# Hake, *Merluccius merluccius* L., in the northeastern Mediterranean Sea: a case of disappearance

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## Summary

Hake was not an important commercial fish in the northeastern Levant until the 1990s when a sudden increase in landings was experienced. However, following a series of profitable years, landings declined sharply. The rapid development of the trawl fleet played a role in the decline; however such an episodic event cannot be explained within the fisheries context alone. In this study the results of sparse historical trawl surveys were evaluated together with oceanographic data, and the impact of hydrographical changes on the appearance / disappearance of hake in the Levant was considered. The formation and movement of different water masses in the area seem to have primary importance for the species. The winter occurrence of modified Atlantic water that temporarily intrudes in the region may favour hake. Parallel with the increase in hake, an increase in clupeid species not common in the area was also observed. The change in the hydrography of the region, which was probably linked to the cold period that prevailed at the same time, temporarily led to an additional late summer pulse in the production cycle. The consequent increase in clupeids along with the changes in the hydrology favoured the advent of clupeid-eating hake in the NE Levant. The growth pattern result of the modal shift in monthly length-frequency distributions also showed that the species underwent a rapid growth phase in winter, which was most likely associated with intense feeding.

## Introduction

The European hake (*Merluccius merluccius* L.) is among the main target species of the Mediterranean demersal fishery and therefore various aspects of its biology (Alegria Hernandez and Jukić, 1990), distribution (Orsi-Relini et al., 2002; Bartolino et al., 2008a), growth (Belcari et al., 2006; Mellon-Duval et al., 2010), genetics (Roldán et al., 1998; Levi et al., 2004) and exploitation (Farruggio and Papaconstantinou, 1998; Martin et al., 2002) have been documented. However the majority of the work has been conducted either in the western part of the Mediterranean or in the Aegean Sea (Papaconstantinou and Stergiou, 1995); very few studies have specifically investigated hake in the Levant Sea (i.e. Al-Absawy, 2010).

Demersal stocks in the NE Levant Sea have been exploited since 1940 when there were only two demersal trawlers in the region (Aasen and Akyüz, 1956). Later, in the 1950s, when the number of trawlers reached 14, a drop in the CPUE drew the attention of the local authorities and a fisheries survey was carried out in the Gulf of Iskenderun (Aasen and Akyüz, 1956; Akyüz, 1957). The survey revealed the first symptoms of over-fishing, but the fishing fleet kept growing. The increase in the number of boats further intensified after the mid-1980s (Fig. 1). The consequences of uncontrolled growth of the fleet have been detrimental to the stocks of targeted species, which have experienced dramatic declines (Bingel et al., 1993; Gucu, 1995, 2006). Initially, hake was among the by-catch. The species gained commercial importance in the mid-1980s and remained commercially important for almost a decade. However, in 1998, its landings declined dramatically and have remained low ever since (Fig. 1).

The Levant Sea is a peculiar basin within the Mediterranean, with a species composition influenced by immigrant species of Indo-Pacific origin (Por, 1978). The impacts of the immigrant species on the native fish fauna are not well documented; however there are a number of reports stating that several fish stocks have been negatively impacted (Galil and Zenetos, 2002; Goren and Galil, 2005), including hake (Oren, 1957).

The status and abundance of hake stocks in the Mediterranean are largely influenced by the oceanography. In the Tyrrhenian Sea recruitment success or failure has been linked to the intensity and the lifetime of vertical stratification (Bartolino et al., 2008b). In the Strait of Sicily nursery areas are determined by eddies and frontal systems (Fiorentino et al., 2003). The transport of southern waters from the Tyrrhenian is associated with the highest abundance of hake recruits in the nurseries of the Northern Ligurian Sea (Abella et al., 2008).

The oceanography of the Eastern Mediterranean is characterized by a complex system of mesoscale eddies, jets and meanders entrained and embedded in the general cyclonic circulation (Hecht et al., 1988). Although some of the main oceanographic features persist, the general circulation is subjected to remarkable interannual variability (Özsoy et al., 1991, 1993). One of the most important temporal variations is the geographical range achieved by the (modified) Atlantic Water (MAW). This water mass enters the Levant Basin through the Creatan Passage and the core of the jet branches southwest of Cyprus (Fig. 2). Part of it bypasses Cyprus to the south and reaches the eastern boundary of the basin. In some years, an arm turns north, advecting the Atlantic water into the NE Levant with a considerable abundance in the form of a filament below the surface layer (Özsoy et al., 1993). However at other times the mainstream flow is blocked off at the Latakia basin, between Cyprus and Syria (Özsoy et al., 1991).

The disappearance of hake in the Levant Sea could embrace three critical issues: a change in the hydrography, the impact of exotic species, and over-fishing. In this study we evaluated the results of sparse historical trawl surveys together with oceanographic data and questioned the role of each of these
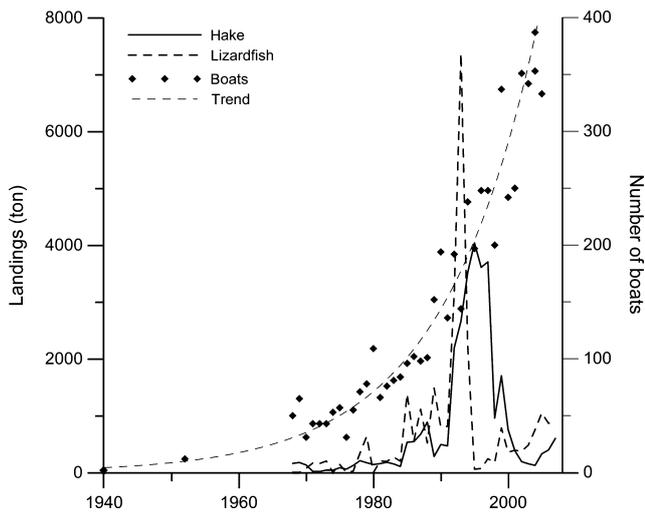
Fig. 1. Number of boats, trend of increasing boats, landings of hake and lizardfish in NE Levant

factors in the appearance / disappearance of hake in the Levant Sea.

## Materials and methods

The study particularly addresses a specific time frame between 1980 and 2000 when unexpected fluctuations occurred in the hake stock over the continental shelf of the northeastern Levantine Sea (Fig. 3). The analyses are based on regional landing statistics from the Turkish Institute of Statistics (Anonymous, 2007) and trawl survey data. Trawl survey data were collected by 'RV Lamas' during various surveys carried out in the region. In all surveys the same local trawl net (locally called 'the Ottoman') design was used; trawling duration was kept constant at 30 min and the same sampling protocol was applied throughout the study; samples were sorted out to the species level; each species was weighed separately; the number of individuals was counted and the total length was measured to the nearest centimetre. Depths at the trawl stations were recorded only after 1982.
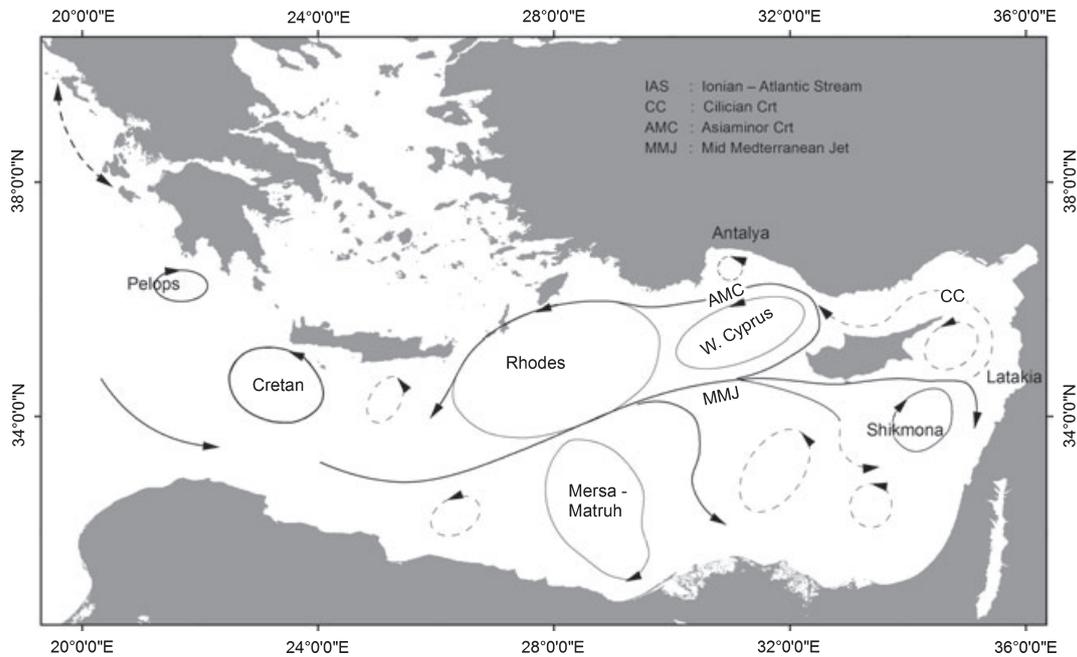


Fig. 2. Direction of main currents and main mesoscale hydrographic features, eastern Mediterranean. Dashed lines = temporal features (redrawn after Hecht et al., 1988)
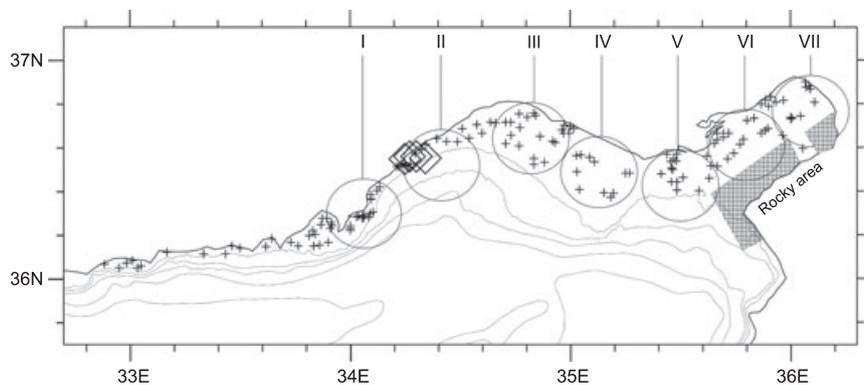


Fig. 3. Study area and position of trawl stations; circles = subregions where trawl samplings were conducted 1980–1982; '+' signs = stations sampled 1983–1999; '◇' = stations sampled 2009–2010

The surveys were conducted for two purposes: to evaluate monthly and annual variations and to ascertain the spatial distribution of the fish stocks. The number of trawl surveys and number of stations covered in each survey are presented in Table 1. Monthly surveys were initiated in 1980 in three regions that were selected based on the intensity of commercial trawling activities taking place in the area. Four trawl hauls covering different depth ranges (0–15, 15–30, 30–50; > 50 m) were carried out in each region. In 1981, the number of sub-regions was increased to seven to cover the entire fishing range of the fishing fleet. Between 1983 and 1984, three basin-wide surveys were conducted. Autumn surveys were carried out with the onset of the fishing season and spring surveys began after closure of the season. In the basin-wide survey a total of 180 trawl hauls were carried out (60 trawl stations in each survey). However, only 168 were used, the remaining hauls being disregarded due to problems occurring during the trawling operation, such as net damage. Later, two additional surveys were conducted in spring 1989 and autumn 1996. In these two surveys only east of 34°E was sampled. Finally, a series of monthly surveys was conducted (May 2007–May 2009), each with four hauls at different depths within region II (Fig. 3). Exact geographic coordinates of the trawl stations are available only for surveys carried out after 1983. The positions of these stations are depicted in Fig. 3 and on the maps in which the geographical distributions of biomass index (BI) are presented. The sampling area of the surveys conducted before 1983 is shown with a circle in Fig. 3.

The monthly frequency distributions were used to estimate the parameters of the seasonally oscillating von Bertalanffy growth function (Pauly, 1984). A curve passing through the modal lengths of each cohort was visually fitted using the graphical utility of FISAT-II software (Gayanilo et al., 2005).

The online dataset provided by METU-IMS (http://www.ims.metu.edu.tr/Inventory/invsrv.dll/provider?PRID = 3) was used to evaluate the oceanographic conditions over the continental shelf prior to the year 2000.

## Results

The monthly trawl survey data indicated in the seven sub-regions studied between 1980 and 1982 that hake presented a similar annual pattern; the species moved into the region, were caught in significant quantity during the winter, remained at the site until late spring, then disappeared during summer and autumn (Fig. 4). Of these sub-regions, I, II III and VI had the highest biomass index (BI). Almost no hake were found in sub-region VII and very few were sampled in sub-regions IV and V. There were only minor differences in the time of first occurrence in the sub-regions. However, there was a noticeable inter-annual difference in the time of appearance ∕ disappearance of the species. In 1982 hake first arrived and then left the area 1 month earlier than in 1981.

In 1983 the species was observed at all stations deeper than 65 m (Figs 5 and 6). The BI over the survey area and over the depth stratum between 65 and 100 m was the lowest compared to the other surveys (Table 2). Similar to the 1980–82 surveys very few hake were found in the Gulf of Iskenderun (sub-regions V, VI and VII).

In spring 1984, the main aggregations were observed in the western part of the study area. The BI was higher than during autumn 1983 and hake were distributed over a larger depth range (Fig. 6). In autumn 1984, the BI increased markedly, this difference due mainly to the stations located in the western part of the survey area; the values in the central part were almost identical (Fig. 5). In spring 1989 the survey area

Table 1
Summary of trawl survey datasets used in the study

| Date | Period | No of stations | Area coverage | Data used for |
|---|---|---|---|---|
| May 1980–May 1981 | Monthly | 12 stations | I–III | Monthly distribution, growth parameters |
| May 1981–Nov 1982 | Monthly | 16 stations | I–VII | Monthly distribution, growth parameters |
| October 1983–October 1984 | Seasonal | 168 stations | I–VII | Spatial distribution, area partitioning |
| April 1989 | Single | 40 stations | II–VII | Spatial distribution, area partitioning |
| November 1996 | Single | 14 stations | I–VII | Spatial distribution |
| May 2007–May 2010 | Monthly | 3 stations | II | Monthly distribution |
| Total | | 1468 trawl hauls | | |
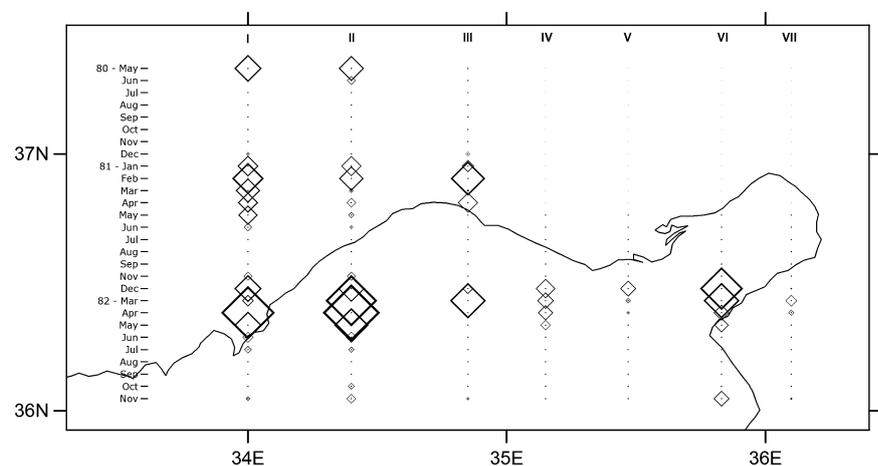


Fig. 4. Monthly distribution of hake biomass index at seven sub-regions (see Fig. 3 for position of sub-regions)
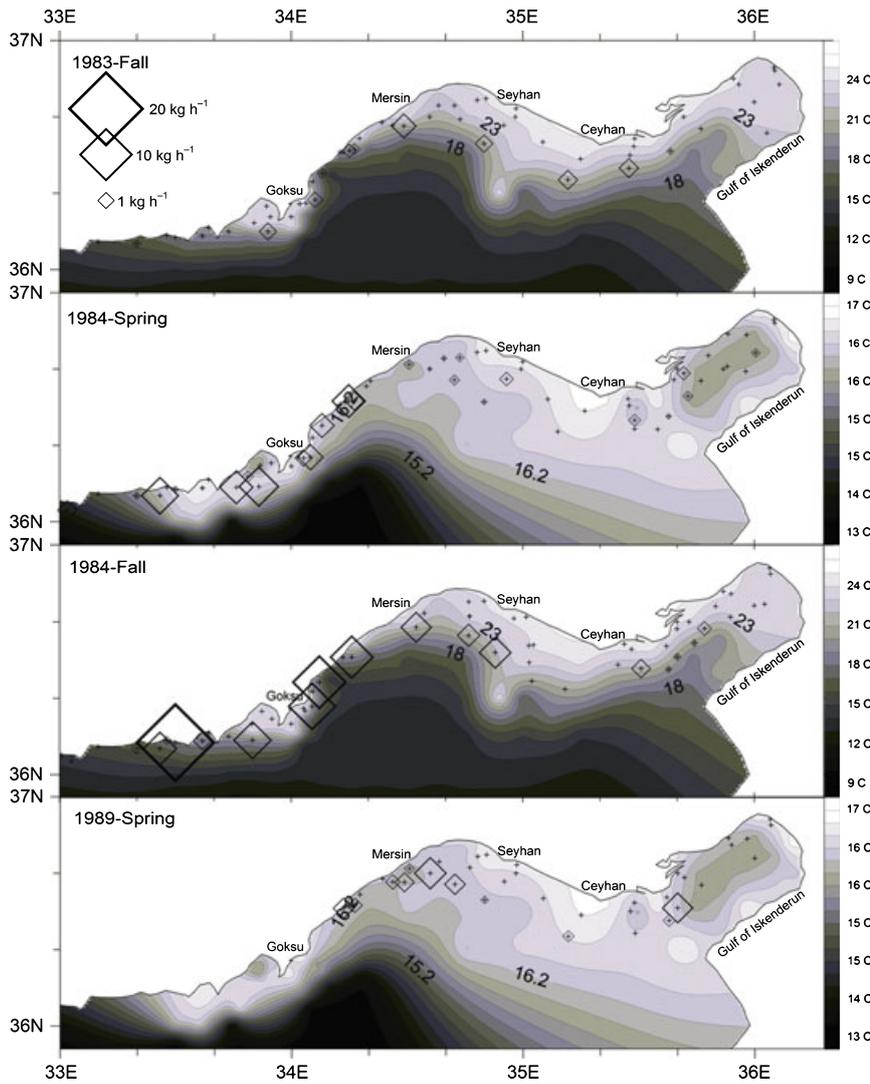
Fig. 5. Distribution of hake in autumn 1983, spring 1984, autumn 1984 and spring 1989. Diamond '◇' is proportional to catch per hour; '+' sign = positions of all trawl stations; background colours and isobars = temperature distribution at bottom. Abbreviations correspond to some locations noted in text (refer to online version for color)

Table 2
Biomass index (tonnes km$^{-2}$) and 95% confidence interval estimated based on basin-wide surveys

|  | BI–total | BI (65–100 m) |
|---|---|---|
| Autumn 1983 | 7.365 (2.580–12.151) | 29.461 (16.009–42.914) |
| Spring 1984 | 20.223 (8.399–32.047) | 48.694 (17.709–79.679) |
| Autumn 1984 | 44.947 (11.353–78.541) | 131.932 (43.345–220.519) |
| Spring 1989 | 14.732 (4.478–24.987) | 45.778 (19.575–71.981) |
| 2007–2010 | 0.280 (0.059–0.500) | 0.184 (0.000–0.395) |



Fig. 6. Seasonal differences in bathymetric distribution of hake (kilogram per unit trawl hour)

covered only areas in eastern 34.2°E; the western part inhabited by the largest aggregation of hake in the previous surveys was not sampled.

With regards to the bathymetric distribution of the species over the study area, the main aggregations of hake were observed between 60 and 85 m in autumn (Fig. 6). In spring, in addition to the peak values at this depth, considerable numbers of hake were also observed at shallower depths. Unlike the two bathymetric aggregations, these hake preferred rather narrow temperature limits ranging from 16.9 to 19.9°C (Fig. 7).

In recent years, the BI has only been available for sub-region II, where the highest hake BIs were found in the 1980s. Monthly trawl surveys conducted between 2007 and 2010
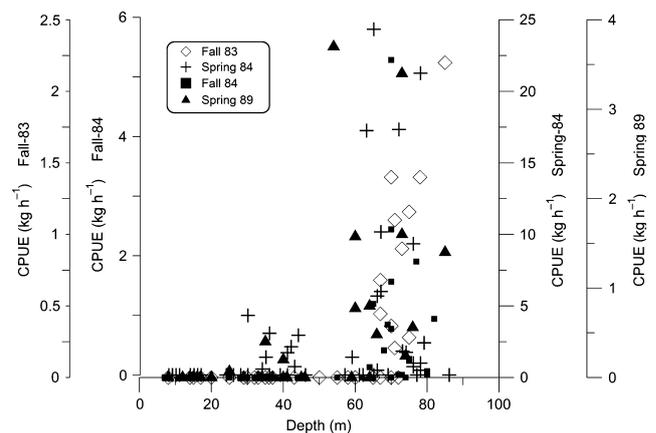
showed a very low BI for hake compared to the values in the 1980s (Table 2).

The monthly length-frequency distributions of the species in 1980–82 are presented in Fig. 8. The slight year-to-year difference in the time of arrival and disappearance (Fig. 4) is better presented in this figure. The first appearance in winter 1980 / 81 was in December; very few relatively large individ-
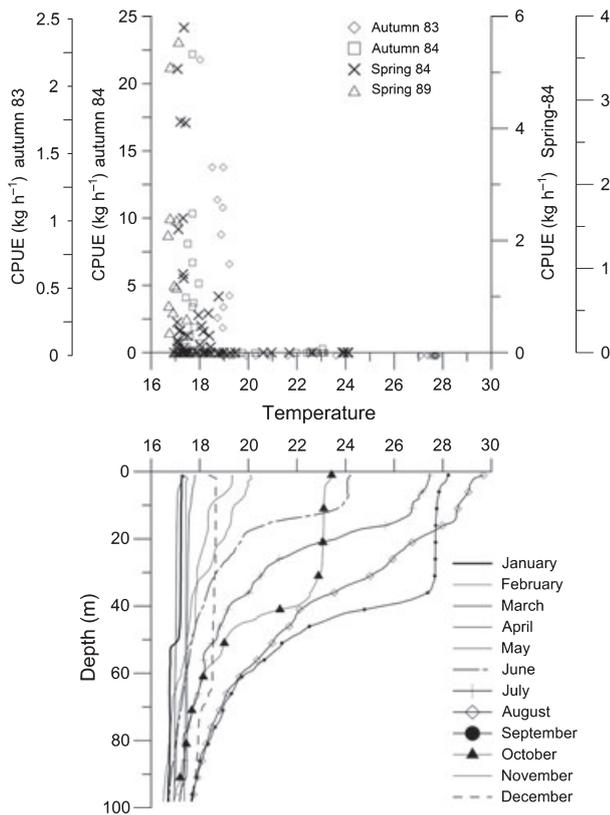
Fig. 7. CPUE of hake and monthly vertical temperature profiles

uals were observed in sub-regions I and III (Figs 4 and 8). A month later, a smaller size group, presumably young-of-the-year arrived in the area. The highest numbers of hake were observed in February, where they remained in the area until June. The following winter, arrival of the first individuals was 1 month earlier and they abandoned the area 1 month later.

The series of length-frequency distributions showed a fluctuating pattern in the growth of the cohorts. The modal length of the youngest cohort was about 14 cm when they moved in and 20 cm just before they disappeared. However, their growth rate seemed to slow down when they were absent from the area, because their size had not increased to the same extent when they returned half a year later. Taking the growth pattern fluctuation into consideration, this is explained by the seasonally oscillating von Bertalanffy growth function (Fig. 8). The phase of the seasonal oscillation (winter point) was estimated as 0.7, indicating that growth slowed down between May and October.
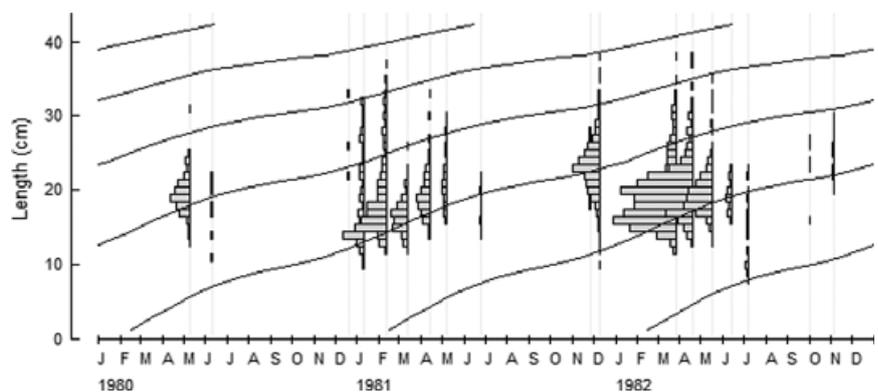
In the early 1980s hake represented a small portion of the catch in the trawl surveys, usually comprising no more than 1–5% of the samples (Table 3). Despite the few seasonal replacements the catch composition of the teleosts in the samples was stable over time, with a few species composing the main bulk of the samples. Hake's Lessepsian competitor, lizardfish (*Saurida undosquamis* Richardson), was observed in the samples throughout the year and at a much higher rank in the teleost population between 1983 and 1984. In spring 1989, however, the CPUE (kg h$^{-1}$) dropped and the species composition changed markedly. The lizardfish was found at only a few stations on the east coast and almost none were observed in the central part of the study area (Fig. 9). In autumn 1996, changes in the composition of the teleost population were more striking. Small pelagic fishes such as *Engraulis encrasicolus*, *Trachurus trachurus*, *Sardina pilchardus* and Lessepsian *Etrumeus teres*, which are rarely caught in the bottom trawl net, were represented in large quantities in the samples (Table 3). In the same samples, the percentage of lizardfish was still low compared to 1983–1984.

Variations in the vertical temperature profiles measured in sub-region II are given in Fig. 7. Beginning in April the surface water gradually warms up and a thermocline begins to develop at the surface as a thin layer covering the first few metres. In July, the lower end of the thermocline exceeds 50 m. In September, the water column to 50 m depth is significantly warmer than the deeper waters and remains so until November. The period of strong temperature stratification coincides with the time when hake are absent on the shelf (Fig. 4). Although the depths around 50 m are cooler in November (Fig. 7), the surface part is still warmer and hake are observed only at depths of < 50 m. In winter, the thermocline, which seems to border the bathymetric distribution of hake, disappears.

The temperature distribution just above the sea floor where hake occur during daytime reflects the remarkable differences found over the continental shelf of the NE Mediterranean. Figure 10 represents the situation in autumn when the hake usually arrive. The near-shore area on the east coast is the warmest part and where the temperatures may be as high as 24.05°C. In the eastern part, a cold-water tongue enters the Gulf of Iskenderun from the bottom. There is also a warm core at the centre, splitting the continental shelf into two hydrographically distinctive zones. Another cold area is between Mersin and Goksu.

The vertical salinity profiles represent two different structures shaped by the oceanography of the eastern Mediterranean (Fig. 11). The water in the shallow depths is usually highly saline, exceeding 39 psu. Below this layer two distinct



Fig. 8. Seasonally oscillating von Bertalanffy growth model fitted to monthly length-frequency distributions $L\infty = 65$ (TL, cm); $K = 0.233$ (year -1); amplitude of oscillation, $C = 0.4$, winter point = 0.7''

Table 3
Teleostean fishes forming 90% of the total catch during trawl surveys

| Autumn 1983 | | Spring 1984 | | Autumn 1984 | | Spring 1989 | | Autumn 1996 | |
|---|---|---|---|---|---|---|---|---|---|
| *Saurida undosquamis* | 20.39 | *Saurida undosquamis* | 18.06 | *Leiognathus klunzingeri* | 23.71 | *Arnoglossus laterna* | 11.72 | *Mullus barbatus* | 17.50 |
| *Mullus barbatus* | 17.26 | *Mullus barbatus* | 17.82 | *Saurida undosquamis* | 20.79 | *Lepidotrigla astoviza* | 11.15 | *Upeneus moluccensis* | 11.55 |
| *Leiognathus klunzingeri* | 10.67 | *Pagellus erythrinus* | 6.88 | *Mullus barbatus* | 10.62 | *Leiognathus klunzingeri* | 8.13 | *Engraulis encrasicolus* | 9.92 |
| *Boops boops* | 7.60 | *Lepidotrigla cavillone* | 5.91 | *Pagellus erythrinus* | 4.71 | *Maena chryselis* | 7.58 | *Leiognathus klunzingeri* | 9.75 |
| *Pagellus erythrinus* | 5.15 | *Spicara flexiosa* | 4.24 | *Citharus linguatula* | 4.19 | *Mullus barbatus* | 7.46 | *Trachurus trachurus* | 6.90 |
| *Citharus linguatula* | 5.06 | *Trigla lucerna* | 3.78 | *Upeneus moluccensis* | 3.64 | *Lepidotrigla cavillone* | 7.09 | *Pagellus acarne* | 6.25 |
| *Trigla lucerna* | 3.77 | *Arnoglossus laterna* | 3.73 | *Sparus aurata* | 2.88 | *Merluccius merluccius* | 5.94 | *Saurida undosquamis* | 4.28 |
| *Stephanolepis diaspros* | 3.34 | *Citharus linguatula* | 3.64 | *Merluccius merluccius* | 2.77 | *Saurida undosquamis* | 5.23 | *Sardina pilchardus* | 3.99 |
| *Lepidotrigla cavillone* | 2.63 | *Pagrus pagrus* | 3.38 | *Diplodus* sp. | 2.40 | *Citharus linguatula* | 4.64 | *Diplodus annularis* | 3.54 |
| *Arnoglossus laterna* | 2.49 | *Leiognathus klunzingeri* | 2.94 | *Stephanolepis diaspros* | 2.35 | *Solea solea* | 3.46 | *Sparus aurata* | 3.34 |
| *Pagellus acarne* | 2.16 | *Bothus podas* | 2.58 | *Lepidotrigla cavillone* | 2.07 | *Gobius* sp. | 3.33 | *Spicara flexuosa* | 3.14 |
| *Spicara flexiosa* | 1.62 | *Upeneus moluccensis* | 2.32 | *Arnoglossus laterna* | 1.90 | *Serranus hepatus* | 2.58 | *Citharus linguatula* | 2.78 |
| *Uranoscopus scaber* | 1.54 | *Stephanolepis diaspros* | 1.97 | *Argyrosomus regium* | 1.71 | *Bothus podas* | 2.46 | *Etmureus teres* | 2.17 |
| *Pagrus pagrus* | 1.20 | *Uranoscopus scaber* | 1.66 | *Uranoscopus scaber* | 1.40 | *Pagellus erythrinus* | 2.43 | *Trichiurus lepturus* | 1.40 |
| *Bothus podas* | 1.19 | *Merluccius merluccius* | 1.63 | *Spicara flexiosa* | 1.15 | *Trigla lucerna* | 1.89 | *Scomber japonicus* | 1.37 |
| *Solea vulgaris* | 1.10 | *Solea vulgaris* | 1.49 | *Bothus podas* | 1.00 | *Upeneus asymmetricus* | 1.35 | *Pagellus erythrinus* | 1.27 |
| *Upeneus moluccensis* | 1.10 | *Trigla lineata* | 1.27 | *Upeneus asymmetricus* | 0.97 | *Lithognathus mormyrus* | 1.03 | ........ | |
| *Ephinephelus aeneus* | 1.08 | *Diplodus vulgaris* | 1.21 | *Ephinephelus aeneus* | 0.95 | *Argyrosomus regium* | 1.02 | *Merluccius merluccius* | 0.16 |
| ....... | | *Argyrosomus regium* | 1.15 | | | *Umbrina cirrhosa* | 1.02 | | |
| *Merluccius merluccius* | 0.51 | *Dentex dentex* | 1.08 | | | | | | |
| | | *Sparus aurata* | 1.04 | | | | | | |
| | | *Diplodus annularis* | 1.02 | | | | | | |
| | | *Serranus cabrilla* | 0.98 | | | | | | |

situations are observed. The high salinity values on the surface gradually decrease, but never drop below 39 in some years, such as in 1990 and 1997. In other years (1988 and 1995) it dropped below 39 at around 50–90 m and then rose again towards deeper depths (Fig. 11). This intermediate water mass is clearly visible on the T–S diagrams (Fig. 11) and is characterized by a temperature of 18–20°C and 38.85–38.9–39.0 salinity. The oceanographic stations at which this peculiar water mass was observed are plotted on the maps (Fig. 11). In autumn 1988 it was observed at all stations except those located at very shallow depths; in autumn 1990, this water mass was completely absent. In autumn 1995 it was again observed at all stations except the most coastal ones, showing a similar pattern to that of 1988. In the oceanographic survey carried out in autumn 1997 the majority of the stations were located at shallow depths near the coast. There were only a few stations in the central area; however, at the edges of the region, transects that were sufficient to identify different water masses entering and exiting the region showed no evidence of the intermediate layer below the mixed layer. In autumn 2005 MAW was observed in the area, however its strength was weak compared to 1988 and 1995. The flow could not intrude into the study area except for a few offshore stations. Likewise, the T–S diagram for autumn 1997 showed no such layer. Landings of hake were high when this subsurface water mass occurred in the area and low when it was not observed (Fig. 1).

## Discussion

The fisheries statistics show a clear increase and a subsequent decline in hake landings in the NE Levant. The biomass index of the 1980s and the recent levels (Table 2) also verify that the hake stock has undergone severe changes in the last three decades and has eventually declined. The trawl survey data used to estimate the biomass indices are not continuous and there were no surveys during the years of highest hake landings. Therefore it is rather difficult to determine whether or not this sudden increase in the catch reflects an actual increase in the size of the stock. However, it is clear that the stable landing figure initially exhibited changed around 1985. The factor(s) responsible for the increase of hake in the area probably came into force at around that time. In 1989 the upward trend was then interrupted for 3 years before hake landings resumed the same positive trend that had been observed between 1985 and 1989. When these three successive years of low catches are disregarded, the landing figures show a
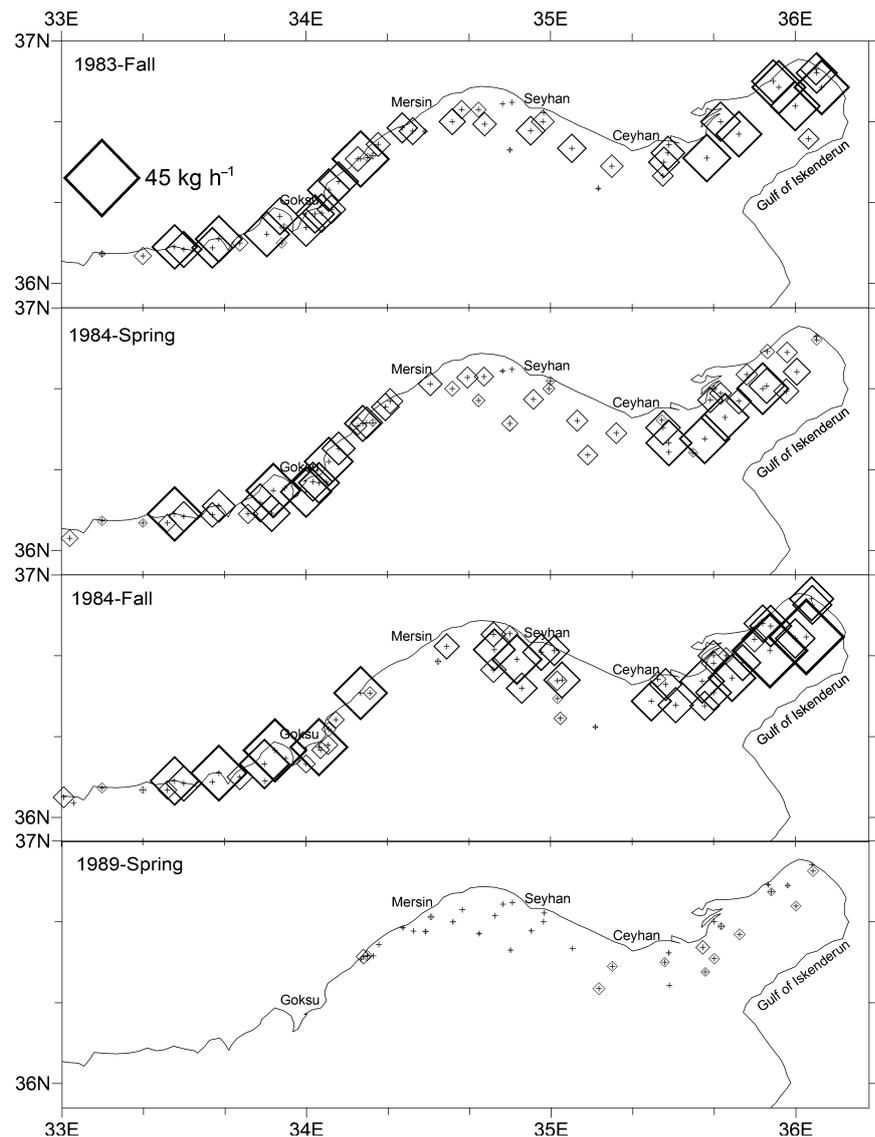
Fig. 9. Distribution of lizard fish, autumn 1983, spring 1984, autumn 1984 and spring 1989. Diamond '◇' = catch per hour; '+' signs = positions of trawl stations

steady increase until 1996, which would have been consistent with the rapid development of the fishing fleet in the region (Fig. 1). The sharp interruptions in the positive trend and the subsequent high values that followed the previous increasing trend, however, may indicate the occurrence of at least two independent factors in that period controlling the size of the hake stocks in the area. The first is responsible for the increase and the other the disappearance of the species.

Changes in the structure and expansion of the fishing fleet range are probably one of the factors responsible for the increase. Until the end of the 1980s the fishing fleet in the area was composed of coastal shrimp trawlers that were equipped and licensed to catch highly commercial, native and Lessepsian penaeids in the shallow coastal waters. The low landings (Fig. 1) as opposed to the relatively high biomass index (Table 2) in the early 1980s may signify that the hake stocks which were located at deeper depths were not yet accessible to the fishery operating in the area. Later, following the Black Sea anchovy crises in 1989, a substantial proportion of the northern fishing fleet moved to the southern seas (Gucu, 2002). Following the entry of the relatively larger and more powerful boats of the Black Sea fleet, the fishing grounds in the NE Levant Sea expanded towards deeper waters; hence, the

catch composition diversified and hake appeared in greater quantities in the landings.

A similar episodic decline in the hake stocks was experienced in Israeli waters in the 1950s, which was attributed to the competitive bathymetric displacement among populations of Erythrean lizardfish and indigenous hake (Oren, 1957). The brushtooth lizardfish, *S. undosquamis*, became an abundant fish in the 1950s; its share in trawl catches rose to 20% in 1955 (Oren, 1957). It was therefore claimed that, as a consequence of the sudden increase of lizardfish in the coastal waters, the native hake was displaced into deeper, cooler waters and thus leaving space for their respective Erythrean competitor (Oren, 1957).

Available only since the 1960s, the landing statistics for the NE Mediterranean suggest a completely reverse situation to that experienced on the Israeli coast. Initially, the landings of hake and lizardfish increased with an almost identical trend. In 1985, landings of both species were significantly higher than in the previous years and remained high until 1989. Following a short period of fluctuating landings (Fig. 1), hake showed a clear increase between 1992 and 1997, followed by a very sharp decline. This sudden change in the landings may signify a factor that altered the current state of the stocks of both
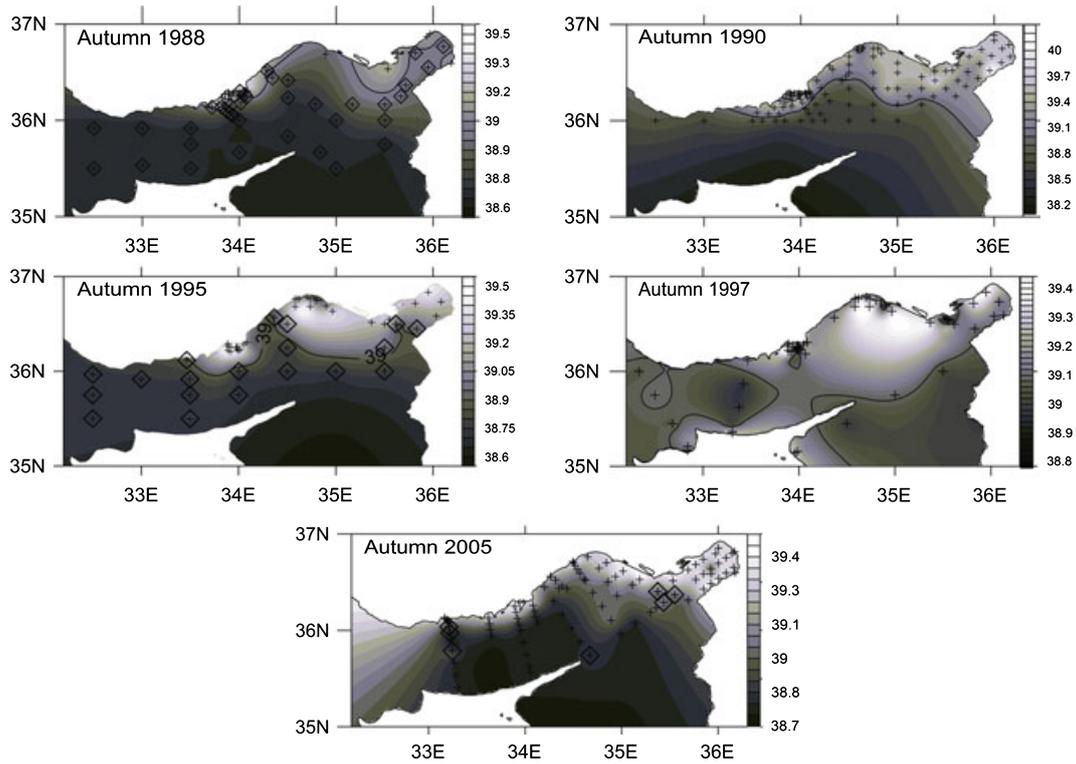
Fig. 10. Salinity distribution over sea floor and oceanographic stations sampled in autumn 1988, 1990, 1995, 1997 and 2005; '◇' = stations where MAW was detected (refer to online version for color)
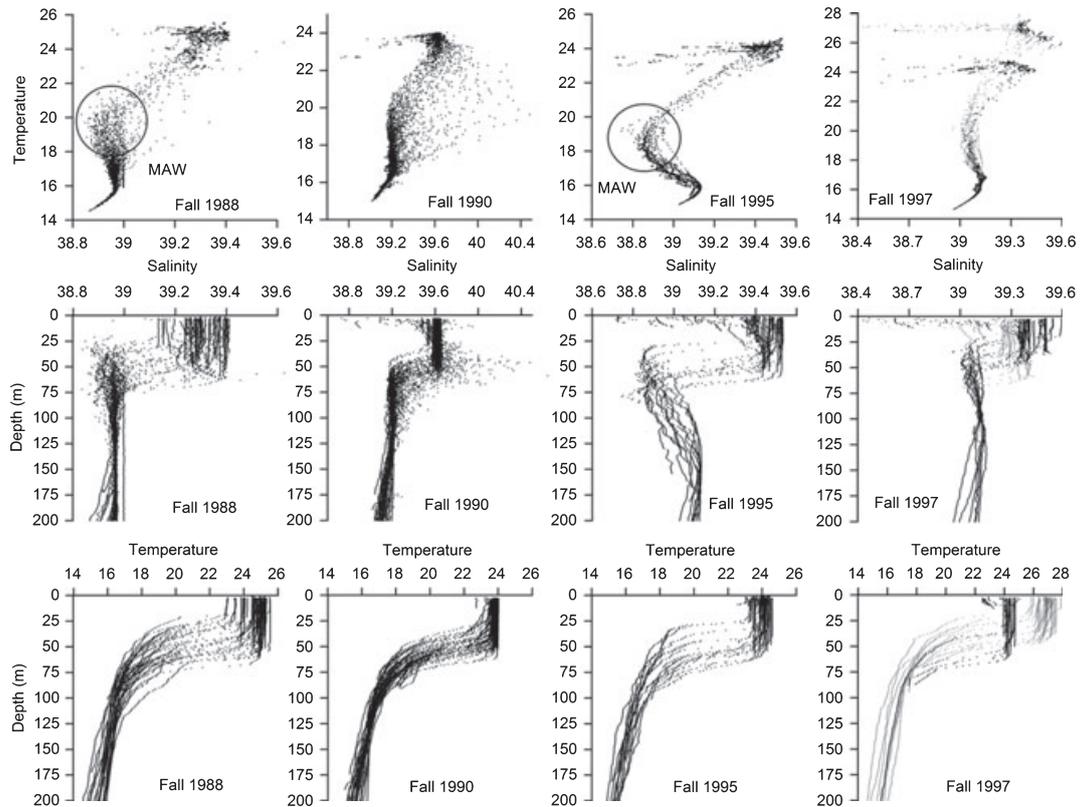


Fig. 11. Vertical salinity and temperature profiles and T–S diagrams for autumn 1988, 1990, 1995 and 1997 (Sept and Oct 1987 combined)

species. Whatever the factor that increased the hake landings, it also triggered an increase in lizardfish landings, which displayed a sharper and higher but shorter peak. It seems that

as an opportunistic species with a high growth rate (Ismen, 2003) and heterochronal spawning strategy (El-Greisy, 2005; El-Halfawy et al., 2007), the lizardfish took advantage of the

new ecological state before hake. Then, in contrast to the situation on the Israeli coast, the hake, which temporarily occurs on the continental shelf, seemed to out-compete and suppress its competitor. A similar pattern has appeared since 2000.

It is known that hake undergo ontogenetic migration between the continental slope and upper shelf area and that juvenile hake migrate to the upper shelf to fulfill their changing dietary requirements (Carpenteri et al., 2005). The majority of hake sampled in the study area were juveniles (95% of the samples ranged between 12 and 28 cm, representing the 0- and I-year class). This group probably comprises those changing their feeding behaviour from bentivorous to piscivorous and hence are in search of small pelagic fishes inhabiting the shallow waters. However, they were observed only from winter to early summer and, with the beginning of summer, they deserted the area (Fig. 4). The monthly length-frequency distributions and the fitted growth curve suggest that part of the group arriving on the shelf is composed of returning cohorts that deserted the area the preceding summer (Fig. 8). Therefore the ascent of the 0-year class juveniles to the shelf area may be part of their ontogenesis; however, the subsequent descent in summer and the repeated ascent of the larger juveniles ( > 20 cm) is probably driven by environmental constraints such as temperature rather than the dietary requirements. Indeed, Fig. 7 suggests a very narrow range of temperature preference, and during summer the temperature over the sea floor rises above this range, possibly forcing hake into the colder, deeper waters and returning to the shelf when the temperature over the shelf area becomes favourable with the winter convection. Other evidence linking hake abundance and temperature was reported in the 1950s on the Israeli coast. The sudden increase in the populations of Lessepsian lizardfish and consequent disappearance of hake was attributed to the exceptionally warm winter of 1954–55, when the sea temperature rose by 1.0–1.5°C (Ben Yami and Glaser, 1974; cf. Goren and Galil, 2005).

Inter-annual differences in the time of arrival and the duration of their stay on the NE Levant may also be explained with respect to the temperature tolerance of hake. In an analysis of AVHRR – SST field time series in the eastern Mediterranean, it was shown that 1984 was an exceptional year with a prolonged winter (Marullo et al., 1999). Comparison of the climatological maps also showed that the winter-to-summer transition of the SST pattern in 1984 took place in June. This is quite delayed compared to other years when the transition took place between April and May (Marullo et al., 1999). This may explain why hake remained in the area longer and had quite a high BI at the end of spring (Table 2). The same SST data series showed that summer 1984 was the coldest in the 1983–1992 period (Marullo et al., 1999). Differences in the hake density in autumn 1983 and 1984 are probably a consequence of this variability; the cooler summer probably drew the species in earlier than in the previous year.

The results also suggest that temperature may not only determine the bathymetric distribution and timing of their occurrence on the shelf area but may also shape the spatial distribution of the species. The temperature at the sea floor and CPUEs of hake in autumn and spring are overlaid in Fig. 5. In autumn 1983, hake was observed only at sites where the bottom temperature was the coldest. In autumn 1984, hake seemed to avoid the isolated warm patch located around 'Goksu' (see Fig. 5) and accumulated at the outer edge of the patch where the temperature was markedly lower. Almost no hake were observed in the eastern half of the study area where the temperature was relatively higher than in the western part. The exceptions were located on the filament of coldwater mass entering the gulf. This cold filament may also explain why sub-region VI had a higher BI than the neighbouring areas in autumn 1981 (Fig. 4). The warm water mass, avoided by hake in the autumn, is a characteristic of the region and called the 'Levantine Surface Water', LSW. It is a product of intense evaporation and therefore a salinity of 39.5 is the major signature of LSW at the end of the summer (Bingel et al., 1993). In autumn this peculiar water mass is confined to the coastal areas (Fig. 10). Beyond these coastal patches is the Modified Atlantic Water (MAW), which is a temporary observation in the NE Levant (Özsoy et al., 1991).

What is important for this study, however, is the coincidence between the occurrence of the MAW in the autumn and the increase in hake landings. The summer conditions – most probably the high temperature – do not favour hake even if the area is covered with the MAW (Fig. 10). However, with the cooling of the surface water in winter, the MAW seems to open a favourable environmental window for hake. The coincidence between the depths of the MAW (Fig. 11), the bathymetric preference of hake (Fig. 6), their preferred temperature ranges (Fig. 7) and the temperature of the MAW (Fig. 11) supports this view.

Contrary to the positive influence of the MAW in NE Levant, a study on recruitment dynamics of hake along the Catalan coast reported negative consequences of Atlantic waters on recruitment success (Olivar et al., 2003) by unfavourably altering the nutrient dynamics and associated availability of plankton on which hake larvae feed. In contrast to the Catalan coast, significant nutrient enrichments and consequent cyanobacteria (Uysal and Köksalan, 2006) and phytoplankton (Uysal et al., 2003) blooms were reported during the periods when the MAW was observed on and at the edge of the continental shelf of the NE Levant Sea. Gucu et al. (1992) also observed a remarkable late autumn increase in secondary production, which coincided with the arrival of the MAW in 1985 (Özsoy et al., 1993). In the study area the MAW-associated temperature therefore might not be the only factor altering the distribution and occurrence of hake; the biological consequences of this water mass might also play a role.

Abella et al. (2008) also observed the coincidence between the location of persistently high production areas and nursery grounds of hake in the Strait of Sicily. They also underlined the importance of oceanographic mesoscale features that govern nutrient enrichment within this context. In contrast to the Catalan coast, in the Strait of Sicily, the jet stream of Atlantic origin is one of the main forcing factors producing such oceanographic features influencing the hake nurseries (Fiorentino et al., 2003).

There are several well-documented examples in which currents, such as the Poleward Current in the Gulf of Biscay (Sánchez and Gil, 2000) and the East Corsica Current in the Ligurian Sea (Abella et al., 2008), determine the major nursery grounds by producing mesoscale eddies that retain hake at early life stages and favour the feeding behaviour of recruits. Colloca et al. (2009) summarized the three major physical processes that are required to achieve high-density nurseries: (i) nutrient enrichment, (ii) high concentration and (iii) retention within a suitable habitat. Although the mesoscale nature and persistence of these oceanographic features are critical, it is also possible to see that current-driven non-persistent features may produce occasional and less pro-

nounced secondary aggregations of hake. Within this context, one possible explanation of the sudden increase in hake abundance in the NE Levant Sea could have been the enhanced productivity over the nursery grounds of hake in the NE Levant, possibly induced by intrusion of the MAW.

The biological process behind the fluctuating hake occurrence seems rather complicated. Large hake ( > 36 cm) have a wider bathymetric distribution range but concentrate on the shelf break during the spawning period (Recasens et al., 1998; Alvarez et al., 2001). In a biweekly ichthyoplankton monitoring survey covering possible spawning sites of hake in the NE Levant between 1998 and 2001, no hake eggs were found while very few post-larvae were observed in the samples (Ak, 2004). This indicates that the spawning grounds of hake may not be located in the close vicinity. In addition, the absence of individuals smaller than the recruitment cut-off length of 13.2–15.8 cm as suggested by Bartolino et al. (2008a,b), is rather suspicious and indicates that the hake nurseries might not be located nearby. Hake in the eastern Mediterranean have a protracted spawning period with a January peak in the percentage of spawning females (50%) (Al-Absawy, 2010). The 0-year class hake grow at monthly rates that gradually decrease from 1.6 to 1.1 cm month$^{-1}$ in the Mediterranean (Arneri and Morales-Nin, 2000). Therefore a recruit coming from a spawning event in January is expected to reach 9 cm in July and 15 cm by the following January. These estimations are consistent with the length-frequency distributions obtained (Fig. 8). The absence of early life stages in the NE Levant and the temporal distance from the spawning peak to the first occurrence of the smallest cohort in the region may therefore be explained by a temporal range expansion or a shift in the stock located in a neighbouring region. If these assumptions are true, and considering the direction of the currents (Fig. 2) and the age of the youngest cohort observed in the NE Levant, it is likely that the core of the hake nurseries is located to the south of the island of Cyprus.

It seems that the seasonality in the occurrence of hake on the shelf has a remarkable impact on its growth rate. The von Bertalanffy growth function fitted to the length-frequency data suggested a $K$ value very close to the 'fast growth' model suggested by de Pontual et al. (2006). However, this fast growth rate seems to display an oscillating pattern. The seasonality in the growth pattern of fish is common and usually follows seasonal temperature oscillations (Fontoura and Agostinho, 1996); that is, the growth rate increases during the warm months and slows down in the cold season. However, in this study, the phase shift of the seasonal oscillation was estimated as 0.7, which counter-intuitively indicates that the growth slowed down during the warm period (between May and October). On the other hand, this is the period when hake deserted the study area. It is known that the main prey item in the juvenile hake ( < 30 cm) diet is small pelagic fishes (Ferraton et al., 2007; Mahe et al., 2007), particularly sardine in the NE Levant (Gucu, 1995). The sardines in the NE Levant are coastal (Avşar, 2000). Given that fast growth can only be achieved when food is available, it may be assumed that growth accelerates when hake ascend to the shallow waters and meet the sardine stocks. In summer, when hydrographical conditions become unfavourable due to the summer warming, hake are forced to abandon the feeding grounds and, therefore, growth rate slows.

The small pelagic fish assemblages of the NE Levant are dominated by the summer spawner Sardinella aurita (Bayhan, 1988; Avşar, 2000), which characterises the warmer climatic regimes in the Mediterranean (Sabatés et al., 2006; Tsikliras, 2008). Other small pelagic species in the NE Levant Sea are in lesser quantities, such as the European sardine Sardina pilchardus and European anchovy Engraulis encrosicolus, both of which generally indicate colder regimes (Lejeusne et al., in press). The coincidence of an unexpected increase in the cold-associated non-summer spawner small pelagics in 1996 (Table 3) and the sudden increase in the hake landings deserves further consideration. The secondary late-summer nutrient enrichment driven by the MAW (Uysal and Köksalan, 2006) would probably not affect the piscivorous juveniles directly; however, increased productivity in the lower trophic levels might have indirect and positive consequences on the prey availability.

Another important episodic event drastically altered the oceanography of the eastern Mediterranean is the Eastern Mediterranean Transient (EMT). A shift in the formation site of the deep and bottom waters from the Adriatic to the Aegean seas changed the properties of these water masses at the beginning of the 1990s (Roether et al., 1996). Although the effects of the EMT on the ecosystem have not been monitored, there is some evidence of its impact at various levels of the ecosystem. For instance, the accelerated penetration of some Lessepsian crustacean species into the southeastern Aegean Sea (Galil and Kevrekidis, 2002), and the coincidence between the remarkable range expansion of the anthozoan Astroides calycularis (Bianchi, 2007) and drastic changes in the zoo-plankton composition in the eastern Mediterranean (Koppelmann and Weikert, 2007) were attributed to the EMT. Given that the sudden increase in the hake landings coincided with the EMT and that the bathymetric range of hake may extend to 1000 m (Roether et al., 1996), it may be postulated that such a deepwater event may eventually affect the hake stocks.

## Conclusion

This study addresses the abrupt increase in the hake landings in the mid-1990s based on the scattered historical information available; samples from entire seasons and years are therefore not complete. However, given the ecological and economic importance of hake and the lack of knowledge from the eastern Mediterranean, we have discussed some of the biological and ecological peculiarities of the species. The fisheries survey data showed us that the occurrence of hake on the NE Levant continental shelf was temporal during the years for which data were available; they occurred on the shelf area only during the cold months. The ascent of the species towards shallower depths where prey (sardine) availability was possibly higher was probably associated with the changing dietary requirements of the juveniles. Additionally, winter convection seemed to draw the species in, whereas they abandoned the area in summer when the thermocline was formed and the water temperature rose above 19.5°C. This migratory pattern is reflected in the growth pattern; they grew faster when they were on the continental shelf – probably due to intense feeding. Growth slowed when they moved away because of the summertime formation of the warm Levantine Surface Water.

The immigrant competitor, Saurida undosquamis, does not seem to have much influence on the abundance of hake. Yet, in contrast to the other areas in the southeast Mediterranean, the data show that S. undosquamis was suppressed during the years when hake landings were high.

The absence of early life stages and strong seasonality in the occurrence of hake indicates that the species might not have a

resident stock in the region. The rapid increase in the catch probably signifies range expansion or the shift in a stock located elsewhere. Intrusion of the MAW might have produced a favourable environment, facilitating the transport of juveniles into the NE Levant. The MAW-driven secondary late summer pulse temporarily observed in the production cycle on the shelf, which strengthens the stocks of winter-spawning clupeids, may be an additional biological link between the advent of piscivorous juveniles in the NE Levant and the MAW.

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