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JUVENILE PELAGIC FISH ASSEMBLAGES IN THE COASTAL WATERS OF LEBANON: DIVERSITY, BIOLOGICAL CHARACTERISTICS, AND LANDINGS

by
GARABED HAGOP KAZANJIAN

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GARABED HAGOP KAZANJIAN

Approved by:

____

Dr. Michel Bariche, Associate Professor — Advisor
Biology

____

Dr. Khouzama M. Knio, Professor — Member of Committee
Biology

____

Dr Imad Saoud, Associate Professor — Member of Committee
Biology

Date of thesis defense: 4 June, 2012

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AN ABSTRACT OF THE THESIS OF

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Small pelagic fishes constituted half of the Mediterranean landings and a considerable portion of the Lebanese catches. In this study, the purse seine fishery was analyzed between 2006 and 2007 in two sites along the northern coast of Lebanon. Thirty-six different fish species were collected, out of which seven constituted more than 97% of the landings. *Engraulis encrasicolus*, *Sardinella aurita* and *Sardina pilchardus* composed 57.7%, 20.9% and 5.6% of the abundance of catches respectively and 31.3%, 19.2%, 9.2% of its biomass. Non-indigenous species comprised 7.2% of the total abundance and 18.7 % of the landing biomass. The fishery targeted mainly the new recruits (0+), and the vast majority of the catches were fishes below their size at first maturity. Diversity and species richness were high in the warmer in the months and low in the colder ones. Temperature and salinity were positively correlated with species richness, while the chlorophyll content of seawater was positively associated with diversity. Clear temporal patterns with distinct shifts of dominance within the landings were detected throughout the year for the most common species. Engraulids dominated catches from October to March, while the rest of the year was characterized by clupeids, *Boops boops,* and *Scomber colias.* A temporal niche partitioning seems to exist in the easternmost Mediterranean pelagic waters, possibly to minimize competition.

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CHAPTER I

INTRODUCTION

A. The Mediterranean Sea

The Mediterranean is a semi-enclosed sea situated among three continents. Together with the Black Sea, it has a surface area of 2,969,000 km^2 (Lleonart and Maynou, 2003). Despite representing only 0.82% of the world's ocean surfaces, the Mediterranean Sea boasts 4% to 18% of the its marine biodiversity, encompassing a total number of 17,000 marine species (Farrugio *et al*., 1993; Bianchi and Morri, 2000; Coll *et al*., 2010). Nearly 10% of the Mediterranean ichthyofauna is endemic to it (Quignard and Tomasini, 2000). It is generally perceived that biodiversity in the Mediterranean gradually decreases with depth and from west to east following a gradient of production, although this claim is at times refuted due to gaps in our knowledge of the eastern Mediterranean basin (Quignard and Tomasini, 2000; Coll *et al*., 2010). Nevertheless, strong unfavorable environmental parameters control the eastern basin. It is more oligotrophic compared to the western basin and is characterized by higher salinity and temperature. As such, the Levantine coast is the warmest and the most saline part of the Mediterranean with a mean sea surface temperature (SST) of 21.8 ˚C (Coll *et al.*, 2010).

B. Shallow Coastal Habitats

Shallow coastal zones often exhibit a high biodiversity as well as strong seasonality and high productivity (Danovaro and Pusceddu, 2007; Raedemaecker *et al.*, 2010). These zones are vital for many fish species that utilize the shallow habitats during their early life cycle. They are especially known to provide food and shelter to juvenile fishes and often function as nursery areas for many species (Pattrick and Strydom, 2008; Raedemaecker *et al.*, 2010; Durrieu de Madron *et al.*, 2011; Kalogirou *et al.*, 2012). The Lebanese coast had already been suggested to be a nursery area for some important commercial pelagic fishes (Bariche *et al.*, 2006). It is of importance then to analyze these species in this habitat and the factors that affect the fish assemblages inhabiting it.

Biotic (predation, competition, spawning, etc.) and abiotic (temperature, salinity, light, nutrient availability, depth, etc.) factors influence the fish community structure in shallow coastal zones (Raedemaecker *et al.*, 2010). Composition and abundance of the fish community are also influenced by habitat type. For instance, in Lebanon, rocky substrates were affiliated with higher diversity and density in comparison to macroalgal beds and sandy areas (Harmelin-Vivien *et al.*, 2005).

C. Recent Changes In The Mediterranean

The invasion of Indo-Pacific organisms through the Suez Canal, termed as Lessepsian migration by Por (1978), have led to modification of the Eastern Mediterranean ecosystems and their pelagic fish assemblages (Galil, 2009; Lleonart, 2011). Lessepsian species, along with other aliens of different origins reported in the Mediterranean (Galil, 2008), will be collectively referred to in this work as Non-Indigenous Species (NIS). These newly introduced species have enriched the littoral zone of the Eastern Mediterranean (Fishelson *et al*., 2002; De Raedemaecker *et al*., 2010). Lessepsian migrants were observed in all types of substrate and complexity, indicating no preferential habitat for colonization (Harmelin-Vivien *et al.*, 2005). Some of these species have furthermore become important components of local fisheries (George and Athanassiou 1967; Gücü and Bingel 2004; Goren and Galil, 2005; Galil, 2009). Two pelagic species: *Herklotsichthys punctatus* (Rüppell, 1837) and *Etrumeus teres* (DeKay, 1842) have reached commercial values within the Levantine basin (Golani, 1993; El Sayed, 2005; Carpentieri *et al*., 2009; Osman *et al*., 2011).

Four times as many exotic species currently reside in the Levantine basin as do in the westernmost Mediterranean (424 vs 109) (Galil, 2009). Entry through the Suez Canal constitutes the biggest source (81%), followed by vessel-transported (13%) and mariculture (3%) (Galil, 2009). The latest studies show that there are now a total of 116 exotic fish species in the Mediterranean (CIESM, 2012). That number is expected to increase as more species are discovered and cited. A considerable percentage of these species are of Indo-Pacific origin (41%), followed by the Indian Ocean (16%), and the Red Sea (12%) (Coll *et al.*, 2010).

The rate and success of the Lessepsian migrants colonizing the eastern Mediterranean has been hypothesized to be due to their occupation of unoccupied niches or to an efficient competition with the native species on resources. Moreover, less diverse communities and stressed ecosystems are said to be more prone to successful biological invasions. The low diversity in fish communities of the eastern Mediterranean further corroborates this point (Harmelin-Vivien *et al*., 2005; Kaligorou *et al.*, 2012). While the southern and eastern Mediterranean appear to go through a process of “tropicalization”, being populated by warm water exotic species, thermophilic native species are being observed more frequently in the colder Northern waters, in a process termed Meridionalization (Azzurro *et al.*, 2011; Bianchi, 2007). For instance, the native south-eastern Mediterranean dominant and thermophilic species *Sardinella aurita* Valenciennes, 1847 has lately increased in Mediterranean landings (FAO, 2005) and has been spreading further north where it had been historically rare (Lleonart, 2011). The effect of such movements on biodiversity and species extinction is yet to be fully studied (Azzurro *et al.*, 2011; Bianchi, 2007; Coll *et al.*, 2010; Quignard and Tomasini, 2000). Being severely impacted by the invasion of species, the Levantine basin is endangered (Coll *et al.,* 2010).

Additionally, in recent times, increased coastal disturbance due to anthropogenic pressures of urbanization, tourism, and destructive fishing practices have greatly altered the habitat structure, the near-shore currents, and the quality of the sea bottom, further affecting the fish communities (Caddy, 2000; Raedemaecker *et al.*, 2010). Pollution has also altered species richness and biodiversity in some littoral assemblages (Fishelson, 2000).

D. Small Pelagic Fisheries

Small pelagic species constitute a significant portion of the total world fisheries catch and approximately half of the total Mediterranean landings (FAO, 2005). In fact, 90% of the total catch of *Engraulis encrasicolus* (Linnaeus, 1758) and 25% of *Sardina pilchardus* (Walbaum, 1792) are landed in the Mediterranean (Fréon and Misund, 1999). These two species dominate the Mediterranean small pelagic fishery, accounting for 59% and 16% of the small pelagic landings respectively (FAO, 2005). Another common species *Sardinella aurita* is dominant on the Southern shore of the Mediterranean (Lleonart, 2011). Medium sized pelagic fish (mackerels, bogue, bonite) constitute an additional 7% of the landings (FAO, 2005). The majority of the Mediterranean catches correspond to recruits of commercial species (Lleonart and Maynou, 2003). The captured fishes are generally sold fresh for human consumption and priced relatively high (Lleonart and Maynou, 2003; Lleonart, 2011).

The Northern coast of the Mediterranean is predominantly populated by Atlantic species, whereas Saharian and sub-tropical species are generally present in its eastern basin. Ponto-Caspic species exclusively reside in the Aegian Sea and Adriatic Sea. (Quignard and Tomasini, 2000). Overall, it is reported that the Mediterranean Sea contains 664 species (575 Osteichthyes, 86 Chondrichthyes and 3 Cyclostomes) (Quignard and Tomasini, 2000). Endemic species represent 8.8% of the fish community in the Mediterranean with the Northern coast encompassing greater endemic richness compared to the rest of the Mediterranean (Quignard and Tomasini, 2000; Coll *et al*., 2010).

Small pelagics have a short life span, feed on plankton (Sabatés *et al*., 2006), and their recruitment is largely regulated by egg and larval survival (La Mesa *et al*., 2009; Sabatés *et al*., 2006) that depends on favorable environmental conditions. Consequently, variations in the ecosystem and climate impact pelagic fish stocks and their fisheries (Fréon and Misund, 1999; Sabatés *et al*., 2006; Somarakis *et al*., 2006). The decline of some anchovy fisheries was also attributed to overfishing (Papaconstantinou and Farrugio, 2000). Due to occupying a substantial biomass at the intermediate levels of the food web (wasp-waist ecosystem), small pelagics have a strong impact on the upper and lower trophic levels. Therefore, fluctuations in the small pelagic populations often modify the ecosystem structure (Bakun, 2006; Cury *et al*., 2000).

The recruitment strength of small pelagics is determined within the first year of life as recruitment success in most of these species is mainly linked to survival in their early life stages (La Mesa *et al.*, 2009). The species, population size, age structure, spawning intensity, and the physical characteristics of the habitat are all considered important for the recruitment process (Maynou *et al*., 2008). In the Levantine basin, a sharp decline in pelagic catches was recorded after the construction of the Aswan dam (Halim *et al*., 1995). Since then, total catches have been on the rise, signifying increased productivity in an area previously described to be oligotrophic. It has to be mentioned that an increase in plankton and acoustic estimates of small pelagic biomass have also been recorded lately in the Eastern Mediterranean (Stergiou *et al*., 1997; FAO, 2005). In Lebanon, the trophic structure of the fish community is dominated by zooplanktivores (55%) while herbivores constituted only a minor share (4%). The majority of the species previously spotted in Lebanon have also been reported in neighboring countries (Harmelin-Vivien *et al.*, 2005). However, knowledge of the superficial (0-50m) and deep (beyond 400m) bathymetric zones in the Mediterranean is to date scarce (Quignard and Tomasini, 2000). Available information on the fish communities of the Mediterranean have been regionally biased, with little known regarding its southern and eastern coasts (Fishelson, 2000; Goren and Galil, 2005; Coll *et al*., 2010; Kaligorou *et al.*, 2012). A seasonal study focusing on the temporal variations of the fish community in the Levantine basin remains to be done (Harmelin-Vivien *et al.*, 2005).

E. The Purse Seine Fishery

Fishing predominantly occurs on the continental shelf (up to 200 metres deep) or on the upper part of the continental slope (El-Haweet, 2001; Lleonart, 2011). Small pelagic species generally reside close to the coast, though many of these species are known to migrate seasonally, which also reflects the seasonal nature of their fisheries (Kallianiotis *et al.*, 2004). During summer, sardine, anchovy, mackerel and horse mackerel approach the coast, marking the start of their fishing season in the Mediterranean. In winter, all these species move back to deeper waters (Papaconstantinou and Farrugio, 2000).

The Mediterranean fishery is mostly comprised of fragmented fleets of small vessels that use a large number of landing sites and target multi-species catches (Lleonart and Maynou, 2003). The gears used to target small pelagics are usually purse seines (sometimes also coupled with light) and pelagic trawls (Lleonart and Maynou, 2003). Small and medium size purse-seine vessels dominate the fishery in the Levantine basin, with some larger trawls and purse-seines in Turkey and Egypt (Papaconstantinou and Farrugio, 2000). This fishery is comprised ofjuveniles of commercial species (Lleonart and Maynou, 2003). This pattern is a result of a long history rather than the product of a management policy (Lleonart and Maynou, 2003).

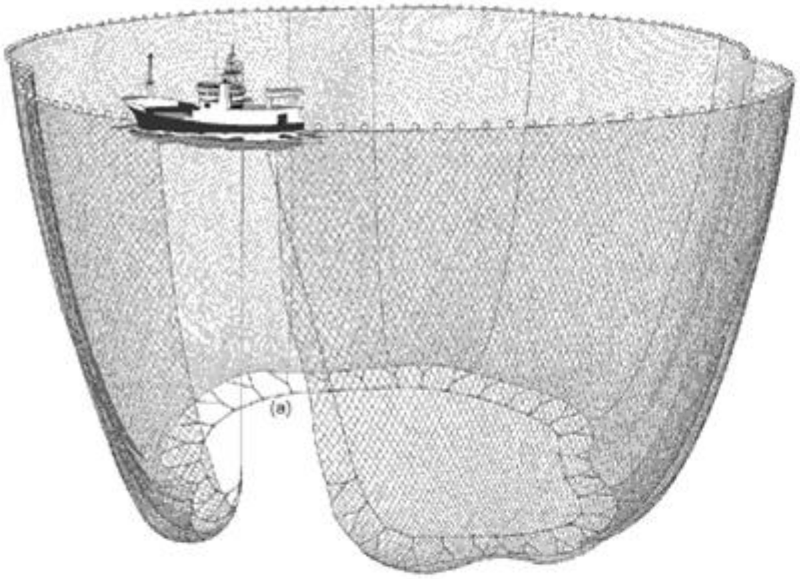

Figure 1: An image depicting a deployed purse-seine net (adapted from the European Cetacean Bycatch Campaign Website)

F. Study Aims

In 2003, a preliminary assessment of the lampara fishery landings was conducted from off the coast of Lebanon (Bariche *et al*., 2006, 2007). This study revealed for the first time information on the diversity of juvenile fish assemblages in the coastal pelagic environment but was restricted to only four months. Following up on its results, the purpose of the present work was:

1. To provide a complete and accurate assessment of the composition, abundance, biomass, distribution, and seasonality of the juvenile fish assemblage off the Lebanese coast over a whole annual cycle
2. To assess the fish diversity, especially in conjunction to the effects of Non Indigenous Species.
3. To describe the life history traits of the most common species through investigating temporal patterns of abundance and size-class structure.

CHAPTER II
MATERIALS AND METHODS

A. Sampling Method and Sites

The study was conducted in the eastern Mediterranean, off the coast of Lebanon at two different sites. Sample collection was carried out with the help of professional fishermen using lampara lights and purse seines every fortnight at each site from October 2006 to October 2007 (Figure 2). Each trip started at midnight and was composed of a maximum of four seine hauls. Sampling occurred mainly over soft bottoms and up to 40 m depth. The extensive length of the net (170 m long, 40 m deep) coupled with its small mesh size (5 mm mesh) allowed the capture of all aggregated fishes under the source of light. A subsample of a fixed volume (3 litres) was removed randomly each time the net was hauled (Bariche *et al*. 2007). Surface seawater temperature was recorded during each sampling trip and monthly averages were calculated. Various environmental parameters (salinity, dissolved oxygen, and seawater chlorophyll content) were retrieved from the World Ocean Database of the NOAA [http://www.nodc.noaa.gov/] and means were calculated for the period 1980-1998.

B. Laboratory Procedures

Collected samples were transported on crushed ice to the laboratory where they were sorted and identified at the species level following various reference works (Whitehead *et al*., 1986; Smith *et al*., 2003; Nelson, 2006; CIESM Atlas of Exotic Species in the Mediterranean). After identification, total length (TL: length from the tip of the snout to tip of upper caudal lobe) was measured to the nearest mm (Anderson &

Neumann, 1996) and total body weight (TW) recorded to the nearest 0.01 g. The specimens were thereafter fixed in 10% formalin and stored for further examination.

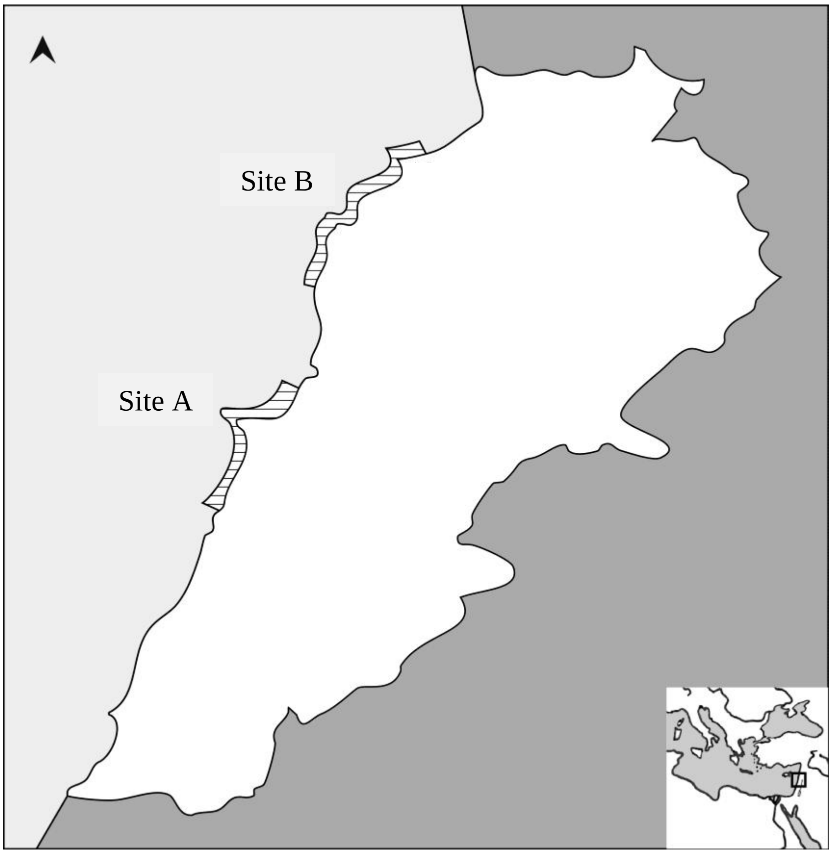

Figure 2: Map of Lebanon showing sampled areas.

C. Data Analysis

Fifty-nine sampling trips yielded a total of 169 samples, each representing a different seine haul. Samples were grouped on a monthly basis for each site. Frequencies of each species were calculated and a Chi-square test of heterogeneity was used to compare the two sites.

Thereafter, samples from the two sites were grouped and species richness (number of species collected), abundance (number of individuals per species), and biomass (total body weight per species) were determined per month. Three indices were also calculated (1) the Simpson Diversity Index [D = 1 - Σpi2], (2) the Shannon-Wiener Diversity index [H'= Σ pi logpi], and (3) the Pielou's evenness index [$J' = \frac{H'}{Hmax}$]; where *pi* is the proportion of total sample belonging to i^{th} species, and Hmax is the maximum value of H' when all proportions are equal (Magurran, 2004).

Normality was tested for the most common species using the Kolmogorov-Smirnov test. Consequently, the non-parametric Spearman rho (p) was used to check for potential association among species (Zar, 1999).

The non-parametric Spearman rho (p) was also calculated to test for correlation between environmental parameters (surface water temperature, salinity, dissolved oxygen levels, and chlorophyll content) and species richness as well as the three indices.

The length-weight relationship of the most common species was analyzed by regression analyses with a hypothesized power function of the formula $TW = aTL^b$, where a and b are regression parameters. Analysis of Variance (ANOVA) tables were assessed for the highest F-values indicative of the best regression, in addition to r^2 values. To check whether each species deviated from isometric growth, values of b were tested by a t-test at the 0.05 significance level to validate if they were significantly different from 3.

Descriptive statistics and graphs were completed using Microsoft® Excel 2010. All other statistical tests were performed using SPSS Statistics (17.0.1) ©, SPSS Inc.

CHAPTER III

RESULTS

A. Composition of fish assemblages

A total of 31,351 specimens were processed during the study period. Thirty-six taxa were recorded, distributed into 18 families and 32 genera (Table 1). Engraulidae and Clupeidae were the most abundant families, representing 57.7% and 33.0% of the catches respectively, followed by Sparidae (4.5%). Clupeidae represented 37.4% of the total landed biomass, while Engraulidae, Sparidae, and Scombridae were 31.3%, 19.7%, and 6.4% respectively. In terms of species richness, Clupeidae and Sparidae were each represented by the greatest number (6 species), followed by Carangidae (4 species) and Scombridae (3 species) (Table 1).

On the species level, *Engraulis encrasicolus* (57.7%) and *Sardinella aurita* (20.9%) composed the majority of the landings in abundance. Common species were *Sardina pilchardus* (5.6%), *Herklotsichthys punctatus* (4.6%), *Boops boops* (Linnaeus, 1758) (3.8%), *Scomber colias* Gmelin, 1789 (2.8%), and *Etrumeus teres* (2.0%). Overall, seven species accounted for 97.4% of the abundance of catches, while 14 species were rarely captured (≤6 individuals) (Table 1). In terms of biomass, seven species accounted for 91.6% of the landings. These were: *Engraulis encrasicolus*: 31.3%, *Sardinella aurita*: 19.2%, *Boops boops*: 16.9%, *Sardina pilchardus*: 9.2%, *Scomber colias*: 5.9%, *Etrumeus teres*: 5.1%, and *Herklotsichthys punctatus*: 3.9%. Most of the catches were juveniles and sub-adults of pelagic fish species, while adults were very rare.

Thirteen NIS, distributed among 10 families, were captured. They constituted 36.11% of the species richness, 7.2% of the abundance, and 18.7% of the biomass of the landings. *Herklotsichthys punctatus* and *Etrumeus teres* were the most abundant among the NIS, representing 63.9% and 27.2% respectively. Six families were only represented by NIS (Callionymidae, Exocoetidae, Leiognathidae, Mullidae, Siganidae, and Tetraodontidae), while eight families included only native Mediterranean species (Table 1).

No significant difference of species monthly frequencies was found between site A and site B (P>>0.05, Table 2), hence the data from the two sites was pooled for this study.

Table 1: List of all species encountered throughout the sampling period, with their respective size range, abundance, and biomass. NIS are marked with an asterisk (*).

Family / Species	Range (mm)	Mean TL (SD)	Abundance	%Abundance
Apogonidae				
Apogon imberbis	55		1	0.003
Atherinidae				
Atherina boyeri	31-89	5.86 (1.04)	159	0.507
*Atherina forskalii**	42-104	8.60 (1.80)	10	0.032
Callionymidae				
*Callionymus filamentosus**	63-68	6.55	2	0.006
Carangidae				
Caranx crysos	50-145	10.19 (2.33)	23	0.073
*Decapterus russelli**	84-131	9.70 (1.82)	6	0.019
Trachurus trachurus	50-158	9.90 (2.66)	41	0.131
Trachurus mediterraneus	37-208	13.11 (3.41)	57	0.182
Centracanthidae				
Spicara smaris	55-146	11.10 (1.31)	61	0.195
Clupeidae				
Sardina pilchardus	32-165	8.20 (1.66)	1746	5.569
*Etrumeus teres**	44-235	9.04 (2.88)	617	1.968
Sardinella aurita	29-200	7.09 (2.22)	6549	20.890
Sardinella maderensis	79-80	79.5	2	0.006
*Herklotsichthys punctatus**	43-108	6.34 (0.96)	1447	4.616
*Dussumieria elopsoides**	134-136	135	2	0.006
Engraulidae				
Engraulis encrasicolus	26-126	6.41 (0.97)	18109	57.764
Exocoetidae				
*Parexocoetus mento**	65-80	7.20 (0.76)	3	0.010
Gobiidae				
Gobius bucchichi	30-35	32.5	2	0.006
Leiognathidae				
*Equulites klunzingeri**	41-75	5.51 (0.90)	28	0.089
Mullidae				
*Upeneus pori**	46-110	9.10 (1.03)	82	0.262
Myctophidae				
Myctophum punctatum	42-84	7.27 (1.11)	15	0.048
Scombridae				
Auxis rochei	140-153	146.5	2	0.006
Euthynnus alletteratus	76-208	12.44 (4.13)	14	0.045
Scomber colias	35-262	7.70 (3.43)	879	2.804
Siganidae				
*Siganus luridus**	111-154	12.80 (1.82)	4	0.013
*Siganus rivulatus**	45-139	10.68 (3.46)	48	0.153
Sparidae				
Boops boops	40-184	10.66 (2.55)	1197	3.818
Dentex maroccanus	63		1	0.003
Diplodus vulgaris	111-113	112	2	0.006
Pagellus acarne	69-140	9.66 (1.10)	170	0.542
Pagellus erythrinus	86-111	9.84 (0.62)	54	0.172
Lithognathus mormyrus	55-56	55.5	2	0.006
Sphyraenidae				
*Sphyraena chrysotaenia**	45-196	12.32 (6.01)	13	0.041
Sphyraena sphyraena	160		1	0.003
Tetraodontidae				
*Tylerius spinosissimus**	27		1	0.003
Trachinidae				
Echiichthys vipera	49		1	0.003
Total			**31351**	**100**

Table 2: χ^2 heterogeneity on monthly frequency of species between site A and site B.

	Site A	Site B	Total	Expected	$\frac{(Obs - Exp)^2}{Exp}$	χ2	ν
Apogon imberbis	0	1	1	0.5	0.5	1	1
Atherina boyeri	2	6	8	4	1	2	1
Atherinomorus lacunosus	1	2	3	1.5	0.17	0.33	1
Auxis rochei	1	1	2	1	0	0	1
Boops boops	6	6	12	6	0	0	1
Callionymus filamentosus	1	1	2	1	0	0	1
Caranx crysos	3	1	4	2	0.5	1	1
Dentex maroccanus	1	0	1	0.5	0.5	1	1
Decapterus russelli	2	2	4	2	0	0	1
Diplodus vulgaris	2	0	2	1	1	2	1
Engraulis encrasicolus	12	13	25	12.5	0.02	0.04	1
Echiichthys vipera	1	0	1	0.5	0.5	1	1
Etrumeus teres	5	7	12	6	0.17	0.33	1
Euthynnus alleteratus	4	4	8	4	0	0	1
Gobius bucchichi	0	1	1	0.5	0.5	1	1
Herklotsichthys punctatus	3	5	8	4	0.25	0.5	1
Lithognathus mormyrus	1	1	2	1	0	0	1
Leiognathus klunzingeri	1	2	3	1.5	0.17	0.33	1
Myctophum punctatum	2	0	2	1	1	2	1
Pagellus acarne	1	1	2	1	0	0	1
Pagellus erythrinus	1	1	2	1	0	0	1
Parexocoetus mento	1	0	1	0.5	0.5	1	1
Sardina pilchardus	4	5	9	4.5	0.06	0.11	1
Sardinella maderensis	1	0	1	0.5	0.5	1	1
Sardinella aurita	8	10	18	9	0.11	0.22	1
Scomber colias	5	6	11	5.5	0.05	0.09	1
Siganus luridus	1	1	2	1	0	0	1
Siganus rivulatus	4	2	6	3	0.33	0.67	1
Sphyraena chrysotaenia	3	4	7	3.5	0.07	0.14	1
Sphyraena sphyraena	1	0	1	0.5	0.5	1	1
Spicara smaris	4	2	6	3	0.33	0.67	1
Trachurus mediterraneus	5	7	12	6	0.17	0.33	1
Trachurus trachurus	2	3	5	2.5	0.1	0.2	1
Tylerius spinosissimus	0	1	1	0.5	0.5	1	1
Upeneus pori	1	1	2	1	0	0	1
Total	**90**	**97**	**187**			**18.97**	**35**
Pooled χ^2 [χ^2 of totals]				**93.5**	**0.13**	**0.26**	**1**

Heterogeneity χ^2 = 18.712
ν = 34
χ^2 (0.05,34) = 48.602

B. Size structure analysis

The length-frequency distribution of the seven most common species indicated the targeted size-range of this fishery (Figure 3). The majority of the catches fell within the range of 50-110 mm, with few catches above 150 mm appearing occasionally. The length-frequency distribution of some species such as *E. teres, S. colias* produced distinct batches/cohorts.

Length-frequency distribution exhibited a mode at 600 mm TL for *E. encrasicolus* (641±97 mm TL) and *H. punctatus* (634±96 mm TL), at 750 mm TL for *S. pilchardus* (710±229 mm TL) and *E. teres* (904±288 mm TL), a mode at 700 mm TL for *S. aurita* (709±2.22 mm TL), at 900 mm TL for *B. boops* (1066 ±255 mm TL), and 500 mm TL for *S. colias* (770±343 mm TL).

Among all of the landings, the smallest individual collected was *Engraulis encrasicolus*, measuring 26 mm TL, while the largest was *Scomber colias*, of 262 mm TL.

Length-weight relationship parameters of the most common species were calculated (Table 4; Figure 4). The power function was determined by the Analysis of Variance (ANOVA) to be the best fitting function. Regression was strongly significant in all of the species, with all r^2 values being greater than 0.92. Furthermore, all studied species showcased positive allometric growth, with *b* values differing significantly from 3 ($P<0.05$) (Table 3).

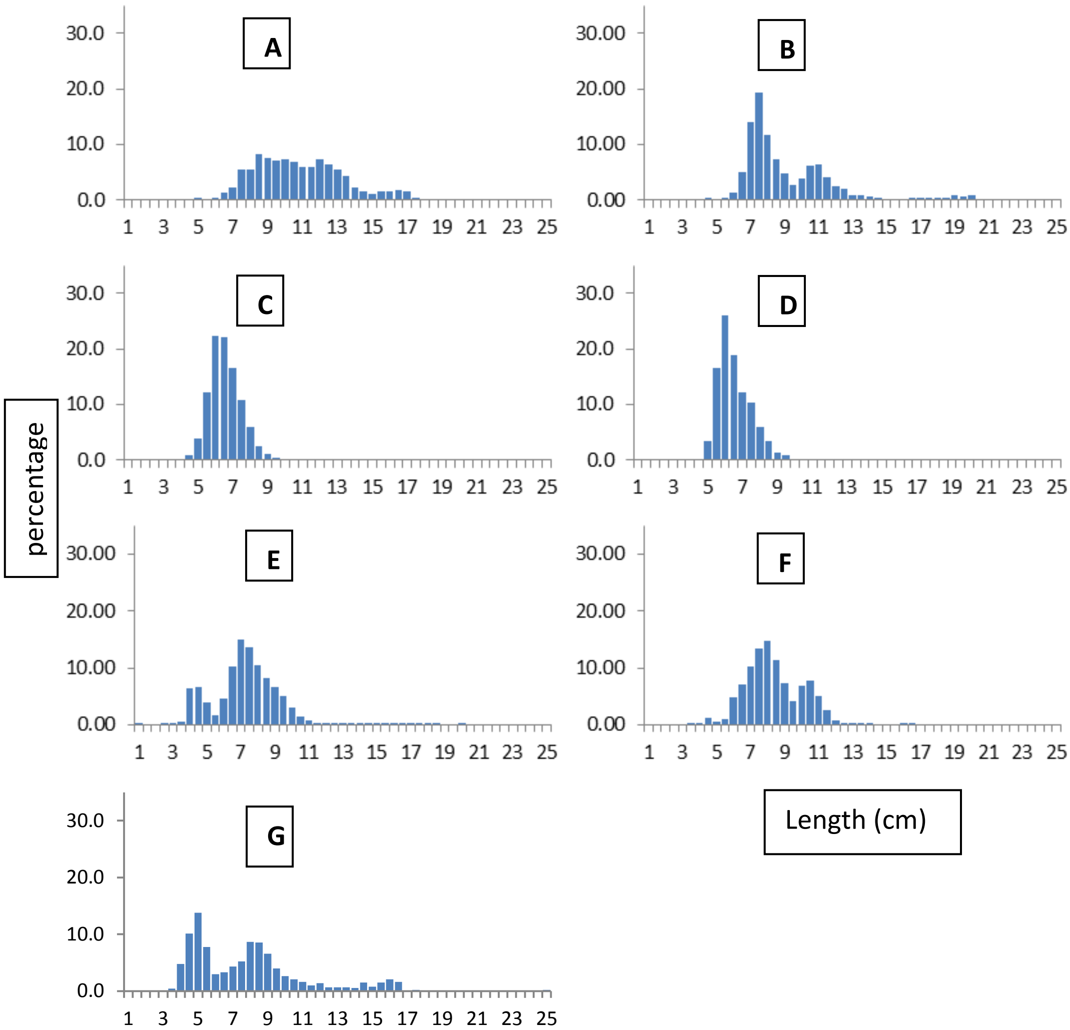

Figure 3: Length-frequency of: (A) *Boops boops*; (B) *Etrumeus teres*; (C) *Engraulis encrasicolus*; (D) *Herklotsichthys punctatus*; (E) *Sardinella aurita*; (F) *Sardina pilchardus*; (G) *Scomber colias.*

Table 3: Descriptive statistics and estimated parameters of the weight–length relationship for the seven common species.

Species	Length characteristics (cm)		Weight characteristics (g)		Parameters of the relationship			
	Mean (S.E.)	Range	Mean (S.E.)	Range	*a*	*b*	r^2	P (*b* =3)
Boops boops	10.66 (2.55)	4.0-18.4	14.00 (10.76)	0.6-65.7	0.0067	3.1499	0.985	7.05235E-09
Engraulis encrasicolus	6.41 (0.97)	2.6-12.6	1.70 (1.08)	0.1-14.8	0.002	3.5716	0.921	5.6702E-219
Etrumeus teres	9.04 (2.88)	4.4-23.5	8.17 (12.55)	0.4-114.7	0.0032	3.3859	0.984	1.73012E-20
Herklotsichthys punctatus	6.34 (0.96)	4.3-10.8	2.62 (1.48)	0.7-13.5	0.0057	3.2708	0.957	2.28549E-10
Sardina pilchardus	8.20 (1.66)	3.2-16.5	3.77 (3.39)	0.2-41.9	0.0039	3.3373	0.988	4.26021E-84
Sardinella aurita	7.09 (2.22)	2.9-20.0	3.35 (3.43)	0.1-75.5	0.0049	3.1678	0.976	2.99468E-29
Scomber colias	7.70 (3.43)	3.5-26.2	6.69 (13.01)	0.3-161.9	0.0055	3.1703	0.992	1.81032E-13

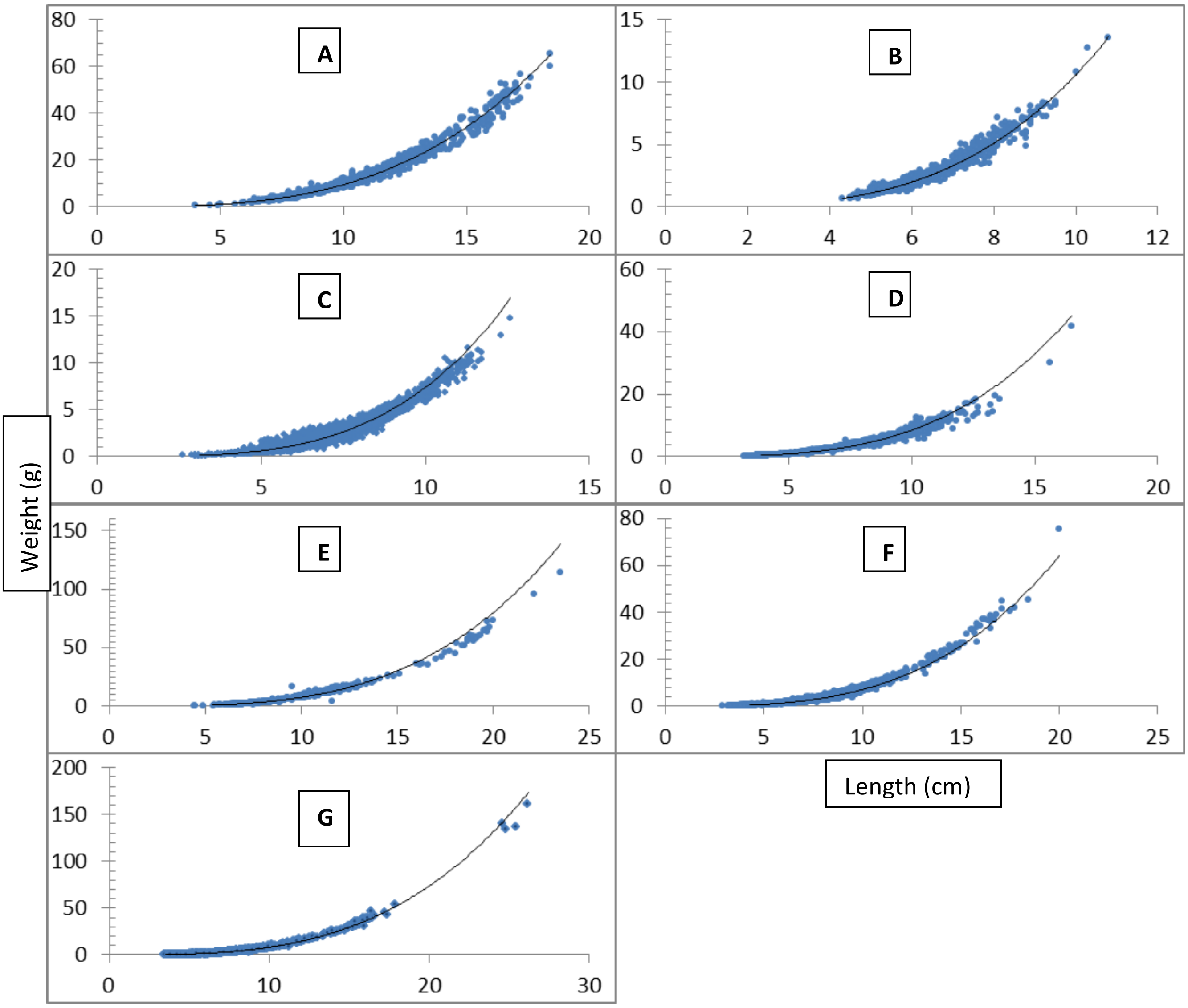

Figure 4: Length-weight relationship of (A) *Boops boops,* (B) *Herklotsichthys punctatus,* (C) *Engraulis encrasicolus,* (D) *Sardina pilchardus,* (E) *Etrumeus teres,* (F) *Sardinella aurita* and (G) *Scomber colias.*

C. Temporal variability

Family Clupeidae was present in the landings throughout the entire sampling period, except for February. Sparidae and Scombridae were only found between March and October, and *Engraulis encrasicolus* (Engraulidae) was observed throughout the 13 months (Figure 7).

The temporal variation in the composition of catches was characterized by a clear shift of dominance between two families along the study period (Figure 5a). Engraulidae dominated the catches (min-max: 74.2%-99.2%) between October and March, while Clupeidae represented the majority of the landings from April to September (55.5%-81.6%). Sparidae constituted a considerable share from March to October (0.5%-15.8%), while Scombridae appeared mostly between the months of April to July (2.4%-15.8%). The rest of the families combined (Others), were collected in moderate numbers (0.2-6.9%) throughout most of the year (Figure 5a).

The occurrence and abundance of the most common species showed great fluctuation during the 13-month period (Figures 6a, 7). *Engraulis encrasicolus* dominated the landings between October and March (min-max: 74.2%-99.2%) (Figure 6a). *S. pilchardus* suddenly appeared in April and constituted the biggest share of the catches (66.6%) during the same month. It gradually decreased in numbers and disappeared in August. While few individuals of *S. aurita* appeared in May, the species dominated the catches between June and September (41.3%-75.1%). During the same period (August-September) *E. encrasicolus* catches were gradually increasing. *Boops boops* was present from March to October (5.2%-11.3%). Among the rest of the common species, *S. colias* was abundant from April to July (2.2%-15.8%), *E. teres* in

May and June (22.2%-6.7%), and *H. punctatus* in October and November (21.5%-15.3%). (Figures 6a, 7).

Temporal fluctuations in biomass showed a slight deviation from the abundance figures (Figure 5b). Engraulidae dominated the catch between October and February, and had the second most shares in biomass in March, surpassed only by Sparidae (52.1%). The latter, mainly composed of *B. boops*, also had significant shares in April (45.9%) and May (24.5%), and throughout July to October (25.0%-33.2%). Clupeidae constituted an important share of the biomass from April till October, whereas Scombridae had a significant contribution between April and July. Throughout the rest of the sampling period, the non-targeted families combined did not contribute to more than 12.2% of the landing biomass.

Prominent differences between the temporal variations in abundance and biomass (Figures 6a and 6b) are the dominance of *B. boops* in March and April because of large individual sizes, in addition to its significant contribution to the biomass from August to October. Additionally, *S. colias*, along with *S. pilchardus*, make up half of the biomass (50.6%) of catches in May (Figures 6b).

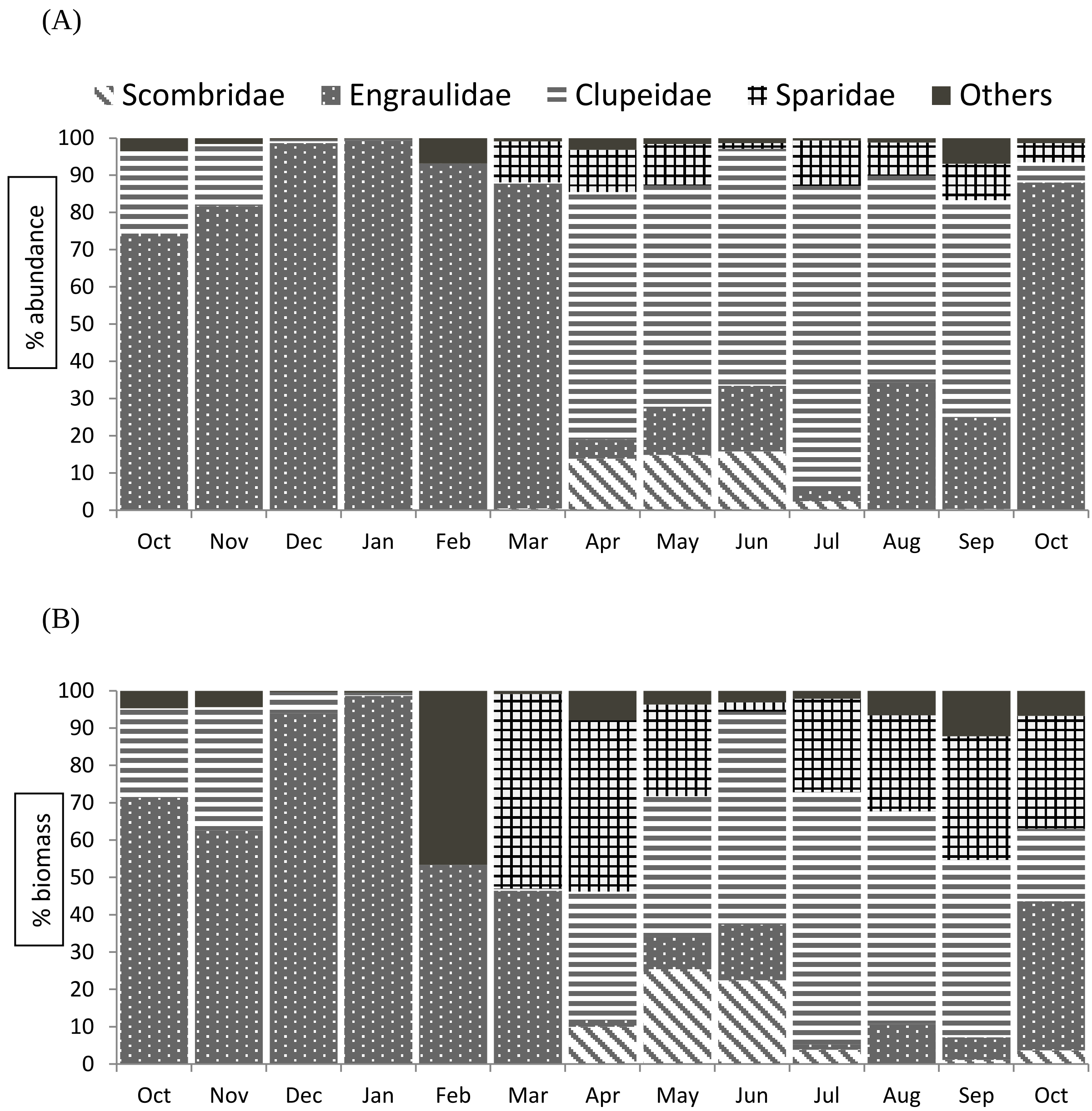

Figure 5: Temporal variation in (a) the percent abundance and (b) percent biomass of common fish families in the purse seine landings off the coast of Lebanon

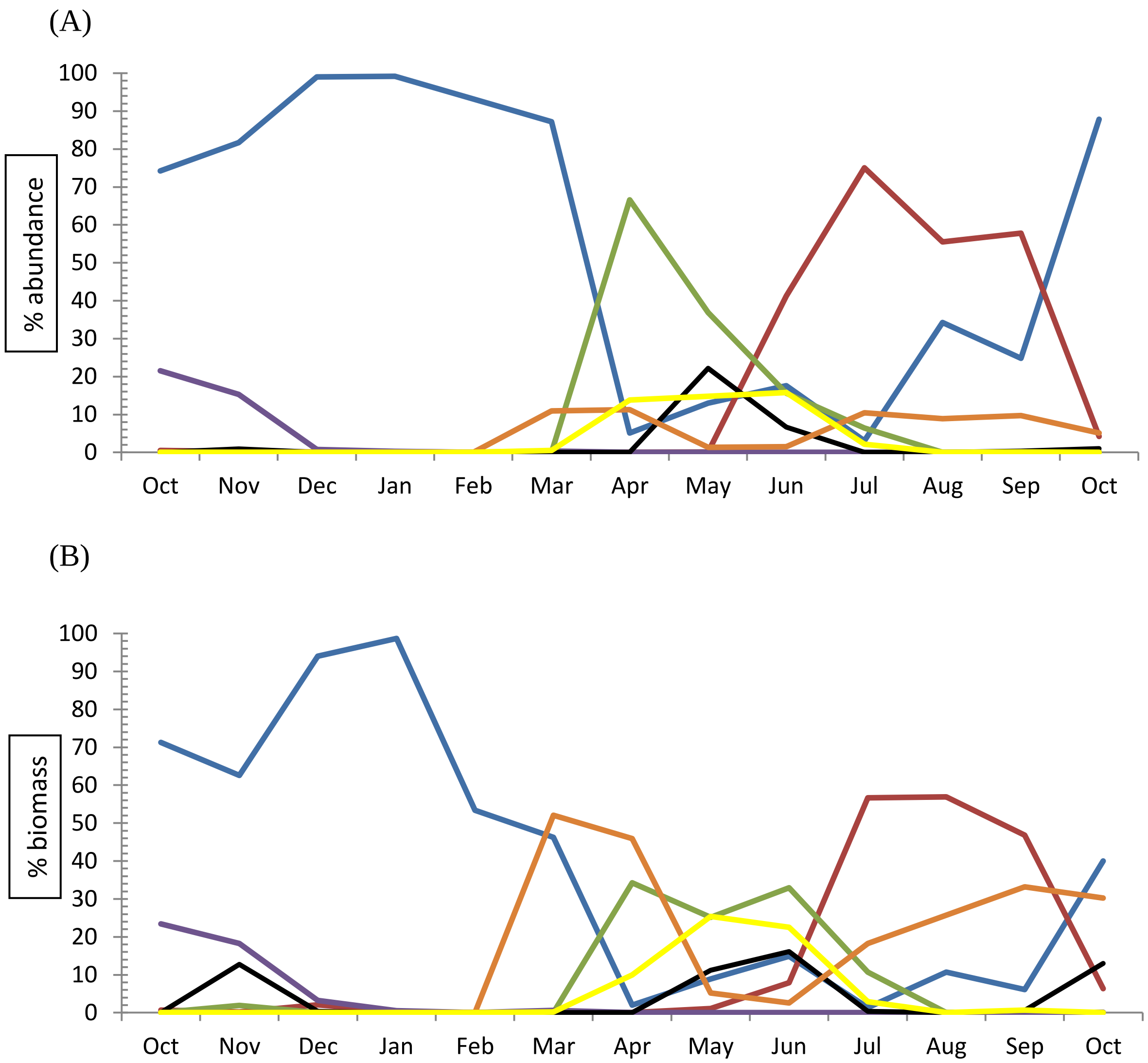

Figure 6: Temporal variation in (a) percent abundance and (b) percent biomass of common species in the purse seine landings off the coast of Lebanon (*Boops boops*: orange; *Engraulis encrasicolus*: blue; *Etrumeus teres*: black; *Herklotsichthys punctatus*: purple; *Sardinella aurita*: red; *Scomber colias*: yellow; *Sardinella pilchardus*: green).

Normality was not satisfied for all species (Kolmogorov-Smirnov test; P<0.05), except for *E. encrasicolus* (Table 4). As such, the Spearman rho test was used to study the correlation in abundance among the common species over time (Table 5).

The abundance of *Engraulis encrasicolus* had a negative relation with that of *S. pilchardus*, *B. boops* (P<0.05), and *S. colias* (P<0.01), and a positive one with the abundance of *H. punctatus* (P<0.01). Conversely, the abundance of *H. punctatus* was negatively associated with that of *S. colias* (P<0.05). In turn, *S. colias* was positively correlated with *S. pilchardus* (P<0.01), whereas the latter was also positively related in abundance to *E. teres* (P<0.05) (Table 5). Between the months of March to October, a negative association was also recorded between the abundance of *B. boops* and that of *E. teres* (P<0.05).

Table 4: Kolmogorov-Smirnov Test of Normality of the most common species.

Tests of Normality			
	Kolmogorov-Smirnov		
	Statistic	df	Sig.
B. boops	.248	13	.027
E. encrasicolus	.202	13	.148
E. teres	.395	13	.000
S. pilchardus	.403	13	.000
S. aurita	.386	13	.000
S. colias	.360	13	.000

Table 5: Spearman's non-parametric Spearman's ρ correlations coefficients between the abundance of each pair of species. P values are in parenthesis.

Species	*B. boops*	*E. encrasicolus*	*E. teres*	*H. punctatus*	*S. aurita*	*S.colias*	*S. pilchardus*
B. boops	1	-.580 (<0.05)	-.001	-.528	.436	.434	.105
E. encrasicolus		1	-.168	.850 (<0.01)	-.111	-.741 (<0.01)	-.583 (<0.05)
E. teres			1	-.126	.330	.408	.588 (<0.05)
H. punctatus				1	-.113	-.597 (<0.05)	-.498
S. aurita					1	.000	.032
S.colias						1	.793 (<0.01)

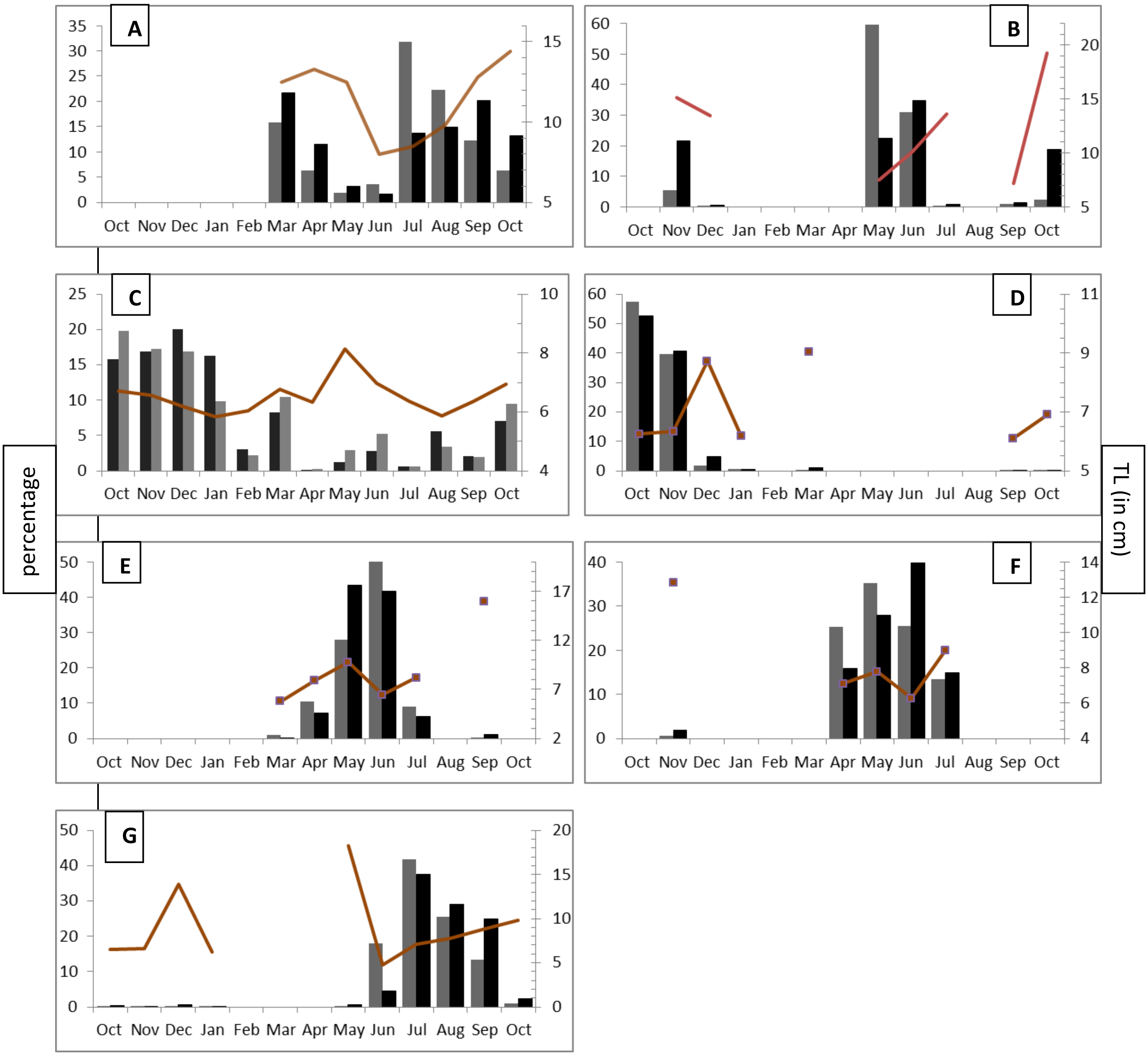

Figure 7: Temporal variation in percentage abundance (grey bar), biomass (black bar), and mean total length (red line. Abundance and biomass percentages are based on primary y-axis (left). Mean length is based on the secondary y-axis (right).
(A) *Boops boops*, (B) *Etrumeus teres*, (C) *Engraulis encrasicolus*, (D) *Herklotsichthys punctatus*, (E) *Scomber colias*, (F) *Sardina pilchardus*, (G) *Sardinella aurita*.

Table 6: Temporal variation in mean length of the most common species throughout the 13 months of sampling.

Species / Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Boops boops						12.50	13.30	12.50	8.00	8.50	9.80	12.80	14.40
Engraulis encrasicolus	6.72	6.55	6.17	5.85	6.05	6.76	6.32	8.14	6.96	6.36	5.88	6.37	6.96
Etrumeus teres		15.10	13.50					7.50	10.10	13.65		7.20	19.28
Herklotsichthys punctatus	6.24	6.33	8.72	6.19		9.05						6.10	6.90
Sardina pilchardus		12.84					7.11	7.77	6.27	8.96			
Sardinella aurita	6.52	6.65	13.94	6.18				18.25	4.80	7.10	7.74	8.81	9.81
Scomber colias						5.80	7.87	9.76	6.45	8.17		15.95	

D. Diversity

Species richness showed a wide range of temporal variability, with minima recorded in February (2 species) and maxima in July (19 species). In general, richness was least between January-April compared to the rest of the year (Figure 8).

All diversity and evenness indices were greatest in May (H'=1.63; D=0.76; J'=0.68) and June (H'=1.57; D=0.74; J'=0.68). Diversity was least in January (H'=0.06; D=0.02), while the lowest evenness value was recorded in December (J'=0.03).

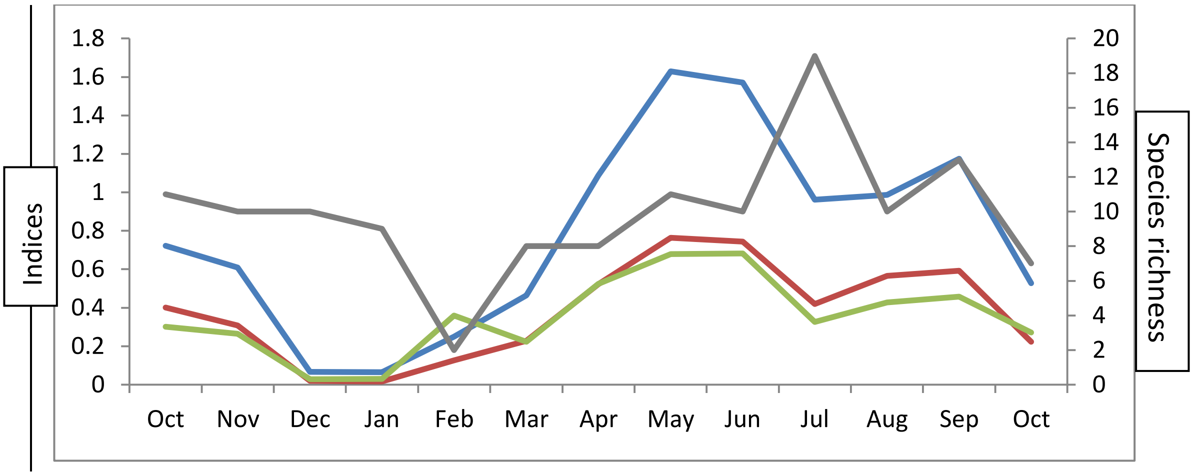

Figure 8: Temporal variation in species richness (grey), Shannon-Wiener diversity index H' (blue), Simpson's index D (red), and Pielou's evenness index J' (green).
All indices are represented by the primary y-axis (right). Species richness is represented by the secondary axis (left).

E. Environmental Parameters

The measured and compiled environmental parameters showed distinctive temporal variations (Figure 9). Temperature and salinity means ranged from 17.3˚C to 28˚C and from 39.29 to 39.55 respectively. The environmental parameters differed significantly from normality ($P<0.05$; Table 7). A strong positive correlation between surface water temperature and salinity was detected ($P<0.001$) (Table 8). In return, surface water temperature and salinity were negatively associated with dissolved oxygen levels ($P<0.001$) and not related with water chlorophyll content. Species richness was positively correlated with temperature and salinity ($P<0.05$) and negatively correlated with dissolved oxygen ($P<0.05$). Similarly, no correlation was found with seawater chlorophyll content. No correlation among diversity indices and temperature, salinity and dissolved oxygen were detected ($P>0.05$). However, seawater chlorophyll content was positively correlated with both Simpson and Shannon-Wiener indices ($P<0.05$) and 'lightly' correlated with evenness ($P<0.1$).

Table 7: Kolmogorov-Smirnov test for normality of the environmental parameters used.

	Statistic	df	Significance
Temperature	0.296	336	0
Salinity	0.159	101	0
Chlorophyll	0.249	101	0
DO	0.304	101	0

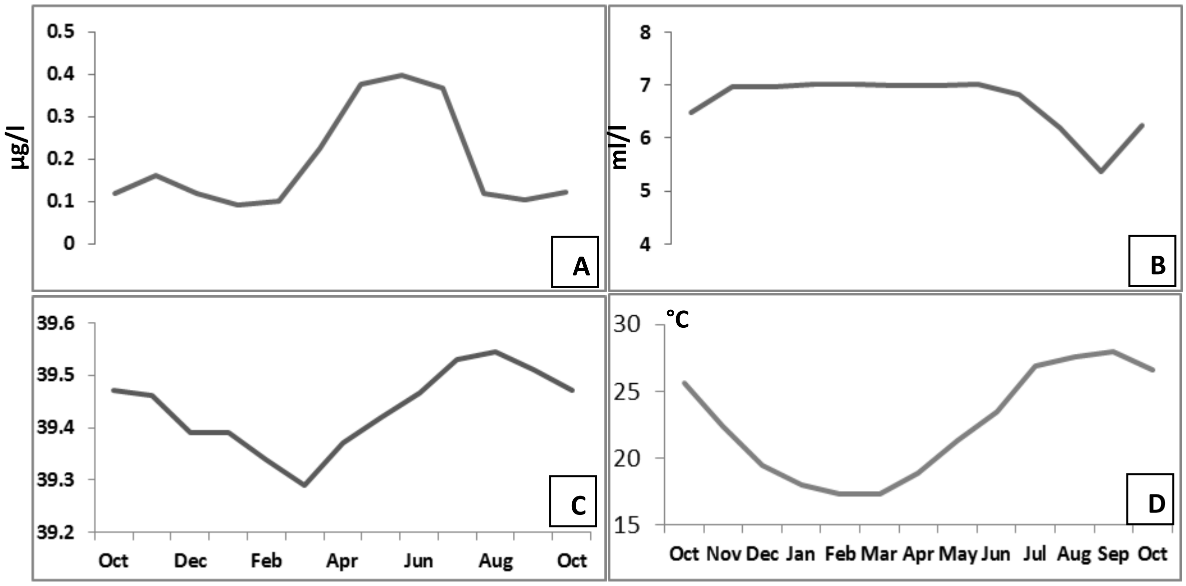

Figure 9: Compiled chlorophyll (A), dissolved oxygen (B), and salinity data(C). Fourth graph (D) shows recorded sea surface temperature.

Table 8: The non-parametric Spearman's ρ correlation coefficients between temperature, salinity, chlorophyll, dissolved oxygen, species richness, Pielou's evenness, Shannon-Wiener diversity index, and Simpson's diversity index. P values are in parentheses.

	Shannon-Wiener Index	Simpson's Index	Evenness	Richness	Dissolved Oxygen	Chlorophyll	Salinity
Temperature	0.517 (0.07)	0.520 (0.07)	0.316 (0.29)	-.914 ($1.21*10^{-5}$)	-.914 ($1.21*10^{-5}$)	-0.019 (0.95)	.971 ($3.49*10^{-8}$)
Salinity	0.444 (0.13)	0.452 (0.12)	0.264 (0.38)	.644 (0.02)	-.895 ($3.58*10^{-5}$)	-0.159 (0.6)	1
Chlorophyll	.678 (0.01)	.647 (0.017	0.510 (0.08)	0.143 (0.64)	0.094 (0.76)	1	
Dissolved Oxygen	-0.353 (0.24)	-0.372 (0.21)	-0.135 (0.66)	-.553 (0.05)	1		
Richness	0.522 (0.07)	.553 (0.05)	0.237 (0.44)	1			
Evenness	.896 ($3.48*10^{-5}$)	.874 ($9.53*10^{-5}$)	1				
Simpson's Index	.989 ($1.75*10^{-10}$)	1					

CHAPTER IV

DISCUSSION

The present study described for the first time the composition of the juvenile pelagic fish assemblages along the coast of Lebanon and identified their temporal occurrence throughout 13 consecutive months. The need to conduct such a study in the area had been previously highlighted (Quignard and Tomasini, 2000; Harmelin-Vivien *et al*., 2005; Coll *et al.*, 2010). It compliments a previous preliminary study performed over four months in the summer of 2003 in the same region (Bariche *et al*., 2006, 2007). In this present study, a total of 36 fish species were observed, among which 18 were not previously reported in Bariche *et al*. (2007). In return, the authors had reported 32 fish species, 13 of which were not encountered in this study. These were: *Alepes djedaba* (Forsskål, 1775), *Arnoglossus laterna* (Walbaum, 1792), *Belone belone* (Linnaeus, 1761), *Gobius niger* Linnaeus, 1758, *Gobius paganellus* Linnaeus, 1758, *Gymnura altavela* (Linnaeus, 1758), *Hygophum benoiti* (Cocco, 1838), *Oblada melanura* (Linnaeus, 1758), *Seriola dumerili* (Risso, 1810), *Serranus hepatus* (Linnaeus, 1758), *Stephanolepis diaspros* Fraser-Brunner, 1940, *Upeneus moluccensis* (Bleeker, 1855), and *Trichiurus lepturus* Linnaeus, 1758. All of these species were caught sporadically and in small numbers (≤10 individuals) except for the latter, of which 80 individuals were caught in a single haul. These species are not targeted by the purse seine fishery and are caught by chance. In the current study at least 12 similar species were identified (Table 1). Despite encountering several non-targeted species, bycatch in this fishery is considered low as demonstrated by the seven common species constituting 97.4% and 91.6% of the abundance and biomass of the landings respectively. Most of the observed species are sold with varying commercial values with only a few species being discarded.

The purse seine naturally excludes demersal and reef associated species. The small mesh size of the net used and the large volume it covered facilitates the capture of most fishes aggregated under the floating light. As such, the landing was mostly composed of juvenile pelagic fishes. Engraulids and Clupeids comprised 90.7% of the abundance and 68.7% of the biomass of the total landing. This is comparable to Bariche *et al*. (2007) who reported 91.0% and 78.8% respectively.

Out of all the reported species, 13 were non-indigenous to the Mediterranean Sea. Despite constituting more than one-third of the species richness of the fish assemblages, NIS constituted a small share (7.2% of abundance; 18.7% of biomass) of the total catch. Among all the pelagic NIS present in the eastern Mediterranean, *Herklotsichthys punctatus* and *Etrumeus teres* are certainly the most captured and have some commercial value. They are especially important during specific periods where *H. punctatus* constituted 21.5% of the catches in October, and *E. teres* constituted 22.2% of the catches in May (Figures 6A; 7B, D). Some species, such as *Atherinomorus forskalii* (Rüppell 1838), *Dussumieria elopsoides* Bleeker, 1849, and *Decapterus russelli* (Rüppell, 1830), exist in smaller populations in the Mediterranean since they are less frequently captured (Table 1). Conversely, some species were completely absent in the random sampling, due to either having a very small population [*Spratelloides delicatulus* (Bennett, 1832)] or evading the fishing gear [*Alepes djedaba*, *Rastrelliger kanagurta* (Cuvier, 1816), *Scomberomorus commerson* (Lacepède, 1800)]. Very limited information exists regarding the NIS catches by purse seines (not necessarily coupled with lampara) in the eastern Mediterranean. The only small pelagic NIS reported by

Wassef *et al*. (1985) caught by the same type of gear was *D. elopsoides* (as *D. acuta*), which represented 1% of the total landings. The abundance of all the pelagic NIS reported by Bariche *et al*. (2007) was similar to that of the present study except for *H. punctatus*, which was considerably less common in the previously reported catch (0.09% vs 4.62%). This is due to the fact that the species occurs in the landing mainly in October and November (Figure 6a), which fell outside the sampling period (May-August) of the previous study. Not a single individual of *H. punctatus* was captured from May to August in the current study.

There seems to be a clear niche partitioning among the various small pelagic species occurring along the Lebanese coast. The period from October to March was dominated by engraulids, whilst the rest of the year was mainly characterized by clupeids, *B. boops,* and *S. colias*. Furthermore, a succession of dominance was evident within clupeids. Abundance of *S. pilchardus* peaked in April, *E. terres* in May, *S. aurita* from July to September, and *H. punctatus* in October and November. This likely allows reduction of competition over resources and probably space.

It would be interesting to analyze the effect of the NIS on the native pelagic fish assemblages. For instance, *E. teres* peaks in months when diversity is highest and several small pelagic species are appearing in significant shares in the landing (*B. boops, E. encrasicolus, S. aurita, S. pilchardus,* and *S. colias*) (Figure 6A). As such, it would be difficult to deduce whether *E. teres* is competing with the rest of the co-occurring species during this period. However, it is of special coincidence that *B. boops* suddenly decreases in numbers considerably when *E. teres* appears, only to re-appear after the decline of the latter. Conversely, *H. punctatus* appeared in September and increased significantly in numbers in October and November, while an abrupt decrease in the abundance of *S. aurita* occurred simultaneously (Figure 6A). *Engraulis encrasicolus* was also present in substantial amounts in the landings at the same time. It is unclear whether *H. punctatus* is competing with *E. encrasicolus* or with *S. aurita*, or both. Since all of these species are zooplanktivores (Sánchez-Velasco and Norbis, 1997; Bowman *et al*., 2000; Marichamy 1971, Sever *et al*., 2005), future research could be directed towards dietary analysis in the regions where all species co-occur. Such interaction ought to be further studied to evaluate the full effects of the invasive species on the Mediterranean species appearing at the same time.

Interestingly, *H. punctatus*, a Lessepsian migrant, remains the only species of its family to appear in considerable numbers during the fall and winter seasons, while being completely absent during the warmer months (Figure 7). Lessepsian species being known as thermophilic organisms (Galil, 2009), this constitutes a particularly interesting observation that needs further investigation. Lack of extensive data on the species in its native ecosystem does not allow for making direct comparisons of the species biology and behavior between its origin and invaded habitat. It is possible that the species underwent a series of behavioral changes in its new environment to achieve better adaptation. It is also plausible that *H. punctatus* has taken itself a niche in the Eastern Mediterranean previously unoccupied prior to its invasion.

Temperature and salinity were positively correlated, as salinity increases with elevated evaporation rates. In contrast, dissolved oxygen was negatively correlated with temperature as seawater solubility decreases at higher temperatures. A positive correlation between temperature and species richness meant more species were caught during the warm summer months (Figure 8). The presence of these species in their nurseries is most likely related to the availability of food when seawater gets warmer.

The decrease in dissolved oxygen, although negatively correlated with species richness, does not hold much weight, as temperature and food availability are the strong factors to be considered. Dissolved oxygen content, due to being also negatively correlated with temperature, produces a parallel trend.

Diversity indices were found to be positively associated with seawater chlorophyll content. The increase in chlorophyll content reflects the phytoplankton bloom, which is usually followed by an increase in zooplankton. In turn, this might explain the observed increase in the zooplanktivore fishes. No correlation was found between water chlorophyll content and species richness, although a clear positive trend was noticed when the latter was considered with a one month lag.

The length-frequency distributions clearly show that the fishery targets the smallest age class (0+) (Figure 3). The presence and abundance of juvenile and sub-adult populations of commercial pelagic species throughout the whole year suggests the role of the studied region as a nursery area to these species. Most of the fishes were caught far below their size at first maturity, meaning before having the opportunity to reproduce at least once. The capture of larger specimens in specific months (Table 6, Figure 7) possibly indicates the presence of the adults that will contribute to the spawning season, as they usually approach the coastal areas for reproduction (Papaconstantinou and Farrugio, 2000).

For instance, the largest individuals (≥151mm TL) of *E. teres* were recorded in October and the first half of November, while juveniles appeared in May. Hence, we can deduce that spawning occurred between October to May, while recruitment took place in May. This is consistent with the reported reproductive period of the species from Egyptian Mediterranean waters ranging from December to May. The length at first maturity of *E. teres* in Egypt is 138mm (Osman *et al*., 2011). *S. colias* spawned from May to August in the Adriatic Sea, where maturity was attained at 183mm FL (Fork length). In the present study, all landings of *S. colias* were smaller than size at sexual maturity except for four individuals caught in early June ranging from 246mm to 262mm TL, well into the reported spawning period. Nonetheless, small recruits are present starting from March till July (Figure 7). *Boops boops* spawn from February to May along the southern coast of Portugal (Monteiro *et al.*, 2006) and from January to May in the southeastern Mediterranean (El-Agamy, 2004), where length at first sexual maturity is reported to be 130mm. Likewise, in this study, *B. boops* first appeared in March with relatively large sizes until May (≥125 mm TL) (Table 6). The small recruits first appeared in low numbers at the end of May (TL<50mm) and gradually became more abundant by July (Figure 7).

It is well reported that the three most important small pelagic species in the Mediterranean (*Engraulis encrasicolus, Sardina pilchardus*, and *Sardinella aurita*) spawn during different times of the year and in different temperature and salinity ranges (Sabatés *et al*., 2006; Maynou *et al*., 2008). *Sardina pilchardus* is reported to spawn in cold waters (12-14°C), although it can spawn up till 19°C (Palomera *et al*., 2007). As such, spawning season is reported to last from October till April in Croatia (Sinovcic´ *et al*., 2007) and November to June along the coast of Morocco (Amenzoui *et al.*, 2006). First sexual maturity is reached at 158mm TL (Amenzoui *et al.*, 2006). In the current study, only two adults were caught in June.

In contrast, *Sardinella aurita* spawns at sea surface water temperatures of 23°C or higher for spawning (Palomera *et al*., 2007). Spawning occurs close to shore in depths of less than 100m (Palomera *et al*., 2007). *Sardinella aurita* spawned in Greece between May and July (Tsikliras and Antonopoulou, 2006). A positive correlation has been already highlighted between sea surface temperature in March and the year class strength of *S. aurita* (Ben Tuvia, 1960; Sabatés *et al*., 2006). This is due to the reproductive season starting earlier in warmer years and extending for a longer period of time (Sabatés *et al*., 2006). Consequently, *S. aurita* dominated the landings from June to September with its new recruits (Table 6). The recruits showed a clear pattern of growth for the few proceeding months. The largest specimens appeared in May (182.5 mm TL) in agreement to its reported spawning period (Table 6).

Engraulis encrasicolus reproduction is optimal in sea surface temperatures ranging between 17°C and 23°C, and a wide salinity range (Palomera *et al*., 2007). In the current study, *E. encrasicolus* appeared throughout the whole year, but was present in large numbers in the landings from October to January. However, it has to be noted that sea surface water temperature in the Levantine basin does not decrease below the threshold of the spawning preferences of the species (Figure7).

It is suggested that *H. punctatus* individuals migrate away from the inshore areas after attaining sexual maturity (Marichamy, 1971). In this study, the majority of the specimens were caught in small sizes, while the largest individuals were collected in March (mean TL=905mm) (Table 6).

The presence of the NIS, such as *H. punctatus* and *E. teres,* might have direct effects on the native Clupeiform populations inhabiting the easternmost part of the Mediterranean (Carpentieri *et al*., 2008). On occasions, the non-indigenous species can become pests and negatively affect the ecosystem (Boudouresque and Verlaque, 2002). Wallentinus and Nyberg (2007) discuss how NIS species can act as ecosystem engineers, altering the habitat itself and, as such, positively or negatively affecting the diversity be it directly or indirectly. Coll *et al*. (2010) added: “Local population losses and niche contraction of native species may not induce immediate extirpation, but they may trigger reduction of genetic diversity and loss of ecosystem functions and processes, and habitat structure”. The present study aimed at establishing rudimentary information about pelagic fish assemblages in a region that lacks proper fisheries documentation. Long term surveys should be carried out to monitor the inter-annual variations in composition and abundance of these fish assemblages and to assess the state of the purse seine fishery in the Levantine basin. The repercussions of targeting the (juvenile) recruits of these commercial species should also be analyzed. It is therefore imperative to investigate about the stock(s) that use the Lebanese coast as a nursery. As such, a regional approach is to be taken to compare the Lebanese landings to that of its neighboring countries. Further research should also be directed to study in detail the reproductive biology of the commercial species in the Levantine basin, and to determine the exact larval duration of these species in the pelagic waters. Finally, competition between the native and NIS should be closely studied to be able to better predict future changes within these fish assemblages.

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