20	66.67	46.67	37.72	57.01
<b>Brachyura</b>	28	6.67	2.19	2.88	33.33	33.33	27.27	20.47
<b>Octopodidae</b>	16	1.78	20.08	4.06	0	0	0	0
<b>Squilladae</b>	32	13.33	23.01	13.49	11.11	2.22	4.45	0.75
<b>Teleostei</b>	24	5.78	3.19	2.50	44.44	17.78	30.56	21.77
<b>Juvenile</b>	44	39.11	25.33	32.89	0	0	0	0
<b>Nephropidae</b>								

Analysis of feeding strategy according to the Costello graphs showed that the Common Guitarfish specimens had a mixed feeding strategy. Shrimps of the Penaeidae family showed to be the most important prey group in the autumn (Figure 32a) and winter seasons (Figure 32b) having the highest  $O\%$  and  $N\%$  values. Juveniles of the Nephropidae family showed to be the secondary important prey group only in autumn (Figure 32a). The least important prey group in both seasons was the Octopodidae family with the lowest  $O\%$  and  $N\%$  values in autumn and null ones in winter. The Teleostei and Brachyura families showed high rarity in autumn but a relatively higher importance in winter, in contrast to the Squilladae family which showed an opposing trend (Figure 32a, b).

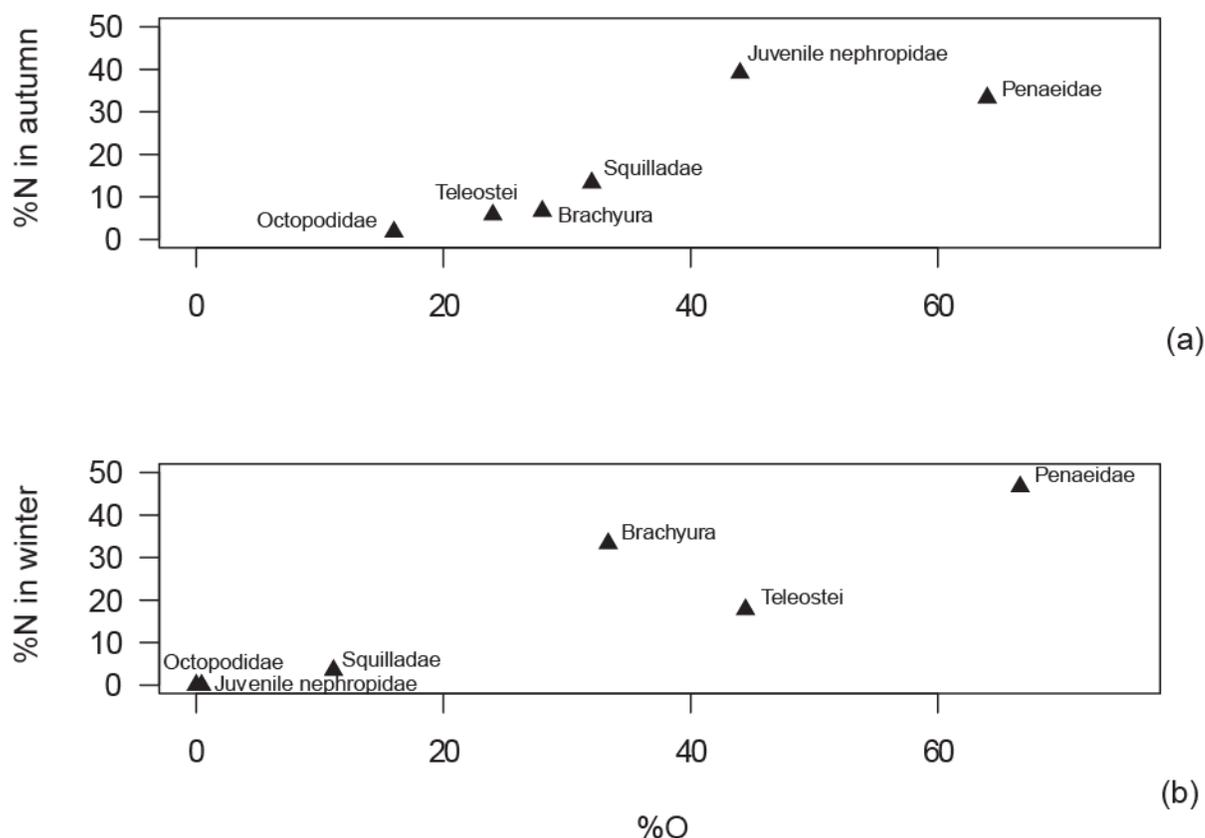


Figure 32: Feeding strategy graphs of the Common Guitarfish specimens in the autumn (a) and winter (b) seasons.

#### 4. Discussion

The majority of the specimens in this study were caught over sandy and muddy bottoms at depths ranging from 15 to 50 m with few individuals at depths greater than 50 and 100 m. These capture depths are similar to those of the same species in Iskenderun Bay, Turkey, as recorded by Cek *et al.* (2009) (depth range: 20 – 100 m) and Ismen *et al.* (2007b) (depth range: 0 – 50 m), and also correlate with Whitehead *et al.* (1984) and Buen (1935) who documented the findings of Common Guitarfish over sandy, muddy, shell and occasionally macro-algal substrates.

In addition, the depth distribution of the Common Guitarfish specimens in the Lebanese waters also correlates with the depth range recorded in Moroccan waters (Sciara *et al.*, 2007) where Common Guitarfish were recorded at depths ranging from 17 to 80 m. The lack of a significant bias in the sex ratio of the examined specimens suggests that there is no sexual segregation by area or depth and/or that there is no sexual selection by the fishing gear. However, the Common

Guitarfish may be segregated by sex, since Ismen *et al.* (2007b) showed a sex ratio of 57% males and 43% females in Iskenderun Bay, and Abdel-Aziz *et al.* (1993) a sex ratio on the same species of 54% females and 46% males in the Alexandria waters. We observe this kind of segregation in other marine species as *Merluccius merluccius* (Piñeiro and Saínza, 2003). Gregarious species better exploit resources when living in groups because it is easy to find and catch prey. However, in case of limited resources, it can become a problem of intra-specific competition. The status of an individual in a population sometimes induces a spatial and/or temporal segregation between size and sex. Therefore, due to the probable availability of resources for the Common Guitarfish in our sample, no segregation between sexes was observed.

The maximum total length in this study (143 cm) corresponds to that observed in Iskenderun Bay (Basusta *et al.*, 2007; Basusta *et al.*, 2008) belonging to female specimens; however, smaller male and female specimens were observed in that region. In addition, a larger  $L_T$  of Common Guitarfish was observed in this study than that observed in Tunisian waters (McEachran and Capapé, 1984b; Bauchot *et al.*, 1987) where the  $L_T$  was noted to reach 100 cm, rarely larger, and usually 80 cm; nevertheless, this was contradicted by larger specimens in the Gabès Gulf (Capapé *et al.*, 1996) where the maximum reported sizes were larger with 140 cm  $L_T$  for males and 162 cm  $L_T$  for females. Abdel-Aziz *et al.* (1993) also noted the largest female and male specimens of Common Guitarfish in the Alexandria waters in Egypt with a  $L_T$  of 181 cm and 172 cm respectively. Taking into consideration the means of total weight and total length in both male and female specimens, the females showed to be both longer and heavier than the males; this observation was noted by Casey *et al.* (1985), Ismen (2003), Skomal and Natanson (2003) and Yamaguchi *et al.* (2005), supporting that female elasmobranchs grow longer than males.

The length-weight relationship obtained in this study correlates with the findings in Iskenderun Bay (Basusta *et al.*, 2008; Basusta *et al.*, 2012a) where the weight of the individual specimens showed to grow at a faster rate than its length. Nevertheless, these results contradict with those observed by Ismen *et al.* (2007b) in the same region where males displayed almost isometric growth ( $b=2.98$ ) and females displayed negative allometric growth ( $b=2.89$ ). The reason of this difference may be attributed to sample sizes, different habitat and physiological status.

This variation in size and growth can be due to overfishing in the region. Indeed, one of the effects of overfishing is the elimination of the largest and oldest individuals from a population or

stock and the stimulation of early maturation. Law (1991) confirmed that by stating that a large change in mortality imposed by fishing generated a big selection pressure for early maturation irrespective of any change in size-at-age. For instance, such a pattern was observed with the Northeast Arctic cod that underwent early induced maturation due to overfishing (Lee and Safina, 1995).

Throughout the year, specimens with various maturity stages were observed in the Lebanese waters suggesting that the Common Guitarfish presents a partially defined seasonal reproduction according to the reproduction strategies found by Wourms (1977) and Hamlett and Koob (1999). A similar pattern was observed by Cek *et al.* (2009) in Iskenderun Bay. Moreover, female viviparous elasmobranchs display larger sizes at maturity than males (Capapé *et al.*, 2006; Consalvo *et al.*, 2007; Pereyra *et al.*, 2008; Pérez-Jiménez and Sosa-Nishizaki, 2008; Blanco-Parra *et al.*, 2009). This was supported in this study where significant differences were observed between male and female sizes according to sexual maturity and mature females were found to be both larger and heavier than males.

Concerning the estimation of  $L_{50}$ , values were found to vary among different regions in the Mediterranean Sea. In the Tunisian coasts (south central Mediterranean), male and female Common Guitarfish were found to mature at 75 cm and 85 cm respectively (Capapé and Zaouali, 1981; Capapé *et al.*, 1997), whereas in Iskenderun Bay (northeastern Mediterranean) the  $L_{50}$  was 70 cm for males and 80 cm for females in the study of Demirhan *et al.* (2010) and 60 cm for males and 69 cm for females in that of Ismen *et al.* (2007b). In addition, in the Egyptian Alexandria waters (southeastern Mediterranean), the lengths at which 50% of the individuals were mature were 70 cm and 87 cm for males and females respectively (Abdel-Aziz *et al.*, 1993). In this study,  $L_{50}$  was estimated to be around 85 cm for females and 78 cm for males which falls in the range of what was observed in the Tunisian coasts for both males and females and in the Egyptian Alexandria coasts for females only. This variation seems to be attributed to the lack of a wide ranged sample consisting of individuals in all size classes or to the difference in values may also be due to the different conditions in every region influencing the physiological characteristics of the population in that region, which can consequently affect its growth and development.

Parturition in the Lebanese waters might have occurred later than December as a single gravid female was caught during the latter month bearing fully formed embryos whose average  $W_T$  and  $L_T$  were in agreement to those observed at the end of parturition by Ismen *et al.* (2007b). The above results do not correlate with those observed in Iskenderun Bay, where the  $I_G$  values peaked in May for females and in November for males indicating that spawning occurred in spring (Demirhan *et al.*, 2010). Furthermore, differences were also observed in the Egyptian Alexandria waters, where mating was found to occur during summer and parturition later in August (Abdel-Aziz *et al.*, 1993). The variations in reproduction of Common Guitarfish may be attributed to the conditions in the study area, the speed of development, and the knowledge that both sexes seem to be reproductively active at different times of the year, as clearly documented by Cek *et al.* (2009).

The storage of nutrients in the liver has been reported for several elasmobranch species (e.g. Springer and Gold (1989)). An elevation in  $I_H$  prior to reproduction is therefore common, since the nutrients in the liver might be utilized during maturation of the ovary. A decline in  $I_H$  was observed along with the  $I_G$  increase indicating that Common Guitarfish undergo significant reserve metabolism to acquire energy for reproductive development as clearly documented in Iskenderun Bay (Demirhan *et al.*, 2010). Moreover, this seasonal variation in  $I_H$  agrees with what was observed in other ovoviviparous cartilaginous fish species (Maruska *et al.*, 1996; Demirhan and Seyhan, 2006). The constant condition factor throughout the study period was indicative of an evident wellness among the Common Guitarfish population and could indicate a lack of any physiological or environmental factor affecting the stock.

Analysis of the stomach contents showed more or less considerable food availability in the Lebanese waters; this was supported by a low coefficient of vacuity considering all specimens and the fact that shallow waters in the region are known to be oligotrophic (Abboud Abi Saab and Kassab, 1997; Ignatiades, 2005). The diet of the Common Guitarfish mainly consisted of benthic invertebrates and fishes with preference for shrimps of the Penaeidae family. These results are in agreement with what was observed by Ismen *et al.* (2007b), Abdel-Aziz *et al.* (1993), and Bauchot *et al.* (1987). Juveniles of the Nephropidae family presented the secondary prey only in autumn, and the Teleostei and Brachyuran families showed an increase in

importance in winter. This seasonal shift in diet seems to be attributed to the availability of each prey item in the study area.

Finally, this study draws attention to the Common Guitarfish population in Lebanon, as rare are the studies that are performed about this species in the Levantine basin. This species is majorly exploited by the longline fishery for its commercial significance due to its low cost especially in the Northern areas of Lebanon; thus, management measures should be implemented to prevent this vast exploitation of this elasmobranch group. Laws should be applied to limit the uncontrollable fishing of this elasmobranch. The data presented here will be useful for the ongoing assessment of populations, fishery stock assessments, ecological risk assessments, and species extinction risk assessments.

### **Acknowledgements**

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# Chapter VI

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**Population biology of the Gulper Shark  
*Centrophorus granulosus* (Bloch & Schneider  
1801) in the Lebanese marine waters, eastern  
Mediterranean**

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# **Biologie de la population du squale chagrin *Centrophorus granulosus* (Bloch & Schneider 1801) dans les eaux marines libanaises, Méditerranée orientale**

## **Résumé**

Le chapitre VI porte sur la biologie et l'écologie de la population du squale chagrin *Centrophorus granulosus* (Bloch et Schneider 1801) dans les eaux côtières libanaises. Bien que fortement exploitée en tant que prise accessoire, aucune étude n'a été menée sur cette espèce d'élaémobranches dans ce domaine. Un total de 38 individus a été recueilli à partir des eaux marines côtières libanaises au moyen de palangres de fond et de trémails de maillages différents, à des profondeurs allant de 115 à 600 m entre mai 2013 et février 2014. La longueur totale de l'échantillon variait entre 45 et 94 cm avec une moyenne de  $80,64 \pm 9,97$  cm. La majorité des mâles et des femelles occupait des classes de taille dont la longueur allait de 70 cm à 80 cm au total, respectivement. Le poids total des échantillons variait de 870 à 6700 g avec une valeur moyenne de  $1312,58 \pm 3,791$  g. Le sexe-ratio n'était pas significativement différent de 1:1 avec 20 mâles et 18 femelles. Une ségrégation sexuelle bathymétrique a été observée pour cette espèce. La Capture par Unité d'Effort (CPUE) a été utilisée comme un indice d'abondance relative pour détecter la distribution spatiale. La relation longueur-poids, l'indice gonado-somatique, l'indice hépato-somatique, et le facteur de condition des squales chagrins dans la zone d'étude ont également été présentés.

**Mots-clés:** Centrophoridae; poissons cartilagineux; distribution; surexploitation; reproduction; Liban.

**Chapter VI: Population biology of the Gulper Shark *Centrophorus granulosus*  
(Bloch & Schneider 1801) in the Lebanese marine waters, eastern  
Mediterranean**

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**Abstract**

This study focuses on the population biology of the Gulper Shark *Centrophorus granulosus* (Bloch and Schneider 1801) in the Lebanese coastal waters. Although heavily exploited as bycatch, no study has been performed on this elasmobranch species in this area. A total of 38 individuals were collected from the coastal Lebanese marine waters by bottom long liners and trammel nets of different meshes at depths ranging from 115 to 600 m between May 2013 and February 2014. The total length of the sample varied between 45 and 94 cm with an average of  $80.64 \pm 9.97$  cm. The majority of males and females occupied size classes ranging from 70 cm to 80 cm total length, respectively. The total weight of the specimens ranged from 870 to 6700 g with an average value of  $3791 \pm 1312.58$  g. The sex ratio was not significantly different from 1:1 with 20 males and 18 females. A bathymetric sexual segregation of this species was observed. Catch per Unit Effort data (CPUE) was used as a relative abundance index to detect spatial distribution. The length-weight relationship, gonado-somatic index, hepato-somatic index, and condition factor of the Gulper Sharks in the study area were also represented.

**Keywords:** Centrophoridae; cartilaginous fish; distribution; overexploitation; reproduction; Lebanon.

## 1. Introduction

The Mediterranean Sea is considered as one of the seven Chondrichthyan biodiversity hotspots and one of the three main hotspots where the biodiversity of sharks and rays was seriously threatened (Dulvy *et al.*, 2014). Among the 80 species of cartilaginous fish known in the Mediterranean (45 sharks, 34 batoids, and one chimaera), 71 were assessed in the frame of the International Union for Conservation of Nature (IUCN) red list and more than 40% (34 species) are threatened and face an elevated risk of extinction (Cavanagh and Gibson, 2007). The main causes of these threats are linked to anthropogenic pressures which degrade marine ecosystems such as habitat degradation, pollution, littoral construction, tourism and overexploitation (Cuttelod *et al.*, 2008). This last factor particularly impacts the elasmobranch populations and fishing activity exerted on these populations is responsible for the reduction of their abundance (Dulvy *et al.*, 2000). This decline in Mediterranean countries is a notable consequence of increased fishing effort in terms of engine power and increased capacity of fishing equipment for both artisanal and industrial fisheries. Elasmobranchs can be caught by various fishing methods although bottom trawling is considered responsible for a large amount of their bycatches and discards throughout the world (Bonfil, 1997).

The Gulper Shark, *Centrophorus granulosus* (Bloch and Schneider 1801) is an elasmobranch of the Centrophoridae family and is classified as Vulnerable by the Red List of the International Union for the Conservation of Nature (Guallart *et al.*, 2006) on the basis of quite an important rate of decline in populations mainly due to overexploitation. It is an ovoviviparous species with the lowest described fecundity and a pregnancy with one embryo lasting for about 2 years (Ranzi, 1932; Tortonese, 1956; Capapé, 1985; Guallart, 1998). This increases the concern of its Vulnerable status as most elasmobranchs have a slow growth rate, late maturity and low fecundity compared to bony fish. This concern led to a low reproductive potential and low capacity for population increase (Stevens *et al.*, 2000).

This species is mainly distributed in eastern, western and central Atlantic, Indian Ocean, western Pacific and Western Australia (Compagno, 1984a; Last and Stevens, 1994; Compagno and Niem, 1998). It is also not recorded in the eastern Pacific (White *et al.*, 2013). In the Mediterranean Sea, it is common in the deep waters of the entire western basin; but it is less

common in the eastern basin (Capapé, 1985; Capapé *et al.*, 2003; Politou *et al.*, 2003; Sion *et al.*, 2004). It is a deep water, usually demersal or benthopelagic species, inhabiting the outer continental shelf with a preference for the upper continental slopes at depths ranging from 100 to 1490 m with most records between 300 to 800 m (Compagno, 1984a; Gilat and Gelman, 1984; Guallart, 1998; Baino *et al.*, 2001).

Gulper Sharks are exploited through bycatch by trammel nets, long liners, gillnets and trawlers (Costantini *et al.*, 2000; Morey *et al.*, 2006), and the fact that they are deep-water sharks with late maturity, slow growth and low fecundity makes them susceptible to overexploitation (Compagno, 1984a; Stevens *et al.*, 2000). When caught, these sharks can be discarded or used by bycatch fisheries, marketed as smoked and dried salted for human consumption or processed into fish meals and a source of liver oil for squalene (Compagno, 1984a), a chemopreventive substance that is thought to prevent cancer (Smith, 2000). Drastic Gulper Shark population decline was observed in the northeastern Atlantic, off the coast of Portugal, due to target long liners between 1990 and 2004 (Gibson *et al.*, 2008).

A few studies on the biology of these deep water sharks were performed in the eastern Mediterranean (Golani and Pisanty, 2000; Megalofonou and Chatzisprou, 2006) and no studies were implemented in the coastal waters of Lebanon, the study area. Some studies in the Mediterranean dealt with the analysis of trace metals (Hornung *et al.*, 1993) and polychlorinated biphenyls (Storelli and Marcotrigiano, 2001) in some organs of Gulper Sharks. Other Mediterranean studies evaluated the reproduction of this species proving its lecithotrophic nature (Guallart and Vicent, 2001).

The Lebanese fishery is artisanal and traditional, where the most common gear used are trammels, longlines, 'roundhaul' nets and beach seines. Trawling is legally forbidden although fishing nets with illegal mesh sizes can be vastly bought from the black market (Fowler, 2005). The majority of the fish caught are bony fish (Majdalani, 2004) and cartilaginous fish landings are particularly low (Fowler, 2005). However, Gulper Sharks are often observed in Lebanese fish markets as bycatch species that are not discarded and sold as fish filets. It presents a quite low commercial value, ranging from 3 to 5 US dollars per one kilogram. The lack of management measures (and in particular any specific to elasmobranchs) and commercial fishing has created

the need to manage the stocks of such elasmobranch species in this region. Due to the vulnerability of this species, immediate actions should be implemented for the management and reduction of its fishing even if the Lebanese artisanal fishing fleet, with a number of 1460 licensed vessels in 2011 (Pinello and Dimech, 2013), can be considered small compared to major commercial fisheries in the Mediterranean.

Biological information needed for stock assessment is lacking for many of the Eastern Mediterranean cartilaginous species, including minimum, maximum, average sizes, as well as length-to-weight relationships. Nonetheless, these data are significant for comprehending growth rate, age structure, and other aspects of population dynamics. Size conversions also have a practical value in fisheries. One measure currently in practice is the establishment of minimum size limits and usually a minimum weight. Since sizes must be estimated at sea, means for converting lengths to weights are essential to fishermen. This study being the first for the Lebanese coastal waters, essentially reflects some biological and ecological aspects of the Gulper Shark population in the Lebanese marine waters in order to contribute to a better knowledge of this population. It aims to give insightson spatial, seasonal and depth distribution, reproduction and growth of this species. Length and weight data, sex ratio, length-weight relationships, gonado-somatic and hepato-somatic indices and condition factor are presented and compared to available data from other areas. This study provides a first evaluation of the population health condition and aims, at longer term, to stimulate the protection of such a vulnerable species.

## 2. Materials and Methods

### 2.1. Sampling and study area

A total of 38 Gulper Sharks were collected along the coast of Lebanon between May 2013 and February 2014 at depths ranging from 115 to 600 m. Individuals collected came from two sources : firstly, through catches of the major Lebanese fisheries using only long liners (16 collected individuals) and secondly, through the catches of the scientific survey under the PESCA-Libano program that was performed in the framework of the CANA program - “Establishing Monitoring and Sustainable Development of the Lebanese Sea” - of the Lebanese National Council for Scientific Research (CNRS-L) during the same time period(22 collected individuals). In the latter survey, gillnets and trammel nets (noted T) with different meshes (26 and 30 mm, noted T4 and T6 respectively) along with long liners (noted L) were lowered at different specified hauls with predetermined depths to evaluate the potentiality of the marine coastal resources in order to support the Lebanese Government in strengthening the management of the marine resources. The study area with the major Lebanese ports and the Gulper Shark catches in the PESCA-Libano scientific survey are presented in Figure 33 according to specific coordinates. The exact positions of the fishery catches were not available because the majority of Lebanese fishermen have no Global Positioning System (GPS) instruments; however, the depth is provided. The specimens were identified according to the two field identification guides of Bariche (2012) and Golani *et al.* (2006). They were preserved in ice and later frozen at -20°C to be eventually treated in the laboratories of the Lebanese National Council for Scientific Research-National Centre for Marine Sciences in Batroun.

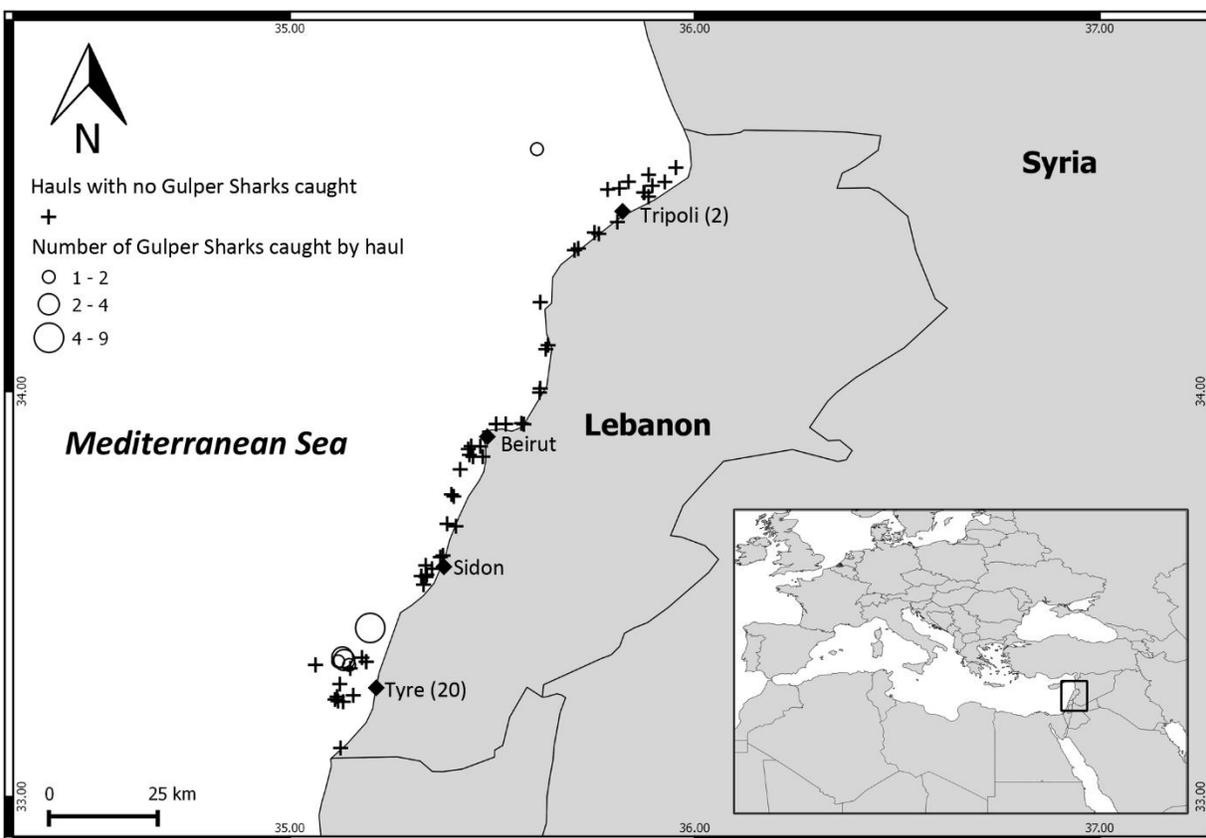


Figure 33: Location of the major ports and of Gulper Shark catches in the PESCA-Libanosurvey along the Lebanese coast (size of the circles is proportional to the number of individuals caught, '+' represents the hauls where no Gulper Sharks were caught, and total number of Gulper Sharks caught is in brackets next to the name of the port)

## 2.2. Morphometric and biological measurements

Upon treatment, the specimens were observed for external damages and sexed macroscopically by the examination of the male claspers. The external length of the clasper ( $L_C$ ) in males was measured from the tip of the clasper to the base of the pelvic fin all using a calliper to the nearest millimetre (mm). In the rest of the paper, all lengths and weights were measured to the nearest centimetre (cm) and nearest gram (g), respectively, using an electronic balance and a measuring tape.

Morphometric measurements were performed for each Gulper Shark specimen. The total weight ( $W_T$ ), total length ( $L_T$ ), fork length ( $L_F$ ) and standard length ( $L_S$ ) were measured prior to

dissection. The liver and gonads were removed along with the expanded uteri in the case of a gravid female. The digestive tube was also removed and the eviscerated weight ( $W_E$ ) was noted.

Hepato-somatic index ( $I_H$ ) gives useful indication of energy reserves because the liver is an important energy storage in fish (Halton *et al.*, 2001). Therefore, the weight of the liver ( $W_L$ ) was measured and used for computation of  $I_H$  (Bulow *et al.*, 1978; Adams and McLean, 1985) where:

$$I_H = W_L \times W_T^{-1} \times 100$$

Gonado-somatic index ( $I_G$ ) allows to investigate the changes in testis and ovaries weight in relation to the weight of fish. Thus, weight of the gonads ( $W_G$ ) including weight of testis in males, and oviductal glands, accessory glands, ovary and oviducts in females (Gristina *et al.*, 2006) were also measured for computation of  $I_G$  (Bougis, 1952) where:

$$I_G = W_G \times W_T^{-1} \times 100$$

Sexual maturity was determined using the Instruction Manual for the MEDITS Survey – Version 6 (MEDITS, 2012), where the ovoviviparous elasmobranch females were classified among 8 maturity stages (1: Immature; 2: Developing; 3a: Capable to reproduce; 3b: Early pregnancy; 3c: Mid pregnancy; 3d: Late pregnancy; 4a: Regressing; 4b: Regenerating), and the males among five maturity stages (1: Immature; 2: Developing; 3a: Spawning capable; 3b: Actively spawning; 4: Regressing).

Finally, the condition factor ( $K$ ) (Fulton, 1904) was also computed using total weight ( $W_T$ ) and total length ( $L_T$ ), where:

$$K = W_T \times L_T^{-3} \times 100$$

The index is commonly used to compare the ‘condition’, ‘fatness’, or ‘well-being’ of fish (Tesch, 1968), based on the assumption that heavier fish of a given length are in better condition (Froese, 2006),

### 2.3. Catch per unit effort

During the PESCA-LIBANO survey, long liners of size 5 hooks and trammel nets of meshes 22, 24, 26, 28, and 30 mm were lowered at specific hauls with predetermined coordinates and depths. Catch per unit effort expressed in kilogram ( $CPUE_{kg}$ ) for the Gulper Shark sample caught during the survey (22 individuals) was calculated according to the following:

$CPUE_{kg}$  according to meshed gear equals to the sum of total weights of Gulper Sharks caught in specific meshed gear per total number of Gulper Sharks caught in the same meshed gear considering the specific meshed gear was lowered once with the same effort duration providing an effort of one.

The same method applies to the long liner catches.  $CPUE_{kg}$  is commonly used in fisheries science as a relative abundance index for each characteristic area at specific times of the year (seasons) or each specific gear.

### 2.4. Regressions and statistical analyses

The statistical software 'R project' (R Development Core Team, 2014) was used for all regressions and statistical analyses, and Quantum Geographic Information System (qGIS) software (QGIS Development Team, 2012) was used for the maps.

The total length and total weight were used to produce a length-weight relationship in a nonlinear power regression ( $W_T = aL_T^b$ ) (LeCren, 1951) where 'a' and 'b' are the parameters to estimate using the *nls* function. The coefficient of determination ( $r^2$ ) was used to evaluate the quality of the model. Nonlinear regressions were used to represent any regression of weight on length because any weights will scale to the cubic power of length (Froese, 2006). In addition, statistical comparison of weight-length relationships between sexes was performed by applying an ANCOVA test using the *anova* function. A Shapiro-Wilk normality test was used to test for the normality of the sample using the *shapiro.test* function, and the Mann-Whitney U test was used to test for differences in length and weight between males and females using the *wilcox.test* function. A Mann-Whitney U test was also used to examine the mean differences between total length and total weight according to type of gear used. Moreover, a Kruskal-Wallis test was used to examine the differences between total length, total weight and gonado-somatic index

according to sexual maturity and between the biological indices ( $I_G$ ,  $I_H$  and  $K$ ) according to season using the *kruskal.test* function. A post-hoc Nemenyi test was used for pairwise multiple comparisons of the ranked data after significant results from the Kruskal-Wallis tests using the *posthoc.kruskal.nemenyi.test* function of the PMCMR package. The sex ratio was calculated for the whole sample and compared to the 1:1 proportion using a Chi-square test (Zar, 2010) using the *chisq.test* function. A Chi-square test was also used to examine the relationships between sex and depth and between maturity stage and depth. The *anova.2way.unbalanced* function (Anderson and Legendre, 1999; Legendre and Anderson, 1999) was used to perform a two-way unbalanced ANOVA on the total weights according to several factors. Two factor modalities were used for region (north; south), season (cold: spring and winter; hot: summer and autumn), depth ([0,400[; [400,600]), and sexual maturity (mature; immature) in the latter analysis. Finally, a Principal Component Analysis (PCA) was implemented using the FactoMineR package and the *PCAmix* function of the PCAmixdata package. PCA provides insight into the underlying structure of a large data by synthesizing the relationships between variables. Individuals and variables are projected on principal axes generated by new variables termed principal components, which are linear combinations (LC) of the initial variables. Principal axes and principal components are ordered according to their decreasing contribution to the variance of the data set. Hence, the first axis is the one along which the set of individuals are the most scattered, i.e. they are best discriminated.

PCA was implemented on the following numerical variables :  $L_C$ ,  $W_T$ ,  $L_T$ ,  $L_F$ ,  $L_S$ ,  $W_E$ ,  $I_H$ ,  $W_L$ ,  $I_G$ ,  $W_G$ ,  $K$ ; and the 4 categorical variables (Season, Haul, Sexual maturity and Depth) where included in the analysis as additional variables with the following modalities : the 8 and 5 modalities of sexual maturity for females and males respectively; 4 modalities of seasons (SPR: spring; SUM: summer; WIN: winter; AUT: autumn); 2 modalities of gears (L: long liners; T: trammel nets) and 3 modalities of depth ([0-200[, [200-400[ and [400-600]). Results are presented on the first two principal components representing 48.55% of the total variance.

### 3. Results

#### 3.1. Morphometric measurements and depth distribution

A total of 38 individuals (18 females and 20 males) of Gulper Sharks ranging from 45 to 94 cm in  $L_T$  (mean  $L_T \pm SD = 80.64 \pm 9.97$  cm,  $N=38$ ) and from 870 to 6700 g in  $W_T$  (mean  $W_T \pm SD = 3791 \pm 1312.58$  g,  $N=38$ ) were studied (Table 20). Moreover, significant differences were observed in the total length and total weight distributions between male and female individuals ( $L_T$ : Mann-Whitney U test,  $U=1$ ,  $N_{Male1}=20$ ,  $N_{Female2}=18$ ,  $P<0.02$ ;  $W_T$ : Mann-Whitney U test,  $U=0.5$ ,  $N_{Male1}=20$ ,  $N_{Female2}=18$ ,  $P<0.02$ ).

Table 20: The mean, minimum (min) and maximum (max) total lengths and weights of females and males of the Gulper Shark sample (S.D.: Standard deviation)

		Total length (cm)			Total weight (g)		
	Number of individuals	Mean and S.D.	Min	Max	Mean and S.D.	Min	Max
<b>Females</b>	18	88.08 ± 3.11	81	94	4997 ± 631.17	3400	6200
<b>Males</b>	20	73.95 ± 9.24	45	83	2706 ± 616.84	870	3400

The sampled individuals were caught at depths ranging from 115 to 600 m. All male individuals were observed at depths greater than 400 m, whereas females were observed throughout the above mentioned range. Moreover, the majority of female individuals (61%) was observed at depth class of 200 – 300 m and that of male individuals (47%) at depth class of 500 – 600 m; females were also observed at depths ranging from 500 to 600 m and no individuals were observed at depth class of 300 – 400 m (Figure 34).

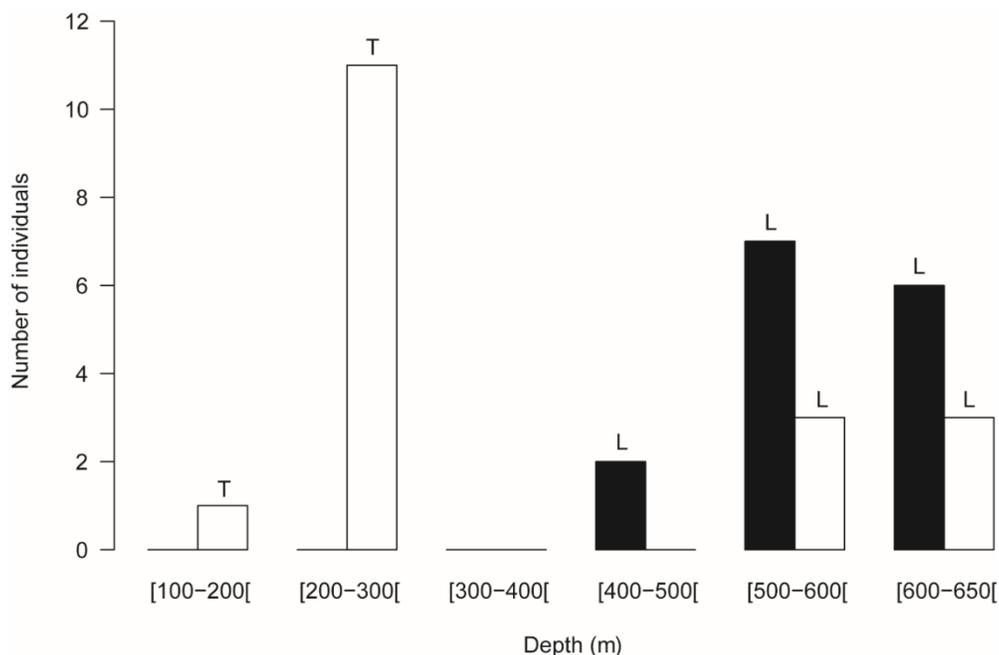


Figure 34: Bar plot representing the number of Gulper Sharks caught by sex (Females: white; Males: black) at various depth classes during the study period by specific gear (T: trammel nets; L: long liners).

Significant differences were observed between the male and female distributions according to depth (Chi-square test,  $X^2_{25}=16.87$ ,  $P=0.0048$ ); however, no significant differences were observed between mature and immature individuals according to depth (Chi-square test,  $X^2_{25}=10.53$ ,  $P=0.0616$ ). In addition, significant differences in weight distributions were observed according to depth (Kruskal-Wallis test,  $H_{22}=12.99$ ,  $P=0.0015$ ), with significant differences between the depth classes [200-400[ and [400-600[ (Nemenyi test,  $P<0.05$ ).

### 3.2. Spatial distribution and gear

Twenty-two individuals of the Gulper Shark sample were caught using long liners and trammel nets of 26 and 30 mm meshes in the PESCA-Libano survey. The  $CPUE_{kg}$  for the survey catches displayed the highest catches using trammel nets of the two meshes in the north and south with  $CPUE_{kg}$  ranging from 4.9 to 5.45 kg per unit effort at depths ranging from 120 to 200 m during the spring and summer seasons. Relatively lower  $CPUE_{kg}$  were observed in the south for longliner catches at depths ranging from 450 to 600 m in spring (Figure 35).

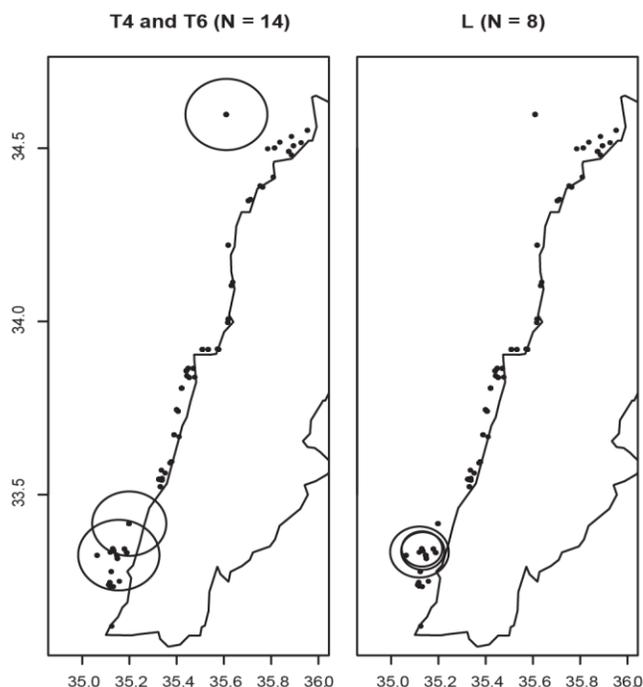


Figure 35: Spatial distribution of the  $CPUE_{kg}$  of the Gulper Shark sample caught in the PESCA-Libano survey using trammel nets of 26 (T4) and 30 mm (T6) meshes and long liners (L) at specific hauls along the Lebanese coast ('N' is the number of Gulper Sharks caught by the specified gear and the black dots represent all the hauls lowered during the survey and where no Gulper Sharks were caught)

In addition, the larger individuals of Gulper Sharks in total length and total weight (Figure 36) were caught by trammel nets than long liners, and significant differences were observed between the total lengths and weights according to the type of gear used ( $L_T$ : Mann-Whitney U test,  $U=27.5, N_{Longline1}=26, N_{Trammel\ Net2}=12, P<0.02$ ;  $W_T$ : Mann-Whitney U test,  $U=30.5, N_{Longline1}=26, N_{Trammel\ Net2}=12, P<0.02$ ). However, a wider size range was observed to be caught when using long liners (Figure 36). Moreover, a significant difference in terms of number of individuals caught by sex was also observed between males and females according to gear used (Chi-square test,  $X^2=16.52, P=4.804 \times 10^{-05}$ ). All males were caught using long liners and the majority of females were caught using trammel nets (Figure 34).

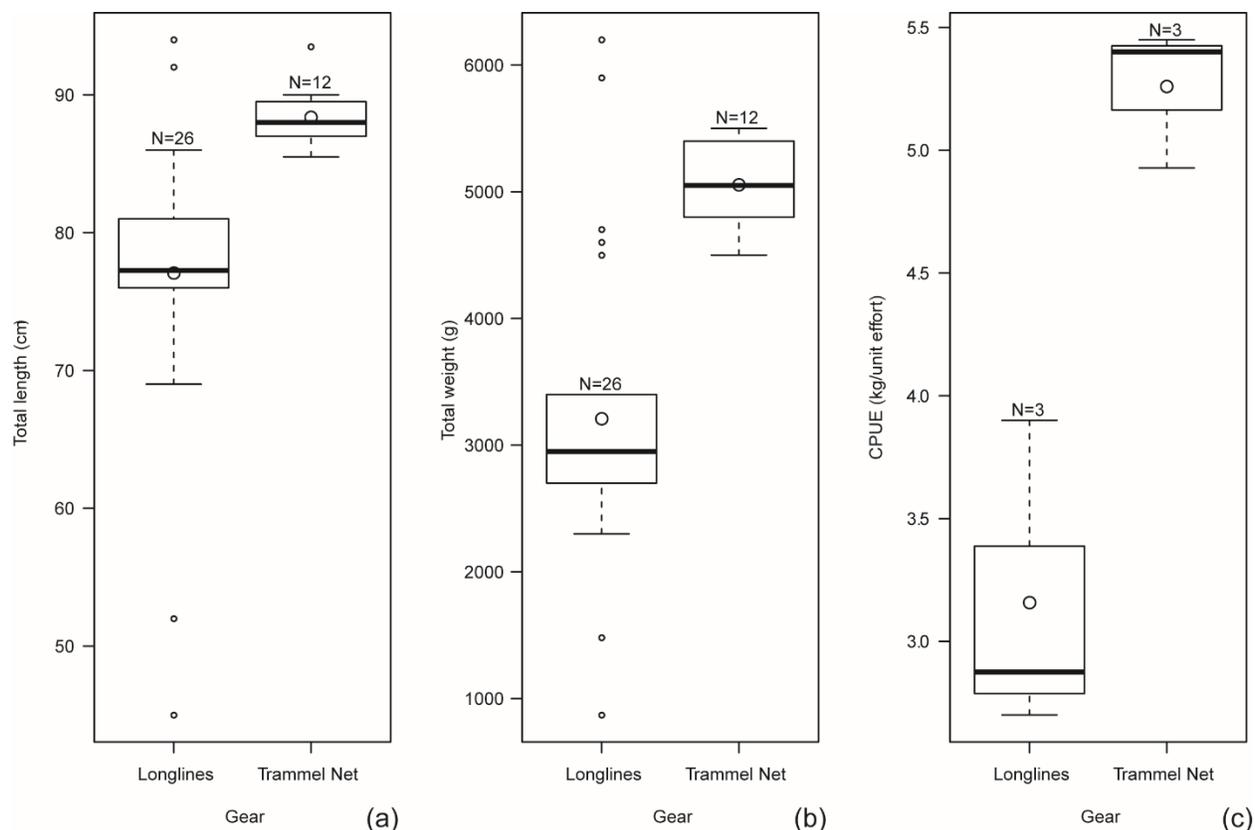


Figure 36: Boxplots of the total length (a), total weight (b), and  $CPUE_{kg}$  (in  $kg \text{ unit effort}^{-1}$  in the survey) of the Gulper Shark individuals caught according to the gear used during the study period (black line in box: median; small points outside box: outliers; large points in box: mean for each type of gear; ‘N’ is the number of Gulper Sharks in the sample)

### 3.3. Sex ratio, length-frequency distribution and length-weight relationship

The sex ratio was calculated to be 1.11, lacked significant bias, and was not significantly different from 1:1 (Chi-square test,  $X^2_{21}=0.11$ ,  $P=0.7456$ ). The length-frequency distribution shows the absence of females in the size classes lower than 80 cm and their domination in the larger size classes (80 and 90 cm). On the contrary, males occupied the smaller size classes (40 to 80 cm) and showed few numbers in the 80 cm size class and were absent in the largest size class (90 cm). Moreover, the majority of males (75%) occupied the 70 cm size class and the majority of females (72%) occupied the 80 cm size class (Figure 37).

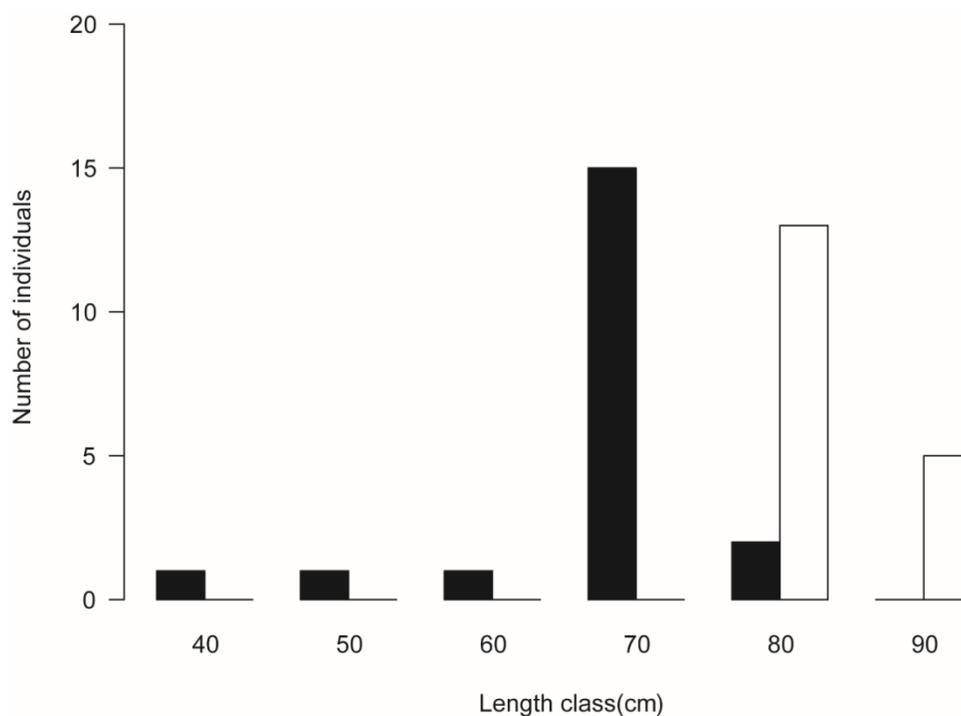


Figure 37: The length-frequency distribution of the Gulper Shark sample during the study period for both sexes (Males: black; females: white)

The ANCOVA test showed significant differences in the statistical comparison of the length-weight relationships between male and female individuals in the Gulper Shark sample (ANCOVA,  $F = 52.89$ ,  $P = 1.706 \times 10^{-08}$ ); therefore, the sexes were not combined. The estimated  $W_T - L_T$  parameters of both male and female specimens of the whole sample demonstrated negative allometric growth ( $b < 3$ ) (Males:  $W_T = 0.3585L_T^{2.071}$ ,  $r^2 = 0.94$ ,  $N = 20$ ; Females:  $W_T = 0.0239L_T^{2.735}$ ,  $r^2 = 0.64$ ,  $N = 18$ ) (Figure 38).

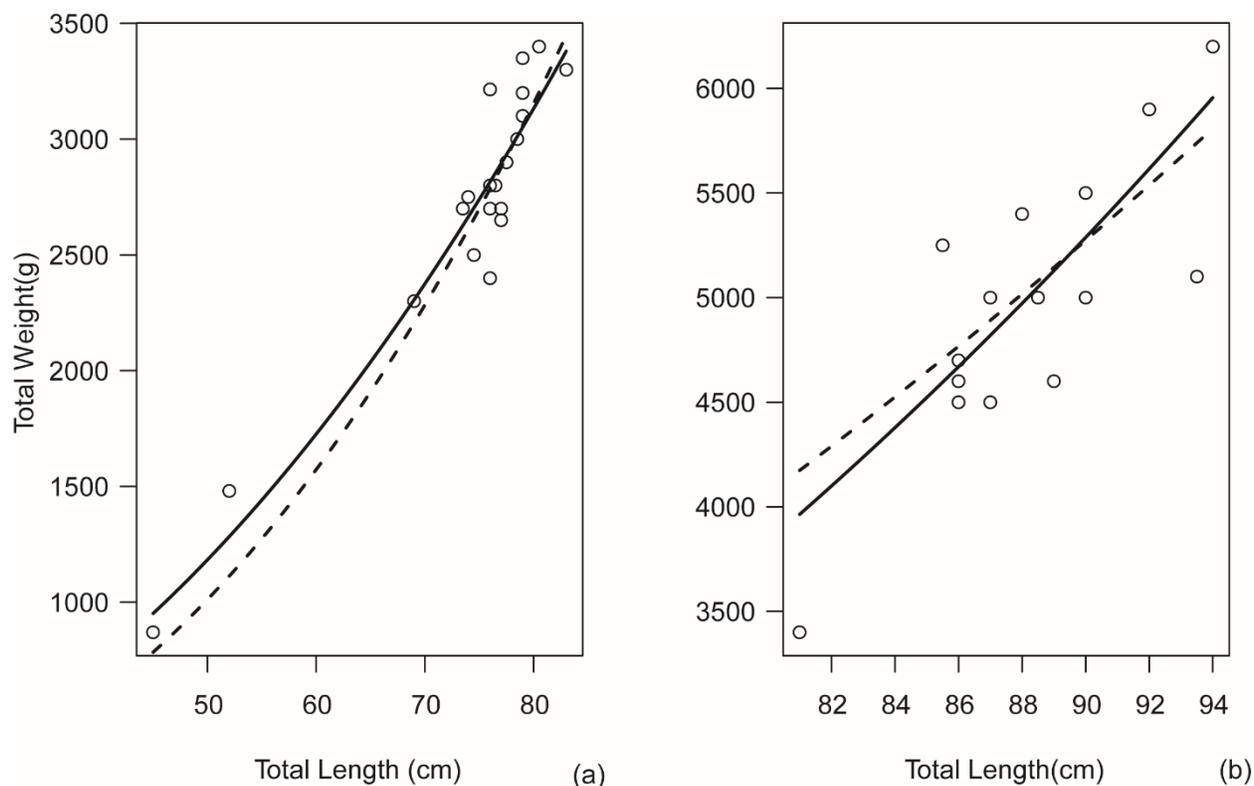


Figure 38: The length-weight relationships for males (a) and females (b) of the Gulper Shark sample (Black line: complete sample; dotted line: sample without immature individuals)

Two other relationships for both males and females were estimated where the immature individuals of stage one and two were removed from the sample, as few individuals were found in these small size classes which could induce a bias in the relationships. The estimated  $W_T - L_T$  parameters of both male and female specimens without the immature individuals also demonstrated negative allometric growth ( $b < 3$ ). (Males:  $W_T = 0.0785L_T^{2.419}$ ,  $r^2 = 0.53$ ,  $N = 16$ ; Females:  $W_T = 0.243 L_T^{2.219}$ ,  $r^2 = 0.45$ ,  $N = 17$ ) (Figure 38). These new relationships can be valid for the sizes ranging between 70 and 85 cm for males and 85 and 95 cm for females.

### 3.4. Sexual maturity and biological indices

All maturity stages were observed during the study period except the ‘developing’ (stage: 2), ‘capable to reproduce’ (stage: 3a), and ‘regenerating’ stages for females and ‘regressing’ (stage: 4) stage for males. Significant differences were observed between the weight and length distributions of the Gulper Shark individuals according to each maturity stage for male individuals and for the whole sample (Whole sample -  $L_T$ : Kruskal-Wallis test,  $H_{26}=26.25$ ,

$P=0.00019$ ;  $W_T$ : Kruskal-Wallis test,  $H_{26}=26.29$ ,  $P=0.00019$  – Male sample -  $L_T$ : Kruskal-Wallis test,  $H_{23}=8.16$ ,  $P=0.0429$ ;  $W_T$ : Kruskal-Wallis test,  $H_{23}=8.81$ ,  $P=0.0319$ ). Nevertheless, no significant differences were observed for the same distributions according to each maturity stage for female individuals ( $L_T$ : Kruskal-Wallis test,  $H_{24}=7.12$ ,  $P=0.1298$ ;  $W_T$ : Kruskal-Wallis test,  $H_{24}=7.12$ ,  $P=0.1295$ ). The post hoc Nemenyi test gave significant differences of total length and total weight means according to sexual maturity between the maturity stages ‘2’ and ‘3b’ (Nemenyi test,  $P<0.05$ ) for the male sample and the stages ‘2’ and ‘3c’ (Nemenyi test,  $P<0.05$ ) and ‘3d’ and ‘3c’ (Nemenyi test,  $P<0.05$ ) for the whole sample.

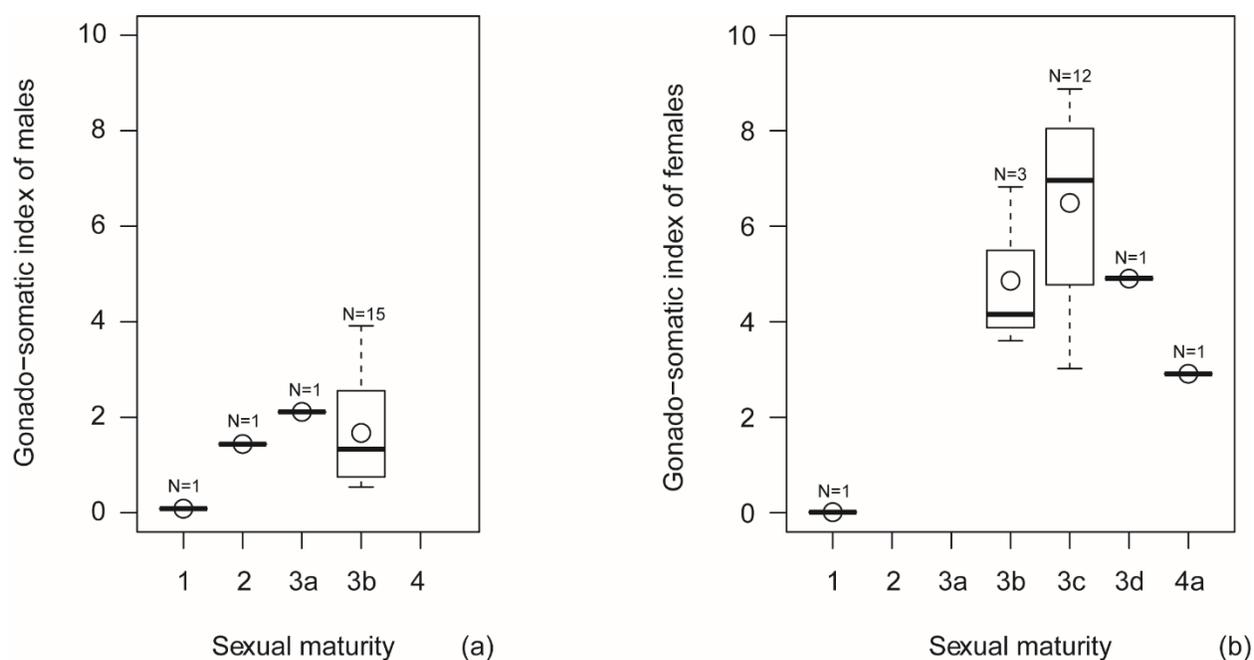


Figure 39: Boxplot representing the gonado-somatic index of the male (a) and female (b) Gulper Shark samples according to the sexual maturity (with 8 maturity stages for females : 1: Immature; 2: Developing; 3a: Capable to reproduce; 3b: Early pregnancy; 3c: Mid pregnancy; 3d: Late pregnancy; 4a: Regressing; 4b: Regenerating; and 5 maturity stages for males : 1: Immature; 2: Developing; 3a: Spawning capable; 3b: Actively spawning; 4: Regressing) during the study period (black line in box: median; points in box: mean for each maturity stage; ‘N’ is the number of Gulper Sharks in the sample)

The majority of male Gulper Sharks in the study period were actively spawning (stage: 3b) with sperm being released out of the cloaca upon pressure. However, the highest mean values of  $I_G$  were observed in stage 3a where the testes were greatly enlarged and full of sperm (Figure 39). In addition, the majority of observed females were in mid pregnancy (stage: 3c) showing the highest values of  $I_G$ . Relatively lower  $I_G$  values were observed in early (stage: 3b) and late (stage:

3d) pregnancies (Figure 39). No significant relationship was observed between the  $I_G$  according to the sexual maturity stages in each male and female samples (Male sample -  $I_G$ : Kruskal-Wallis test,  $H_{22}=3.07$ ,  $P=0.3806$ ; Female sample -  $I_G$ : Kruskal-Wallis test,  $H_{23}=6.77$ ,  $P=0.1488$ ). However, a significant relationship was observed between  $I_G$  according to the sexual maturity stages in the whole sample with significant differences between stages '2' and '3c' and between '3c' and '3d' (Whole sample -  $I_G$ : Kruskal-Wallis test,  $H_{25}=22.79$ ,  $P=0.0009$ ; Nemenyi test,  $P<0.05$ ). Moreover, no significant relationships were observed between clasper lengths of male Gulper Sharks and total length (Pearson rank correlation,  $r_p = 0.14$ ,  $N=18$ ,  $P>0.01$ ). The smallest mature male ( $L_T = 73.5$  cm) had a clasper length of 75 mm (Figure 40). The male gonad weight ranged from 2 to 100 g and showed no significant increase with total length (Pearson rank correlation,  $r_p = 0.35$ ,  $N=18$ ,  $P>0.01$ ) (Figure 40).

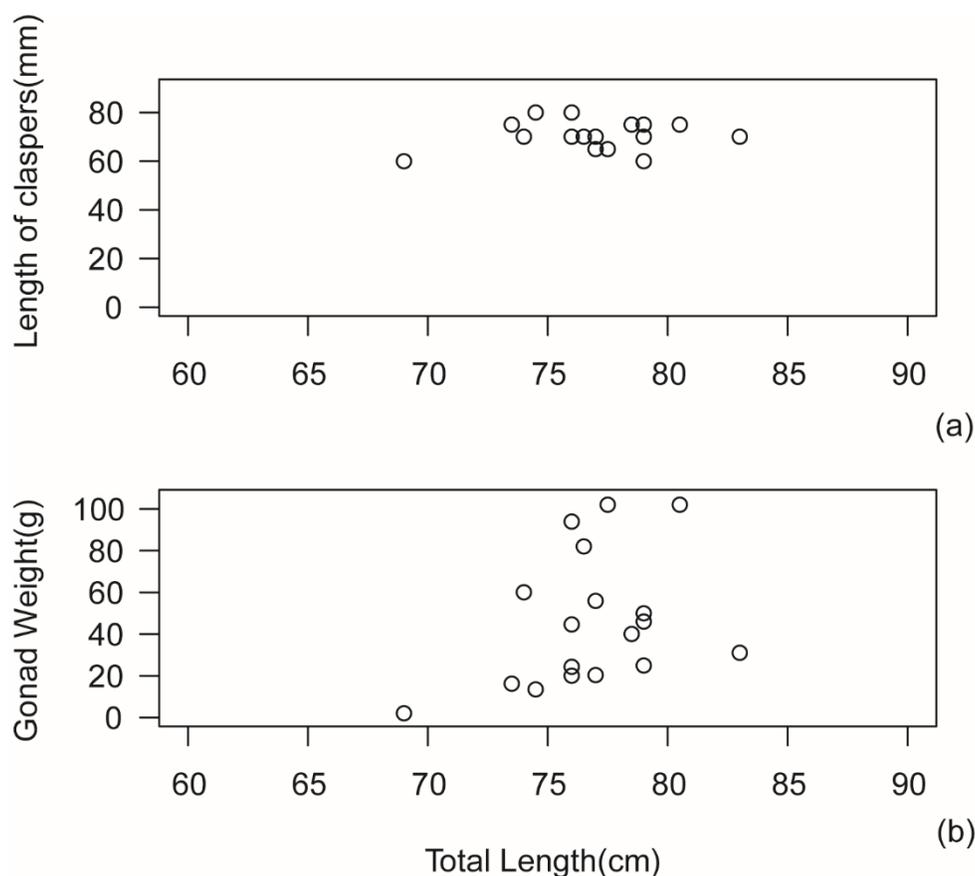


Figure 40: The relationships between length of the claspers (a) and weight of the gonads (b) with total length of the male Gulper Sharks

Early, mid and late pregnant females were observed in spring, summer and autumn 2013 and only early pregnant females were observed in winter 2014 in the study area at depths of 100 to 200 m in spring and summer and 500 to 600 m in autumn and winter. One late pregnant female observed in July 2013 bore two embryos, one male ( $W_T = 121$  g;  $L_T = 13$  cm) and one female ( $W_T = 123$  g;  $L_T = 27.5$  cm). A total of 7 embryos were observed in all the late pregnant females of the sample. All these embryos were easily sexed and had a total weight ranging from 52.2 to 153 g and a total length ranging from 21 to 30 cm. The smallest mature female had a total length of 85.5 cm.

The presence of pregnant females comes in parallel with the increase in  $I_G$  observed in autumn and spring with high values of gonado-somatic index (mean  $I_G \pm SD = 6.10 \pm 1.73$ ,  $N=11$ ) during the latter season. The  $I_G$  of the males showed important values (mean  $I_G \pm SD = 2.73 \pm 0.86$ ,  $N=7$ ) in spring as compared to other seasons. In addition,  $I_H$  values of the females showed to be lower than that of males throughout the four seasons. The lowest values were observed in spring along with the elevated values of  $I_G$ . The males showed the highest values of  $I_H$  in spring (mean  $I_H \pm SD = 57.95 \pm 4.56$ ,  $N=7$ ) and relatively lower values than the general mean during the rest of the seasons. The general mean for male condition factor throughout the four seasons was less than that of females. The  $K$  of male individuals showed almost constant values with slight fluctuations throughout the study period, while that of female individuals showed wider fluctuations with the highest values in summer (mean  $K \pm SD = 0.77 \pm 0.03$ ,  $N=2$ ) (Figure 41).

Finally, there were no significant differences between  $I_H$  (whole sample) and  $K$  (whole sample and male sample) of the Gulper Shark individuals according to seasons (Whole sample -  $I_H$ : Kruskal-Wallis test,  $H_{23}=0.57$ ,  $P=0.9029$ ;  $K$ : Kruskal-Wallis test,  $H_{23}=0.95$ ,  $P=0.8113$  – Male sample -  $K$ : Kruskal-Wallis test,  $H_{23}=1.16$ ,  $P=0.7626$ ), whereas significant differences were observed in  $I_G$  (whole sample and male sample) and  $I_H$  (male sample) according to seasons during the same period (Whole sample -  $I_G$ : Kruskal-Wallis test,  $H_{23}=9.04$ ,  $P=0.0287$ – Male sample -  $I_H$ : Kruskal-Wallis test,  $H_{23}=12.68$ ,  $P=0.0054$ ;  $I_G$ : Kruskal-Wallis test,  $H_{23}=13.60$ ,  $P=0.0035$ ). Females showed no significant difference in all biological indices according to season ( $I_H$ : Kruskal-Wallis test,  $H_{23}=6.72$ ,  $P=0.0813$ ;  $I_G$ : Kruskal-Wallis test,  $H_{23}=2.98$ ,  $P=0.3932$ ;  $K$ : Kruskal-Wallis test,  $H_{23}=1.83$ ,  $P=0.6079$ ). The post hoc Nemenyi test gave significant differences for  $I_G$  and  $I_H$  according to season between the spring and autumn seasons for both

indices (Nemenyi test,  $P < 0.05$ ) of the male sample; however, no post hoc significant differences were observed for  $I_G$  according to season for the whole sample (Nemenyi test,  $P > 0.05$ ).

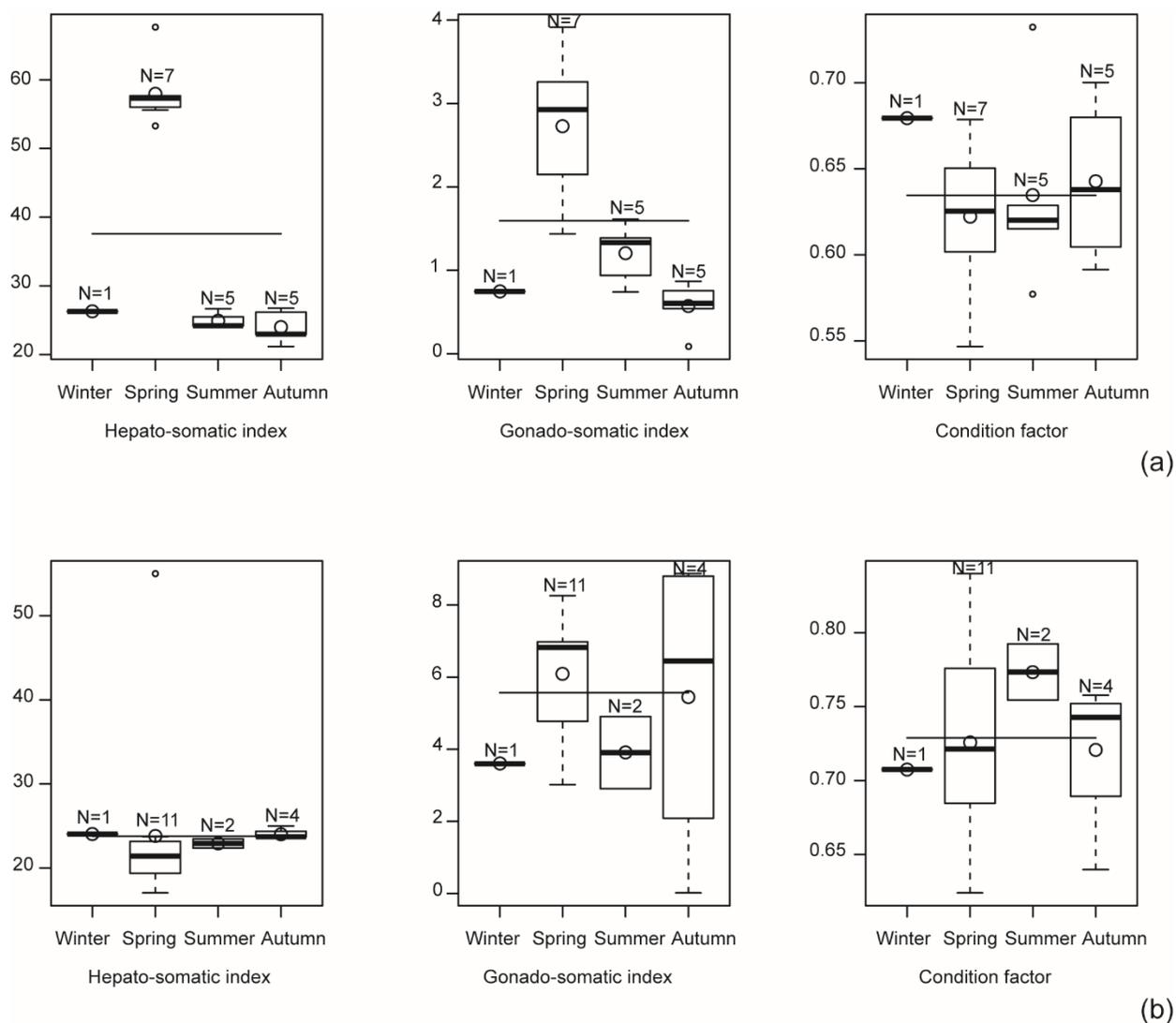


Figure 41: Boxplots representing the hepato-somatic index, gonado-somatic index, and condition factor of the Gulper Shark male individuals (a) and female individuals (b) according to seasons during the study period (black line in box: median; line outside box: general mean between seasons; large points in box: mean in each season; small points outside box: outliers; 'N' is the number of Gulper Sharks in the sample)

### 3.5. Two-way Unbalanced ANOVA and Principal Component Analysis (PCA)

Regarding the two-way unbalanced ANOVA, no significant double interaction between all 2x2 factors was observed (Two-way ANOVA,  $P > 0.05$ ). The PCA showed that the main numerical variables contributing to axis 1 were  $W_T$ ,  $L_F$ ,  $L_S$ ,  $W_G$ ,  $W_E$ , and  $I_G$ , whereas those contributing to axis 2 were  $W_L$ , and  $I_H$ . The main categorical variables contributing to axis 1 were ‘Depth’, ‘Gear’, ‘Sex’, and ‘Sexual maturity’, whereas those contributing to axis 2 were ‘Season’ and ‘Region’. In addition, mature females showed to be caught by trammel nets at depths between 0 and 400 m have the largest morphometrics and gonad weights opposite to the immature males on the negative side of axis 1. Regarding axis 2, the largest livers were found in individuals caught during the spring season in the southern region of Lebanon opposite to those caught during the winter and summer seasons in the northern region on the negative side of the axis (Figure 42).

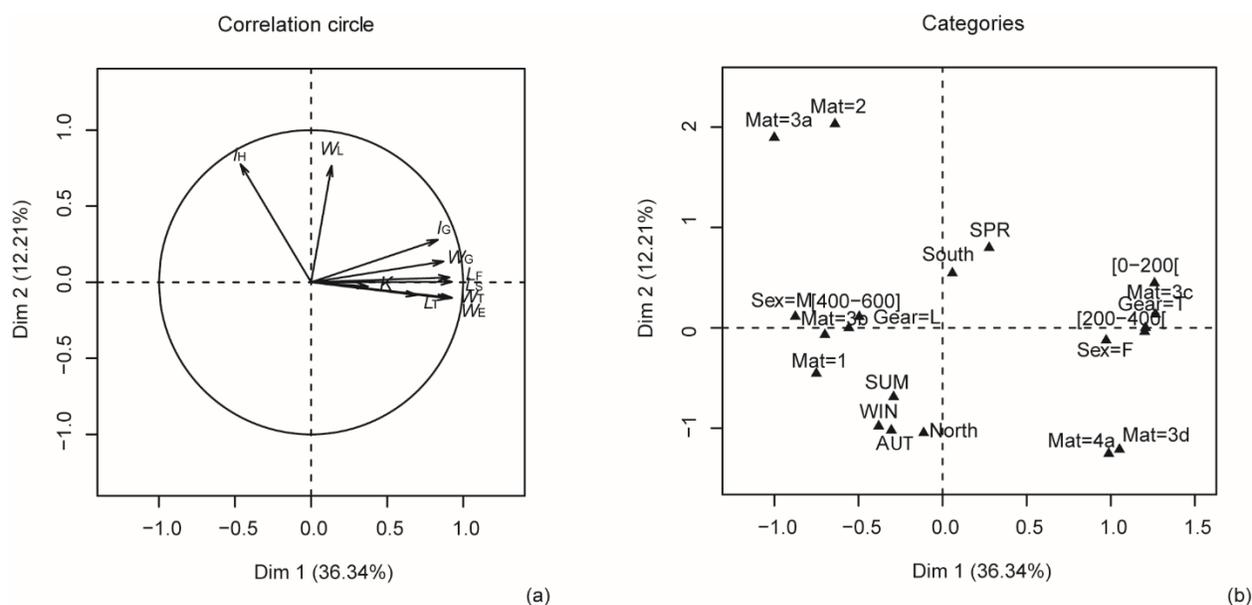


Figure 42: The ‘Correlation circle’ of the numerical variables ( $L_C$ : external length of the clasper;  $W_T$ : total weight,  $L_T$ : total length,  $L_F$ : fork length ;  $L_S$ : standard length ;  $W_E$ : eviscerated weight,  $I_H$ : hepato-somatic index ;  $W_L$ : weight of the liver ;  $I_G$ : Gonado-somatic index ;  $W_G$ : weight of the gonads ;  $K$ : condition factor) (a) and the ‘Categories’ plot of the four categorical variables (Season, Haul, Sexual maturity and Depth) with (Mat: Sexual maturity; SPR: spring; SUM: summer; WIN: winter; AUT: Autumn; L: long liners; T: trammel nets) (b) showing components 1 and 2 of the Principal Component Analysis

## 4. Discussion

Several factors influence population dynamics and maintenance of the population. This work presents the factors which can be important for the future management of the Gulper Shark, *Centrophorus granulosus*.

### 4.1. Spatial and seasonal distribution, habitat and life cycle

Muñoz-Chapuli (1984) hypothesized that demersal sharks are segregated by size and sex in the Atlantic. Based on bathymetric distributions of a number of species, including *Centrophorus granulosus* and *Galeus melastomus*, he hypothesized that such sharks have nursery grounds on the continental shelf to which pregnant females migrate, while adult males remain at greater depths. Golani and Pisanty (2000) confirmed this assumption for Gulper Shark by observing that the males of this species dominated intermediate depths (550-800 m) and females dominated shallow depths (200-400 m) along the coast of Israel. These results agree with those observed in this study and confirm the probable bathymetric sexual segregation of this species.

The  $CPUE_{kg}$  results suggest that the Gulper Sharks are present northern and southern of Lebanon. In addition, the maximum observed  $CPUE_{kg}$  value (5.45 kg/unit effort) in summer using trammel nets of mesh 26 mm was higher than that observed in the Ionian Sea for the same species using a commercial trawler (in kg/hr) at a higher depth during the autumn season (Politou *et al.*, 2003). This result can be attributed to type of gear utilized, method of  $CPUE_{kg}$  estimation and seasonal depth distribution of this species. In addition, the higher  $CPUE_{kg}$  observed in the trammel net catches compared to those of the long liner catches implies that trammel nets constitute a more important mean for demersal shark bycatch than long liners according to this study. However, Stergiou *et al.* (2002) showed that bottom long liners incidentally bring several demersal species, such as, *Mustelus sp.*, *Squalus sp.*, *Torpedo sp.* and some Rajidae; since Gulper Sharks are demersal, it is obvious that bottom long liners also generate a significant mean for the bycatch for this species. Furthermore, the impact of gear selectivity is also shown in this study, where trammel nets caught larger individuals but with a narrower length range than long liners that caught smaller individuals with a wider length range. A similar pattern for gear selectivity was observed for several elasmobranch species southern of Portugal (Coelho *et al.*, 2005).

## 4.2. Size and growth

The maximum length recorded for Gulper Sharks in this study (94 cm) correlates with that observed along the coast of Crete (Megalofonou and Chatzisprou, 2006) and the coast of Israel (Golani and Pisanty, 2000), both of which are located in the eastern Mediterranean, where the maximum total lengths observed were 95 and 96.7 cm respectively. However, the highest total length observed in this work was smaller than that observed along the coasts of Tunisia, western Mediterranean, where a total length of 128 cm was recorded for the same species (Capapé, 1985; Capapé *et al.*, 2003). This variation in maximum total lengths between eastern and western Mediterranean can be attributed to the fact that shallow waters in the eastern Mediterranean are known to be oligotrophic (Abboud Abi Saab and Kassab, 1997; Ignatiades, 2005) which may have affected the physiological status and growth of this species.

The negative allometric growth ( $b < 3$ ) revealed in this study for both males and females of the studied sample comes in agreement with that observed by Capapé (1985) for adult Gulper Shark specimens along the Tunisian coast. Nevertheless, the latter author revealed that young and sub-mature Gulper Sharks showed positive allometric growth in the Tunisian waters, and the same positive pattern was also observed off the island of Crete (Megalofonou and Chatzisprou, 2006) and in Antalya Bay (Güven *et al.*, 2012) for adults of the same species. This variation in “b” coefficients can be probably due to the domination of large mature individuals in the male and female samples and the absence of a wide length range in the female sample of the studied Gulper Sharks. Moreover, the important difference in adult Gulper Sharks allometric growth parameters between the present study and that off the island of Crete can also be attributed to the environment and physiological status of the Gulper Sharks in both regions. In all cases, a sample with a wide length range for both sexes should be analysed to attain a more precise estimation of allometric parameters.

The smallest mature Gulper Shark male observed in this study was smaller than the smallest mature female. This fact agrees with other studies (Capapé, 1985; Fischer *et al.*, 1987; Guallart, 1998) which stated that male Gulper Sharks mature at a smaller size than females. Although Megalofonou and Chatzisprou (2006) stated that gonad weights increase rapidly with total length for Gulper Sharks, no significant relationship between male gonad weight and total length

was observed in this study. This can be attributed to the domination of mature male individuals and the absence of small to medium-sized individuals from the sample, which was also revealed by the close clasper lengths according to the range of male total lengths.

### 4.3. Reproduction and biological indices

The presence of pregnant females at various stages could indicate that the Levantine area along the coast of Lebanon is a reproductive area for this species. Moreover, several previous studies noted that gravid Gulper Shark females carried one single embryo or a single large egg (Ranzi, 1932; Tortonese, 1956; Capapé, 1985; Guallart, 1998). However, this was not the case in one of the Gulper Shark females in this study that carried two embryos. The sizes of all the embryos in this study coincide with those at birth noted by several authors for this species (Fischer *et al.*, 1987; Guallart and Vicent, 2001), which indicates upcoming parturition. In addition, the presence of two pups per litter in this female can suggest that it might belong to a synonymous species, *Centrophorus uyato* Rafinesque 1810, as it has been reported in the Mediterranean Sea (Guallart *et al.*, 2006). This latter species is the closest to *Centrophorus granulosus* in the Mediterranean Sea and is described as ovoviviparous with a maximum of two pups per litter (McLaughlin and Morrissey, 2005). Nevertheless, this issue of two species present in the Mediterranean presents a taxonomically controversial hypothesis because most Mediterranean authors note that there is only one species of *Centrophorus* (*Centrophorus granulosus*) in the Mediterranean Sea (Tortonese, 1969; Rancurel, 1983; Capapé, 1985; Muñoz-Chapuli and Ramos, 1989; Guallart, 1998). Another explanatory hypothesis could be that a physiological stress caused the ovulation of two mature oocytes and their fertilization at probably different times. This can be supported by the fact that oocytes in the ovaries continue to develop even during gestation, since most pregnant females carry large embryos and large oocytes simultaneously, suggesting that ovulation can occur soon after parturition (Capapé, 1985; Guallart and Vicent, 2001) or even before parturition as hypothesized in this paper.

Concerning the variation of biological indices, it is obvious that  $I_G$  reaches its highest values in early and mid-pregnancy for females and prior to spawning in males due to the formation of well-filled rounded uteri with yolk content in females and greatly enlarged testes in males, all of which can increase gonad weight and positively affect  $I_G$ .

The lower mean values of  $I_H$  in the female sample throughout the study period could be due to the domination of pregnant females, which explains the high  $I_G$  values in spring and autumn. Moreover, it has been recorded that  $I_H$  decreases during maturation and pregnancy for some elasmobranches (Yano, 1995; Demirhan *et al.*, 2010). Therefore, this decline in  $I_H$  for females, especially in spring, along with the highest  $I_G$  values, could imply that Gulper Shark females metabolized liver reserves during gestation. In reverse, the presence of high  $I_H$  and  $I_G$  values for male Gulper Sharks in spring coincides with what was observed by Capapé (1980) for *Raja asterias* where an increase in the gonad weight was accompanied by a storage of substances in the liver. This could indicate a sexual dimorphism in liver weight and reserve metabolism between male and female Gulper Sharks. In addition, according to the variation of  $I_H$  in both male and female Gulper Sharks and the fact that this species has a relatively long gestation period of two years, it is apparent that this long gestation involves metabolic energy expenses for a longer period (Guallart and Vicent, 2001) and the size of the liver changes according to reproductive stage, an observation which was also described for a squalid by Yano (1995).

The condition factor can provide information on the general condition of fishes in the habitat they live, as well as indicate phenomena such as spawning period, alterations in population density and feeding conditions (Braga, 1986). Regarding the condition factor of the Gulper Shark sample, the almost constant values for the males throughout the study period was indicative of an evident wellness among the male population and could indicate a lack of any physiological or environmental factor affecting the stock. Nonetheless, the wide fluctuations in  $K$  of the females could be due to the physiological stress caused by gestation or mating, as some male or female elasmobranches display low condition factors indicating probable stress during mating season (Loefer and Sedberry, 2003).

Finally, this study draws attention to the Gulper Shark population along the Lebanese coast, as scarce are the studies that are performed about this species in the Levantine basin. This species is majorly exploited as bycatch by long liners and trammel nets, at times discarded or sold in fisheries with low cost. Thus, management measures should be implemented to prevent the vast exploitation of this elasmobranch group as bycatch that is classified internationally as Vulnerable. Laws should be applied to decrease the exploitation of this species. The data

presented in this study will be useful for the ongoing assessment of populations, fishery stock, ecological risk, and species extinction risk.

### **Acknowledgements**

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# **Chapter VII**

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**General discussion,  
conclusion and perspectives**

## **Chapter VII: General discussion, conclusion and perspectives**

The present study is the first of its sort along the Lebanese coast. Its main interest is to contribute to a better knowledge of the status of chondrichthyans in this area. These species are subject to various threats worldwide, especially in the Mediterranean Sea, which is considered one of the three hotspots where the diversity of elasmobranchs is threatened (Dulvy *et al.*, 2014). Overfishing, bycatch, and habitat loss are the major pressures affecting this fish class (Cuttelod *et al.*, 2008). Its presence was already described for most regions of the Mediterranean except in its eastern basin along the Lebanese coast. The fact that these fishes are exploited in this region urges the need to implement management measures of their fishing and decrees to protect them. In this context, two main aspects are discussed:

- The diversity and distribution of these fish along the Lebanese coast
- The life-history traits of two exploited elasmobranchs in the area

### **1. Elasmobranchs: Presence, diversity and fisheries in Lebanon**

#### **1.1. Presence and diversity**

Cartilaginous fishes are demanded worldwide for their highly valuable parts (e.g. fins); thus, fisheries targeting them expanded (Barausse *et al.*, 2014). No major fisheries targeting chondrichthyans are present in the Mediterranean Sea; nonetheless, its artisanal and traditional fisheries, mixed species fisheries, and the trawlers of some regions have posed a major source of chondrichthyans bycatch (Caddy, 1993; Musick and Bonfil, 2005; Stevens *et al.*, 2005; Walker *et al.*, 2005). Elasmobranchs also constitute bycatch in traditional tuna traps (Storai *et al.*, 2011). Examples for that are the threats posed by artisanal Lebanese fishermen on chondrichthyans along the coast of Lebanon, where these fish are either targeted by bottom longlines or incidentally caught.

During the course of this study, a total of 25 cartilaginous fish species were recorded along the coast at several depths ranging from 10 to 600 m. The number of species constitutes almost 30% of all species found in the Mediterranean, and it is less than that recorded in several regions of the Eastern Mediterranean, such as, Cyprus (45 species) (Hadjichristophorou, 2006), Turkey (63

species) (Bilecenoglu *et al.*, 2014), Syria (38 species) (Ali and Saad, 2003; Saad *et al.*, 2004) and Israel (Golani, 2006). More chondrichthyans (44 species) were also recorded in studies performed along the Lebanese coast around 5 decades ago by George *et al.* (1964), George and Athanassiou (1965), George and Athanassiou (1966a), George and Athanassiou (1966b), George and Athanassiou (1967), and George *et al.* (1971). Even less chondrichthyans (22) were recorded in a more recent study (Mouneimne, 1978; 2002). The seasonal and regional fluctuations and peaks of diversity indices reflects the biodiversity of chondrichthyans along the Lebanese coast. This diversity is indispensable to maintain the stability of the ecosystem (considering elasmobranchs as top predators) and protect the overall environmental quality (Ehrlich and Wilson, 1991).

### **1.1.1. Abundance index**

The analysis of the Catch Per Unit Effort (CPUE) and total weight variation of the elasmobranchs observed during this study provided indications of the spatio-temporal variation of their distribution and abundance. This variation could be attributed to (a) environmental or (b) human effects. The nature of Lebanese water, availability of prey, daily and seasonal movements for breeding and feeding, as well as, fishing techniques and the depths at fishing can explain the variation in distribution and abundance of these fish according to examples in Bianchi (1992), Koslow (1993), and Gordon *et al.* (1995). Due to the uniqueness of this study in the region, no trend could be estimated concerning the variation in abundance and biomass of cartilaginous fish inhabiting the coastal waters. Therefore, all cartilaginous fish catches (whether incidental or targeted) should be reported for proper future statistical estimation of spatio-temporal trends for a better management and protection. Furthermore, the present study used information from scientific surveys and commercial fisheries. This method could determine spatial and temporal distributions of exploited fish, such as, the case of the spatio-temporal distribution (estimated from the CPUE of survey and fishery data) of the recruiting and spawning Celtic Sea whiting (Verdoit *et al.*, 2003). Commercial data has an advantage of not causing additional mortality, but it is less precise due to the lack of Global Positioning Systems (GPS). Scientific data is standardized. The presence of complete data sets in the latter study enabled the proper estimation of CPUE from both scientific survey and fishery data. Some gear used in the survey was not uniformly lowered throughout the coast, at all depth strata, and all seasons; for instance, longlines were only deployed in the south due to lack of financial support (low funds as longlines

break easily, their mending is expensive, and sometimes bait was not available) and political reasons (conflicts arose in Tripoli in the north during the sampling period). Moreover, no gear was lowered during the autumn season. Although the data collected was limited, the results of the survey were interesting. The quantity of elasmobranchs caught during this survey indicates that proper management techniques should be implemented. Future surveys should be carried out in a more uniform manner regarding seasons, gear used, and distribution of hauls for a better estimation and more clarified species richness and wider CPUE indications.

### **1.1.2. Spatio-temporal variations**

Regarding the spatio-temporal diversity and distribution of this fish class, both showed seasonal variations and slight regional differences in this study. Habitat selection by elasmobranchs depends on several biotic and abiotic factors. Temperature and depth account for much of the spatial variation in the species composition of demersal fish communities. Temperature is the key abiotic factor that controls the rate of metabolism and growth and prey abundance is the key biotic factor that influences habitat quality (Swain and Benoit, 2006). In Shark Bay, Australia, a higher density of elasmobranchs was observed during the warm seasons, probably driven by thermoregulation (Vaudo and Heithaus, 2009). Furthermore, based on 32-year of monitoring by a bottom-trawl survey, Southern Gulf of St Lawrence, Canada, the geographic range of the Thorny Skate (*Amblyraja radiata* (Donovan, 1808)) contracted sharply and distribution shifted into a narrow band of warm deep waters. However, these changes in skate distribution coincided with a decline in skate biomass and a cooling of bottom waters. Therefore, this contraction in the geographic range of skates was a density-dependent response, more closely related to the decline in skate abundance than to the change in environmental conditions (Swain and Benoit, 2006). Habitat structure can also influence nearshore cartilaginous and bony fish assemblages. For instance, the occurrence of skates and rays in Babadillimani bight in the northeastern Mediterranean showed sediment preferences as investigated by Yeldan and Avsar (2006). Skates in the latter region preferred highly silty bottoms while rays were more densely distributed along shallower areas and sandy silt. Furthermore, Schlaff *et al.* (2014) reviewed the influence of environmental factors on shark and ray movement, behavior and habitat use. These authors showed that temperature, salinity, dissolved oxygen, tide, photoperiod, barometric pressure and pH have also been documented to act as drivers of movement in shark and ray species. In this context, studying abiotic factors, bathymetric structure of the bottoms and associating sediment

types with the presence of chondrichthyans could also provide more information about variation in the observed spatial distribution. The lack of bathymetric data, bottom and sediment type along the Lebanese coast was faced during the course of this study. Having been able to manipulate survey sampling conditions, bottom sampling should have been also carried out for every haul in order to associate the presence of the elasmobranchs caught to the bottom structure. Such additional sampling was not performed during the survey due to lack of time and specific (material and humans) resources in the vessels hired.

### **1.1.3. Marine Protected Areas**

The results of diversity in this study can encourage to a longer term the implementation of Marine Protected Areas (MPAs) along the coast. Although two nature reserves are already present along the Lebanese coast (Tyre Coast Nature Reserve – south; Palm Islands Nature Reserve – north), the Ministry of the Environment has proposed 9 coastal marine sites as MPAs (Nakoura; Sidon Rocks; Raoucheh Cliffs and Caves; Beirut Port Outer Platform; Byblos; Madfoun Rocky Area; Batroun Phoenician Wall; Ras El Chekaa Cliffs; Enfeh Peninsula) (Lebanese Ministry of Environment-IUCN, 2012) (Figure 43) based on scientific assessments (Bariche, 2008; ACCOBAMS, 2010; OCEANA MedNet, 2011), field surveys and richness. The results of this study can add basic data to stimulate the increase of MPAs along the coast, aiming for further and wider coastal protection and sustainable management. The increased presence of MPAs along the coast can stimulate the fishing management in that protected area, and subsequently enhance the protection of susceptible marine organisms, such as, chondrichthyans. MPAs constitute valuable assets that aid in the sustainable use of fisheries resources and prohibit fishing activities during breeding or nursery seasons in order to allow the restoration of important of susceptible resources. Moreover, it is also important to stimulate the creation of MPA networks to enable the connectivity between MPAs.

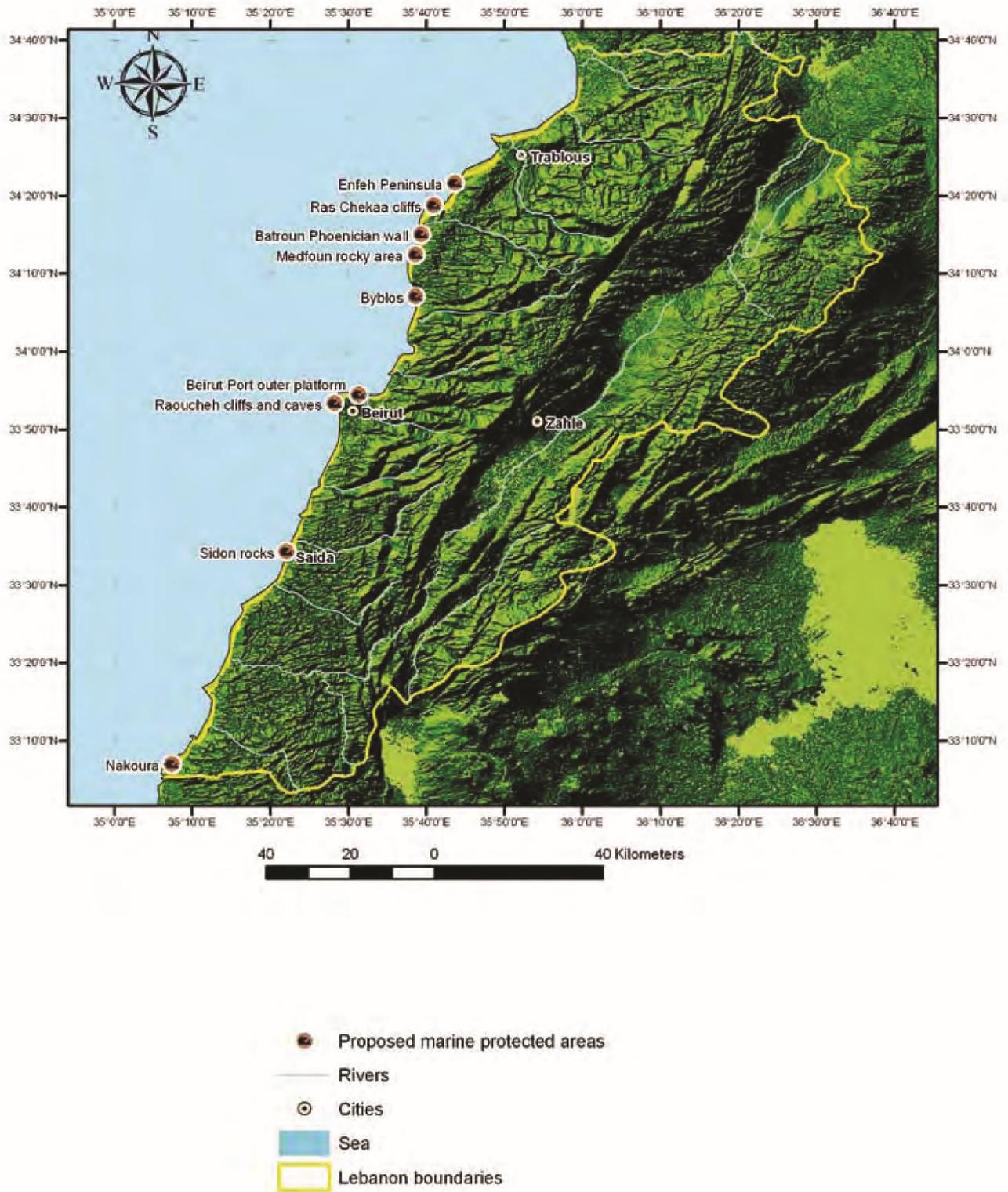


Figure 43: The proposed marine MPAs along the Lebanese coast (Lebanese Ministry of Environment-IUCN, 2012)

According to the fact that most fishing operations take place in the north and the results obtained on the diversity of elasmobranchs in Lebanon indicating that higher diversity and abundance were observed in the south, we can hypothesize that elasmobranch diversity is already altered in the north by fishing. Thus, we can suggest that MPAs should be enforced in the northern areas of Lebanon and also the implementation of a large MPA in the south in order to preserve this high diversity. In addition, we could propose the implementation of measures in the marine areas around the two Lebanese coastal nature reserves whose existence makes these measures easier to implement.

#### **1.1.4. Species identification**

The identification and reporting of cartilaginous fish upon catch is almost lacking in Lebanon with the absence of scientists working in this field. Fishermen have general names for these fish, sometimes giving one name for several species with almost similar morphology. This has been observed in several developing countries worldwide. These countries struggle to identify species caught. They only specify the species and the genus for 17 percent of the cartilaginous fish caught, but store 45 percent of the catch at the highest level of classification. In contrast, developed countries identify the species and the genus of 72 percent of the catches and record only 7 percent of their catch in the class level (Figure 44). Many developing countries complain of a lack of taxonomists or scientists and officials trained in monitoring and evaluating these species, with inadequate access to basic tools for shark identification (FAO, 2014). In this context, DNA barcoding constitutes a good method that can revolutionize species identification and decrease problems related to misidentification. Using molecular techniques to identify shark species and their body parts from specimens morphologically difficult to identify, or to confirm morphological species identification has become an accepted technique (Shivji *et al.*, 2002; Clarke *et al.*, 2006a; Holmes *et al.*, 2009a). DNA barcoding has also been applied to elasmobranch products. This method has demonstrated high levels of fraudulent substitutions in sales of sharks (Barbuto *et al.*, 2010), identified endangered species in confiscated shark fins (Holmes *et al.*, 2009b) and revealed the sale of endangered sawfish as “shark” fillets in markets in Brazil (Melo Palmeira *et al.*, 2013).

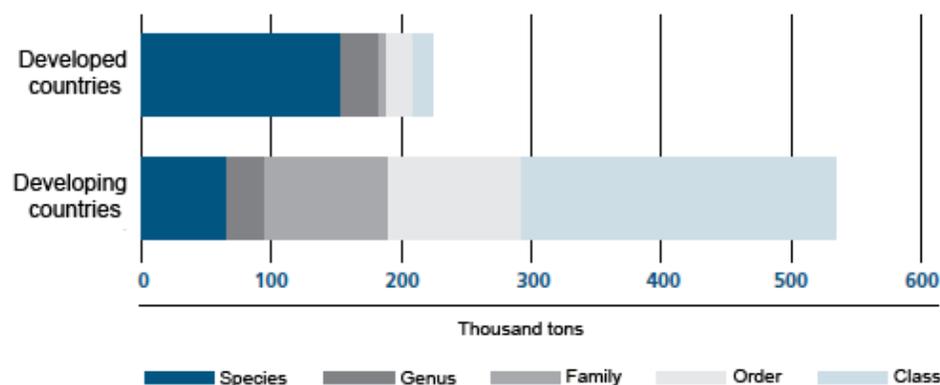


Figure 44: Shark catches reported by developed and developing countries classified by according to the taxonomic levels (FAO, 2014)

### 1.1.5. Lack of fishing logbooks

In addition, the lack of logbooks containing all catch information in Lebanese fisheries is one reason for the fact that CPUE was not estimated for the elasmobranchs collected from fisheries. Instead, the only reflection for biomass was the total weight of the collected elasmobranchs. No vessel information or catch duration is noted in professional Lebanese fisheries. Lebanese artisanal fishermen collect their catches and mix them with other catches in local fisheries to be sold during daily auctions or to walking-by customers. Therefore, estimating the CPUE in such conditions and reporting the fish species landed (whether bony or cartilaginous) is difficult and almost impossible.

### 1.1.6. Fisheries

Moreover, this study shows that the artisanal fisheries along the Lebanese coast are exploiting chondrichthyans to an extent. Elasmobranchs are shown to be observed in fisheries, especially in Tripoli (northern Lebanon) all year long, where the highest percentage of navigation licenses and the majority of fishing operations occur in the latter region (Majdalani, 2005). Being top predators, overexploitation of elasmobranchs can have a damaging effect on the whole ecosystem by disturbing the complex equilibrium provided by these predators. Elasmobranchs can be categorized by species maximum length to determine susceptibility of decline under exploitation. Generally, species greater than 100 cm are characterized by life-history and population traits that place them at greater risk of population decline (Frisk *et al.*, 2001). Elasmobranch fishing and bycatch remain little known and poorly characterized especially along

the Lebanese coast. Elasmobranchs taken as bycatch in fisheries targeting other species could be eradicated long before appropriate management policies would be implemented (Walker, 1998). Soon after heavy exploitation, the catch rates of elasmobranchs can rapidly decrease (Bonfil, 1994). Examples of elasmobranch overexploitation have already been observed in several areas of the world: common skate (*Raja batis*) is now locally extinct from the Irish Sea (Walker, 1998; Dulvy *et al.*, 2000); Thorny Skate (*Amblyraja radiata*) in the southern Gulf of St. Lawrence is currently at the lowest biomass level ever observed (Swain and Benoit, 2006); White Skate (*Rostroraja alba*) and longnose skate (*Dipturus oxyrinchus*) are now locally extinct from the Irish Sea and Bristol Channel areas (Dulvy *et al.*, 2000). Therefore, the identification of the spatio-temporal distribution and diversity, habitat selection and consistent estimations of fishing and discard mortality of cartilaginous fish species along the Lebanese coast are of high importance in understanding the impact of fisheries on this fish class in a poorly studied area of the Mediterranean.

### **1.2. Length-weight relationships**

This study also presents some length-weight data of 8 elasmobranchs, some of which having a threatened status in the Red List of the International Union for the Conservation of Nature (IUCN). The estimation of length-weight relationships has a very important practical value in fisheries management. Along the coast of Lebanon, basic biological data needed for elasmobranch stock assessment are lacking. Length-weight relationships are important for understanding growth rate, age structure, some aspects of population dynamics, as well as, constituting a tool to protect and conserve this fish class. Some length-weight relationships in this study showed a similar trend as some for the same species in different areas of the Eastern Mediterranean; however, some even showed an opposite pattern. In this context, data from different regions should be combined to estimate length-weight relationships of several threatened elasmobranchs that can be used for a wider area. Therefore, the length-weight relationships presented in this study are only useful and efficient for the elasmobranch populations inhabiting the Lebanese coast and for the specific length ranges and sexes investigated. These data can stimulate laws to limit overexploitation of these fishes through direct fishing and bycatch by establishing a minimum catch weight limit and abiding to these weights when the lengths are estimated at sea. Furthermore, seasonal length-weight relationships should be also estimated for the investigation of probable variation in growth by seasons.

Length-weight should also be estimated according to maturity stage as differences could be observed between the growths in different stages; for example, differences in length-weight parameters were observed between adult, sub-mature and juveniles of the Gulper Shark, *Centrophorus granulosus*, along the coast of Tunisia (Capapé, 1985). Such estimations could not be carried out during this study due to the absence of specific species during certain seasons and the relatively small sample sizes with a limited number of individuals in each maturity stage.

## **2. Life history aspects and overexploitation**

Cartilaginous fish act as top predators in marine ecosystems (Wetherbee and Cortés, 2004). Their chronic overfishing has reduced population sizes, fragmented large populations into small, locally-isolated ones (Nadon *et al.*, 2012), and led to trophic cascades (Myers *et al.*, 2007). Despite these rapid declines, little is known about their ability to persist in smaller, more fragmented populations and to recover from human-induced bottlenecks (Field *et al.*, 2009). In the Mediterranean, little is known about the overall organization, structure, and complexity of the group/population of sharks. However, in tropical waters some studies display some behavioral aspects of sharks. For example, some females of species like the Sharptooth Lemon Shark, *Negaprion acutidens*, exhibit behavioral patterns (philopatry) by returning to the same nursery on multiple years to give birth. The latter population also shows patterns of connectivity between the islands in archipelago and dispersal which are used as a strategy to avoid mating with closely related partners (Mourier *et al.*, 2013). Philopatry was also observed in the same region for some females of the Blacktip Reef Shark, *Carcharhinus melanopterus*, that migrated to the same nursery for every birthing event (Mourier and Planes, 2013).

While life history provides considerable awareness to the response of chondrichthyan populations to exploitation, the incidental catches and direct targeting of elasmobranchs in Lebanon has led to the urge to increase awareness of conservation needs. In addition, the Lebanese production of elasmobranchs was 60 tons in 2003 accounting for 2% of all groups caught (Martin *et al.*, 2006). No catch assessment surveys were conducted for the past 30 years covering the entire coast, and Lebanon has stopped sending data to FAO since 2006 (Pinello and Dimech, 2013). As claimed previously, the reality that artisanal fishermen face every day is far from the official landing records of elasmobranchs. Therefore, human resources, especially

taxonomists, should be encouraged to help data collection or recordings of artisanal fishing operations. This will ameliorate landing statistics through the basic use of scientific names and not generalized names.

In Lebanon, several elasmobranchs are captured, either through directed fishing operations or through bycatch. The results of this thesis show that that Common Guitarfish, *Rhinobatos rhinobatos*, is the most commonly targeted elasmobranch in the Lebanese longline fisheries, especially in Tripoli. This elasmobranch, considered Endangered by IUCN, also shows an intense exploitation pattern in Iskenderun Bay, northeastern Mediterranean (Cicek, 2006; Ismen *et al.*, 2007b). Although declared extinct in the northern Mediterranean, it persists in areas of the southern Mediterranean, particularly the Gulf of Gabés (Sciara *et al.*, 2007); nonetheless, the results of this study confirm its presence in the eastern Mediterranean with a significant commercial value in the northern region of Lebanon. The Gulper Shark, *Centrophorus granulosus*, however, is more commonly exploited as bycatch. This species presents very conservative life history traits with a long gestation period displaying a Vulnerable IUCN status; thus, its conservation and protection must be facilitated along the Lebanese coast.

Many studies link fish life histories to overexploitation. Exploitation affects life history. Changes to age and size at maturity, longevity, and quite possibly fecundity and egg size are the product of phenotypic and genetic responses to fishing (Rochet, 1998; Law, 2000; Hutchings, 2002). An example related to bony fish is the Atlantic cod (*Gadus morhua*) whose 30- to 40-year declines have been associated with significant reductions in age and length at maturity, changes mostly explained as genetic responses to fishing (Hutchings, 2005). Cartilaginous fishes are less productive and more vulnerable to extinction than bony fishes due to their life history traits (Myers and Worm, 2005; Simpfendorfer *et al.*, 2011). Their low productivity (small litters, slow growth rates, late sexual maturity and long gestation periods) make them incapable to compensate increased mortality rendering them more vulnerable to extinction (MacArthur and Wilson, 1967). Many studies also linked life history traits to risk of overexploitation and extinction in cartilaginous fishes (Hoenig and Gruber, 1990; Kirkwood *et al.*, 1994; Cortés, 1998; Smith *et al.*, 1998; Heppell *et al.*, 1999; Cortés, 2002; Gedamke *et al.*, 2007), and considering this group's natural vulnerability and long life spans, conservation measures should be reviewed to avoid local extinctions. Legally and practically limiting the fishing of

elasmobranchs is the main measure that should be applied (Increase control on ports and in fisheries, set quotas to limit biomass of elasmobranchs caught, in addition to enforcing MPAs). Awareness should be also spread among the fishermen community for better understanding of the importance of elasmobranchs as top predators in the marine ecosystem. Accordingly, this thesis presented the life history of two intensely exploited elasmobranchs. Knowing that no official landing records are found for these two species, the results of the thesis provide evidence that can identify the threats posed by artisanal fisheries for the survival of the Gulper Shark and the Common Guitarfish local populations. Moreover, it can be hypothesized that fisheries have certainly already modified life-history traits for the studied populations. For instance, sizes at maturity or mean sizes obtained in the results could be less than those in areas not subject to fishing pressure.

Some life history traits were not studied during the course of this thesis. For instance, timing limits and lack of financial and technical resources obstructed the age estimation of these species. The age estimation can complement growth studies enhancing the reflection of population dynamics. Estimations of age and growth of deep-water chondrichthyans can suggest variable life histories. For instance, such estimations can disclose low turnover rates and also considerable variability in age at maturity and longevity among them (Machado and Figueiredo, 2000; Clarke *et al.*, 2002; Sion *et al.*, 2002; Moura *et al.*, 2004; Irvine *et al.*, 2006).

In addition, the conventional stomach content analysis was carried out for the Common Guitarfish in order to shed light on the biological aspect of this population. No such analysis was performed for the Gulper Shark because no food was found in all stomachs sampled. This approach in analysis has been criticized for the ‘snapshot’ nature of sampling although providing considerable information about the trophic ecology of many animals (Pinnegar and Polunin, 1999; Pinnegar *et al.*, 2001). It has also been criticized due to the prevalence of unrecognized dietary items (Pinnegar *et al.*, 2001), bias from regurgitation during capture (Renones *et al.*, 2002), and the difficulty to obtain sufficient sampling frequency to draw significant conclusions (Vander Zanden *et al.*, 1997). In this study, a limited amount of samples containing prey in their stomachs were obtained for Common Guitarfish, and none were obtained for Gulper Sharks. The aim of this approach was to include as many quantitative analyses as possible and it was performed for the Common Guitarfish population only. Nonetheless, such analysis should have

been supported by a stable isotope analysis in order to alleviate biases when present. Stable-isotope analysis provides estimates of assimilated foods based on measurements of stable isotopes of nitrogen and carbon in tissues of marine consumers (Owens, 1988; Fry and Sherr, 1989) up to several months back depending on the tissue analyzed. Accordingly, Cortes (1999) recommended that more attention be focused on the stable isotope approach at least as a validation of conventional dietary analyses.

The use of isotopic ratios of carbon and nitrogen measured in the tissues of consumers as ecological tracers is mainly based on the fact that: 1) The different primary producers of an ecosystem have different isotopic compositions. These are due to the different fixed nutrients that have different isotopic compositions, the different carbon and nitrogen sources used, and/or the biochemical cycle that these primary producers use for photosynthesis (Peterson and Fry, 1987; Gannes *et al.*, 1998). 2) The enrichment in  $^{13}\text{C}$  and  $^{15}\text{N}$  between a source (prey) and its consumer is relatively predictable for omnivorous consumers and/or carnivores (TEF for "Trophic Enrichment Factor"). It is less important for  $^{13}\text{C}$  (1 ‰) than  $^{15}\text{N}$  (3.4 ‰ on average) (Post, 2002). This TEF may be lower but also more variable in herbivorous consumers and can be used to calculate  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ . Consumer  $\delta^{13}\text{C}$  values are generally used as tracers of their feeding or habitat zone, as their isotopic composition is similar to that of primary producers in the food web to which they belong (France, 1995; Hobson, 1999). Values of  $\delta^{15}\text{N}$  are more used as indicators of the trophic position of organisms in their food chain and largely used to calculate the absolute trophic level species in many ecosystems (Hobson and Welch, 1992; Lesage *et al.*, 2001; Le Loc'h *et al.*, 2008) (Figure 45).

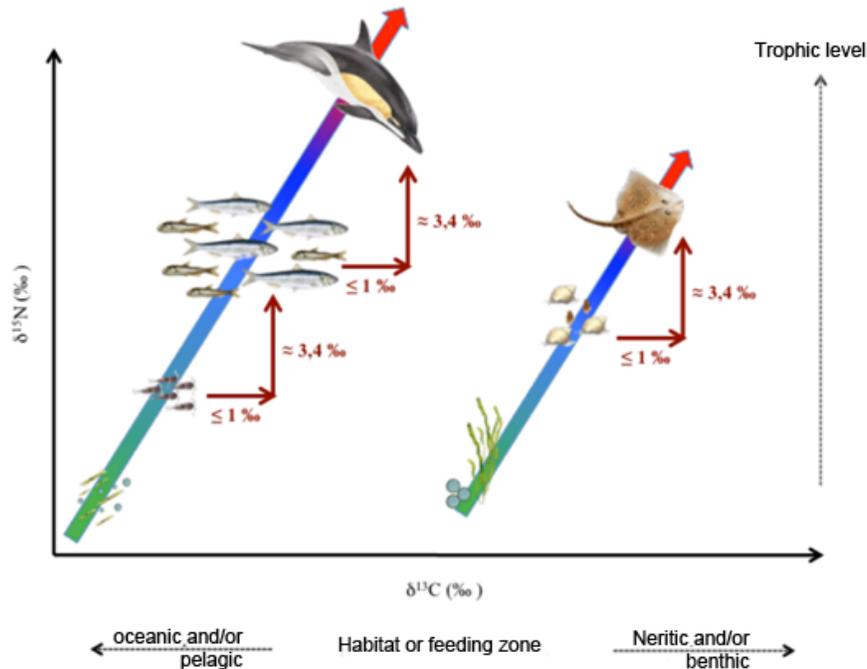


Figure 45: A schematic diagram of the use of stable isotopes of carbon and nitrogen in the marine environment (Chouvelon, 2011)

This study only included stomach content analysis because it is simpler, requires less resources and is less time-consuming owing that this thesis included several study aspects other than dietary analyses. Moreover, no potential prey sampling was performed because most Common Guitarfish were collected from the commercial fishery in Tripoli. Therefore, no data of prey isotopic composition was found.

Sexes and maturity stages were determined macroscopically. Some authors use only macroscopic features to determine the periods of vitellogenesis, gestation and parturition (Abdel-Aziz *et al.*, 1993; Megalofonou and Chatzisyrou, 2006; Ismen *et al.*, 2007b). However, without examining testes and ovaries under light microscopy, such determination remains doubtful. Research by Maruska *et al.* (1996) on batoids demonstrated that the gonado-somatic index and macroscopic observation of the gonads are insufficient measures of reproductive activity. The internal structure of the testis and ovaries each maturity stage should be described histologically to verify the macroscopic maturity scale and to allow for a better understanding of reproduction in terms of maturity acquisition and reproductive cycle. A lot of aspects other than reproductive histology

were performed during the course of this study. Lack of time and sufficient funding prevented such additional biological measures during this thesis.

### **3. General situation and recommendations**

The Lebanese fishing fleet is composed of small scale artisanal vessels less than 12 m in length and typical of many Mediterranean countries (Brême, 2004; Majdalani, 2004; Carpentieri and Colloca, 2005; Majdalani, 2005; Lelli *et al.*, 2006; Martin *et al.*, 2006; PescaMed, 2011; Sacchi and Dimech, 2011). All the effort of the fleet is concentrated within the 6 nautical miles with higher percentage within the 3 nautical miles leading to a high fishing pressure on the coastal fisheries resources (Bariche *et al.*, 2006; Sacchi and Dimech, 2011; Colloca and Lelli, 2012). An estimated 4,850 tons with a value of 26.98 Million USD was landed by all fleet in 2011 (Figure 46). The average price per kilogram of the production in Lebanon was \$5.6 which is relatively high compared to the European prices (\$6.1). The most important channel for the sale of production is the auction market (Pinello and Dimech, 2013).

Formal stock assessments have not been carried out in Lebanon. Fishing practices target juvenile fishes because the market favors the smallest fishes, which are consumed whole and without gutting far (Bariche *et al.*, 2006; Sacchi and Dimech, 2011). The small pelagic fishery constitutes two thirds of the Lebanese landings. This fishery is based on 4 main species including *Engraulis encrasicolus*, *Sardina pilchardus*, *Sardinella aurita* and *Scomber japonicus* (Pinello and Dimech, 2013).

FISHERY	Minor gear < 6 m 	Minor gear 6 - 12 m 	Purse Seine 6 - 12 m 
<b>BENEFITS</b>			
Revenues (value of landings)	\$\$ 4.6 million	\$\$\$\$\$\$\$ 19.3 million	\$\$ 2.9 million
Number of fishers employed	 513	 2,312	 403
Annual catch for human consumption	 528 tons	 2,210 tons	 2,112 tons
Salary per crew	\$\$ 3,261	\$\$ 3,143	\$ 2,210
Annual fuel oil consumption	 641,840 l	 3,414,205 l	 306,869 l
Catch per tonne of fuel consumed	 =  0.8 t	 =  0.6 t	 =  6.9 t
Catch per Unit of Effort (CPUE)	 9.8 Kg /day	 10.2 Kg/day	 206.6 Kg/day

Figure 46: Main results of the survey carried out by Pinello and Dimech (2013) regarding fisheries in Lebanon during 2011

Fishing does not take place beyond the 6 nautical miles; therefore, the fish stocks beyond that can be considered as virgin stocks although their status is not known. Indeed, it is illegal in Lebanon to fish beyond the 6 nautical mile limit, and this is heavily controlled by the Lebanese army and the fishing vessels are not equipped to fish beyond that distance from the coast (Sacchi and Dimech, 2011).

A recent study was conducted in order to have a preliminary idea of situation of stocks beyond the 6 nautical miles. Colloca and Lelli (2012) assessed the potentiality of offshore fishing grounds for local artisanal fishery and conducted a short survey in the area between Tyre and Naqoura in the south, using both monofilament gillnets to target hake (*Merluccius merluccius*) and Spanish traps designed to catch the striped soldier shrimp (*Plesionika edwardsii*). Hake was the most abundant species in the catch with CPUE up to 6.6 kg/km net day in the offshore

sampling stations. The traps for the soldier shrimps gave mean CPUEs of 210-310 g/trap/day, which is higher than those obtained in other parts of the Mediterranean.

No stock assessment or recordings related to chondrichthyan landings have been conducted along the Lebanese coast. Although the majority of fishermen target bony fish, some target elasmobranchs and others land most of their elasmobranch bycatch. No official data is present regarding the precise number of elasmobranchs landed along the Lebanese coast, although 60 tons of elasmobranch landings were recorded in 2003 (Martin *et al.*, 2006). We can hypothesize that the main chondrichthyan bycatch occurs with the minor gear of 6 to 12 m because they are the most operational in Lebanon (Majdalani, 2005).

Furthermore, according to our observations, elasmobranchs are landed and sold in certain regions along the coast, such as Tripoli in the north. Some are observed in fisheries in Sidon, however, not in Tyre, although both mentioned regions are present in the south. It can be inferred that the presence of elasmobranchs in fisheries can be attributed to the society and requirements in each region along the coast. Moreover, the data collected from fisheries is sufficient to agree that management measures should be implemented to limit the capture of elasmobranchs and prohibit the exploitation of those that are threatened according to IUCN.

Consequently, following the present study that reflected the situation of elasmobranchs along the Lebanese coast, certain actions should be taken to induce the conservation and sustainable management of this fish class. It is recommended that research programs on systematics, life history and population dynamics should be carried out in a manner harmless for species of concern (for instance, tagging or use of 'Remotely Operated Underwater vehicle' (ROV). Moreover, critical habitats should be identified and mapped in order to issue laws preventing the capture of chondrichthyans in such areas. The Lebanese Ministry of Agriculture must take action to collect reliable statistics on the landings and bycatch of elasmobranchs to facilitate their future sustainable management. Action plans and research programs must be developed in order to reduce elasmobranch bycatch and initiate fisheries management strategies for commercially exploited species. Bycatches can be limited by targeted spatio-temporal fisheries closures (Dunn *et al.*, 2011), banning total effort and limiting the level of effort, and setting limits on permissible levels of bycatch (Hall, 1996). Hall (1996) reviewed several mitigation measures specific for the management of bycatch. For instance, the latter presented five possible lines of defense available

to reduce bycatches: (1) increasing the selectivity of the fishery by choices of gear, areas, or seasons; (2) modifying deployment conditions; (3) increasing the fraction released alive either from the gear, or (4) later, from the deck; or (5) increasing the utilization to make catches out of the incidental captures.

#### **4. Conclusion and perspectives**

The current study has confirmed the presence of cartilaginous fish species and demonstrated their diversity, although still poorly known. This thesis has collected new information on the fundamental biology of two exploited cartilaginous fishes along the Lebanese coast, allowing for a better understanding of their general ecology particularly to implement decrees specific for their sustainable management and conservation. This study has also shed light to the lack in studies, especially in genetics, distribution, and stock assessment of this fish class in the Eastern Mediterranean. The majority of studies are focused on the life history characteristics of the species' biological cycle, growth, reproduction and nutrition. This thesis confirmed that these fish are caught along the Lebanese coast, where some are sold and others discarded dead at sea. It also reflected the dangers faced by two exploited species (*C. granulatus* and *R. rhinobatos*) that are considered threatened according to IUCN. Accordingly, it is recommended that actions should be implemented to enforce the sustainable management, protection and conservation of chondrichthyans inhabiting the Lebanese coastal waters. It is evident that management and conservation actions will not be accomplished efficiently due to social issues related to the fishermen community. The latter rely on natural fisheries resources for their economic independence and might hinder several conservation action plans. Therefore, such reality must not restrain researchers from providing basic and applied science.

##### **4.1. Perspectives about life history traits and fisheries**

Following this study, it can be interesting to initiate age determination research. Age determination studies have been carried out in several areas of the Mediterranean and have at term succeeded in describing some life history aspects of certain populations. Age estimations can be performed using vertebrae for some species, such as *Rhinobatos rhinobatos* (Ismen *et al.*, 2007b; Basusta *et al.*, 2008), *Torpedo marmorata* (Duman and Basusta, 2013), *Dasyatis pastinaca* (Ismen, 2003), and *Raja radula* (Yigin and Ismen, 2014) or spines for others, such as

*Squalus acanthias* (Avsar, 2001; Bublely *et al.*, 2012). Estimating age allows the calculation of the growth rate, mortality rate and productivity, making it one of the most influential variables for estimating a population's status and assessing the risks associated with overfishing (Cailliet and Goldman, 2004; Goldman, 2005). Unfortunately, this life history characteristic is lacking for most cartilaginous species within the eastern Mediterranean Sea, and absent in our study area; therefore, studies dealing with this topic are indispensable. In this context, dorsal spines of the Gulper Shark collected specimens were preserved in alcohol for further age determination studies using spines.

Moreover, a perspective should address the internal structure of the testis and ovaries each maturity stage histologically to verify the macroscopic maturity scale and to allow for a better understanding of reproduction in term of maturity acquisition and reproductive cycle.

In this study, parasitism was not observed; however, some studying link parasitism to certain life history traits; for instance, the effect cause by parasites on reproductive organs of deep-sea squaloid sharks (Yano and Musick, 2000) or in gill filaments causing energy losses (Benz and Adamson, 1990).

Due to the absence of market follow-ups concerning the process of marketed elasmobranchs, it can be efficient to organize a study dealing with the economic impact of cartilaginous fish production in Lebanese fisheries. Such a topic might display the social demand for elasmobranch meat and summarize the vague social benefits of these fish in Lebanon. This can also aid in regulating the catches and exploitation of these fish, particularly those showing a threatened status.

#### **4.2. New study tools**

In addition, an important perspective of this study will be to validate and complement the cartilaginous fish diversity, distribution and abundance results by using harmless alternative data collection methods. For instance, the usage of a 'Remotely Operated Underwater Vehicle' (ROV) to scan areas, where cartilaginous fish are claimed to be abundant, will be an effective approach. This alternative method will allow to take photographs or videos of live chondrichthyans in their habitat. Moreover, elasmobranch tagging programs can be carried out in this context, if available funds and means are present. Valuable information on a wide variety of

aspects of elasmobranch biology, including life history parameters, stock status, behavioral and distribution patterns, and migration patterns can be provided by tagging studies. The ability to note the presence of a particular fish or group of fish in time and space by marking provides a significant tool to the fishery managers (Rounsefell and Everhart, 1953) and may be the most cost-effective, reliable, and direct means to collect data for studying populations (Everhart and Youngs, 1981; Gordon, 1990). Tags are made of various materials, are sometimes designed for specific species or groups of animals, and have been used with varied success. The most common physical tag is external, with some form of anchor that penetrates the skin or other tissues, and includes a component for recognition of individuals (Bergman *et al.*, 1992). Moreover, Leurs *et al.* (2015) evaluated risks and advantages of using surface laser photogrammetry on Great White Sharks suggesting that this method can successfully increase length estimation, accuracy and illustrates the potential utility of this technique for growth and stock assessments on free-ranging marine organisms. In addition, stereo-video photogrammetry was also used to document swimming and non-swimming behaviors of various life-history stages of the Grey Nurse Shark, *Carcharias Taurus*, in Australia (Smith *et al.*, 2015).

### **4.3. Perspectives about genetic studies**

Furthermore, most studies on elasmobranch population structure have relied on fishery catch data (Fitzmaurice, 1974; Aldebert, 1997) or on tagging programs (Templeman, 1984; Little, 1995; Duarte *et al.*, 2002) to determine species distribution, abundance or dispersal potential and to detect demographic fluctuations. Nonetheless, these approaches cannot completely assess population sub-structuring (e.g. definition of stocks) or clarify the phylogenetic relationship among species. In the last two decades, molecular techniques have been used to address these aspects in a wide range of animal populations, including many fish species (Rocha-Olivares *et al.*, 2000; Takeyama *et al.*, 2001). Molecular genetics have become increasingly important in conservation issues (Alves *et al.*, 2001). For example, the difficulty in identifying species involved has made monitoring the trade of shark-derived products (Chapman *et al.*, 2003; Abercrombie *et al.*, 2005) and preventing quantitative stock assessments (Clarke *et al.*, 2006b) problematic. However, mixtures of genomic DNAs can be used to discriminate protected species from those that are valid commercial taxa (Pank *et al.*, 2001; Shivji *et al.*, 2002; Chapman *et al.*, 2003). Insights from genetic analyses can be useful for addressing population genetic issues, revealing whether two disjunctive populations share a common gene pool (Heist *et al.*, 1995) or

clarifying taxonomic relationships between species (Gardner and Ward, 2002). In this context, an important perspective dealing with cartilaginous fish genetic studies can be addressed along the Lebanese coast in the future. Such studies will be unique for this region and even among the few in the Mediterranean Sea (Hoelzel *et al.*, 2006; Moftah *et al.*, 2011). These studies might permit the differentiation between populations in the eastern and western part of Mediterranean, possibly displaying any genetic changes any chondrichthyan population might have underwent due to several factors. They might also aid in a proper taxonomic structuring of the chondrichthyan populations inhabiting the Lebanese coastal waters. For instance, dispersal ability and associated traits such as habitat preference and size are major factors affecting the population genetic structure of elasmobranchs (Veríssimo *et al.*, 2010; Karl *et al.*, 2011). Significant intraspecific genetic structuring has been reported for small, regionally restricted species, such as *Raja clavata* (Chevolot *et al.*, 2006) or *Squalus acanthias* (Veríssimo *et al.*, 2010), whereas more subtle population differentiation is evident over at least part of the ranges of larger, highly free-swimming, oceanic fish with global distributions, such as *I. oxyrinchus* (Schrey and Heist, 2003), *C. maximus* (Hoelzel *et al.*, 2006) and *R. typus* (Castro *et al.*, 2007; Schmidt *et al.*, 2009). Nevertheless, exceptions to this pattern are caused by environmental factors that directly affect the life history characteristics of fishes (Hauser and Ward, 1998). Moreover, microsatellite analyses of the Blacktip Reef Shark, *Carcharhinus melanopterus*, was performed by Vignaud *et al.* (2013) in French Polynesia and suggested a fragmented habitat for this species in that region. The result of the latter study added emphasis to the case that total bans on shark fishing are a better conservation approach for sharks than marine protected area networks.

Consequently, this study constitutes a basic cornerstone and opens a wide door for many other complementary ones to come. Cartilaginous fish research should be maintained for better understanding, protection and conservation of this fish class in Lebanon. These top predators have a major role in the marine ecosystem. Their loss affects the balance of the ecosystem, and our role, as scientists, is to maintain their protection by compromising between major social demand for these fish and the balance of Mother Nature.

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# **Annex**

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**Annex I: Population Structure and Sexual Maturity of the Pufferfish *Lagocephalus Sceleratus* (Osteichthyes, Tetraodontidae) in the Lebanese and Syrian Marine Waters (Eastern Mediterranean)**

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**Abstract:** The pufferfish *Lagocephalus sceleratus* is an invasive Lessepsian species of Indo-Pacific origin that has established an increasing population over the past decade in the Levantine basin of the Mediterranean. Besides its toxicity due to the accumulation of tetrodotoxin in its body, it is causing damage to fishing gears and fishermen's catches. This study aims to provide data on the population structure and sexual maturity of this species in the eastern basin of the Mediterranean. A total of 214 individuals were collected in the coastal marine waters of Lebanon and Syria, between January 2012 and June 2013 by means of different types of nets and lines, on soft bottoms, at depths ranging from 10 m to 170 m. The TL (total length) of the samples varies between 10.8 cm and 71 cm. The most common size classes, represented by 125 individuals, are the ones between 30 cm and 50 cm TL, with a bulge at 40 cm, represented by 44 individuals. The average TL is 43.99 cm (standard deviation:  $SD = 17.65$ ) for both males and females. The TW (total weight) of the specimens ranges between 14 g and 4,603 g with an average value of 1,458.52 g ( $SD = 1,329.49$ ). The sex ratio (M/F) is 1:1.35 with a total number of 87 males, 118 females and nine unidentified individuals. The length-weight relationship ( $TW = aTL^b$ ) shows a negative allometric growth with  $b = 2.9481$  and  $R^2 = 0.9806$ . The condition factor ( $K$ ) is close to one for all samples. The average value of the GSI (gonadosomatic index) shows a substantial increase from winter to spring. The spawning takes place between April and June.

**Key words:** *Lagocephalus sceleratus*, Lessepsian species, population structure, eastern Mediterranean.



# Population Structure and Sexual Maturity of the Pufferfish *Lagocephalus sceleratus* (Osteichthyes, Tetraodontidae) in the Lebanese and Syrian Marine Waters (Eastern Mediterranean)

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**Key words:** *Lagocephalus sceleratus*, Lessepsian species, population structure, eastern Mediterranean.

## 1. Introduction

The Mediterranean Sea is home to numerous invasive marine species, some of which have already established prosperous populations. These invasive species might have entered through several routes: the Suez Canal, the Gibraltar Strait, ship ballast water, accidental release and other means. Nevertheless, the Suez Canal is considered the major route for migrating indo-pacific species, also referred to as Lessepsian

species, from the Red Sea into the Mediterranean. In total, the number of alien species has reached more than 790 in the Mediterranean Sea, with some of the invaders through the Suez Canal having been very successful colonizers of Mediterranean marine ecosystems [1-5]. The ichthyofaunal profiles of the eastern Mediterranean Sea, especially of the Levantine sub-basin, have been severely affected by Lessepsian migration [6-8].

The pufferfish *Lagocephalus sceleratus* commonly known as the silver-cheeked toadfish is a widely distributed species inhabiting the tropical Indian and Pacific Oceans, from which it originated. It made its

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way to the Mediterranean through the Suez Canal. It invaded the eastern Mediterranean during the last decade causing damages to fishing gears and fishermen's catches. A record in February 2003 from Gokova Bay in the southern Aegean coast of Turkey [9] demonstrated for the first time the presence of this species in the Mediterranean Sea. A previous record from the Mediterranean Sea by Mouneimne [10] was a misidentification of *L. suezensis* [11]. The rapid expansion of *L. sceleratus* can be easily observed as the fish had reached the North Aegean Sea in 2006, three years after it was reported in Turkey in 2003 [12-15]; four years later in 2010, it was observed at the southern end of the Gulf of Gabès in Tunisia (central Mediterranean) [16]. Today, it is regarded to be among the worst invasive species in the Mediterranean Sea with a significant impact on the surrounding ecosystem and on the fisheries sector [2, 17-19].

Like other puffer fishes, it is capable of inflating its body by swallowing water. It has two strong teeth in each jaw which are capable of ripping and damaging fishing nets lines and long lines. In the Mediterranean, this fish was found to be voracious and carnivorous, feeding mainly on shrimps, crabs, fish—including individuals of its own species—and cephalopods [20-21]. Today, it is regarded to be among the most destructive invasive species in the Mediterranean Sea with a significant impact on the surrounding ecosystem and on the fisheries sector [2, 17-19].

*L. sceleratus* is considered to be a serious hazard to consumers since it contains a strong paralytic marine toxin called TTX (tetrodotoxin), which can be lethal to humans [12, 13, 22-24]. Occasional accidental intoxications, including deaths, have been reported from all over the world due to eating pufferfish. The majority of reported cases have occurred in southeastern Asia including Malaysia, Taiwan and Hong Kong [25-27] and the Red Sea [22, 28]. In Egypt, although landing of this fish is forbidden as commercial species, they are illegally collected and

consumed as food in the Red Sea and Gulf of Suez areas. Zaki [28] described the clinical manifestations, age, sex and time elapsed between the ingestion and the death of eight cases due to pufferfishes poisoning in Suez City. In the eastern Mediterranean, many cases of TTX poisoning have been reported [23]. In 2005, two cases of human intoxication due to the consumption of pufferfish were recorded in Lebanon.

The aim of the current study is to provide essential data and basic information on population structure and sexual maturity of the pufferfish along the Lebanese and Syrian coastal waters.

## **2. Material and Methods**

This study was performed along the Lebanese and Syrian coastal zone located in the Levantine basin of the eastern Mediterranean Sea (Fig. 1). The length of the coast line is 390 km (220 km in Lebanon and 170 km in Syria). The mean surface water temperature in the study area ranges from 16 °C to 18 °C in winter, 22 °C to 24 °C in autumn and spring reaching 29 °C in summer. Salinity is constant throughout the year and ranges between 39.4 and 39.8. Specimens of the pufferfish *L. sceleratus* were collected from commercial catches at the principal fishing ports of Lebanon and Syria between January 2012 and June 2013. The collection of samples was performed by professional fishermen using different fishing gears such as beach seines, encircling trammels, gillnets and long lines. These gears were lowered at depths ranging from 10 m to 200 m. All samples were placed in labeled plastic bags, transported to the laboratory immersed in crushed ice and then processed. For each fish, the TL (total length) was measured to the nearest 0.1 cm and TW (total weight) to the nearest 0.1 g. Sex and maturity stages were determined macroscopically, and the GW (weight of the gonads) was recorded to the nearest 0.01 g. Stages of maturity were classified as follows: (1) immature; (2) developing; (3) mature, spawning; (4) regressing; (5) regenerating [22]. The spawning season was determined following the monthly

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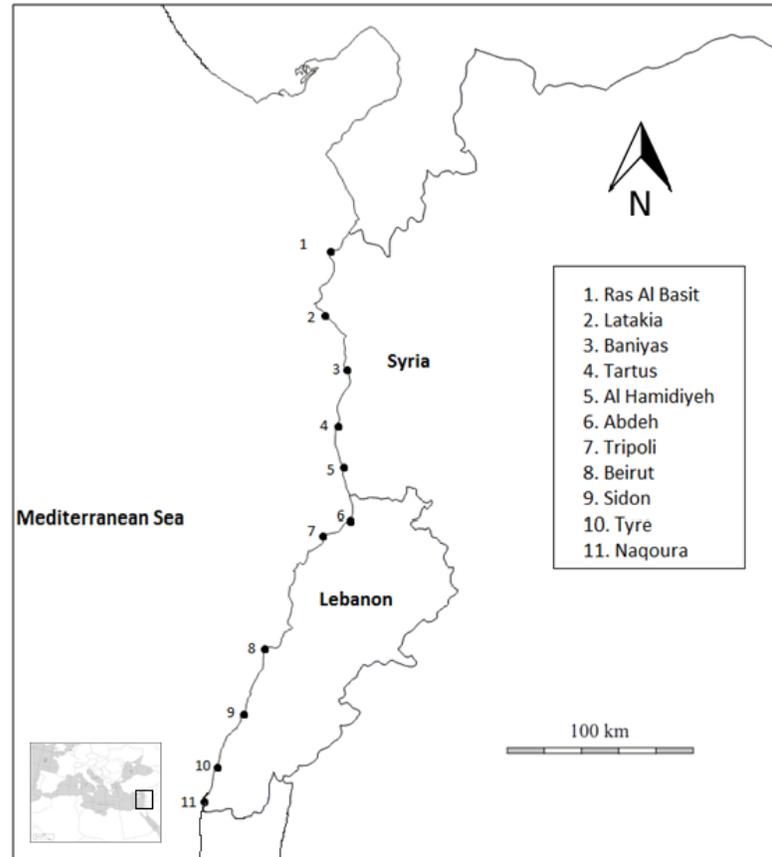


Fig. 1 Sampling stations performed along the Lebanese and Syrian coasts.

changes of the GSI (gonadosomatic index), calculated as follows  $GSI = 100GW/TW$  [29].

The overall sex ratio of the sampled population was analyzed. The length-weight relationship was calculated for all the sampling period according to the following equation:

$$TW = aTL^b$$

where,  $TW$  is the total weight,  $a$  is the intercept of the relationship,  $TL$  is the total length and  $b$  is the slope. The variations in the condition factor ( $K$ ) were calculated according to Ref. [30],  $K = TW/TL^3 \times 100$  where  $b$  is the constant resulting from the length-weight relationship. Length-frequency histograms were constructed with individuals grouped into 5 cm size class.

### 3. Results

A total of 214 individuals were collected (118

females, 87 males and nine undetermined) and examined during the study period. The TL for all individuals ranged from 10.8 cm to 71 cm with a mean length of  $43.99 \pm 17.65$  cm. The mean length for females was  $46.12 \pm 17.97$  cm, and  $39.62 \pm 17.53$  cm for males. The TW ranged from 14 g to 4,603 g with a mean weight of  $1,458.52 \pm 1,329.49$  g. The mean weight was  $1,701 \pm 1,535.17$  g for females and  $1,413.83 \pm 1,026.89$  g for males (Table 1).

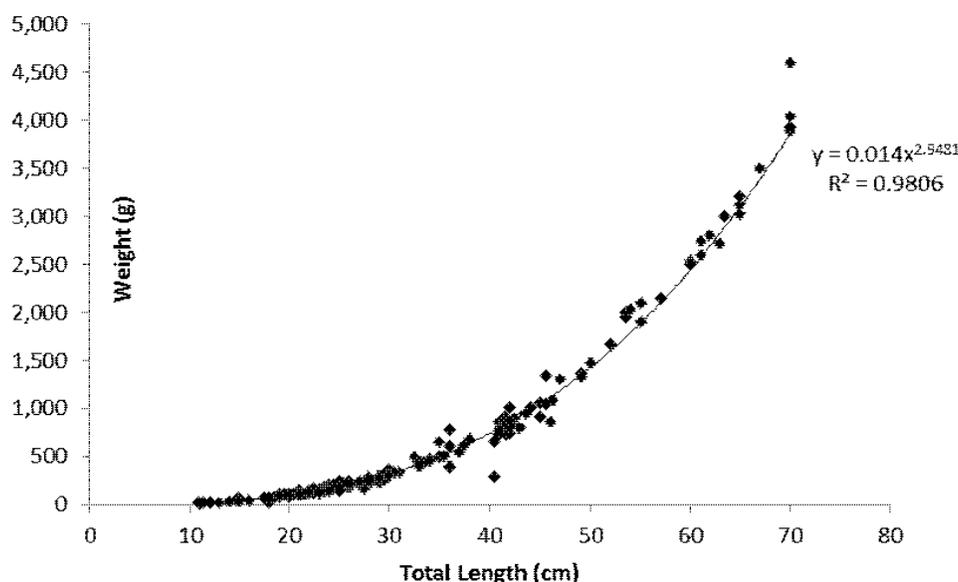
The individuals of *L. sceleratus* were generally caught over soft bottoms, the preferred habitat for this species [13, 31], at depths ranging from 10 m to 170 m.

The overall sex ratio of males to females was 1:1.35, which is not significantly different from 1:1 ( $P > 0.05$ ) and indicated a well-balanced population in the eastern Mediterranean Sea [22]. The females dominated the catch in all the study period.

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**Table 1** Mean, minimum and maximum values for length and weight of the female and male specimens of *L. sceleratus*.

	Number of individuals	Length (cm)			Weight (g)		
		Mean and <i>SD</i>	Minimum	Maximum	Mean and <i>SD</i>	Minimum	Maximum
Total	214	43.99 ( <i>SD</i> = 17.65)	10.8	71	1,458.52 ( <i>SD</i> = 1,329.4)	14	4,603
Females	118	46.12 ( <i>SD</i> = 17.97)	10.8	70	1,701.68 ( <i>SD</i> = 1,535.1)	16	4,603
Males	87	39.62 ( <i>SD</i> = 17.53)	15	71	1,413.83 ( <i>SD</i> = 1,026.8)	37.40	3,000
ND	9	52.37 ( <i>SD</i> = 16.14)	11	36	142 ( <i>SD</i> = 217.39)	14	393



**Fig. 2** The length-weight relationship of the *L. sceleratus*.

Length-weight relationships are important in fisheries biology because they allow the estimation of the average weight of the fish at a given length, by establishing a mathematical relationship between weight and length. The overall length-weight relationship for both males and females of *L. sceleratus* (Fig. 2) showed a good fit to the exponential curve ( $R^2 = 0.9806$ ); the values of  $a$  and  $b$  were 0.014 and 2.9481, respectively.

The length-frequency histogram shows that 58% (125 individuals) of the catches are between 30 cm and 50 cm size class. No individuals were caught in the size classes of 25 cm and 55 cm. The majority of classes were dominated by females, with the exception of size class 40 cm that held the highest number of individuals (44 ind.) and where the number of males was identical to the number of females, and size

classes 45 cm and 50 cm, where the males were more numerous (Fig. 3).

The period of reproduction for both males and females was reconstructed by examining the temporal variation of both gonad maturity stages and gonadosomatic index. In order to exclude all immature individuals and minimize bias, only fish with TL above 100% maturity were considered. According to the gonad maturity stages (Fig. 4), 32% (69 ind.) of the individuals caught were mature. The stages of developing and mature individuals represented 61% (132 ind.) of the total sample; only 8% (17 ind.) and 9% (19 ind.) of the caught individuals corresponded to the stages regressing and regenerating individuals.

According to size classification (Fig. 3), the length at which 50% of *L. sceleratus* individuals had reached maturity was 44.4 cm.

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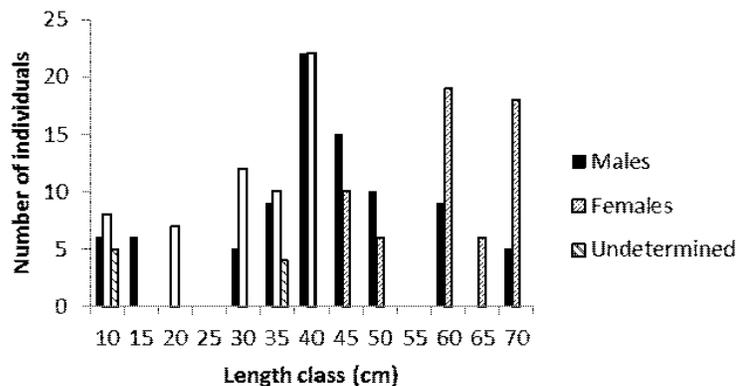


Fig. 3 The length-frequency distribution of the *L. sceleratus* sample caught along the Lebanese and Syrian coasts.

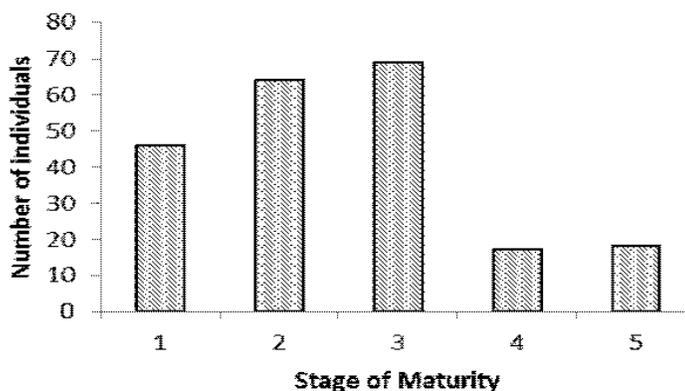


Fig. 4 The number of individuals according to the stages of maturity.

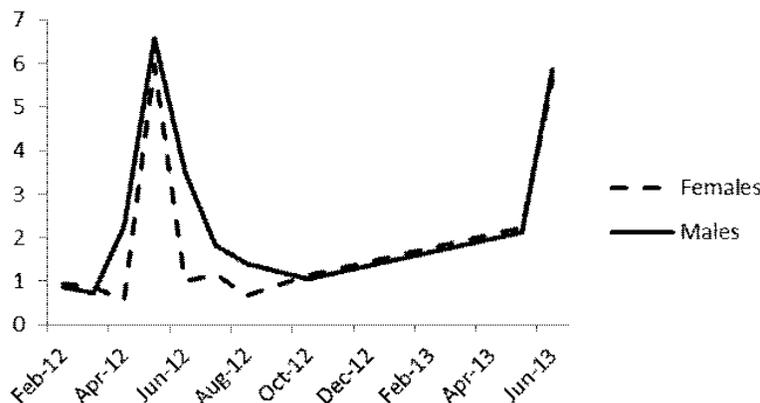


Fig. 5 The GSI (gonado-somatic index) for the males and females of the *L. sceleratus* sample caught along the Lebanese and Syrian coasts (12 = 2012, 13 = 2013).

The average values of GSI results (Fig. 5) showed a substantial increase from winter to spring. The maximum values were recorded between April and July for males and between April and June for females

indicating that *L. sceleratus* has an extensive spawning season. Males and females in the regressing stage were found during the months of summer, while the regenerating stages were observed during autumn

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and winter. *L. sceleratus* was found to have a similar average condition factor ( $K$ ) close to 1 throughout the year with only summer possessing higher values among the seasons for males.

#### 4. Discussions and Conclusions

The longest individual's length examined in our case (71 cm) is higher than that reported by Chan [32] (18 cm) in Malaysia, and relatively higher than those observed by Kalogirou [31] (64 cm) in the coastal habitats of Rhodes Island, by Ashkar [23] (60 cm) on the Israeli coast and by Aydin [21] in Antalya Bay (65 cm); however, it was smaller than that reported by Sabrah et al. [22] in the Gulf of Suez (78.5 cm). According to Takeda [33] and Masuda et al. [34], pufferfish can reach 110 cm. The mean length of females ( $46.12 \pm 17.65$  cm) was significantly higher than that observed for males ( $39.62 \pm 17.52$  cm) and females were also significantly heavier than males. These results coincide with those obtained by Sabrah et al. [22] and Kalogirou [31] but are higher than those observed by Aydin [21] in Antalya Bay. Moreover, the maximum weight of fish observed in the present study (4,603 g) is higher than that observed by Aydin [21] (3,465 g) and lower than that reported by Smith and Heemstra (7,000 g) [35].

The depth distribution of the *L. sceleratus* in this study is wider than that observed by May and Maxwell [36] who had found this species in tropical waters at depths ranging from 18 m to 100 m, but lower than that observed by Yaglioglu et al. [37] at 250 m in the Red Sea. Fig. 6 shows that 94% (202 ind.)

of individuals occupy depths less than 100 m, with a relatively high density in depths ranging from 20 m to 60 m (68%; 147 ind.), and only 12 individuals occupy depths ranging from 100 m to 170 m. In fact, only one individual was caught at the latter depth. The presence of this species at depths greater than 100 m is probably due to feeding because shallow waters in this region are known to be oligotrophic [38, 39].

The value of the length-weight relationship for both males and females of *L. sceleratus* revealed negative allometric growth in all individuals. The  $a$  and  $b$  values resulting from this study correspond to the values obtained by all of Sabrah et al. [22], in the Gulf of Suez, Edelist [40] from the Israeli coast, Aydin [21] in Antalya Bay and Kalogirou [31] from Rhodes Island, who obtained similar growth patterns. However, this result does not correspond to that obtained by Anderson and Neuman [41] and Froese [42] who found that the fish is growing at the same rate in weight and length.

The length classes' distribution shows that 30 cm to 50 cm size class represents 58% of the collected specimens in accordance with that observed by Kalogirou [31] who found that 57% of catches belonged to the size class 30-40 cm on *Posidonia oceanica* habitats and 56% of catches belonged to the size class 20-30 cm on sandy bottom.

The size of reached maturity in this study (45 cm) is agreed with that observed by Sabrah et al. [22] in the Gulf of Suez (42-43 cm), and higher than that observed by Kalogirou [31] in the coastal habitats of Rhodes Island (36 cm).

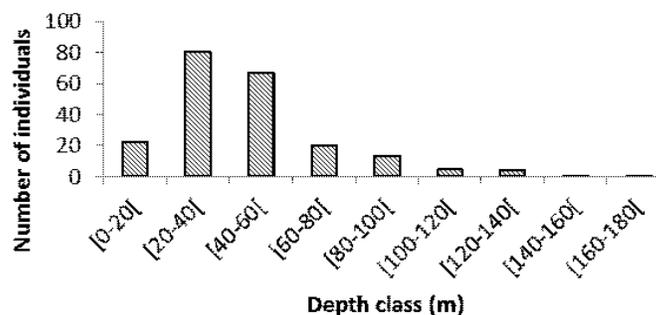


Fig. 6 The number of individuals of the *L. sceleratus* sample according to depths.

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In this study, the spawning period, occurring between April and July, coincides with that observed by Aydin [21] in Antalya Bay. However, it started earlier than that observed by Sabrah et al. [22] in the Gulf of Suez and by Kalogirou [31] in the coastal habitats of Rhodes Island, who noted that this period occurred in summer. The precocious sexual maturity is probably due to the influence of higher values of temperature and salinity parameters in the part of the eastern Mediterranean region extended from Antalya to south of Lebanon [43-45]. *L. sceleratus* has undergone very rapid geographical expansion in the Mediterranean; in 10 years it has invaded the eastern basin of the Mediterranean and made landfall in the Tunisian Central Mediterranean [16]. Its growth is exponential; it occupies almost all habitats with preference for soft bottoms and can be found at depths reaching 250 m. It causes damage to fishermen by attacking fishing nets and caught fish. Several cases of poisoning have been reported due to the consumption of parts of this animal containing TTX. If fishing and consumption of this species remains tacit in some countries such as Japan [46] and Egypt [22], all the Mediterranean countries shall recommend legislating and prohibiting fishing for this animal. Regular monitoring for the presence of this species in the Mediterranean must be performed to control its geographical distribution and limit the damage it can cause.

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## Annex II: The classification of the class Chondrichthyes according to Nelson, 2006

Class **Chondrichthyes: cartilaginous fishes**

<p><b>Order</b> Chimaeriformes</p> <p><b>Families</b> Callorhynchidae Rhinochimaeridae Chimaeridae</p>	<p><b>chimaeras</b></p> <p>plownose chimaeras longnose chimaeras shortnose chimaeras or ratfishes</p>	<p><b>Order</b> Heterodontiformes</p> <p><b>Family</b> Heterodontidae</p>	<p>bullhead sharks bullhead sharks</p>
<p><b>Order</b> Orectolobiformes</p> <p><b>Families</b> Parascyllidae Brachaeluridae Orectolobidae Hemiscyllidae Stegostomatidae Ginglymostomatidae Rhincodontidae</p>	<p><b>carpet sharks</b></p> <p>collared carpet sharks blind sharks wobbegongs bamboo sharks zebra shark nurse sharks whale sharks</p>	<p><b>Order</b> Lamniformes</p> <p><b>Families</b> Odontaspidae Mitsukurinidae Pseudocarchariidae Megachasmidae Alopiidae Cetorhinidae Lamnidae</p>	<p><b>mackerel sharks</b></p> <p>sand tiger sharks goblin sharks crocodile sharks megamouth sharks thresher sharks basking sharks mackerel sharks</p>
<p><b>Order</b> Carcharhiniformes</p> <p><b>Families</b> Scyliorhinidae Proscyllidae Pseudotriakidae Leptochariidae Triakidae Hemigaleidae Carcharhinidae Sphyrnidae</p>	<p><b>ground sharks</b></p> <p>cat sharks finback cat sharks false cat sharks barbeled hound sharks hound sharks weasel sharks requiem sharks hammerhead sharks</p>	<p><b>Order</b> Hexanchiformes</p> <p><b>Families</b> Chlamydoselachidae Hexanchidae</p>	<p><b>six-gill sharks</b></p> <p>frill sharks cow sharks</p>
<p><b>Order</b> Echinorhiniformes</p> <p><b>Family</b> Echinorhinidae</p>	<p><b>bramble sharks</b></p> <p>bramble sharks</p>	<p><b>Order</b> Squaliformes</p> <p><b>Families</b> Squalidae Centrophoridae Etmopteridae Somniosidae Oxynotidae Dalatiidae</p>	<p><b>dogfish sharks</b></p> <p>dogfish sharks gulper sharks lantern sharks sleepers sharks rough sharks kitefin sharks</p>
<p><b>Order</b> Squatiniformes</p> <p><b>Family</b> Squatinidae</p>	<p><b>angel sharks</b></p> <p>angel sharks</p>	<p><b>Order</b> Pristiophoriformes</p> <p><b>Family</b> Pristiophoridae</p>	<p><b>saw sharks</b></p> <p>saw sharks</p>
<p><b>Order</b> Torpediniformes</p> <p><b>Families</b> Torpedinidae Narcinidae</p>	<p><b>electric rays</b></p> <p>torpedo electric rays numbfishes</p>	<p><b>Order</b> Pristiformes</p> <p><b>Family</b> Pristidae</p>	<p><b>sawfishes</b></p> <p>sawfishes</p>
<p><b>Order</b> Rajiformes</p> <p><b>Families</b> Rhinidae Rhynchobatidae Rhinobatidae Rajidae</p>	<p><b>skates</b></p> <p>bowmouth guitarfishes wedgfishes guitarfishes skates</p>	<p><b>Order</b> Myliobatiformes</p> <p><b>Families</b> Platyrrhinidae Zanobatidae Hexatrydonidae Plesiobatidae Urolophidae Urotrygonidae  Dasyatidae Potamotrygonidae Gymnuridae Myliobatidae</p>	<p><b>stingrays</b></p> <p>thornbacks panrays sixgill stingrays deepwater stingrays round stingrays American round stingrays whiptail stingrays river stingrays butterfly rays eagle rays</p>

**Subclass: Holocephali**

**Subclass: Elasmobranchii**

Annex III: The law related to chondrichthyan fishing in the Lebanese government

## The Lebanese government

### Ministry of Agriculture

قرار رقم 1/ 1045

شروط عامة لصيد اسماك القرش/كلاب البحر

إن وزير الزراعة،

بناء على المرسوم رقم 11217 تاريخ 2014/2/15 (تشكيل الحكومة) ،

بناء على القانون الصادر بقرار رقم 2775 تاريخ 28 أيلول 1929 (مراقبة الصيد البحري والساحلي)،

بناءً على القانون رقم 613 تاريخ 2004/11/20 (الاجازة للحكومة ابرام التعديلات المتعلقة باتفاقية انشاء الهيئة العامة لمصايد اسماك البحر الابيض المتوسط)،

بناءً على القانون رقم 34 تاريخ 2008/10/16 (الاجازة للحكومة الانضمام الى اتفاقية حماية البيئة البحرية والمنطقة الساحلية للبحر المتوسط)،

بناء على توصية الهيئة العامة لمصايد البحر الابيض المتوسط (GFCM/36/2012/3)،

بناء على [المرسوم رقم 5246 تاريخ 1994/6/20](#) (تنظيم وزارة الزراعة) لا سيما المادة 100 منه،

بناء على مطالعة رئيس دائرة الصيد المائي بالتكليف،

بناء على اقتراح مدير عام الزراعة بالإنابة،

وبعد استشارة مجلس شورى الدولة (الرأي رقم 2013/109-2014 تاريخ 2014/3/24، والرأي رقم

2014/273-2015 تاريخ 2014/10/27)،

يقرر ما يأتي:

**المادة الأولى:** يمنع صيد او التقاط او نقل او بيع او استهلاك او خزن اسماك القرش/كلاب البحر التالية:

الاسم العلمي	الاسم الانكليزي	الاسم العربي
<i>Galeorhinus galeus</i>	Tope shark	كلب بحر
<i>Isurus oxyrinchus</i>	Shortfin mako	كلب بحر
<i>Lamna nasus</i>	Porbeagle	كلب بحر
<i>Leucoraja circularis</i>	Sandy ray	بقرة
<i>Leucoraja melitensis</i>	Maltese ray	بقرة
<i>Rhinobatos cemiculus</i>	Blackchin guitarfish	مرّ
<i>Rhinobatos rhinobatos</i>	Common guitarfish	مرّ
<i>Sphyrna lewini</i>	Scalloped hammerhead	قرش ابومطرقة
<i>Sphyrna mokarran</i>	Great hammerhead	قرش ابومطرقة
<i>Sphyrna zygaena</i>	Smooth hammerhead	قرش ابومطرقة/اسكندر

**المادة الثانية:** يتوجب على الصيادين بحال التقاطهم أي من اسماك القرش/كلاب البحر المذكورة اعلاه حية ان يعمدوا الى اطلاق سراحها فوراً (وبعد نزع الصنابير منها اذا وجدت) بطريقة تمنع تعرضها للخطر. كما يتوجب عليهم رمي اسماك القرش/كلاب البحر الميتة فوراً في البحر.

**المادة الثالثة:** يتوجب على الصيادين بحال التقاطهم أي من اسماك القرش/كلاب البحر، حية او ميتة، خلال عمليات الصيد ان يعلموا دائرة الصيد المائي والبري او مصالح وزارة الزراعة الاقليمية بنوع وعدد هذه الاسماك.

**المادة الرابعة:** يجب على الصيادين اتخاذ كافة الاجراءات الممكنة لتجنب صيد او التقاط اسماك القرش/كلاب البحر المذكورة اعلاه.

**المادة الخامسة:** يمنع قطع او نقل او عرض او بيع او استهلاك او خزن زعانف كل انواع اسماك القرش/كلاب البحر.

**المادة السادسة:** يمنع قطع او نقل او عرض او بيع او استهلاك او خزن كل انواع اسماك القرش/كلاب البحر المقطوع رأسها و/او المسلوخ جلدها.

**المادة السابعة:** يعمل بهذا القرار فور صدوره، ويبلغ حيث تدعو الحاجة.

بيروت في 2014/11/25

**تبلغ نسخة إلى:**

وزير الزراعة

اكرم شهاب

- رئاسة مجلس الوزراء
- وزارة الداخلية والبلديات
- وزارة الدفاع الوطني
- وزارة الأشغال العامة والنقل
- وزارة البيئة
- وزارة الاقتصاد - مديرية حماية المستهلك
- الجريدة الرسمية (للتفضل بالنشر)
- مديرية التنمية الريفية والثروات الطبيعية
- المصالح الإقليمية
- نقابات وتعاونيات الصيادون (بواسطة المصالح الإقليمية)
- المحفوظات

**Annex IV:** List of abbreviations of all parameters along with their units of measurement in the order of their appearance in Chapter 2: Materials and Methods.

<b>Parameter Abbreviation</b>	<b>Full name</b>	<b>Measurement unit</b>
$L_C$	External length of claspers	Millimeters (mm)
$L_T$	Total length	Centimeters (cm)
$L_F$	Fork length	Centimeters (cm)
$L_S$	Standard length	Centimeters (cm)
$W_T$	Total weight	Grams (g)
$W_L$	Weight of the liver	Grams (g)
$W_G$	Weight of the gonads	Grams (g)
$W_E$	Eviscerated weight	Grams (g)
$I_H$	Hepato-somatic index	
$I_G$	Gonado-somatic index	
$K$	Condition factor	
$W_S$	Weight of the stomach	Grams (g)
$C_V$	Coefficient of vacuity	
$E_V$	Number of empty stomachs	
$F_I$	Percentage of fullness	Percent (%)
$W_P$	Weight of prey items in each stomach	Grams (g)
$O_{\%}$	The frequency of occurrence	Percent (%)
$N_P$	The number of stomachs containing a specific prey group	
$M$	The number of stomachs with prey remains	
$N_{\%}$	The coefficient of prey numerical abundance	Percent (%)
$n$	The number of prey of each taxonomic group	
$n_P$	The total number of prey items	

$W_{\%}$	The percentage of weight	Percent (%)
$m$	The mass of prey of each taxonomic group	Grams (g)
$m_P$	The total mass of prey items	
$I_{RI}$	Index of relative importance	
$I_{\%RI}$	Percent of $I_{RI}$	Percent (%)
$L_F$	Fork length	Centimeters (cm)
$L_S$	Standard length	Centimeters (cm)
$CPUE_{kg,G,M}$	Catch Per Unit Effort in kilograms according to each meshed gear (Index $G$ : gear; Index $M$ : mesh)	Kilograms per unit effort (kg/unit effort)
$N_{Ci,G,M}$	The total number of cartilaginous species $i$ caught in the same meshed gear or longline also in the predetermined haul	
$CPUE_{number,G,M}$	Catch Per Unit Effort in number according to each meshed gear (Index $G$ : gear; Index $M$ : mesh)	Number per unit effort (num/unit effort)
$E$	Effort	
$S$	The total number of species recorded in the sample	
$N$	The total number of individuals in the same sample	
$H'$	Shannon Index	
$p_i$	The proportion of individuals found in the $i$ th species	
$n_i$	The total number of individuals in the $i$ th species	
$J'$	Shannon evenness measure (Pielou's evenness)	
$H_{max}$	The maximum diversity where all	

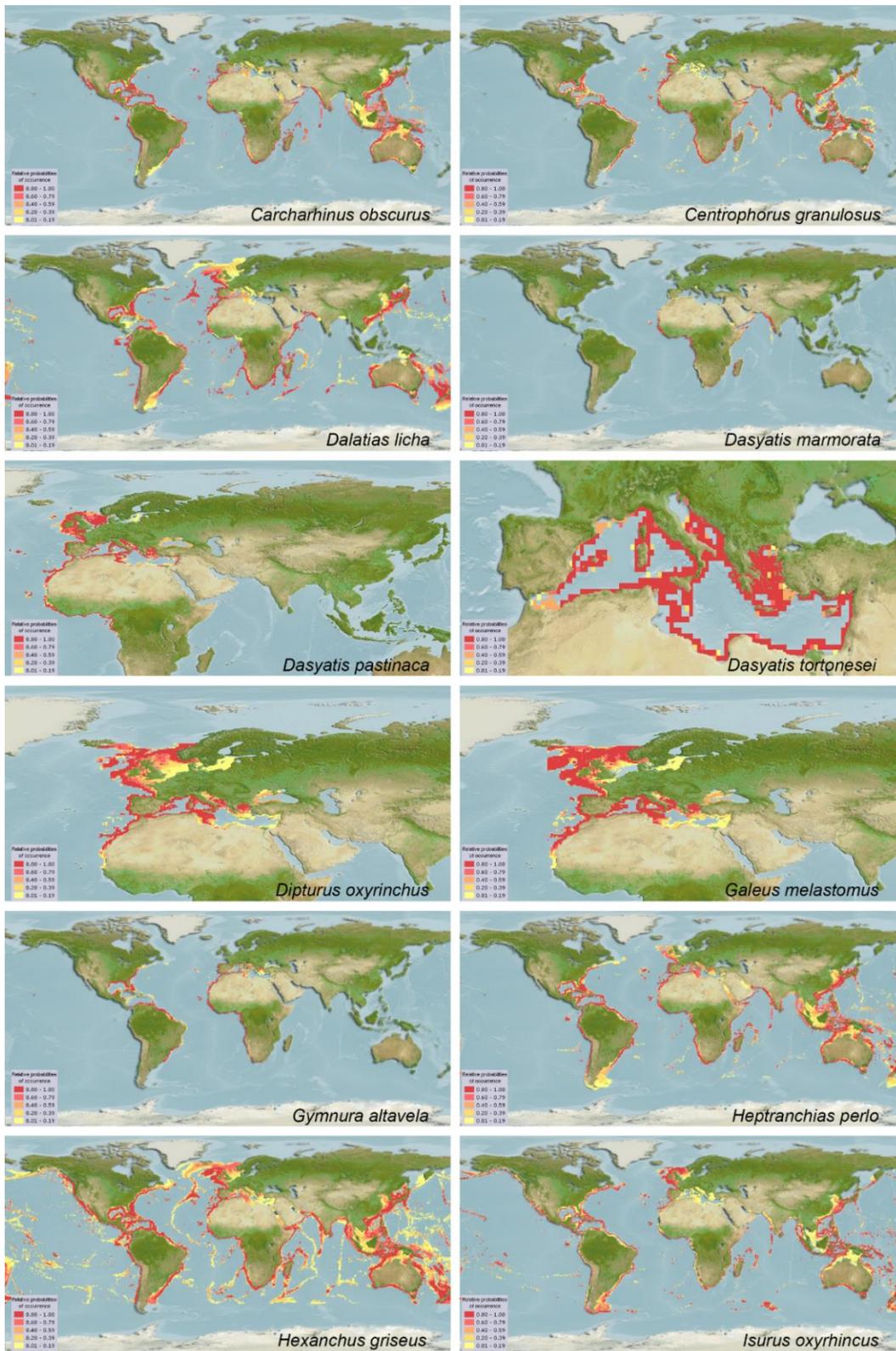
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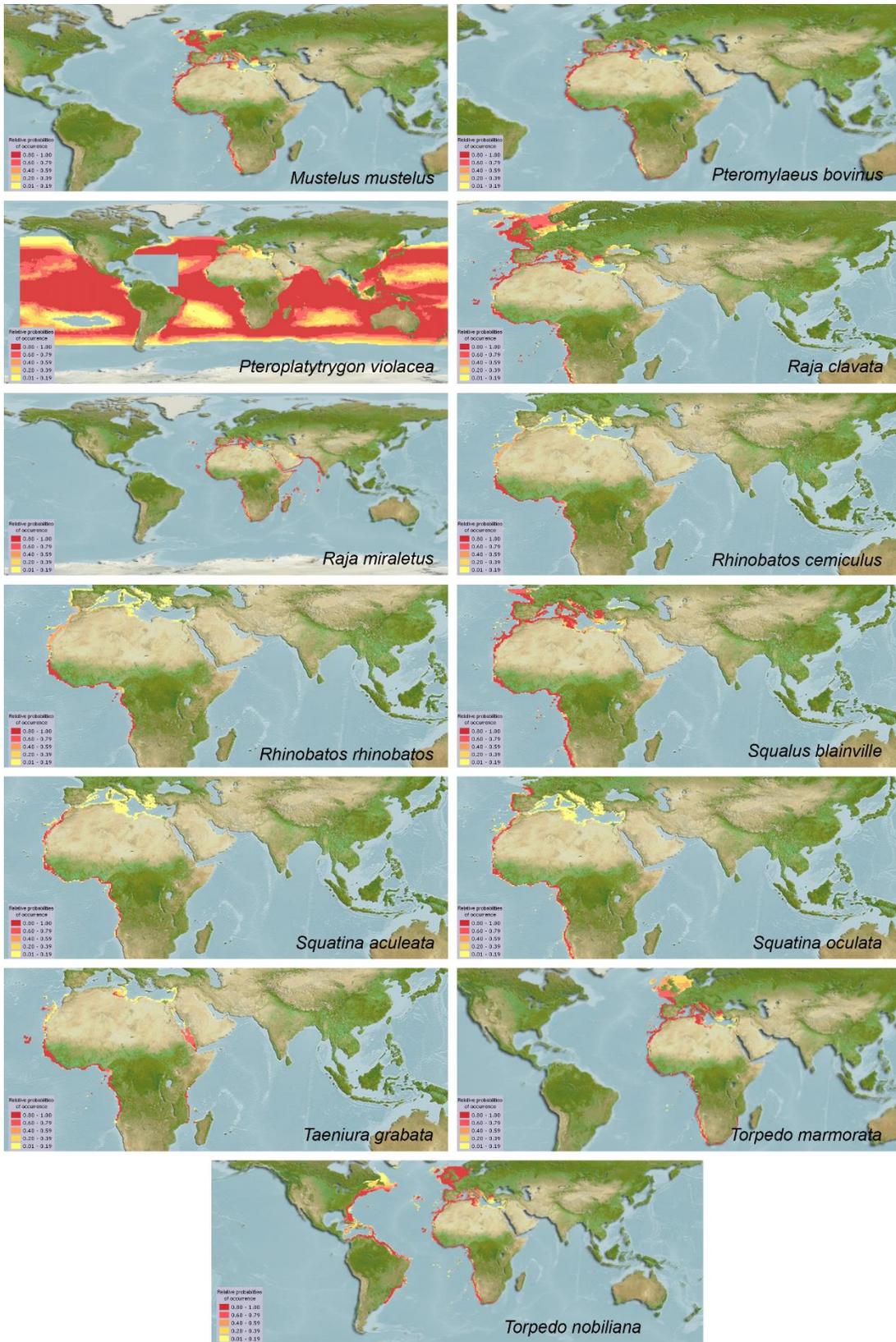
	species had equal abundances	
<b>1-D</b>	Simpson's Index	
$\Delta^+$	Taxonomic diversity/distinctness	
<b>P</b>	The proportion of mature elasmobranch specimens in each determined length class	

**Annex V:** Table containing all the species classified up to their class used to calculate the taxonomic distances using the function *taxa2dist* on ‘R project’

<b>Species</b>	<b>Genus</b>	<b>Family</b>	<b>Order</b>	<b>Class</b>
<i>aculeata</i>	<i>Squatina</i>	Squatinaidae	Squatiniiformes	Chondrichthyes
<i>obscurus</i>	<i>Carcharhinus</i>	Carcharhinidae	Carcharhiniiformes	Chondrichthyes
<i>granulosus</i>	<i>Centrophorus</i>	Centrophoridae	Squaliformes	Chondrichthyes
<i>licha</i>	<i>Dalatias</i>	Dalatidae	Squaliformes	Chondrichthyes
<i>marmorata</i>	<i>Dasyatis</i>	Dasyatidae	Myliobatiformes	Chondrichthyes
<i>pastinaca</i>	<i>Dasyatis</i>	Dasyatidae	Myliobatiformes	Chondrichthyes
<i>tortonesei</i>	<i>Dasyatis</i>	Dasyatidae	Myliobatiformes	Chondrichthyes
<i>oxyrinchus</i>	<i>Dipturus</i>	Rajidae	Rajiformes	Chondrichthyes
<i>melastomus</i>	<i>Galeus</i>	Scyliorhinidae	Carcharhiniiformes	Chondrichthyes
<i>altavela</i>	<i>Gymnura</i>	Gymnuridae	Myliobatiformes	Chondrichthyes
<i>perlo</i>	<i>Heptranchias</i>	Hexanchidae	Hexanchiformes	Chondrichthyes
<i>griseus</i>	<i>Hexanchus</i>	Hexanchidae	Hexanchiformes	Chondrichthyes
<i>oxyrhincus</i>	<i>Isurus</i>	Lamnidae	Lamniformes	Chondrichthyes
<i>mustelus</i>	<i>Mustelus</i>	Triakidae	Carcharhiniiformes	Chondrichthyes
<i>bovinus</i>	<i>Pteromylaeus</i>	Myliobatididae	Myliobatiformes	Chondrichthyes
<i>violacea</i>	<i>Pteroplatytrygon</i>	Dasyatidae	Myliobatiformes	Chondrichthyes
<i>clavata</i>	<i>Raja</i>	Rajidae	Rajiformes	Chondrichthyes
<i>miraletus</i>	<i>Raja</i>	Rajidae	Rajiformes	Chondrichthyes
<i>cemiculus</i>	<i>Rhinobatos</i>	Rhinobatidae	Rajiformes	Chondrichthyes
<i>rhinobatos</i>	<i>Rhinobatos</i>	Rhinobatidae	Rajiformes	Chondrichthyes
<i>blainvillei</i>	<i>Squalus</i>	Squalidae	Squaliformes	Chondrichthyes
<i>oculata</i>	<i>Squatina</i>	Squatinaidae	Squatiniiformes	Chondrichthyes
<i>grabata</i>	<i>Taeniura</i>	Dasyatidae	Myliobatiformes	Chondrichthyes
<i>Tmarmorata</i>	<i>Torpedo</i>	Torpedinidae	Torpediniiformes	Chondrichthyes
<i>nobiliana</i>	<i>Torpedo</i>	Torpedinidae	Torpediniiformes	Chondrichthyes

**Annex VI: The native distribution maps of the species recorded along the Lebanese coasts in this study (AquaMaps, 2013)**





**Préambule concernant la langue de rédaction de la thèse.**

La langue des thèses et mémoires dans les établissements publics et privés d'enseignement est le français, sauf exceptions justifiées par les nécessités de l'enseignement des langues et cultures régionales ou étrangères ou lorsque les enseignants sont des professeurs associés ou invités étrangers. La maîtrise de la langue française fait partie des objectifs fondamentaux de l'enseignement. Pour les thèses en cotutelle, la langue dans laquelle est rédigée la thèse en cotutelle est définie par la convention conclue entre les établissements contractants. **Lorsque cette langue n'est pas le français, la rédaction est complétée par un résumé substantiel en langue française.**

Une synthèse d'une vingtaine de pages en français, intégrée au manuscrit, mettant en évidence les apports principaux du travail de thèse est requise par l'Ecole Doctorale 305.

Résumé substantiel de la thèse en langue française

**Biologie, distribution et diversité des poissons cartilagineux le long  
de la côte libanaise, Méditerranée orientale**

A l'heure actuelle, la biodiversité marine (fonctionnelle, spécifique génétique, taxonomique ou encore écosystémique) est menacée par l'augmentation des activités anthropiques. La surpêche notamment, en diminuant les effectifs des populations, peut affecter la diversité biologique des espèces, qui pour certaines ne sont plus en mesure de maintenir leur rôle fonctionnel au sein de la chaîne trophique, en tant que proie, prédateur, ou compétiteur, et peut aboutir à des extinctions écologiques et fonctionnelles.

**Chapitre I - Introduction générale. Contexte, problématique et objectifs.**

La Méditerranée est la plus grande et la plus profonde des mers fermées sur Terre. Elle est reliée à l'océan Atlantique à l'ouest à travers le détroit de Gibraltar et la mer de Marmara et la Mer Noire à l'est à travers le détroit des Dardanelles. Elle a été connectée artificiellement à la mer Rouge et à la région de l'Indo-Pacifique lors de la construction du canal de Suez en 1869.

**Biodiversité.** La faune marine récente de la mer Méditerranée est principalement dérivée de l'océan Atlantique, mais la variété de climats et l'hydrologie particulière de cette mer a contribué à la co-occurrence et à la survie d'organismes issus de régions tempérées et sub-tropicales. Bien que le bassin méditerranéen ne représente que moins de 1% de la surface de l'océan mondial, sa biodiversité est exceptionnelle pour une si faible surface. En effet, il comprend jusqu'à 18% des espèces marines macroscopiques mondiales dont 25 à 30% sont endémiques. Actuellement, la mer Méditerranée détient 17 000 espèces, soit 7% de toutes les espèces marines connues. Le niveau d'endémisme est particulièrement élevé sur les îles méditerranéennes, où les espèces ont évolué pour survivre dans des habitats très spécifiques. Cependant, la biodiversité de la Méditerranée a été, dans le passé, et sera, dans le futur, continuellement modifiée et modelée par des catastrophes naturelles et anthropiques.

**Menaces.** Les effets des activités humaines sont plus importants en Méditerranée en comparaison à toutes les autres mers du monde. Les connaissances sur les processus, la répartition écologique des espèces, l'état des écosystèmes et les causes de l'érosion de la biodiversité sont encore vagues, d'autant plus que la plupart du bassin méditerranéen est non géré et exposé à des menaces. Bon nombre des caractéristiques écologiques de la mer Méditerranée sont menacées avec des zones où des menaces potentielles élevées se cumulent, notamment au niveau des bassins occidental et oriental et dans une moindre mesure dans la région sud-est. Les causes les plus importantes des menaces actuelles et futures pour les espèces méditerranéennes sont la perte et la dégradation des habitats, la pollution, la surexploitation (aquaculture non durable et surpêche), l'eutrophisation, le trafic maritime, les espèces exotiques envahissantes, les perturbations humaines, le changement climatique et les prises accessoires. Au total, le nombre total d'espèces lessepsiennes marines (envahisseurs via le canal de Suez) s'élève à plus de 790 en mer Méditerranée, dont certaines ayant colonisé avec succès les écosystèmes marins méditerranéens. Une étude récente s'est intéressée à la structure de la population et à la maturité sexuelle du poisson lesseptien *Lagocephalus sceleratus* dans les eaux libanaises et syriennes, afin de faire la lumière sur la gravité du problème pour cette espèce (Khalaf et al., 2014 - ANNEXE I) dans cette région. En outre, la Méditerranée est également influencée par des espèces introduites à partir de l'océan Atlantique par le détroit de Gibraltar et qui ont atteint la mer Adriatique et même, pour certaines, le bassin oriental. Leur nombre croissant a un impact sur les populations indigènes et peut amener à une réduction de l'abondance des espèces endémiques. En outre, la surexploitation et les prises accessoires sont des problèmes importants qui affectent de nombreuses espèces marines menacées, telles que les poissons osseux et cartilagineux, les dauphins et les tortues marines. En particulier, la surexploitation des top-prédateurs, engendrant un changement de biomasse et de composition spécifique, pourrait avoir un impact plus important que prévu sur la stabilité des écosystèmes, en particulier marins, que la suppression d'espèces de plus bas niveaux trophiques.

**Pêcheries.** Un peu plus de 1% des débarquements mondiaux proviennent de la pêche en Méditerranée. Les pêcheries méditerranéennes ciblent différentes ressources essentiellement les

stocks pélagiques. Elles sont caractérisées par de petits bateaux artisanaux et des débarquements multi-spécifiques. Une importante pêche industrielle cible principalement les petits pélagiques (essentiellement anchois et sardines) qui sont surtout capturés au moyen de sennes coulissantes et des chaluts pélagiques. Les évaluations des captures sont difficiles en Méditerranée en raison des caractéristiques multi-spécifiques-multi-engins de la plupart de ses activités de pêche, de la dispersion des sites de débarquement et de la faible proportion des captures qui passe généralement par le biais des marchés de poissons organisés. Les pêcheries méditerranéennes sont divisées en quatre sous-zones, dont chacune a ses propres divisions: occidentale, centrale, orientale et la mer Noire.

### **Chondrichthyens. Statut, pêcheries et menaces.**

**Aperçu dans le monde entier.** Les chondrichthyens ou poissons cartilagineux constituent l'une des familles de vertébrés les plus anciennes et les plus écologiquement diversifiées comprenant les requins, les raies et les chimères. Ils peuvent être présents dans la zone subtidale, bathyale (200-2000 m) et même dans les habitats abyssaux (plus de 2 000 m). La plupart d'entre eux sont des prédateurs de haut niveau trophique, bien que certaines espèces peuvent se spécialiser sur des petits animaux benthiques, comme les polychètes ou les amphipodes. Les poissons cartilagineux sont caractérisés par leurs traits d'histoire de vie conservatifs (longue période de gestation et important investissement maternel, ...). Les trois principales régions où la biodiversité des requins et des raies est particulièrement menacée sont l'Indo-Pacifique, la mer Rouge, et la mer Méditerranée et des actions nationales et internationales sont nécessaires pour les protéger, en particulier, de la surpêche.

Ils sont principalement capturés en tant que prises accessoires, de bonne valeur commerciale, de pêcheries ciblant surtout des espèces de poissons téléostéens plus productives, comme le thon ou les poissons de fond. Selon les pêcheries, ils sont principalement exploités pour leur chair, ailerons, foie et branchies. Dans certains cas, leur valeur commerciale peut être très élevée (cas des ailerons). Par conséquent, la pression de pêche sur les chondrichthyens est en augmentation. De plus, la plupart des captures de chondrichthyens ne sont pas réglementées et souvent mal identifiées, non enregistrées, agrégées ou rejetées à la mer, ce qui entraîne un manque

d'information spécifique concernant les débarquements de ces espèces, et on estime que les captures réelles sont 3 ou 4 fois plus grandes que celles rapportées.

**Chondrichthyens de Méditerranée.** La mer Méditerranée contient 80 espèces de chondrichthyens (près de 7% de l'ensemble des chondrichthyens dans le monde) comprenant 45 espèces de requins provenant de 17 familles et 34 espèces de batoïdes issues de 9 familles et une espèce de chimères. Elle est identifiée comme l'une des trois régions où la diversité des requins et des raies est particulièrement gravement menacée. L'Union Internationale pour la Conservation de la Nature (UICN), a évalué 71 espèces dont 42.25% ont été classées vulnérables et en danger critique d'extinction, 18.31% quasi menacées et pour 25.35% d'entre elles les données sont insuffisantes. D'autres auteurs ont évalué à 86 le nombre d'espèces d'élasmobranches en mer Méditerranée. La plus forte concentration d'élasmobranches est observée dans les eaux côtières de la Méditerranée occidentale, en particulier dans le bassin nord-occidental, probablement en raison de la nature hautement oligotrophe du bassin oriental.

**La pêche et les menaces des chondrichthyens de Méditerranée.** L'état des poissons cartilagineux en mer Méditerranée est beaucoup plus déplorable que ce qu'il l'est dans le reste du monde: 42% des espèces de requins sont menacées dans cette région contre 17% dans le monde, ce qui fait de la Méditerranée la mer la plus dangereuse au monde pour ces espèces. Les principaux pays pêchant les élasmobranches en Méditerranée sont la Turquie, la Tunisie, la Grèce, l'Italie et l'Espagne et les espèces les plus couramment prises dans les pêcheries côtières méditerranéennes sont: *Mustelus spp*, *Rajids*, *Scyliorhinus spp*, *Squalus spp*, *Myliobatids* et *Dasyatids*. Les captures accidentelles et les activités de pêche intensives sont de sévères menaces pour les élasmobranches.

Aussi, 8 chondrichthyens invasifs originaires de l'Atlantique ou de l'Indo-Pacifique ont été répertoriés en Méditerranée dont 2 ont été observés en Méditerranée orientale.

Le changement climatique, dont les effets sont accélérés en Méditerranée, peut également avoir un effet potentiel sur les poissons, en particulier les chondrichthyens. L'augmentation de la

température du domaine marin et les changements d'autres variables environnementales peut amener à un déclin des populations des populations de poissons et de leurs biomasses.

**Divers outils de gestion pour les écosystèmes côtiers.** Actuellement, au niveau national et international, les politiciens, scientifiques et gestionnaires disposent d'un nombre important d'outils pour la gestion des zones côtières et des écosystèmes marins.

Au cours des trois dernières décennies, plusieurs conventions importantes ont mis en évidence la nécessité de la conservation des populations d'élastomobranches et de leur gestion à l'échelle mondiale et régionale: la convention sur la conservation de la vie sauvage et du milieu naturel (Berne, 1979) ; la convention sur les espèces migratrices (Bonn, Novembre 1983) ; le protocole pour les Aires Spécialement Protégées et la Diversité Biologique en Méditerranée (SPA-BD), la convention de Barcelone, (Juin 1995) ; Alimentation des Nations Unies et l'agriculture, le plan d'action international pour la conservation et la gestion des requins (1999 - FAO / PAI-Requins) ; la convention sur le commerce international des espèces menacées d'extinction (CITES, Novembre 2002) ; le programme pour l'Environnement des Nations Unies, le plan d'action pour la Méditerranée pour la conservation des poissons cartilagineux (Novembre 2003).

Plusieurs rapports ont été établis reflétant l'état et la conservation des chondrichthyens. Certains auteurs ont mené une réflexion sur la conservation des poissons cartilagineux en Méditerranée en soulignant le statut d'espèce menacée de plusieurs requins et raies en spécifiant les répercussions de la surpêche, notamment celles du marché des ailerons de requin, le problème des prises accessoires, de la pollution et de la perte d'habitat sur cette classe de poisson. En 2003, le Centre d'Activités Régionales pour les Aires Spécialement Protégées (CAR / ASP), dans le cadre du Programme des Nations Unies pour l'environnement (PNUE), a créé un plan d'action pour la conservation des poissons cartilagineux en mer Méditerranée. Ce plan d'action vise à promouvoir la conservation des populations de Condrichtyens, la protection renforcée de certaines espèces sélectionnées (en voie de disparition), la protection et la restauration des habitats critiques, l'amélioration des connaissances scientifiques, la reconstitution des stocks épuisés, et les actions de sensibilisation du public concernant la conservation de cette catégorie de poisson.

**Les chondrichthyens de Méditerranée orientale.** La présence de chondrichthyens est décrite dans plusieurs zones de la Méditerranée orientale à travers plusieurs études effectuées dans la région. Leur présence dans la partie sud-est de la Méditerranée orientale a notamment ont été mise en évidence par des études menées de la côte nord de l'Égypte jusqu'aux côtes d'Israël.

Au Liban, la zone d'étude de la thèse, la pêche libanaise traditionnelle est composée de bateaux de pêche artisanale à petite échelle et les chalutiers sont interdits. La production libanaise d'élastomobranches était de 60 tonnes en 2003 ce qui représente 2% de tous les groupes capturés. Quelques captures d'élastomobranches sont accessoires et certains pêcheurs ciblent quelques espèces commercialement importantes comme la guitare de mer commune *Rhinobatos rhinobatos* (Linnaeus, 1758) et le squalé chagrin commun *Centrophorus granulosus* (Bloch et Schneider, 1801).

De nombreux requins de poids élevés ou des raies tels que ceux des membres des familles des Hexanchidés, Carcharinidae ou Lamnidae pour les requins et des Dasyatidae et Myliobatididae pour les batoides sont souvent observés dans les poissonneries de certaines régions libanaises du nord et du sud du pays. Les poissons capturés sont nettoyés et coupés en filets afin d'être vendus ensuite à des restaurants ou à des clients les achetant au marché avec des prix allant de 4 à 6\$ par kilogramme.

A partir des recommandations de la "Commission générale des pêches pour la Méditerranée" CGPM /36/2012/3 et de la Convention de Barcelone, le Ministère de l'Agriculture libanaise a publié le décret numéro 1/1045 du 13/12/2013, qui établit des normes et des interdictions concernant la pêche ou la vente de certaines espèces de requins et de raies comme le la guitare de mer commune *Rhinobatos spp.*, les requins marteaux *Sphyrna spp.*, et d'autres espèces ciblées dans le commerce.

**Traits d'histoire de vie des chondrichthyens.** Les traits d'histoire de vie sont moulés par l'énergie disponible dans l'environnement pour la distribution entre les différents processus biologiques et par les interactions qui influencent les décisions de distribution. L'énergie disponible pour la distribution dépend en définitive de la productivité primaire de l'écosystème,

tandis que la force des interactions biologiques dépend de nombreuses caractéristiques de l'écosystème, y compris la structure physique et la diversité.

Les études sur les paramètres du cycle de vie tels que l'âge et la croissance, ainsi que des informations de base sur la répartition, l'abondance, les mouvements, l'alimentation, la reproduction et la génétique, sont essentiels pour les biologistes et écologues afin de comprendre et prédire la manière dont les populations vont grandir et leurs réactions à la pression de pêche.

La vulnérabilité des espèces de poissons cartilagineux est liée à la combinaison d'une grande taille maximale corporelle, une croissance lente, une maturité tardive (à une grande taille), et une longue durée de vie. En conséquence, les études sur les traits d'histoire de vie sont indispensables pour la protection, la conservation et la gestion de la pêche de ces grands prédateurs dont le rôle dans l'écosystème est essentiel.

### **Objectifs de l'étude**

Le commencement de travaux de recherche sur les espèces de poissons cartilagineux le long de la côte libanaise s'avérait être une nécessité. En effet, cette classe de poissons a été progressivement exploitée dans cette région et les décrets du ministère libanais ne sont pas toujours appliqués de manière efficace. En outre, il n'existe presque aucune connaissance écrite reflétant la présence et la répartition des espèces de chondrichthyens le long de la côte libanaise. Leur présence est souvent documentée et présentée dans diverses régions de la Méditerranée et notamment celle du bassin oriental; néanmoins, des lacunes existent le long de la côte libanaise. Par conséquent, l'absence de données, l'exploitation et l'absence de gestion de cette catégorie de poisson ont été les moteurs de base de cette étude.

Cette thèse vise à contribuer à une meilleure connaissance des poissons cartilagineux du milieu marin libanais. L'accent a été porté sur les axes suivants:

1- L'établissement d'un inventaire des chondrichthyens le long de la côte libanaise et la réalisation d'une revue bibliographique consacrée aux espèces de poissons cartilagineux en Méditerranée orientale.

2- L'étude de la biodiversité et de la distribution spatio-temporelle des chondrichthyens le long de la côte libanaise.

3- Un focus sur la biologie et l'écologie de deux espèces menacées d'élastomobranches et commercialement importantes (une espèce de requins et un batoïde).

Certains chapitres de la thèse sont présentés sous la forme d'articles. Suite à présente introduction générale, constituant le **chapitre 1**, la thèse est divisée comme suit:

Le **chapitre 2** a été consacré à la présentation des "Matériels et méthodes" généraux de la thèse contenant une description de la zone étudiée, des méthodologies expérimentales, des calculs, des tests et des analyses statistiques effectués au cours de cette étude.

Une revue bibliographique décrivant toutes les études sur les espèces de poissons cartilagineux en Méditerranée orientale est présentée au **chapitre 3**. Il résume toutes les informations publiées sur les stocks, l'apparition, la distribution, le statut, la conservation, de l'âge et de la croissance, les relations poids-longueur, les aspects de la reproduction, la nutrition et les habitudes alimentaires et d'autres aspects du cycle de vie des espèces de poissons cartilagineux en Méditerranée orientale.

Le **chapitre 4** est consacré à la représentation de la biodiversité et de la distribution spatio-temporelle des espèces de poissons cartilagineux dans la zone d'étude en utilisant deux méthodes de collecte de données complémentaires: (a) une étude scientifique du CIHEAM PESCA-Libano réalisée avec la participation du Ministère de l'Agriculture et du Centre national pour les sciences marines - Conseil national libanais pour la recherche scientifique (CNRSL) et (b) des données issues des pêcheries et des captures des pêcheurs. Dans cette section, la capture par unité d'effort (CPUE) a été utilisée, en tant qu'indice d'abondance, pour présenter la répartition spatio-temporelle des espèces, et les variations spatio-temporelles de plusieurs indices de biodiversité ont été étudiées. Ce chapitre se compose également d'une courte communication présentant les relations poids-longueur de trois requins et cinq batoïdes établies au cours de cette étude.

Ensuite, une étude de la biologie et de l'écologie d'un batoïde en voie de disparition, la guitare de mer commune, *Rhinobatos rhinobatos*, qui est une espèce commercialement importante des

pêcheries libanaises est présenté dans le **chapitre 5**. Ce chapitre vise à une meilleure connaissance des paramètres des modèles de la dynamique de cette population de poissons exploitée afin d'assurer la viabilité à long terme de sa pêche.

Le **chapitre 6** présente la biologie et l'écologie du squale chagrin commun, *Centrophorus granulosus*, classé comme vulnérable par l'UICN, qui est aussi une espèce exploitée soit en tant que prises accessoires ou ciblée. Ce chapitre vise également à décrire les caractéristiques des traits histoire de vie de cette population de requins d'eau profonde exploitée afin d'améliorer sa protection et sa gestion en vue de la maintenir.

Enfin, une discussion générale, conclusion, et les perspectives de ce travail sont présentés dans le dernier chapitre (**chapitre 7**) et plusieurs annexes sont incluses à la fin de la thèse afin de compléter certains aspects.

Ci-après sont brièvement résumés le contenu et les principaux apports de chacun des chapitres et de la thèse.

### Chapitre II - Matériel et Méthode

**Présentation de la côte libanaise.** La zone d'étude est située au Liban qui est l'un des plus petits pays du monde avec une surface de 10 452 km<sup>2</sup>. Il est entouré par la Syrie au nord et à l'est, par la Palestine au sud et situé dans le bassin Levantin de la mer Méditerranée. La côte du Liban s'étend sur 220 km de long avec un plateau continental étroit, en particulier dans le sud. Elle est à l'heure actuelle, menacée par l'urbanisation (les principales villes côtières sont majoritairement jointives). Les fonds sont essentiellement rugueux avec de larges plaques rocheuses qui conviennent au déploiement d'engins de pêche démersaux.

De manière générale, le Liban bénéficie d'un climat typiquement méditerranéen avec deux saisons très contrastées: un hiver froid et fortement humide; et un été long, chaud et sec et deux saisons intermédiaires (printemps et automne). La variation mensuelle moyenne de la température de la surface de la mer entre 2000 et 2012 a varié entre un minimum de 17.82°C en

mars et un maximum de 29.71°C en août, et la variation mensuelle moyenne de la température de l'air a varié entre un minimum de 12.4 °C en janvier et un maximum de 27.59°C en août.

**Courants et bathymétrie.** Un courant général de surface venant de l'océan Atlantique passe par le détroit de Gibraltar dans la Méditerranée. La majeure partie de ce courant se déplace vers l'est parallèlement à la côte nord-africaine, mais perd progressivement de sa force à l'approche des côtes orientales. L'intensité de ce courant et la quantité d'eau atteignant le bassin Levantin dépend de son écoulement à travers le détroit de Gibraltar. Par conséquent, la direction dominante de la circulation générale le long de la côte du Liban est celle du nord durant la plupart de l'année en plus de la présence d'un courant tourbillonnaire de sens général antihoraire en Méditerranée orientale. Ce courant est modifié localement par la configuration de la côte et la topographie de l'étroit plateau continental (3 - 4 km). L'isobathe des 200 m est situé à 8- 10 km de la côte au sud et à 20 km au nord. La profondeur moyenne du plateau continental est de 20 à 40 m et la pente, parallèle à la côte et située à une distance de 25 à 30 km de cette dernière, s'étend de 1100 à 1400 m de profondeur, avant d'atteindre la plaine abyssale.

**Secteur de la pêche.** La pêche libanaise est artisanale et traditionnelle. La flotte de pêche libanaise est composée de bateaux de pêche artisanaux de moins de 12 m de longueur et typiques de nombreux pays méditerranéens. Elle est composée de 1 460 navires de commerce ayant une licence de pêche. Un nombre total de 42 ports est réparti tout le long de la côte libanaise. La majorité (42%) de la capacité de la flotte est concentrée à Tripoli, dans le nord du pays, tandis que 24% de la flotte totale fonctionne à partir de Beyrouth, au centre du pays et 23% opère dans la partie sud du pays.

Les engins les plus couramment utilisés comprennent des trémails, palangres, sennes coulissantes, et lamparos et le chalutage est interdit par la loi, bien que des filets de pêche de maillages illégaux sont largement disponibles sur le marché noir. Seuls quelques navires disposent d'un système de positionnement global (GPS) et seulement 20% des navires sont équipés de petits sondeurs.

La production issue des captures au Liban au cours des 10 dernières années a été d'environ 3500 tonnes par an. Cependant, ces données ne reflètent pas l'état actuel et réel de la production halieutique libanaise.

**Collecte des données.** La collecte des données a été réalisée à partir de décembre 2012 jusqu'en octobre 2014, selon trois protocoles différents afin de cibler le maximum d'espèces de poissons cartilagineux le long de la côte libanaise.

Le projet CIHEAM PESCA-Libano. Le projet CIHEAM PESCA Libano avec la participation du ministère de l'Agriculture et le Centre national pour les sciences marines - Conseil national libanais pour la recherche scientifique (CNRSL) a évalué le potentiel des ressources côtières marines afin de soutenir le gouvernement libanais dans le renforcement de la gestion des ressources marines.

Un échantillonnage a été réalisé dans le cadre de ce projet en 2012 et 2013, durant lequel trois types d'engins (filets maillant, trémail et palangre) ont été déployés dans 61 sites différents le long de la côte du Liban et à des profondeurs allant de 10 à 600 m.

Des données sur les poissons cartilagineux ont été recueillies à partir de ce projet et pour chaque station échantillonnée, le type d'engin déployé, les coordonnées et la profondeur étaient notés.

Six pêcheurs artisanaux issus de six ports différents ont été embauchés pour déployer les engins à des coordonnées spécifiées. En général, l'équipage incluait 2 à 4 personnes (avec au minimum un scientifique) et un maximum de 2 mises à l'eau d'engin a été effectué par jour, selon les conditions météorologiques et les conditions techniques du navire. Pour chaque trait, la profondeur, le point GPS et les mailles des filets utilisés étaient notés. Aucun appât n'était employé lors du déploiement des filets, mais des appâts ont systématiquement été accrochés aux hameçons des palangres (poissons hachés, tels que des harengs, des maquereaux ou des thons).

Pêcheurs et pêcheries. En plus des données scientifiques, un autre type de collecte des données a consisté à embaucher au hasard quelques pêcheurs professionnels exerçant tout le long de la côte libanaise, avec la collaboration du Conseil national libanais pour la recherche scientifique

(CNRSL) - Centre national pour les sciences marines, et à pratiquer des pêches expérimentales au moyen de palangres à des profondeurs allant de 30 à 600 m afin de capturer des poissons cartilagineux d'un maximum d'espèces. La plupart des pêcheurs artisanaux libanais ne disposant pas de GPS, la position exacte des données collectées de cette manière n'a pas pu être enregistrée; cependant, la profondeur a pu être notée.

La collecte des données a également consisté à visiter diverses poissonneries le long de la côte libanaise au minimum 5 fois par mois. La principale poissonnerie visitée était localisée à Tripoli, où les captures de poissons cartilagineux étaient constantes.

**Mesures morphométriques.** Pour tous les échantillonnages réalisés, lorsque des spécimens étaient disponibles diverses données biologiques ont pu être collectées, en plus de leur identification.

Les espèces ont été identifiées selon divers guides d'identification des poissons de la Méditerranée orientale et les sexes étaient différenciés afin d'en déduire le sexe-ratio. Diverses mesures ont été prélevées pour chaque spécimen : la longueur totale, la longueur de la fourche et la longueur extérieure des ptérygopodes (uniquement pour les spécimens de sexe masculin).

**Indices biologiques.** Des dissections ont également été effectuées et des mesures supplémentaires ont été prises en plus du poids total: le poids du foie et des gonades (y compris le poids des testicules pour les mâles, et celui des glandes accessoires, des ovaires et oviductes pour les femelles) au moyen d'une balance électronique. Ces mesures ont été utilisées pour calculer des indices biologiques importants, tels que l'indice hépato-somatique (nécessaire pour l'étude des fonctions biologiques du fait que le foie est un accumulateur d'énergie important pour les poissons), l'indice de gonado-somatique (détermine les variations de poids des gonades au long du processus de maturation par rapport au poids du poisson) et le facteur de condition (indique les périodes de stress ou de phénomènes physiologiques, tels que, le frai, l'accouplement, les modifications de la densité de la population, les conditions d'alimentation, ou les variations de température). Après l'enlèvement des systèmes digestifs et de reproduction, le poids éviscéré des poissons a également été noté.

**Maturité sexuelle.** Après identification, le type de reproduction (ovipares ou vivipares aplacentaire) des spécimens issus des captures a été déterminé au moyen de divers guides méthodologiques. Lors de la dissection, la maturité sexuelle de chaque élasmobranche capturé a également été déterminée par l'observation des gonades mâles et femelles par l'observation de l'aspect des gonades pour les élasmobranches vivipares aplacentaire.

**Analyse des contenus stomacaux.** L'analyse des contenus stomacaux n'a été réalisée dans cette étude que pour l'espèce *Rhinobatos rhinobatos*, pour laquelle plusieurs estomacs étaient pleins. Au cours de la dissection de cette espèce cible, les estomacs ont été enlevés et leurs poids totaux ont été mesurés. Les estomacs contenant de la nourriture ont été préservés dans du formaldéhyde 4% jusqu'à identification du contenu. Le nombre d'estomacs vides a également été noté. Chaque proie a été identifiée au plus proche taxon possible et comptabilisé. Le poids total de chaque groupe proie a été mesuré si possible au gramme le plus proche.

Composition du régime alimentaire. Le coefficient de vacuité, reflétant la richesse ou le manque de nourriture dans l'environnement a été calculé et le pourcentage de remplissage de l'estomac a été évalué et classé par catégories. De plus, trois indices ont été calculés pour montrer l'importance des différentes proies dans le régime alimentaire des espèces cibles : la fréquence d'occurrence, le coefficient d'abondance numérique des proies et les pourcentages de poids. Ces trois indices ont servi au calcul d'un 4ème indice, l'indice d'importance relative, afin de mieux refléter l'importance de chaque proie dans les estomacs des espèces cibles.

Stratégie nutritives. Enfin, des pourcentages de l'indice d'importance relative ont été établis pour chaque type de proie afin de faciliter les comparaisons entre les types d'aliments. La stratégie d'alimentation de l'espèce cible a été analysée afin d'illustrer en particulier la dominance et la rareté de chaque groupe de proies durant les deux saisons et de la stratégie d'alimentation (spécialiste ou généraliste).

**Captures par unité d'effort.** La capture par unité d'effort (CPUE) a été calculée seulement pour les espèces cartilagineuses capturées au cours de l'échantillonnage scientifique CIHEAM-PESCA Libano, au cours duquel des palangres, trémails et filets maillants ont été déployés à des traits spécifiques avec des coordonnées et des profondeurs prédéterminées. La CPUE pour les poissons cartilagineux pris lors de l'échantillonnage a été calculée au moyen du logiciel statistique 'R' en kilogrammes et en nombre.

**Indices de biodiversité.** Le nombre total d'individus et le nombre total d'espèces recensées dans l'échantillon a été déterminé afin d'évaluer les variations saisonnière et spatiale de biodiversité. Pour ce faire plusieurs indices de diversité ont été calculés : l'indice de Shannon, l'indice de Simpson et l'indice de diversité taxonomique

Enfin, la comparaison et l'interprétation des données a nécessité l'utilisation de plusieurs tests (Wilcoxon, Kruskal –Wallis, Chi-deux de Pearson, Permanova...) et analyses statistiques (Analyse en composante principale, Analyse canonique des correspondances ...) ou outils de modélisation (régressions linéaires et non linéaires, ANCOVA, ...). Au préalable, des transformations de données (i. e. logarithmiques) se sont quelquefois avérées nécessaires, selon le cas d'étude considéré.

<b>Chapitre III - Les poissons cartilagineux de la Méditerranée orientale: revue de la littérature sur la biologie, l'écologie et la distribution géographique de ces espèces</b>
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Le chapitre III a été dédié à une synthèse bibliographique sur la biologie, l'écologie et la répartition géographique des poissons cartilagineux de la Méditerranée orientale. Le but de cette revue était de présenter les diverses études et leurs lacunes et les régions où les espèces de poissons cartilagineux sont peu présentes et étudiées.

Un focus a été porté sur les informations concernant les inventaires existants, la présence et la répartition, le statut, la conservation, l'âge et la croissance, les relations longueur-poids, les aspects de la reproduction, les habitudes de nutrition et d'alimentation et d'autres aspects du cycle de vie de ces espèces. Cette synthèse présente également les résultats issus d'un nouvel inventaire des poissons cartilagineux effectué le long de la côte libanaise, où ont été enregistrées 25 espèces (11 requins et 14 batoïdes) appartenant à 15 familles entre 2012 et 2014. La synthèse indique que les captures accidentelles de ces poissons est à l'origine de leur déclin en mer Méditerranée. Cette étude confirme également la présence de lacunes dans les études relatives aux espèces de poissons cartilagineux, avec certaines régions faisant l'objet de nombreuses études alors que peu d'études voire aucune n'existe dans d'autres régions de la Méditerranée orientale, comme la côte libanaise. Cette revue devrait permettre d'aider à une meilleure compréhension, gestion, et protection de cette catégorie de poissons menacés.

**Chapitre IV - Diversité et relations longueur-Poids**

**Chapitre IV - Partie 1. Diversité, distribution et abondance des élastombranches le long de la côte libanaise et principaux facteurs influents (Méditerranée orientale).**

Dans une première partie du chapitre 4, l'accent a été mis sur les différents aspects de la distribution spatiale et saisonnière, la diversité, la biologie et l'écologie des élastombranches. Cette étude constitue la seule évaluation des ressources en élastombranches le long de la côte libanaise, en Méditerranée orientale. Les données concernant les poissons cartilagineux sont issues de captures obtenues à partir de deux méthodes de collecte de données complémentaires, issues : (a) du projet scientifique CIHEAM PESCA-Libano réalisé avec la participation du Ministère de l'Agriculture et le Centre national pour les sciences marines - Conseil national libanais pour la recherche scientifique (CNRSL) et (b) des poissonneries et des pêcheurs. Au cours du suivi scientifique, des filets maillants expérimentaux, trémails et palangres ont été déployés à des profondeurs allant jusqu'à 600 m en 2013. Les poissons cartilagineux issus des données commerciales ont été recueillis auprès des principales poissonneries, qui ont été visitées périodiquement le long de la côte libanaise et de captures issues de pêches expérimentales réalisées avec des pêcheurs pendant la même année. La capture par unité d'effort a été utilisée comme un indice de l'abondance des élastombranches capturés et a montré des variations saisonnières et spatiales de distribution et selon la profondeur. L'utilisation de données scientifiques et commerciales de manière complémentaire a permis de constituer une image plus précise de l'effet de la pêche sur les espèces d'élastombranches. Au total, 314 spécimens de poissons cartilagineux ont été échantillonnés dont 25 espèces de poissons cartilagineux, 11 espèces de requins et 14 espèces de batoïdes. Aucune chimère n'a été enregistrée. Les requins échantillonnés étaient constitués majoritairement des espèces : *Centrophorus granulosus*, *Galeus melastomus*, *Squalus blainville* et *Mustelus mustelus*. La majorité des batoïdes était constituée de *Rhinobatos rhinobatos*, *Rhinobatos cemiculus*, *Torpedo marmorata*, *Torpedo nobiliana*, *Raja miraletus* et *Raja clavata*. Les différents spécimens de poissons cartilagineux ont été pêchés à des profondeurs allant de 10 à 600 m. La diversité spatio-temporelle a également été évaluée et a montré des valeurs plus élevées dans la région sud de la côte et pendant les saisons de printemps et d'hiver. Cette étude peut servir de base pour évaluer les menaces des opérations de pêche et

être une base de réflexion pour la mise en place de mesures de conservation possibles pour les espèces de poissons cartilagineux le long de la côte Libanaise en vue d'une gestion plus durable des ressources.

#### **Chapitre IV - Partie II. Les relations longueur-poids de trois requins et cinq batoïdes dans les eaux marines libanaises, Méditerranée orientale.**

Dans la seconde partie du chapitre 4, des relations taille-poids ont été présentées pour 8 espèces d'élasmobranches, 3 requins et 5 batoïdes, dans les eaux marines libanaises, en Méditerranée orientale. Ces élasmobranches ont été collectés à l'aide de palangres, trémails et filets maillants de décembre 2012 à octobre 2014. Les valeurs du paramètre  $b$  des relations longueur-poids  $W = aL^b$  allaient de 1.752 à 3.337. Les relations poids-longueur ne variaient pas selon le sexe, sauf pour le requin *Centrophorus granulosus* (Bloch & Schneider 1801) et le batoïdes *Torpedo marmorata* (Risso 1810). Ces relations ne doivent être appliquées que dans les gammes de longueurs observées.

Dans les 2 avant derniers chapitres de la thèse, un focus a été porté sur la biologie et l'écologie de deux espèces commercialement importantes et bien exploitées dans les eaux côtières libanaises. Ainsi, la biologie des populations du batoïde *Rhinobatos rhinobatos* (**chapitre V**) et du requin *Centrophorus granulosus* (**chapitre VI**) a été évaluée séparément sur des individus issus des deux sources de données combinées (scientifiques et commerciales).

#### **Chapitre V - Biologie des populations d'une espèce en voie de disparition : la guitare de mer commune *Rhinobatos rhinobatos* L. 1758 dans les eaux marines libanaises, Méditerranée orientale**

Le chapitre 5 a été consacré à l'étude de la biologie et l'écologie de la population de la guitare de mer commune *Rhinobatos rhinobatos* L. 1758, qui est répertoriée sur la liste rouge par l'Union Internationale pour la Conservation de la Nature comme une espèce de poisson cartilagineux en voie de disparition. Bien que fortement exploitée, jusqu'à maintenant, aucune étude n'a été menée sur cette espèce d'élasmobranches le long de la côte libanaise dans le bassin Levantin en

Méditerranée orientale. Un total de 67 spécimens a été recueilli par les palangriers de fond issus des différents ports des eaux marines côtières libanaises à des profondeurs allant de 10 à 110 m entre décembre 2012 et janvier 2014. La longueur totale des spécimens de l'échantillon variait entre 50 et 143 cm avec une moyenne de  $76,21 \pm 19,7$  cm. Les classes de taille les plus courantes se répartissaient entre 60 et 70 cm de longueur totale. Le poids total des échantillons se situait entre 410 et 10000 g avec une valeur moyenne de  $1841,3 \pm 1,987$  g. Le sexe-ratio n'était pas significativement différent de 1:1 avec un nombre total de 34 mâles et 33 femelles. La relation longueur-poids a montré une croissance allométrique positive avec  $b = 3.096$  et  $R^2 = 0,99$ . La longueur à laquelle 50% des individus étaient mûres était de  $84,73 \pm 5,81$  cm pour les femelles et  $78,57 \pm 4,88$  cm pour les mâles. Les indices gonado-somatique et hépato-somatiques ainsi que le facteur de condition ont été représentés, et la parturition semblaient avoir eu lieu en hiver. Les principales proies trouvées dans les estomacs appartenaient à la famille Penaeidae en automne et en hiver. Les résultats de cette étude aideront à paramétrer les modèles de dynamique des populations de ce stock de poisson exploité afin d'assurer la durabilité à long terme de cette pêche.

**Chapitre VI - Biologie de la population du squale chagrin *Centrophorus granulosus* (Bloch & Schneider 1801) dans les eaux marines libanaises, Méditerranée orientale**

Le chapitre 6 a porté sur la biologie et l'écologie de la population du squale chagrin *Centrophorus granulosus* (Bloch et Schneider 1801) dans les eaux côtières libanaises. Bien que fortement exploitée en tant que prise accessoire, aucune étude n'a été menée sur cette espèce d'élaémobranches dans ce domaine. Un total de 38 individus a été recueilli à partir des eaux marines côtières libanaises au moyen de palangriers de fond et de trémails de maillages différents, à des profondeurs allant de 115 à 600 m entre mai 2013 et février 2014. La longueur totale de l'échantillon variait entre 45 et 94 cm avec une moyenne de  $80,64 \pm 9,97$  cm. La majorité des mâles et des femelles occupait des classes de taille dont la longueur allait de 70 cm à 80 cm au total, respectivement. Le poids total des échantillons variait de 870 à 6700 g avec une valeur moyenne de  $1312,58 \pm 3,791$  g. Le sexe-ratio n'était pas significativement différent de 1:1 avec 20 mâles et 18 femelles. Une ségrégation sexuelle bathymétrique a été observée pour cette espèce. La Capture par Unité d'Effort a été utilisée comme un indice d'abondance relative pour

détecter la distribution spatiale. La relation longueur-poids, l'indice gonado -somatique, l'indice hépato-somatique, et le facteur de condition du squale chagrin dans la zone d'étude ont également été présentés.

## **Chapitre VII - Discussion générale, conclusion et perspectives**

Les élasmobranches sont soumis à diverses menaces à travers le monde, en particulier en mer Méditerranée, considérée comme l'une des trois principales régions où la diversité des élasmobranches est menacée. Dans ce contexte, deux principaux aspects ont été abordés :

- La distribution et la diversité de ces poissons le long de la côte libanaise ;
- L'approfondissement des connaissances relatives à certains traits d'histoire de vie de deux espèces d'élasmobranches majoritairement exploitées dans la région.

**Distribution, diversité et pêche au Liban.** Le nombre d'espèces d'élasmobranches inventorié dans cette étude le long de la côte libanaise constituait un peu plus de 30% de toutes les espèces présentes en Méditerranée, et il était inférieur à celui enregistré dans plusieurs régions de la Méditerranée orientale, telles que Chypre (45 espèces), la Turquie (63 espèces), la Syrie (38 espèces) et Israël (57 espèces). Les fluctuations et les pics des indices de diversité des chondrichthyens selon les saisons et les régions le long de la côte libanaise ont été étudiés. Dans ce contexte, il est indispensable de conserver cette diversité pour maintenir la stabilité de l'écosystème (du fait que les élasmobranches sont des prédateurs à haut niveau trophique) et de protéger la qualité globale de l'environnement.

**Aires marines protégées.** Les résultats de cette étude relatifs à la diversité de ces espèces peuvent inciter à plus long terme à la création de nouvelles Aires Marines Protégées (AMP) le long du littoral libanais, en plus des 2 AMP existantes au Liban. En effet, une plus grande surface d'AMP le long de la côte libanaise pourrait améliorer et stimuler la gestion de la pêche au sein et autour de la zone protégée, et par la suite renforcer la protection des organismes marins sensibles, comme les chondrichthyens. En effet, les cœurs de réserve des AMP constituent de

précieux atouts pour faciliter la gestion durable des ressources halieutiques. L'interdiction des activités de pêche durant les saisons de reproduction ou sur les zones de nurseries permet d'accélérer la restauration des ressources sensibles et vise à long terme une meilleure protection du littoral.

D'après le fait que la plupart des opérations de pêche se déroulent dans le nord du pays et les résultats obtenus sur la diversité des élasmobranches au Liban, indiquant qu'une plus grande diversité et abondance ont été observées dans le sud, nous pouvons émettre l'hypothèse que la diversité des élasmobranches pourrait être déjà altérée dans le nord par la pêche. Ainsi, nous pouvons suggérer que la création de nouvelles AMP devrait être développée dans les zones du nord du Liban. Aussi, la mise en œuvre d'une plus grande AMP dans le sud permettrait d'améliorer la préservation de l'importante diversité observée dans cette région. En outre, nous pourrions proposer la mise en place de mesures spécifiques dans les zones marines autour des deux réserves naturelles côtières libanaises dont l'existence pourrait rendre ces mesures plus faciles à implémenter.

**Indice d'abondance.** L'analyse des captures par unité d'effort, utilisées en tant qu'indice d'abondance, a fourni des indications sur les variations spatio-temporelles de la distribution et de l'abondance des élasmobranches. Ces variations pourraient être attribuables soit à l'environnement soit aux impacts anthropiques. La nature des eaux libanaises, la disponibilité des proies, les mouvements journaliers pour l'alimentation et saisonniers pour la reproduction, ainsi que les techniques de pêche employées ou les profondeurs de pêche peuvent expliquer la variation de la répartition et de l'abondance observée pour ces poissons. Certains engins utilisés au cours de l'échantillonnage n'ont pas été uniformément déployés tout au long de la côte, à toutes les strates de profondeur, et toutes les saisons. Par exemple, les palangres n'ont été déployées que dans le sud en raison notamment du manque de moyens financiers et de raisons politiques (conflits dans le nord du pays à Tripoli au cours de la période d'échantillonnage). En raison de l'unicité de cette étude dans la région, aucune tendance ne peut être estimée concernant les variations de l'abondance et de la biomasse des poissons cartilagineux des eaux côtière libanaises.

En outre, la présente étude a utilisé des informations provenant de données issues de pêches scientifiques et commerciales. Les données commerciales ont l'avantage de ne pas provoquer de mortalité accrue, mais sont moins précises en raison de l'absence de systèmes de positionnement global (GPS). Les données scientifiques ont l'avantage d'être standardisées. L'utilisation conjointe de ces deux types de données dans cette dernière étude a permis d'améliorer l'estimation des CPUE.

**Variations spatio-temporelles.** La sélection de l'habitat par les élastomobranches dépend de plusieurs facteurs biotiques et abiotiques. En particulier, la température et la profondeur sont à l'origine de la plus grande part de la variation spatiale de la composition des communautés de poissons démersaux. La structure de l'habitat est un autre facteur pouvant influencer la distribution des élastomobranches côtiers et des assemblages de poissons osseux associés. Par conséquent, l'étude des facteurs abiotiques, tels que la structure bathymétrique des fonds ou les types de sédiments associés à la présence de chondrichthyens pourrait aussi fournir plus d'informations sur les variations de la répartition spatiale observée. Dans cette étude, nous avons été confrontés à un manque de données sur le type de sédiments et bathymétriques le long de la côte libanaise. Il aurait été intéressant d'effectuer un échantillonnage du fond lors de chaque pose d'engins afin d'associer la présence des élastomobranches capturés à la structure de fond.

**Identification des espèces.** L'identification et la déclaration des poissons cartilagineux à partir des captures est presque absente au Liban du fait du manque de scientifiques travaillant dans ce domaine. Les pêcheurs ne précisent que les noms généraux pour ces poissons, parfois en donnant un nom pour plusieurs espèces de morphologie presque similaire. De nombreux autres pays ont aussi des difficultés pour identifier les espèces capturées. Dans ce contexte, les codes-barres ADN (barcoding) constituent une méthode qui pourrait révolutionner l'identification des espèces et réduire les problèmes liés aux mauvaises identifications. L'utilisation des techniques moléculaires est devenue une technique désormais acceptée pour identifier les espèces de requins ou pour confirmer l'identification morphologique des espèces notamment à partir de parties du corps des spécimens morphologiquement difficiles à identifier, telles que les ailerons. Le barcoding a déjà été appliqué aux élastomobranches et cette méthode a pu montrer dans certaines

études des niveaux élevés de substitutions frauduleuses des ventes de requins et a permis d'identifier des espèces en voie de disparition parmi un échantillon d'ailerons de requins confisqués sur certains marchés notamment au Brésil.

**Manque de carnets de pêche et relations poids-longueur.** En outre, le manque de carnets contenant toutes les informations de capture des pêches libanaises est une des raisons du fait que les CPUE n'ont pas pu être estimées pour les élasmobranches collectés à partir des pêcheries. A défaut, seule la biomasse a pu être évaluée.

Cette étude a présenté également des données longueur-poids de 8 élasmobranches, dont certains ayant un statut d'espèce menacée sur la liste rouge de UICN. Par conséquent, les relations longueur-poids présentées dans cette étude sont uniquement utiles et efficaces pour les populations d'élasmobranches de la côte libanaise et pour les gammes de longueur et les sexes spécifiques étudiés.

**Traits d'histoire de vie et sur-exploitation.** La surpêche chronique des élasmobranches a réduit les tailles de ces populations, et les populations initialement plus grandes ont été fragmentées en des populations plus réduites, localement isolées(Nadon *et al.*, 2012)(Nadon *et al.*, 2012), et a amené à des cascades trophiques. Malgré ce déclin rapide, des lacunes persistent concernant leurs capacités à se maintenir et à se rétablir suite aux divers impacts anthropiques.

En Méditerranée, peu d'informations sont disponibles sur l'organisation générale, la structure et la complexité des relations sociales entre les requins. Des études en milieux tropicaux ont montré que ces relations peuvent être assez complexes selon les espèces et jouer un rôle important dans leur répartition spatio-temporelle. Les résultats de cette thèse montrent que la guitare de mer commune, *Rhinobatos rhinobatos*, est l'espèce d'élasmobranches la plus souvent ciblée et capturée dans les pêcheries à la palangre libanaises, en particulier à Tripoli, avec une valeur commerciale significative. Bien que déclarée éteinte dans le nord de la Méditerranée, elle persiste dans les régions du sud de la Méditerranée, en particulier dans le golfe de Gabès.

Limiter la pêche des élasmobranches est la principale mesure qui devrait être appliquée (renforcement du contrôle des ports et de la pêche, fixer des quotas de pêche, renforcer le nombre d'AMPs,...). Des actions de sensibilisation devraient être également entreprises auprès de la communauté de pêcheurs afin de mieux les informer sur l'importance des élasmobranches en tant que prédateurs de haut niveau trophique dans l'écosystème marin.

En outre, une analyse conventionnelle du contenu stomacal a été réalisée pour la guitare de mer commune afin d'approfondir certains aspects biologiques de cette population. Cette analyse n'a pu être effectuée pour *Centrophorus granulosus* du fait que tous les estomacs étaient vides. L'utilisation de techniques d'analyses des isotopes aurait permis de limiter certains biais de la technique employée. L'utilisation des rapports isotopiques du carbone et de l'azote mesurés dans les tissus des consommateurs comme traceurs écologiques repose principalement sur le fait que les différents producteurs primaires d'un écosystème ont des compositions isotopiques différentes. Elles sont dues aux différents nutriments fixes qui ont des compositions isotopiques différentes, aux différentes sources de carbone et d'azote utilisés, et/ou aux cycles biochimiques que ces producteurs primaires utilisent pour la photosynthèse. Les valeurs de  $\delta^{15}\text{N}$  sont plus utilisées comme indicateurs de la position trophique des organismes dans leur chaîne alimentaire et largement utilisées pour calculer le niveau trophique absolu des espèces dans de nombreux écosystèmes.

Tout l'effort de la flotte libanaise est concentré dans les 6 miles nautiques avec un pourcentage plus élevé dans les 3 miles nautiques conduisant à une forte pression de pêche des ressources halieutiques sur la côte. En effet, il est illégal au Liban de pêcher au-delà de la limite des 6 miles nautiques et les bateaux de pêche ne sont pas équipés pour pêcher au-delà de cette distance de la côte. La présence d'élasmobranches dans les pêcheries est due à la demande et aux coutumes alimentaires locales, spécifiques à certaines régions le long de la côte. Les données collectées par les pêcheries sont suffisantes pour convenir que des mesures de gestion plus importantes devraient être mises en œuvre pour limiter la capture des élasmobranches et interdire l'exploitation de ceux qui sont menacés selon l'IUCN.

Par conséquent, la présente étude a montré que certaines mesures devraient être prises pour faciliter la conservation et la gestion durable de cette classe de poisson. Par exemple, par la réduction des prises accessoires (*i.e* par l'augmentation de la sélectivité de la pêche les choix des

engins, des zones ou des saisons). Cette étude a également mis en lumière les lacunes concernant cette classe de poissons en Méditerranée orientale, en particulier, le manque d'études génétiques ou encore celles relatives à la distribution et à l'évaluation des stocks. La majorité des études sont axées sur les caractéristiques des traits d'histoire de vie des espèces telles que les cycles biologiques, la croissance, la reproduction et la nutrition. L'estimation de l'âge permet de calculer le taux de croissance, le taux de mortalité et la productivité, ce qui fait de l'âge l'une des variables les plus importantes pour estimer la situation d'une population et évaluer les risques associés à la surpêche. Les épines dorsales ont été prélevées sur le squalo chagrin et des estimations d'âges seront réalisables à terme pour cette espèce.

En outre, une perspective serait d'aborder la structure interne des testicules et des ovaires de chaque stade de maturité histologiquement afin de vérifier la maturité observée à l'échelle macroscopique et pour permettre une meilleure compréhension de la reproduction en terme d'acquisition de la maturité et des cycles de reproduction. Aussi, les techniques de marquage en permettant de suivre la présence d'un poisson ou d'un groupe de poissons particulier dans le temps et l'espace, fournit un outil important pour les gestionnaires des pêches et peut-être un autre moyen, rentable, fiable et direct pour collecter des données pour l'étude des populations.

La perte des prédateurs de haut niveau que sont les élasmobranches affecte l'équilibre de l'écosystème et notre rôle en tant que scientifiques est de maintenir leur protection en essayant de trouver un compromis entre la demande sociale majeure pour ces poissons et l'équilibre de Mère Nature.

## **Abstract**

The aim of this study is to contribute to a better knowledge of cartilaginous fish in the Lebanese coastal waters, Eastern Mediterranean. Emphasis was placed on various aspects of the distribution, diversity, biology and ecology of these species. In this study, a total of 314 specimens of cartilaginous fish were sampled. These specimens constituted of 25 cartilaginous fish species, 11 shark species and 14 batoid species. No chimaeras were recorded. The data was collected from two sources: (a) an experimental survey in the framework of the CIHEAM PESCA-Libano project and (b) periodic observation of fisheries and catches of hired fishermen. Spatio-temporal distribution was evaluated using the Catch Per Unit Effort of the experimental survey data. Spatio-temporal diversity was also estimated taking into account the total number of species caught in the survey and fisheries/fishermen data. Length-weight relationships for three sharks and five batoids were also presented for species of the combined data sources having more than 10 individuals. Finally, the biology and ecology of two commercially significant and exploited species were also presented as a first step in their fishery management and conservation.

**Keywords:** Chondrichthyans; conservation; distribution; life history; Lebanon; Levantine basin

## **Résumé**

L'objectif de cette étude était de contribuer à une meilleure compréhension des poissons cartilagineux des eaux côtières libanaises du bassin oriental de la Méditerranée. Dans ce contexte, les différents aspects relatifs à la distribution, la diversité, la biologie et l'écologie de ces espèces ont été développés. Au total, 315 spécimens de poissons cartilagineux ont été échantillonnés appartenant à 25 espèces, dont 11 espèces de requins et 14 espèces de batoïdes. Aucune chimère n'a été enregistrée. Les données ont été collectées à partir (a) de captures expérimentales dans le cadre du projet "CIHEAM PESCA-Libano" et (b) d'observations périodiques des poissons dans les poissonneries et capturés par les pêcheurs. A partir des données de captures expérimentales, la distribution spatio-temporelle a été évaluée à travers le calcul de 'la capture par unité d'effort'. Cette dernière a été estimée à la fois à partir des données scientifiques et commerciales, en prenant en considération le nombre total d'espèces. Différentes relations longueur-poids ont été établies pour 3 requins et 5 batoïdes, et cela pour les espèces présentant un nombre d'individus supérieur à 10. Finalement, la biologie et l'écologie de deux espèces commerciales bien exploitées dans les eaux côtières libanaises ont été présentées.

**Mots clés:** Chondrichthyens; conservation; distribution; traits de vie; Liban; Bassin Levantin