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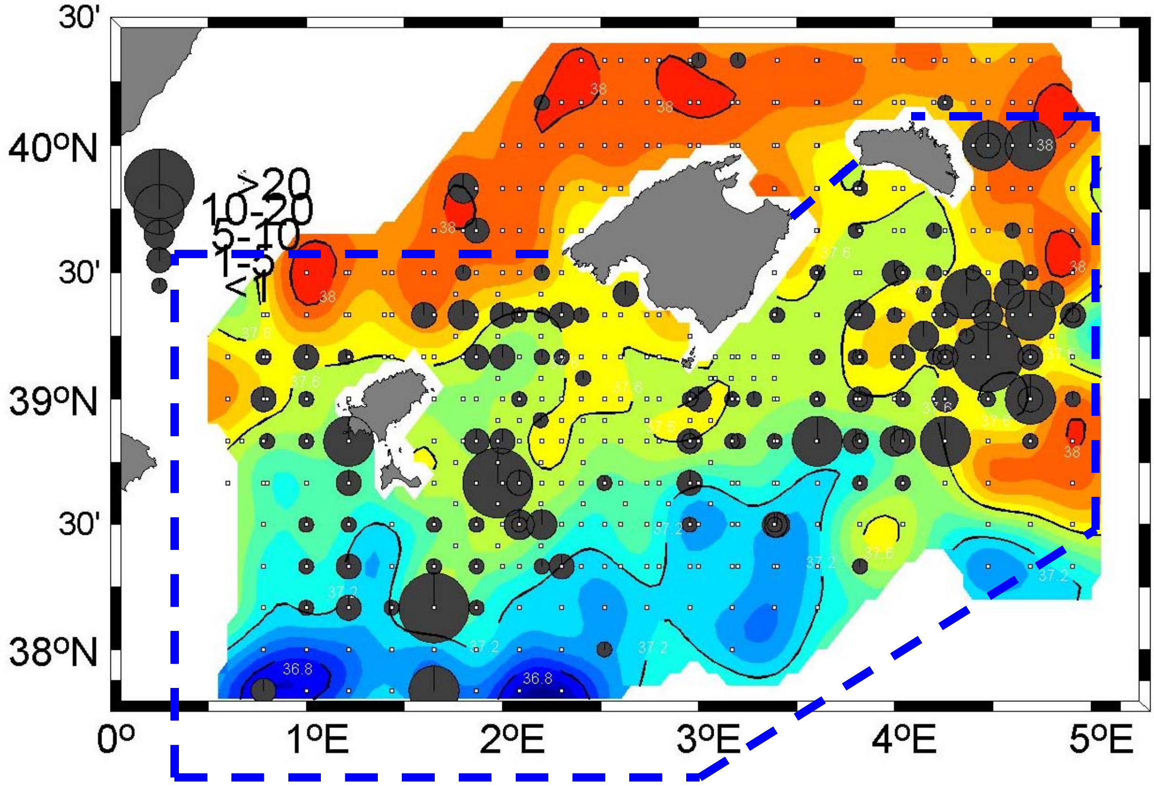
Spatial management to support recovery of the Atlantic bluefin tuna in the Mediterranean



The case for implementing a bluefin tuna sanctuary (or permanent fishing closure) in the Balearic Sea

Report published by WWF Mediterranean, May 2008

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Why this study

The East Atlantic bluefin tuna (BFT) stock has been exposed to rampant overfishing in the Atlantic Ocean and the Mediterranean Sea, particularly during the past decade (1996 to 2007). In 2006 both WWF and the scientific committee (SCRS[1]) of ICCAT[2] reported that real annual catches had exceeded the total allowable catch (TAC) - set then at 32,000 t per year - by some 20,000 tones, demonstrating a complete managerial failure of the fishery. Also in 2006, SCRS carried out an assessment of the stock, with results pointing to severe stock depletion and on-going overfishing, including the risk of collapse of the fishery and the stock unless astringent management measures are urgently adopted. Nevertheless, the management plan adopted in November 2006 by ICCAT did not follow scientific advice and allowed fishing during the peak of spawning with a quota set at twice the level scientifically recommended to recover the stock. During the first year of implementation of this new plan (wrongly labeled as the "recovery plan"), widespread violation of ICCAT rules were reported, including real catches largely exceeding the new quota, with even Europe officially acknowledging catches worth 25% over its quota.

In March 2008 WWF launched the first study ever developed aimed at quantifying the real size of the purse seine fleet harvesting BFT in the Mediterranean, which accounts for most of the total catch of the stock[3]. WWF's assessment pointed to huge structural overcapacity in the fishery, with a yearly catch potential worth twice the total annual TAC and 3.5 times the sustainable level advised by ICCAT scientists. To add insult to injury, the overcapacity trend was found to be still worsening, with recorded new buildings of large tuna purse seiners in many Mediterranean countries. Whereas it is evident that only a dramatic cut in fishing capacity - through decommissioning schemes involving vessel scrapping - can deliver a basis for a sustainable fishery to take place, it is obvious that we are very far from even a mere inflexion point in the overcapacity trend. Given the risk of imminent collapse of the fishery, management measures need to be urgently adopted tailored to the current situation of structural overcapacity, in such a way that its implementation effectively limits the potentiality of the bloated fleets to translate their fishing capacity into catches. The situation is all the more urgent since current management measures, by

[1] Standing Committee on Research and Statistics
[2] ICCAT – International Commission for the Conservation of Atlantic Tunas – (www.iccat.int) is the Regional Fisheries Management Organization (RFMO) which regulates this particular bluefin tuna fishery.
[3] The report "Race for the last bluefin" is downloadable from www.panda.org/tuna

allowing fishing during the peak of spawning in May and June and not including any spatial closure, don´t include any meaningful spatial or temporal restrictions of fishing effort that might ensure that resulting fishing mortality is commensurate to sustainable – or even only legal - levels.

The report "Race for the last bluefin" was widely endorsed by fishermen and decision makers, who share WWF's analysis on the rampant overcapacity in the BFT fishery. Such a dramatic degree of structural overcapacity, and the evidence that management measures adopted in 2006 were largely inadequate and insufficient, lead WWF to reinforce its call for urgently implementing strict time/area closures (temporal and spatial control of fishing effort) as the only realistic way to reduce catches by this inflated fleet.

Emphasis on recovery must urgently translate into:

1) A seasonal closure of the entire fishery covering the whole months of May and, particularly, June,
2) The permanent protection of spawning adults in key spawning grounds, such as in waters around the Balearic Islands, in the form of no-fish zones or sanctuaries, and
3) Avoiding completely the capture of juveniles (fish under 30 kg).

The 2008 meeting of ICCAT in November will be the very last chance to save this species from population and fishery collapse. The complete review of the failed management plan adopted in 2006 is officially scheduled for 2008's meeting. Beyond BFT, ICCAT Contracting Parties also have the historical responsibility to save the international scheme on multinational governance of fisheries management, by restoring its highly damaged credibility.

<u>What WWF proposes</u>

From the scientific information exposed in the current report, commissioned to an international expert on bluefin tuna reproduction in the Mediterranean, two important points can be gathered:

1) BFT vulnerability to fishing dramatically increases in the Mediterranean during the months of May to July, when it gathers in this region to spawn, and

2) historically the waters around the Balearic Archipelago have constituted one of the most important spawning grounds for BFT in the Mediterranean; the local spawning population was the first one to be wiped out, starting a sequential overfishing process which now affects every corner of the Mediterranean basin.

WWF thus proposes, besides other necessary management measures like dramatic fleet capacity reduction and zero tolerance for juvenile fishing, to impose effective temporal and spatial management measures, in the form of a complete closure of the fishery during the months of May and, particularly, June, and the establishment of a no-fishing sanctuary in the waters of the Balearic Islands, to increase the protection of spawning BFT in the Mediterranean.

The case for a complete closure of the fishery during the months of May and June:

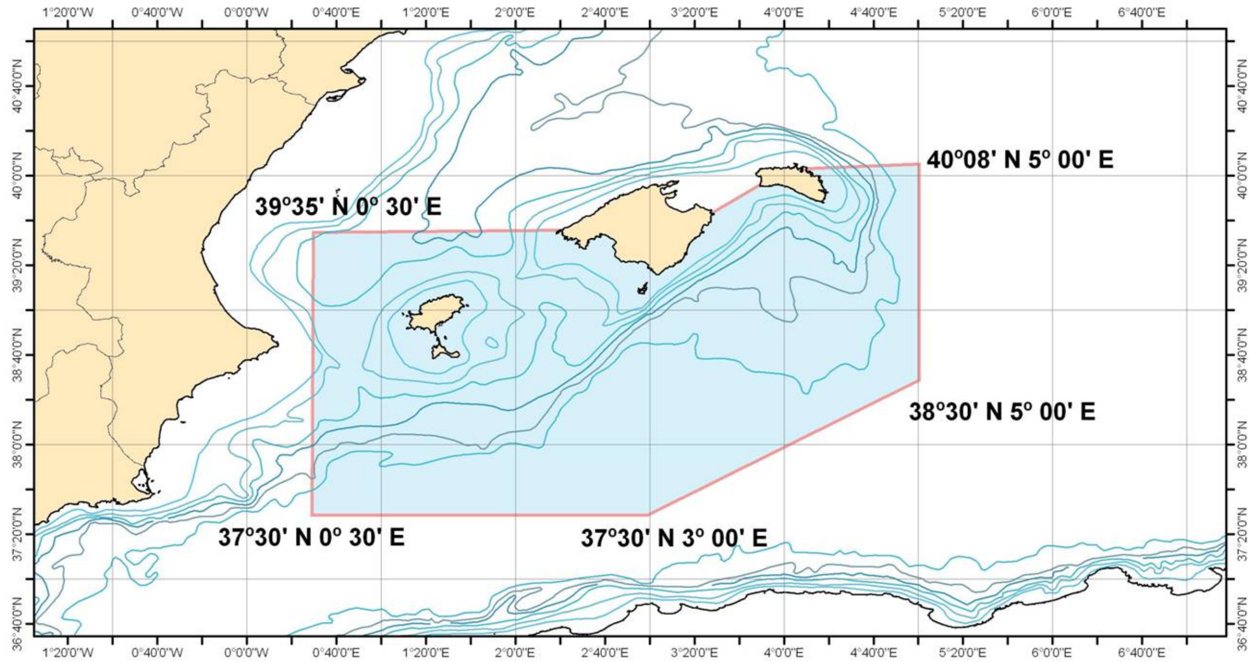
The current report explains that the annual arrival and spawning of BFT in the Mediterranean Sea in the months of spring has been known for centuries, but more recent scientific surveys on larval abundance and adult fecundity have been able to pinpoint the month of June as the main spawning season for this species (with spawning starting earlier, in May, in the eastern Mediterranean according to scientific literature). The current seasonal closure of the fishery to purse seine fleets, however, set from 1st July to the end of the year, does not in the least cover this main spawning season, and completely exposes these reproductive adults to fishing by a grossly bloated fleet. An extension of the seasonal closure of the purse seine fishery to cover the **entire months of May and June** would no doubt greatly induce the recovery of this species in the Mediterranean, as recommended by the SCRS in 2006. The ease in the enforcement of this management measure, compared to the enforcement of TACs, is a strong advantage and gives a strong case for its implementation.

The case for a tuna sanctuary, or a permanent closure of tuna fishing activities, in the Balearic Sea:

The bulk of the current report concentrates on identifying key BFT spawning grounds, and makes a strong case for the waters south of the Balearic Archipelago as being one of the best zones within the Mediterranean to establish the first sanctuary for the protection of spawning BFT. There are various arguments given to support this proposal. Firstly, recent studies have shown that bluefin spawning continues taking place in this area, with egg densities reaching the highest levels ever recorded in the whole of the Mediterranean basin. Furthermore, catches in the Balearic Sea have decreased in recent years, since Spanish and French purse seine fleets captured about 15,000 tons in 1995, and only 2,270 tons in 2006. This can be partly due to the displacement of the fleet to other areas in the central Mediterranean; but probably this fleet shift was induced by a previous decrease of captures.The closure of the Balearic Sea area to the fleet targeting bluefin would permit that both the absolute and relative importance of the Balearic Sea as bluefin spawning ground are increased, contributing to the recovery of the stock. The fact that nowadays the purse seine fleet targeting bluefin operates mainly in the central Mediterranean facilitates the acceptance of a “bluefin sanctuary” in the Balearic Sea area. On the other hand, the measure would have many collateral positive effects, in the case that the protection would be extended to other large pelagics, by limiting fishing activities within the protected area as well, both recreational and professional, targeting such large pelagic species. Indeed, as highlighted by the report, the area around the Balearic Sea is an outstanding area for the reproduction of virtually all tuna species occurring in the Mediterranean.

On the legal side, it should be reminded here that Spain already established some ten years ago a vast fishing protection zone around the Balearic Archipelago, which means that most of the area proposed as a sanctuary currently qualifies as EU Community waters. Moreover, the Balearic Islands regional Parliament has recently approved a proposal that urges to the Spanish Government, the EU and ICCAT to implement such a protection area. A similar proposal has also been approved by the Senate of Spain.

According to detailed scientific information, as summarized in figures 9 to 14 of the technical report, WWF proposes that the geographical limits of this protection area should thus be those mapped in the following figure:



<u>WWF's current position</u>

To summarize, it's WWF's view that current priorities for saving BFT from its commercial and ecological extinction are twofold:

1) ICCAT to adopt a real recovery plan in November 2008, including management conservation measures aligned with scientific advice, as detailed above, and

2) drastically reducing the capacity of the fleets targeting this species, particularly the huge purse seine fleet.

Until the above measures are adopted and conditions for their full implementation are strictly secured, **WWF calls on ICCAT Contracting Parties to adopt a moratorium on the fishery, and on citizens, retailers, chefs ad restaurateurs to boycott any trade and consumption of this species[4]**.

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[4] with the sole exception of the intrinsically sustainable trap fishery

Relevance of the Balearic Sea for the spawning of the bluefin tuna in the Mediterranean Sea

A technical report commissioned by WWF to:

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1. Overview of the biology, fisheries and research of the Atlantic bluefin tuna

1.1 Background on Atlantic bluefin tuna biology and ecology

Atlantic bluefin tuna (*Thunnus thynnus*), the largest scombriform, is undoubtedly an emblematic species, considered a quintessential predator of pelagic ecosystems (Rooker *et al*., 2007). It is regarded also as one of the most evolved teleosts (Buck, 1995), being even referred to as "the most noble fish in the sea". One of its more striking biological features is the so called "rete mirabilis", a complex structure in the circulatory system of tunas which allow them, besides the internalisation of slow-oxidative swimming muscles, to minimize heat loss and maintain internal temperature above that of seawater. This endothermic capacity is more developed in bluefin tuna than in other tunas (Graham and Dickson, 2001), permitting it to withstand waters as cold as 3ºC, as well as waters up to 30ºC (Block and Stevens, 2001). In consequence, bluefin tuna presents the widest geographical extension among this group, inhabiting the North Atlantic ocean from Newfoundland to Brazil, and from Norway to the Mediterranean and Cape Blanc at 20^{O} north latitude on the West African coast, and being hence the only large pelagic fish living permanently in temperate Atlantic waters (Bard *et al*., 1998; Fromentin and Fonteneau, 2001). These physiological features, besides other derived evolutionary traits such as morphological adaptations which lend the bluefin tuna a prodigious swimming capacity – one specimen tagged in the Bahamas was caught less than 50 days later off the coast of Norway, 6,700 km away (Mather, 1962) - enable this species to effectively exploit a wide range of pelagic environments and carry out extensive ontogenetic and genetic migrations.

Since 1980 the International Commission for the Conservation of Atlantic Tunas (ICCAT), established in 1969 to coordinate the research and management of highly migratory tuna and billfish in the North Atlantic, has managed Atlantic bluefin tuna as two stocks with the boundary between the two spatial units being the 45º meridian. The factors supporting such a decision were: the occurrences of small-to-large sized individuals on both sides of the ocean, the distribution of larvae and juveniles both in the Mediterranean and the Gulf of Mexico, no evidential spawning activity in the mid-Atlantic, historical records of traps in the Gibraltar area showing that bluefin tuna adults enter the Mediterranean ahead of the spawning season, leaving once finished and finally, irregularities of trans-Atlantic tag returns (ICCAT, 2002). Although trans-Atlantic migration of individuals from both production zones is well documented (Lutcavage *et al*., 1999; Block *et al*. 2001, 2005) and specimens from both stocks share foraging grounds in the mid-Atlantic, chemical markers and genetics support the two stock hypothesis (Boustany *et al*., 2006; Carlsson *et al*., 2007; Rooker *et al*., 2003, 2004, 2006). Thus, it seems to be demonstrated that those adults born in the Gulf of Mexico migrate to this area in spring to spawn in April-May, whereas those born in the Mediterranean Sea come back to this sea when they reach maturity, in late spring, to spawn in June-July in the western and central areas. This has been inferred primarily from larval distribution and histological examination of gonad condition and confirmed recently from electronic tagging studies, which have shown a clear homing behaviour in several tagged specimens (Stokesbury *et al*., 2004; Block *et al*., 2005; Teo *et al*., 2007). In the eastern Mediterranean spawning occurs earlier, in May-June; but it has been hypothesized that bluefin tuna inhabiting the Levantine Mediterranean basin constitute a separate population which remains all year round in this area (Carlsson *et al*., 2004). This statement, based on genetic analysis, would be supported by the fact that individuals tagged in the eastern Mediterranean have always been recaptured within the Levantine basin (De Metrio *et al*., 2005). However, although these data support the assertion that bluefin tuna spawning areas are centred in the Gulf of Mexico and Mediterranean Sea, the presence of adult bluefin tuna has been reported in other areas during presumed spawning seasons (Lutcavage *et al*., 1999), and bluefin tuna larvae have been caught in some of these areas, such as the Bahamas Islands (McGowan and Richards, 1989).

Atlantic bluefin tuna is an oviparous and iteroparous species, like the rest of tuna. It has an asynchronous oocyte development and is a multiple batch spawner. In the Mediterranean spawning frequency has been estimated at 0.85 days for active spawners (Medina *et al*., 2007). Earlier studies have found that 50% of female bluefin tuna mature at approximately 3 years of age for the eastern Atlantic stock (103 cm curved fork length) and 100% are mature at ages 4-5 (Rodriguez-Roda, 1967), which has been confirmed by recent studies (Corriero *et al*., 2005), whereas those of the western stock reach maturity at 8 years (200 cm), similar to other *Thunnus* species (Shaeffer, 2001). These differences also support the two stocks hypothesis. Rodriguez-Roda (1967) reported a total fecundity of 97 to 137 oocytes per gram of body weight in bluefin tuna caught along the coast of Spain, and a stereological study carried out on spawning bluefin tuna from the Balearic Islands (Medina *et al*., 2002) showed similar results (93 oocytes g^{-1} body weight). However, the latter has re-estimated these numbers taking into account the shrinkage associated with tissue treatment, stating that they could be overestimated by about 28% (Medina *et al*., 2007). Thus, bluefin tuna relative batch fecundity would be similar, not greater, to that of other *Thunnus* species. Considering that archival tag data indicate that effective time spent on spawning grounds could be as short as two weeks (Gunn and Block, 2001) and an average batch fecundity of 6.5 million eggs, the average annual fecundity would be around 77 million eggs per fish. Another factor to take into account to estimate the reproductive potential of bluefin tuna is if adults spawn every year, as generally accepted, or only every 2-3 years, as the results from electronic tagging experiments mentioned above (Lutcavage *et al*., 1999) and experiments in captivity (Lioka *et al*., 2000) would suggest.

Regarding the aforementioned homing behaviour, Fromentin and Powers (2005) consider that Atlantic bluefin tuna is more likely to perform repeat homing, a process by which younger individuals learn spatial orientation from older individuals (Dodson, 1988), rather than natal homing (strict fidelity to the birth location due to imprinting during larval stages (Dittman and Quinn, 1996)). This behaviour would be advantageous when fish can repeat experiences (i.e. iteroparous reproduction) and when they live in unstable and unpredictable environments such as oceanic waters where the probabilities of recruitment failures are high (Dodson, 1988; McQuinn, 1997). To support this hypothesis Fromentin and Powers (2005) argue that schools of migrating bluefin tuna spawners include a broad range of individual sizes (Ravier and Fromentin, 2004), and also that past works mention other spawning locations than those believed to occur today, which could be due to the disappearances of some spawning habitats or the shifts of preferences of some areas to others. These authors also consider that the traditional unit stock approach, related to discrete populations both geographically and reproductively isolated, cannot explain the complex bluefin tuna population structure. As alternative approaches, they propose the contingent hypothesis (Secor, 1999), which purport that divergent energy allocations during early live stages can cause divergent migration or habitat uses among groups of fish, and the metapopulation theory, from which bluefin tuna would be seen as a collection of discrete local populations, occupying distinct and patchy suitable habitats and displaying their own dynamics but with a degree of demographic influence from other local populations through dispersal (Hanski, 1999; Kritzer and Sale, 2004). This issue is fascinating from the ecological viewpoint and crucial for management, as the effects of exploitation and the potential of the population to recover from overfishing depend on ecological processes which are in effect (Fromentin and Powers, 2005).

1.2 History of Atlantic bluefin tuna fisheries and scientific research

The knowledge of these large-scale migrations has been used by fishermen to set traps along the migratory routes of the Atlantic bluefin tuna for thousands of years. The first evidences of bluefin tuna fishing in the Mediterranean date back to around 7000 B.C. (Desse and Desse-Berset, 1994; Doumenge, 1998). Phoenicians were the pioneers in developing fixed nets and beach seines, around 4000 years ago, to capture migrating bluefin tuna and Romans continued this kind of exploitation, exporting bluefin tuna products, as “tarikos” (salted meat) and “garum” (fermented fish sauce), from fishing areas – Gibraltar Strait, Sicily - to the rest of the Empire (Cort, 2005). Traps such as those in current use have been employed throughout the Mediterranean from the 14th century (Ravier and Fromentin, 2001). In relation to this long fishing history, and also on account of its fascinating biological characteristics of impressive size and weight (>3 m and up to 900 Kg), swimming speed (90 Km/h) and migratory behaviour, bluefin tuna have gained the attention of scientists from antiquity. Aristotle (fourth century B.C.) and Pliny the Elder (first century A.C.) already speculated that Atlantic bluefin tuna performed a large anticyclonic movement all around the Mediterranean. Cetti (1777) was the first in stating that bluefin tuna come into the Mediterranean from the North Atlantic to spawn. Scientific interest has continued into modern times, and complete studies on bluefin tuna fisheries and biology were carried out at the end of the 19th and early and mid 20th centuries (Bragança, 1899; Sella, 1929a,b; Rodriguez-Roda, 1964). The exploitation pattern based mainly on fixed nets hardly changed until the middle of the 20th century (Thomazi, 1947; Doumenge, 1998). On this basis fishing effort may have remained more or less stable over the later six hundred years, between the 14th century and the 1950s. After analysing the evolution of Atlantic bluefin tuna captures within this period, Ravier and Fromentin (2001) uncovered that the eastern Atlantic bluefin tuna population displayed long-term fluctuations with a period of about 100-120 years and hypothesized that such cycles would result from annual variations in recruitment. Some years later the same authors (Ravier and Fromentin, 2004) indicated that fluctuations appeared to be closely and negatively related to long term trends in temperature. Notwithstanding the existence of environmentally induced low abundance periods, the relatively low fishing mortality exerted by the traditional exploitation pattern did not lead to any collapse of the Atlantic bluefin tuna stocks, permitting the recovery of the stocks when environmental scenarios became favourable again for recruitment success, and should hence be considered to have been a sustainable fishery.

1.3 Current status of the stock and research

However, this situation has changed dramatically in recent decades. During the 1960s fishing effort intensified as the international market developed for canned and fresh bluefin tuna. By the late 1960s the western stock of Atlantic bluefin tuna showed pronounced signs of overfishing; since landings peaked at nearly 20,000 tons in 1964 they sharply declined to less than 5,000 tons in 1968. By the 1970s and early 1980s, large numbers of purse seiners targeting small schooling bluefin tuna supplied canneries, while other fleets, such as longliners, sought giant bluefin tuna for export to Japan, where the fresh fatty bluefin tuna flesh is considered a delicacy. The increasing demand from the Japanese sushi-sashimi market provoked a rise of bluefin tuna prices and, in consequence, purse seiners started targeting adult bluefin tuna too, expanding their fishing areas in the Mediterranean, and longliners began to exploit the central North Atlantic intensively. Despite the conservation measures undertaken during this period by ICCAT to protect the western stock, including restrictive TACs, this population continued to decline and by 1992 its biomass was estimated to be only 10% of its 1975 level (Buck, 1995). By the early 1980s there was still little concern about the status of the much more abundant, in those days, eastern stock. As a result, the fishing effort on this stock, driven by the incessant growth of market prices, augmented from year to year, and a dramatic increase of landings, from less than 20,000 tons in 1970 to a maximum of more than 50,000 tons in 1996, occurred. Furthermore, the spreading of bluefin tuna farming all around the Mediterranean Sea since 1997 (Miyake *et al*., 2003), centred on cages where wild specimens are transferred alive for fattening, has made the fishery even more profitable, inducing the rapid development of new and powerful fleets, especially in Mediterranean countries (Fromentin and Powers, 2005).

The productivity of the eastern stock in the nineties was estimated through different methods to be around 25,000 tons (ICCAT, 1997, 1999) and in consequence ICCAT implemented a TAC system to reduce overfishing, limiting bluefin tuna catches from the eastern stock to around 32,000 tons. However, ICCAT experts have estimated that landings have been maintained at well over 50,000 tons from thence (ICCAT, 2005). This is mainly due to the overcapitalization of the fleet, since the earnings from fishing activity would not compensate the fixed cost of fishing vessels (including capitalization of the mortgages) in the case that capture limits would be strictly accomplished (WWF, 2006). On this account, the present scenario will continue to induce illegal fishing and under-reporting unless a significant reduction in fishing capacity is put into effect. Farming has also contributed to misreporting because this practice makes controlling catches difficult. In 2000, the quantitative stock assessment procedure was postponed for the first time ever, because of increasing uncertainties. Such assessments have been carried out again in the last few years, concluding that the eastern stock is not being harvested at a sustainable level and it is likely in a state of decline (ICCAT, 2003, 2006). The last evaluation realized by the ICCAT Standing Committee of Research and Statistics (SCRS) (ICCAT, 2007) confirmed that the stock is being overexploited, depicting a dangerous scenario, since it shows a continuous decrease from the mid nineties of both recruitment and spawning stock biomass. The current stock would therefore be approximately 1/3 of that estimated in the early seventies, and if pressure persists it is likely to lead to the collapse of the fishery, at least from the commercial point of view.

Parallel to the development of the fisheries and the increasing concern over stock status during the second half of last century, scientific research on Atlantic bluefin tuna was intensified. In the mid 1990s several extensive reviews compiling available information were published (Clay, 1991; Magnuson *et al*., 1994; Mather *et al*., 1995) and more recently other detailed reviews have synthesised the new information arising from the studies carried out during the last decade applying new techniques, such as electronic tagging, genetic markers and otolith microchemistry (Fromentin and Powers, 2005; Rooker *et al*., 2007). Combined with past information, new findings have significantly enhanced our understanding of bluefin tuna biology and ecology. Unfortunately, linkages between this new scientific knowledge and exploitation and management are still lacking (Fromentin and Powers, 2005).

Taking into account the current status of the stocks, new protective measures which could be effectively put in force should be imposed to prevent the economical extinction of this valuable, and renewable if it were properly managed, resource. Among these technical measures, the possibility of establishing spatial fishing closures in sensible habitats for Atlantic bluefin tuna, such as spawning grounds, should be considered.

2. The reproduction of Atlantic bluefin tuna off the Balearic Islands

2.1 Historical review of larval studies in the Mediterranean Sea with emphasis on the Balearic Archipelago

Long ago numerous authors have stated that Atlantic bluefin tuna spawned in the Mediterranean Sea. Aristotle hypothesised that the reproduction of bluefin tuna took place in the Black Sea, where the presence of spawners and eggs have been reported by Vodianitzki and Kazanova (1954) and Akyüz and Artüz (1957). Cetti (1777) mentioned that bluefin tuna spawning occurs along the Sardinian coast and D'Amico (1816) indicated that Sicilian waters were also a spawning area for bluefin tuna. Roule (1917) proposed that the waters off Sardinia, Tunisia and Sicily, as well as those around the Balearic Islands were bluefin tuna spawning grounds.

Piccinetti and Piccinetti-Manfrin published a complete review in 1970, based mainly on the analysis of 26 scientific works on juvenile bluefin tuna distribution, which summarised the information available in the Mediterranean area about the locations, dates of occurrences, weight and length ranges, and abundances of age 0 bluefin juveniles. They included also in this analysis some works dealing with bluefin tuna larvae, such as those of Ehrembaum (1924), Sanzo (1933), Dieuzeide (1951) and the aforementioned Vodianitzki and Kazanova (1954) and Akiüz and Artüz (1957).

Ehrembaum's paper (1924) is one of the first references to the presence of bluefin tuna larvae in the Mediterranean. Analysing the plankton samples provided by the Dana Expeditions, carried out all around the Mediterranean Sea between 1908 and 1910, this author attributed some of these larvae to Atlantic bluefin tuna; but they were in fact albacore (*Thunnus alalunga)* larvae, which on the other hand were properly identified and described by this author in the same work. However, the larvae that Ehrembaum ascribed to little tunny (*Euthynnus alleteratus)* were undoubtedly Atlantic bluefin tuna (Richards, 1976). Thus, Sella (1924) was the first scientist who identified bluefin tuna larvae correctly in the Mediterranean, from biological samples taken in the Messina area. Some years later, Sanzo (1929a,b, 1933) described, among those of other tuna, the embryonic and early larval stages of bluefin tuna (Sanzo,1929a,b, 1933) and albacore (Sanzo, 1933). To carry out these studies Sanzo sampled fertilized tuna eggs in the Messina strait area, transferring them live to the laboratory. Such eggs were identified according to prior descriptions published by himself in 1909, 1910 and 1929, and described the resulting larvae. Unfortunately, due to uncertainties in egg identifications, larvae attributed to albacore and Atlantic bluefin tuna were misidentified, being in fact bullet tuna (*Auxis rochei*) larvae. After the publication of these pioneering works no relevant contribution to bluefin tuna larvae in the Mediterranean appeared until the 1970s, with the exception of the works of Dieuzeide (1951) and Vodianitzki and Kazanova (1954) mentioned above.

In 1971 and 1972 French and Spanish scientists carried out ichthyoplanktonic surveys directed to tuna larvae sampling around the Balearic Islands (Duclerc *et al*., 1973). These surveys demonstrated the presence of Atlantic bluefin tuna larvae, and also larvae of other tuna species such as albacore and bullet tuna, near the islands of Mallorca and Menorca. In the following years the Mediterranean Science Commission (CIESM) backed further tuna larvae exploratory surveys in several areas of the Mediterranean. These surveys showed positive results, reporting again the presence of bluefin tuna, albacore and bullet tuna larvae in Balearic waters (Dicenta *et al*., 1975); of bullet tuna and very few albacore and bluefin tuna larvae off Algerian coasts (Piccinetti *et al*., 1976, 1977a); some bullet tuna and bluefin tuna in the Adriatic Sea (Piccinetti *et al*., 1977b) and also few bullet tuna larvae, and 1 single larvae of black skipjack (*Euthynnus lineatus*), in the Aegean Sea (Barrois, 1977). Re-analysing the ichthyoplankton samples from the Maroc-Iberia I survey (Rodriguez-Roda 1975), carried out in the Bay of Cadiz, Alborán Sea and the SE coast of Iberian peninsula, up to the Nao Cape, Rodriguez-Roda and Dicenta (1981) only found 17 bluefin tuna larvae in the vicinity of the Cape of Gata. These results provide clear arguments to refuse the hypothesis proposed by Pavesi (1887) and Bragança (1899), supported by Roule (1914, 1917), who stated that Mediterranean bluefin tuna constitute an autochthonous stock, completely independent of the Atlantic bluefin tuna, which would spawn near Gibraltar Strait.

In the following years, further “regional” surveys were realized in some of the aforementioned Mediterranean areas (Dicenta, 1983 -Balearic Islands-; Piccinetti and Piccinetti-Manfrin, 1978 -Adriatic Sea-), displaying similar results. Several surveys were carried out also around Sicily, both in the Tyrrhenian and Ionian Seas (Dicenta *et al.*, 1979; Potoschi *et al*., 1994; Cavallaro *et al*., 1996), in which larvae of Atlantic bluefin tuna, albacore and bullet tuna were caught. It is worth mentioning that in the north-western Mediterranean only larvae of bullet tuna and Atlantic bonito (*Sarda sarda*) have been found (Sabatés and Recasens, 2001).

In 1975 and 1977 the Spanish Institute of Oceanography (IEO) carried out larger scale tuna larvae surveys all around the western Mediterranean (Dicenta, 1977; Dicenta and Piccinetti, 1978). Although in these surveys the maximum bluefin tuna larvae densities were registered in the Tyrrhenian Sea, in both cases the second major concentrations of bluefin tuna, as well as the maximum densities of bullet tuna and albacore larvae, occurred near the Balearic Islands.

In 1994, under the auspices of ICCAT, similar basin scale tuna larvae surveys, covering the entire Mediterranean Sea, were conducted by the Japanese R/V Shoyu Maru (Tsuji *et al*., 1994, 1997; Nishida *et al*., 1998) and the Italian R/V Urania (Piccinetti *et al*., 1996a and b). In the Japanese cruise sampling intensity was much higher in the Tyrrhenian Sea, where bluefin tuna larvae were expected to be caught in larger quantities; but in this case maximum bluefin tuna larvae abundances were detected south-east of Sicily, in the Ionian Sea. The Italian survey showed similar results, with bluefin tuna larvae being mainly concentrated all around Sicily (Sicily channel, southern Tyrrhenian and northern Ionian Seas), as well as south of the Balearic Islands. The highest bluefin tuna larval density corresponded to an isolated spot northeast of Sirte Gulf (15,379 under 1,000 m^2 of sea surface), near Lybian coasts, indicating that Atlantic bluefin tuna spawns also in the eastern Mediterranean. This fact has been confirmed recently, since bluefin tuna larvae, as well as albacore and little tunny larvae, have been found south of the Anatolian peninsula (Karakulak *et al*., 2004; Oray and Karakulak, 2005). However, the second and third maximum bluefin larval abundance values were recorded again south of the Balearic Archipelago (4,021 and 792 larvae *1,000m^{-2} respectively).

Results from other tuna larval surveys conducted off the Balearic Islands in the 1980s would support this statement, since resulting scientific papers (Dicenta, 1983; Alemany, 1997) reported also relatively high occurrences and abundances of tuna larvae, not only of bluefin tuna, but also of albacore and bullet tuna, all around the Balearic Islands. Due to the variety of sampling methodologies and strategies it is difficult to compare the abundances and frequencies of occurrence of bluefin tuna larvae accounted in the available bibliography in order to determine the relative importance of the different spawning grounds detected within the Mediterranean. However, results of the aforementioned basin scale larval surveys (Dicenta, 1977, 1978; Dicenta and Piccinetti, 1978; Tsuji *et al*., 1994, 1997; Piccineti *et al.*, 1996; Nishida *et al*., 1998) corroborate the importance of the Balearic waters spawning grounds for the reproduction of Atlantic bluefin and other tunas, since Atlantic bluefin tuna larvae always appeared in this area and larval densities were always among the highest recorded, as mentioned above.

Moreover, recent ichthyoplanktonic studies carried out off the Balearic Archipelago have indicated the presence not only of larvae of several tuna species, such as bullet tuna (Fig. 1), little tunny (Fig. 2), Atlantic bluefin tuna (Fig. 3) and albacore (Fig. 4); but also of other scombriforms such as swordfish (*Xiphias gladius*) (Fig. 5) and billfish (*Tetrapturus* sp.) in those waters (Fig. 6). It must be highlighted that in a survey carried out east of Mallorca Island, not far from the coast (Alemany *et al*., 2006) very high numbers of albacore larvae, never recorded in any other place, were caught (4,990 larvae in only 26 hauls, with peaking densities of 41 larvae * 100m^{-3}). Bluefin tuna larvae appeared also in these samples; but in lower densities since bluefin tuna spawning peaks earlier in the summer season. It is worth mentioning that 232 billfish larvae were also captured, an exceptional result taking into account that only some eggs and larvae of this species had been previously cited (Lo Bianco, 1903; Sparta, 1953).

Summing up, from all these studies it could be inferred that although Atlantic bluefin tuna spawns probably all around the Mediterranean, with the exception of the north-western Mediterranean and the Adriatic Sea, and probably also the Alborán Sea as Piccinetti and Piccinetti-Manfrin (1970) have suggested, waters around the Balearic Islands and Sicily are the most important spawning grounds for Atlantic bluefin tuna, as recognised by Mather *et al*. (1995).

2.2 Characterisation of spawning of Atlantic bluefin tuna in the Balearic Sea

High occurrences of tuna larvae near islands, very close to the coast, have been reported by Miller (1979) and Leis *et al*. (1991). It has been hypothesized that this fact could be caused by the so called "island mass effect" (Doty and Oguri, 1956), suggesting that increased planktonic biomass would enhance early larval survival. Another hypothesis is that it would simply be a result of higher abundances of adults near islands, where tunas aggregate for feeding (Boehlert and Mundy, 1994). These hypotheses make sense in typical oceanic islands; but do not seem applicable to the Mediterranean archipelagos. In fact, nearby mainland coastal areas are more productive than the clean oligotrophic waters around islands. Moreover, adult bluefin tunas migrate the Mediterranean for spawning, not for feeding. An alternative hypothesis is that scombriform larvae would be favored by the scarcity of predators and competitors in these waters. So, they could come across environmental loopholes that increase their survival chances (Bakun and Broad, 2003). Their mobility would allow them to exploit available food resources more efficiently, despite their scarcity. On the other hand, it must be taken into account that mesoscale hydrographic features produced by the interaction between island topography and water masses, such as fronts and eddies, increase local productivity and retention (Bakun, 2006), and spawning strategies of tuna adults could be adapted to release eggs near these offshore richer areas. From the results of some statistical multivariate analyses carried out to determine the influence of environmental variables on fish larval distribution, Alemany *et al*. (2006) suggested a relationship between the presence of bluefin tuna larvae and inflows of surface Atlantic waters in the Balearic Sea. Biologists agree that the spawning behaviour of bluefin tuna is strongly affected by environmental factors and that this sensitivity is intensified during the reproductive period (Mather *et al*., 1995). Sella (1927, 1929a, 1929b, 1932a, 1932b) proposed that mature bluefin tuna sought specific hydrological conditions, not the maximum values of temperature and salinity as suggested by Roule (1914, 1917). He maintained that maturation occurred in the period of the most rapid thermal increment, as have been confirmed by later studies (Rodriguez-Roda, 1964, 1967; Medina *et al*. 2002), and also that the larger maturing bluefin tuna evidently preferred somewhat colder and less saline waters than smaller ones. Scordia (1938), although she did not think that bluefin tuna from the Atlantic spawned in the Mediterranean, concluded that the arrival of Atlantic current waters was the determining cause of the reproductive migration of the bluefin tuna. Sarà (1964, 1973) also maintained that the entrance of bluefin tuna into the traps depended greatly on the position of Atlantic currents, and believed that large maturing tuna taken in the traps had followed the Atlantic current from the ocean into the Mediterranean.

Obviously, studies of bluefin tuna larval distribution in relation to mesoscale hydrographic features, could confirm these hypotheses. Some of the aforementioned works on bluefin tuna larval abundance and distribution also present information about environmental parameters, even mapping the hydrographic scenarios over the study areas (Tsuji *et al*., 1997); but except that of Alemany *et al*. (2006), none of them determined the statistical significance of the relationships among larval distributions and environmental parameters. In fact, despite the numerous available bibliographies on bluefin tuna or other scombroid larval abundances and distributions in the Mediterranean Sea, there are still important gaps in the knowledge of bluefin tuna larval ecology.

Being aware of the risk of collapse of this stock, the Standing Committee of ICCAT recommended in 1999 to deepen the knowledge of the biology of this species and the environmental influence on its ecology, including its early life stages, looking for relevant information on what could help to ensure the sustainability of this important resource.

In line with this demand, the Spanish Institute of Oceanography initiated a research program in 2001, named TUNIBAL, directed to the study of bluefin tuna and related species´ larval ecologies in waters surrounding the Balearic Archipelago, aiming to contribute to the understanding of the bluefin tuna recruitment process.

Within the framework of this program five hydrographic-plankton surveys were conducted from 2001 to 2005 off the Balearic Archipelago. In each survey, a regular sampling grid of about 200 stations10 nautical miles apart, covering an irregular polygon of approximately 180 nm in north-south and 220 nm in west-east direction, was sampled. CTD casts and oblique Bongo 60 and surface Bongo 90 plankton tows, among other sampling operations, were carried out. Preliminary results from these surveys have been presented in several fora. Among the contributions dealing with tuna larvae distributions, the more relevant are those presented to the SCRS-ICCAT meetings (García *et al*., 2002, 2003 a and b, 2005), the 26th and 29th Larval Fish Conferences (Alemany *et al*., 2002, 2005) and CLIOTOP/GLOBEC workshops and symposiums (Alemany and Vélez, 2005; Alemany, 2007; Alemany *et al*., 2007; Garcia *et al*., 2007).

In these surveys Atlantic bluefin tuna, albacore and bullet tuna larvae appeared frequently, in one sixth, one-third and half of quantitative Bongo 60 samples respectively, whereas larvae of other tuna and bonitos, such as little tunny, skipjack tuna (*Katsuwonus pelamys*) (Fig. 7) and Atlantic bonito (Fig. 8) were caught only occasionally. Mean larval abundances in these samples were relatively high: 31 larvae 10 m^{-2} for Atlantic bluefin tuna, 17 for albacore and 31 for bullet tuna. All species presented a patchy distribution, since more than 90% of the stations showed larval densities under 10 larvae * 100 m^{-3} (70% even less than 2 larvae 100 m^{-3}) whereas in some isolated spots abundances as high as 867 (Atlantic bluefin tuna) or 872 (bullet tuna) larvae * 10 m^2 were recorded (Alemany *et al*., submitted). These values are well over any other bluefin tuna larval abundance cited in the Mediterranean. Single Quotient Parameter analyses were applied in this study to determine the environmental preferences of each species for spawning, including physical (temperature, salinity, dissolved oxygen), spatial (latitude, longitude, depth, geostrophic currents velocities) and biological (mesozooplankton biomass) variables. From these studies it can be stated that the complex hydrodynamic scenarios around the Balearic Islands, resulting from the interaction between the inflowing surface Atlantic water masses (AW) and Mediterranean surface waters (MW), play a key role in determining the abundance and distribution of tuna larvae in this area, especially in the case of Atlantic bluefin tuna, as can be observed in the series of figures 9 to 13. Spawning of this species seems to take place mainly in offshore mixed waters, as suggested by their preferences for waters with salinity between 36,9 and 37,7, located near frontal areas, in the confluence of AW and MW. Larval distribution suggests also that spawners reach the Balearic Sea area associated to the inflowing AW, supporting the Sarà (1964, 1973) hypothesis.

Hydrographically, the Balearic region is considered a transition zone between Mediterranean and Atlantic waters. In summer, coinciding with the Atlantic bluefin tuna spawning peak, surface waters of recent Atlantic origin reach the Balearic islands as filaments or eddies separated from the the main current of Atlantic waters that enters the Mediterranean through the Strait of Gibraltar due to the instability of the Almeria-Oran front. The interaction between Atlantic and Mediterranean surface water masses, as well as their interaction with island topography, results in a complex hydrodynamic situation characterized by strong geostrophic circulation and intense frontal systems (Lopéz-Jurado *et al*. ,1995; Pinot *et al*., 1995; Vélez-Belchí *et al*., 2001).

The general hydrographic scenario was, at large scale, the same in all TUNIBAL surveys: Mediterranean surface waters (MW) predominating in the northern sub-basin, whereas south of the Balearic Archipelago inflowing Atlantic surface waters (AW) occupied most of the Algerian sub-basin. As a consequence of the encounter of the two types of water masses, a density front is generally found; with the denser Mediterranean waters distributed in the north of the study area, while the lighter Atlantic waters occupy the southern part. Additionally the southern area of the Balearic Sea, due to its bottom topography, is an area of constant generation of anticyclonic eddies. This large scale situation defines the Balearic Archipelago, and particularly its southern part, as a convergence area, and therefore as a strong retention zone.

On the contrary, an important variability was observed among years when considering the distribution and characteristics of mesoscale hydrographic features, as can be seen in the series of figures 9 to 13. It is these hydrographic conditions that have probably made the Balearic Sea one of the main Atlantic bluefin tuna spawning sites, as is evident when aggregating Atlantic bluefin tuna abundances around the Balearic Archipelago from 2001-2005 (Fig. 14). This latter figure defines the range of the spawning area for Atlantic bluefin tuna in the Balearic Sea, once interannual variability is integrated.

3. Figures

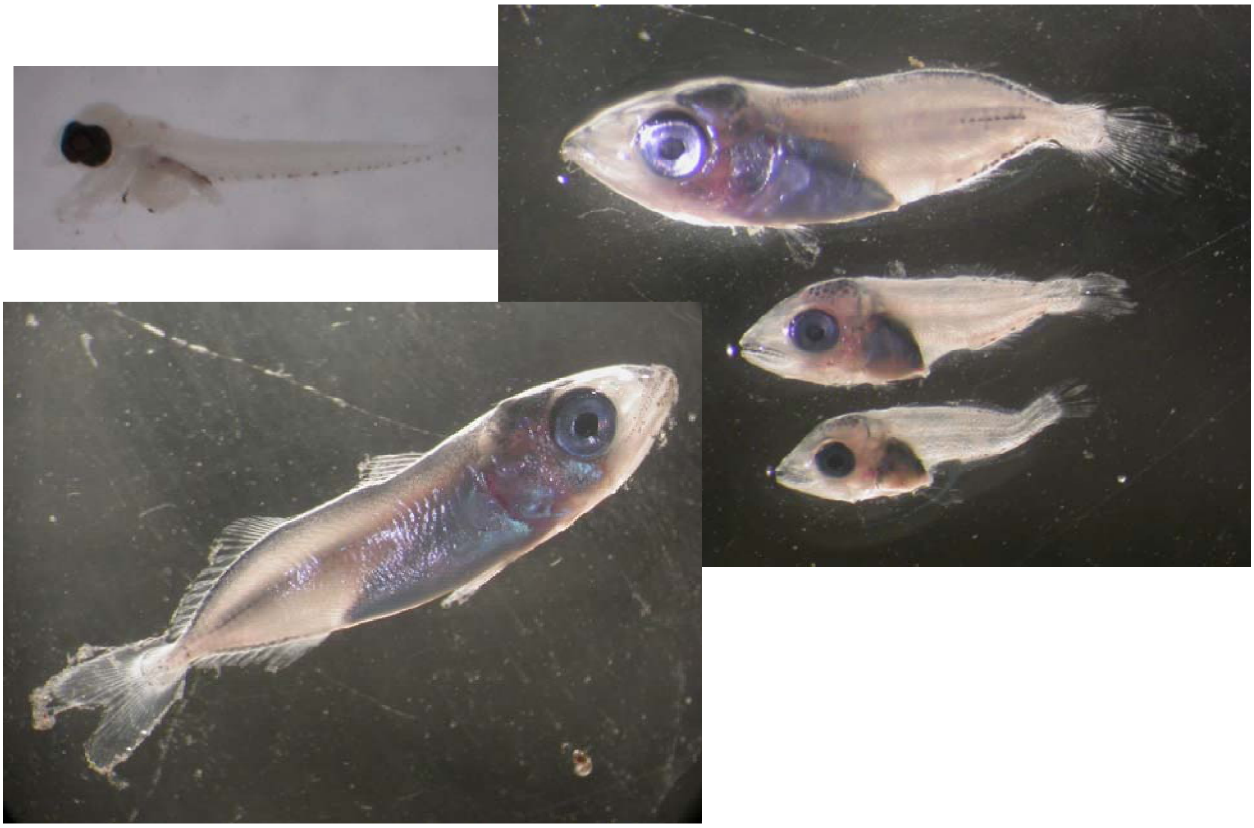

Fig. 1 The larva of the bullet tuna (*Auxis rochei*).

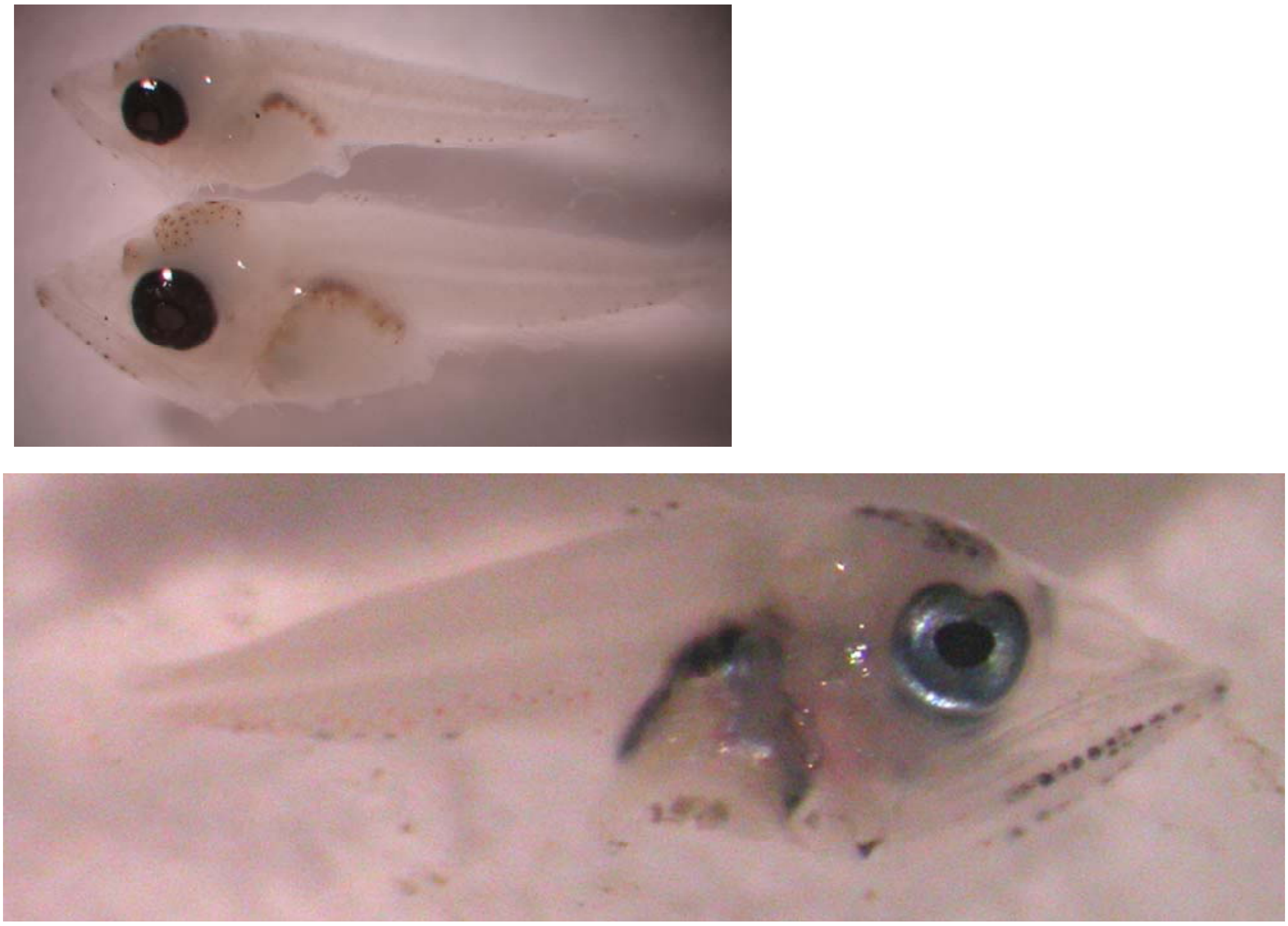

Fig. 2 The larva of the little tunny (*Euthynnus alletteratus*).

Fig. 3 The larva of the Atlantic bluefin tuna (*Thunnus thynnus*).

Fig. 4 The larva of the albacore (*Thunnus alalunga*).

Fig. 5 The larva of the swordfish (*Xiphias gladius*).

Fig. 6 The larva of the billfish (*Tetrapturus sp.*).

Fig. 7 The larva of the skipjack (*Katsuwonus pelamys*).

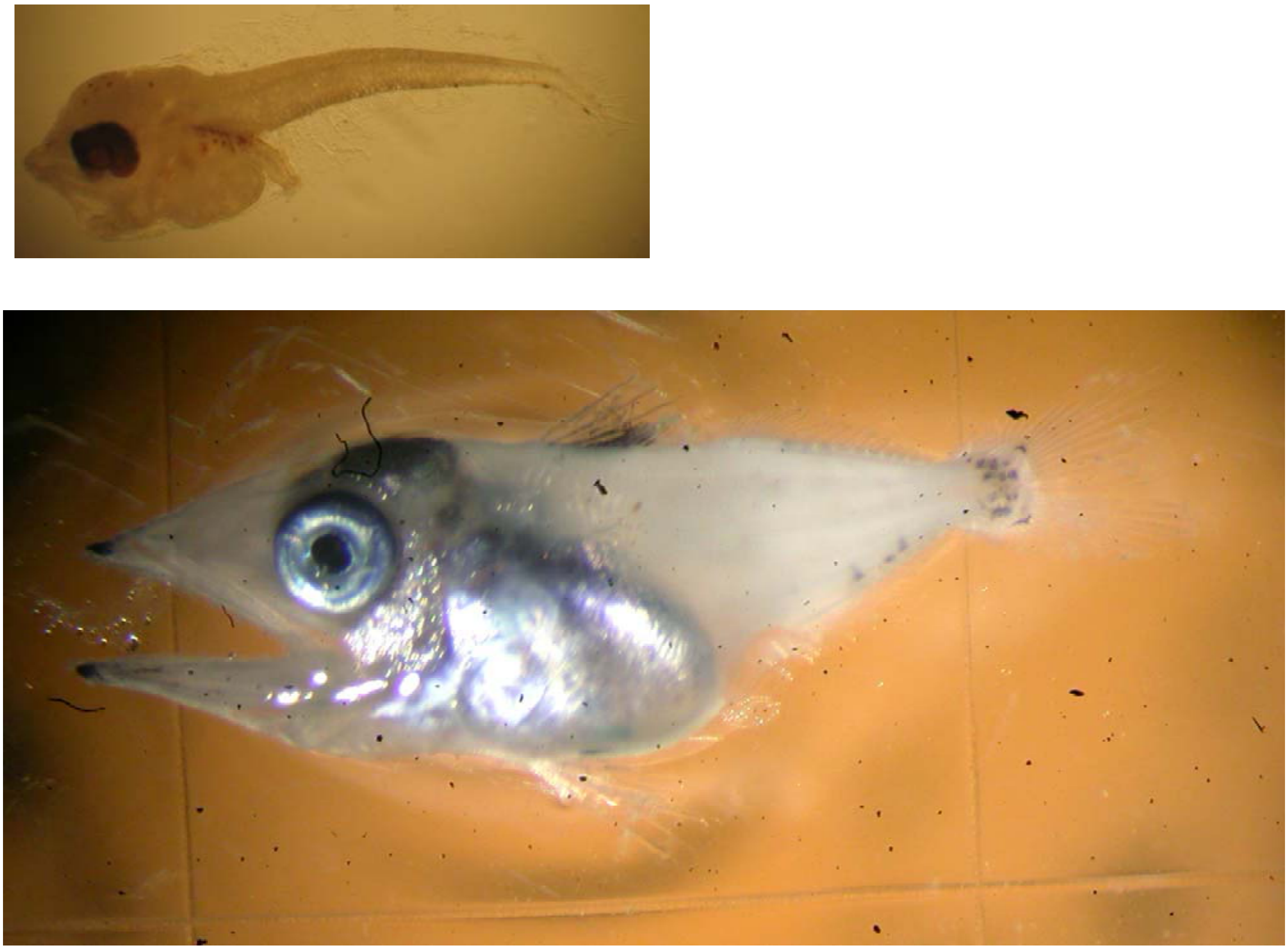

Fig. 8 The larva of the Atlantic bonito (*Sarda sarda*).

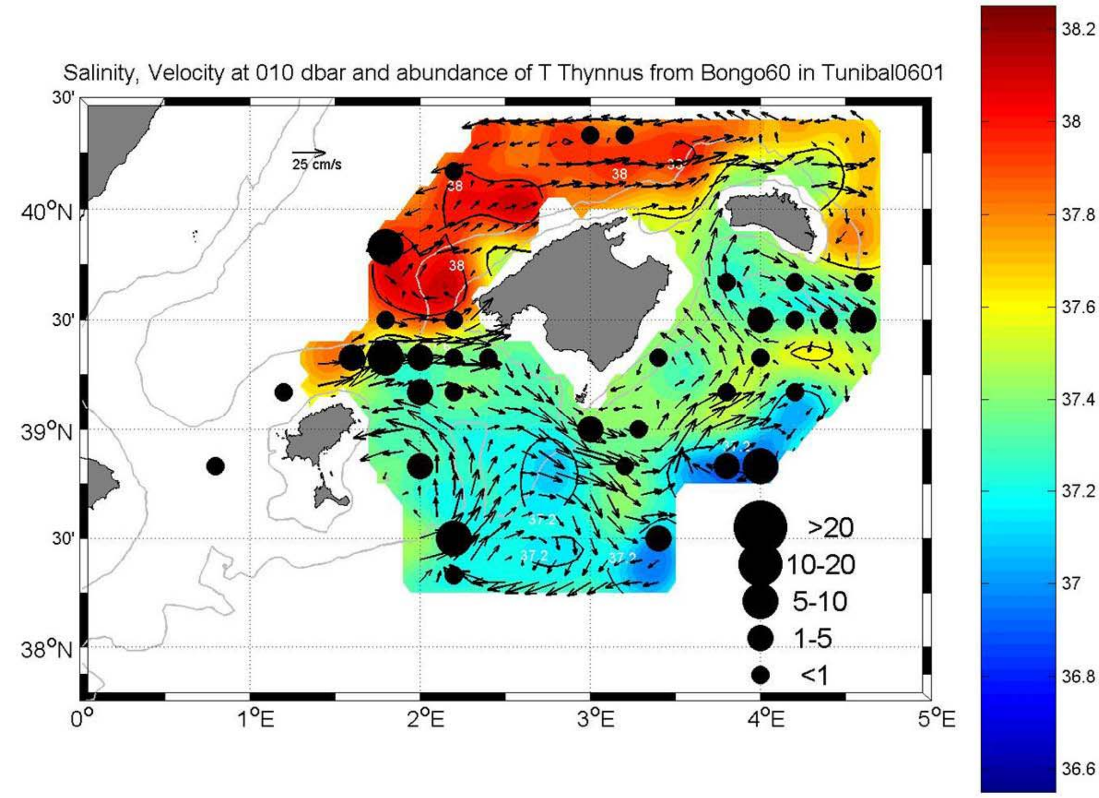

Fig. 9 The abundance of Atlantic bluefin tuna larvae around the Balearic Archipelago in June 2001, in relation to salinity and current velocity.

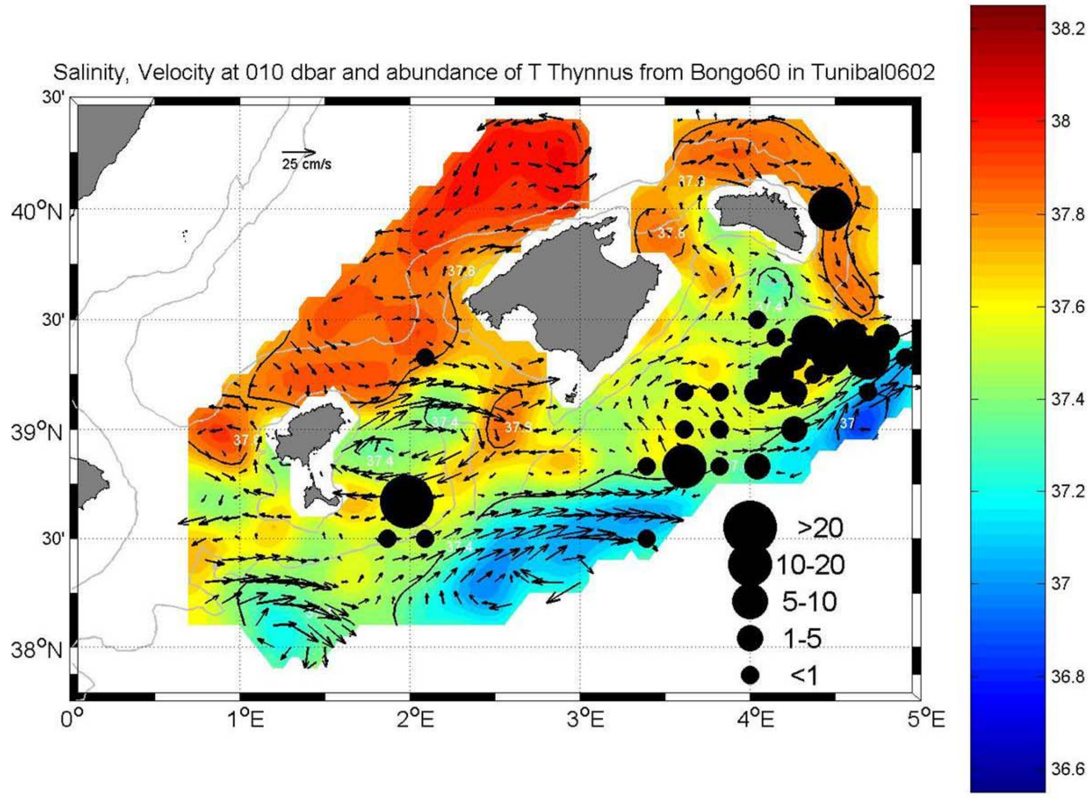

Fig. 10 The abundance of Atlantic bluefin tuna larvae around the Balearic Archipelago in June 2002, in relation to salinity and current velocity.

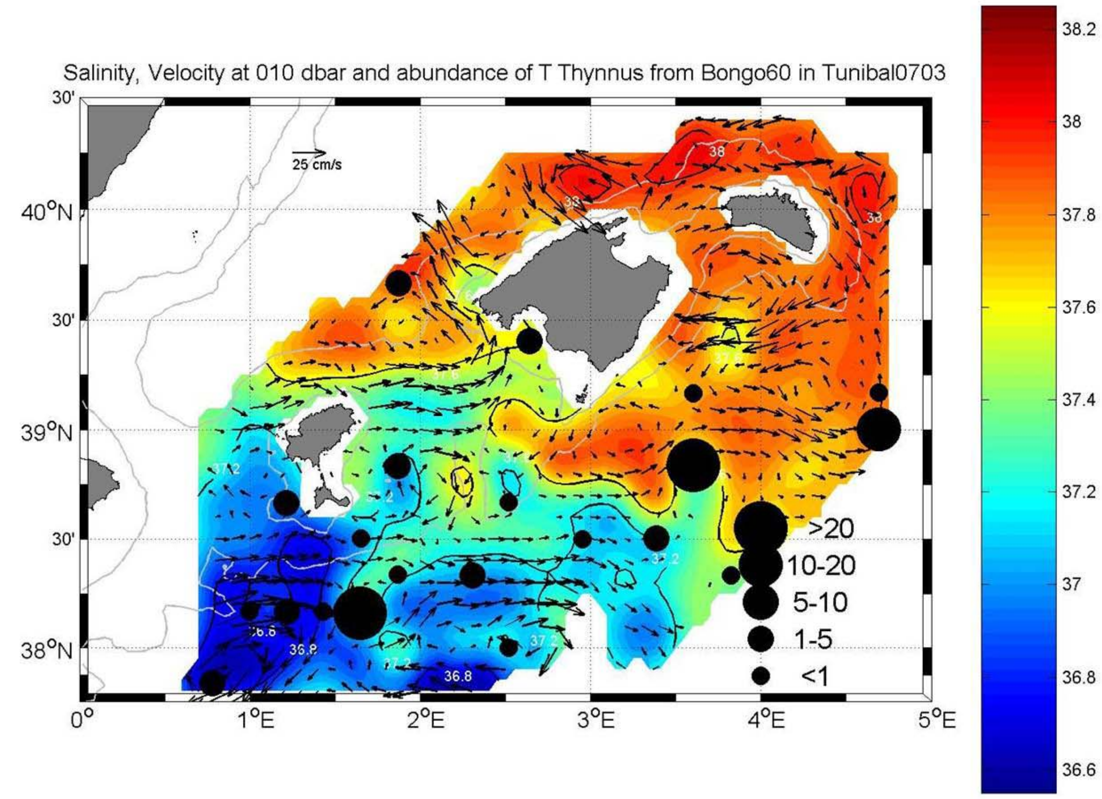

Fig. 11 The abundance of Atlantic bluefin tuna larvae around the Balearic Archipelago in July 2003, in relation to salinity and current velocity.

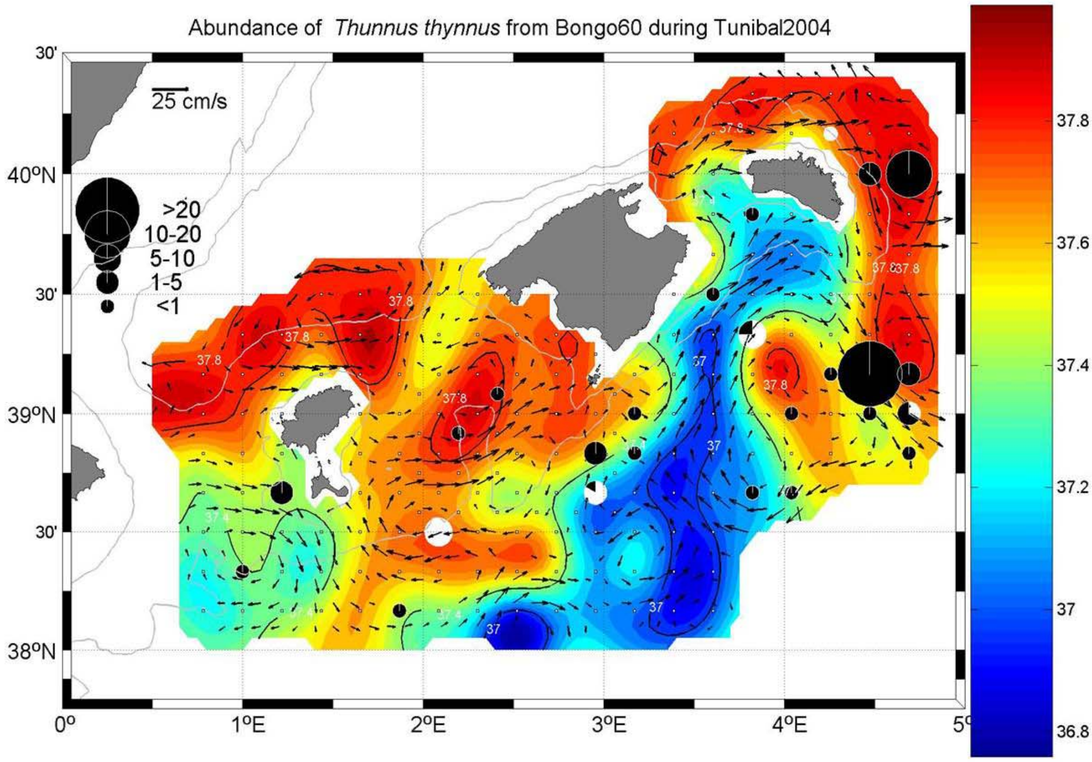

Fig. 12 The abundance of Atlantic bluefin tuna larvae around the Balearic Archipelago in summer 2004, in relation to salinity and current velocity.

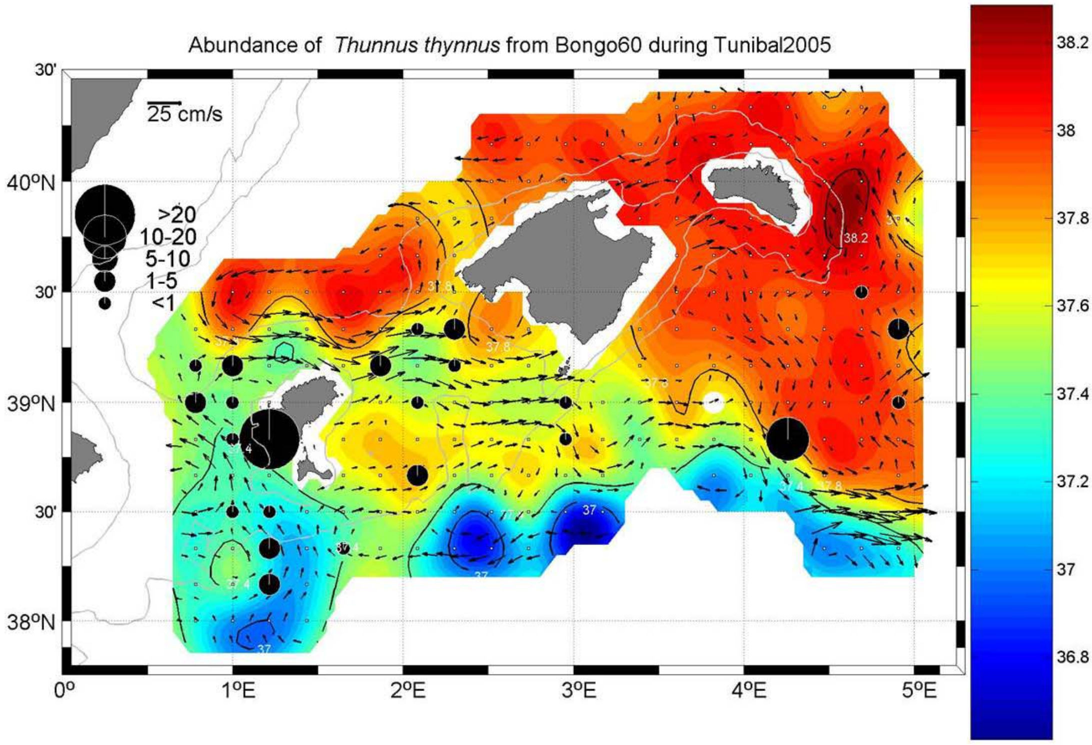

Fig. 13 The abundance of Atlantic bluefin tuna larvae around the Balearic Archipelago in summer 2005, in relation to salinity and current velocity.

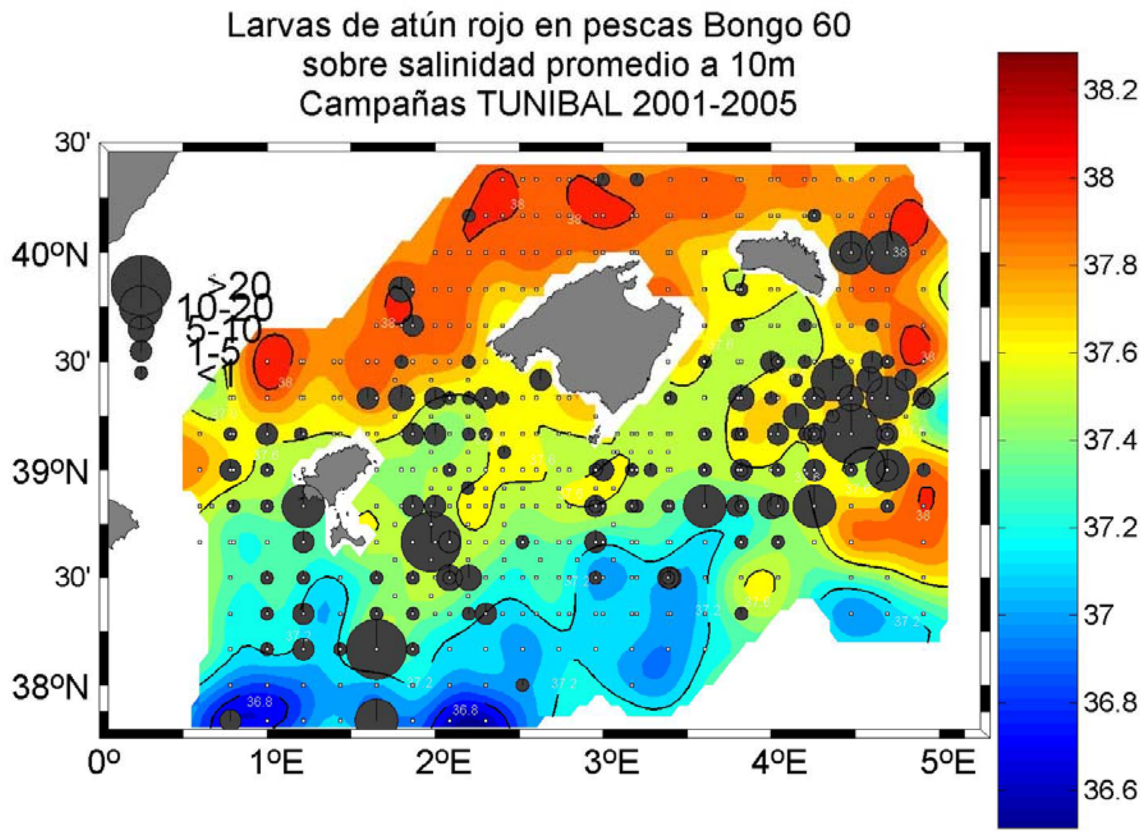

Fig. 14 The abundance of Atlantic bluefin tuna larvae around the Balearic Archipelago in the summers of 2001-2005, in relation to mean salinity field.

References

Akyuz, E.F., Artuz, G. (1957) Some observations on the biology of tuna (*Thunnus thynnus*) caught in Turkish waters. *Proceedings and Technical Papers, General Fisheries Council for the Mediterranean, Rome*, **4(14)**, 93-99.

Alemany, F. (1997) Ictioplancton del Mar Balear. Ph.D. Thesis, Universidad Illes Balears, Palma de Mallorca.

Alemany, F., Deudero, S., Morales-Nin, B., López-Jurado, J.L., Palmer, M., Palomera, I., Jansà, J. (2006) Influence of physical environmental factors on the composition and horizontal distribution of summer larval fish assemblages off Mallorca Island (Balearic archipelago, Western Mediterranean). *Journal of Plankton Research*, **28(5)**, 473-487.

Alemany, F., García, A., Gonzalez-Pola, C., Jansà, J., López Jurado, J.L., Rodríguez, J.M., Velez Belchi, P. (2002) Oceanographic characterisation of bluefin tuna (*Thunnus thynnus*) spawning grounds and associated tuna species off the Balearic Archipelago (Western Mediterranean). 26th Fish Larval Conference, Bergen, July 2002. Poster.

Alemany, F., García, A., Bernal, M., Velez-Belchí, P., López Jurado, J.L., Cortés, D., González Pola, C., Rodríguez, J.M. and Ramírez, T. (2005) Abundance and distribution of Thunnus larvae in the Balearic sea (NW Mediterranean) in relation to mesoscale hydrogarphic features. 29th Larval Fish Conference, Barcelona, July 2005. Oral presentation.

Alemany, F.A., García, A., Quintanilla, L.F., Vélez-Belchi, P., Cortés, D., Rodríguez, J.M., Fernández, M.L., González-Pola, C. and López-Jurado, J.L. (2007) Abundance and distribution of tuna larvae off the Balearic Islands in relation to oceanographic features and environmental variables. 1st GLOBEC/CLIOTOP Symposium, La Paz, December 2007.

Alemany, F. and Vélez-Belchi, P.J. (2005) Hydrological influence on bluefin tuna and related species spawning and larval distribution off the Balearic archipelago. 1st CLIOTOP Workshop of Working Group 1 on Early Life History of Top Predators, Málaga, October 2005.

Amico, F. C. de. (1816) Osservazioni pratiche intorno la pesca, il corso, il cammino dei tonni. Messina. Practical observations about the Italian fishery, the migrations, and the route of the tuna.

Bakun, A. and Broad, K. (2003) Environmental 'loopholes' and fish population dynamics: comparative pattern recognition with focus on El Nino effects in the Pacific. *Fisheries Oceanography*, **12(4-5)**, 458-473.

Bakun, A. (2006) Fronts and eddies as key structures in the habitat of marine fish larvae: opportunity, adaptive response and competitive advantage. *Scientia Marina*, **70(suppl. 2)**, 105-122.

Bard, F.X., Bach, P. and Habitat, J. E. (1996) Ecophysiologie des thons. Quoi de neuf depuis 15 ans? *ICCAT Symposium on Tuna,* **Vol (1)***,* 319-340.

Barrois, J.M. (1977) Donnes preliminaries sur quelques larves de thonides recuillies en mer Egge. *Rapport Comission International Mer Mediterraneé*, **24**, 5.

Block, B. A., Teo, S.L.H., Walli, A., Boustany, A., Stikesbury, M.J.W., Farwell, C.J., Weng, K.C., Dewar, H. and Williams, T.D. (2005) Electronic tagging and population structure of Atlantic bluefin tuna. *Nature*, **434**,1121-1127.

Block, B.A. and Stevens, E.D. (Eds.) (2001) Tuna: Physiology, Ecology and Evolution. Academic Press, London, UK, 468 pp.

Block, B.A., Dewar, H., Blackwell, S.B. (2001) Migratory movements, depth preferences, and thermal biology of Atlantic bluefin tuna. *Science*, **293**,1310-1314.

Boehlert, G. W. and Mundy, B. C. (1994) Vertical and onshore-offshore distributional patterns of tuna larvae in relation to physical habitat features. *Marine Ecology Progress Series*, **107**, 1-13.

Boustany, A.M., Reeb, C.A., Teo, S.L., De Metrio, G., Block, B.A. (2006) Genetic data and electronic tagging indicate that the Gulf of Mexico and Mediterranean Sea are reproductively isolated stocks of bluefin tuna (*Thunnus thynnus*). *SCRS,* **089**.

Bragança, C. (1899) Investigaçoes scientificas feitas a bordo do yatch Amelia. Pescas Maritimas. I. A pesca do atun no Algarve em 1898, Lisboa, 104 pp.

Buck, E.H. (1995) Atlantic bluefin tuna: International management of a shared resource. CRS Issue Brief for Congress, 95-367 ENR.

Carlsson, J., McDowell, J.R., Carsson, L. and Graves. J.E. (2007) Genetic identity of YOY bluefin tuna from eastern and western Atlantic spawning areas. *Heredity*, **98**, 23-28.

Carlsson, J., McDowell, J.R., Díaz-Jaimes, P., Carlsson, J.E.L., Boles, S.L., Goldo, J.R. and Graves, J.E. (2004) Microsatellite and mitochondrial DNA analyses of Atlantic bluefin tuna (*Thunnus thynnus thynnus)* population structure in the Mediterranean Sea. *Molecular Ecology*, **13**, 3345-3356.

Cavallaro, G., Manfrin, G., Lo Duca, G. and Cavallaro, M. (1996) The presence of tuna larvae in the Strait of Messina. *Collective Volumes of Scientific Papers of ICCAT*, **46(2)**, 222-224.

Cetti, F. (1777) Storia naturale di Sardegna.3. Anphibi e pesci. Sassari, Stamperia di J. Piattoli 1-208.

Clay. D. (1991) Atlantic bluefin tuna (*Thunnus thynnus*): A review. Inter-American Tropical Tuna Commission, Special Report, **7**, 89-180.

Correiro, A., Karakulak, S., Santamaria, N., Deflorio, M., Spedicato, D., Addis, P., Desantis, S., Cirillo, F., Fenech-Farrugia, A., Vassallo-Agius, R., de la Serna, J.M., Oray, I., Cau, A. and De Metrio, G. (2005) Size and age at sexual maturity of female bluefin tuna (*Thunnus thynnus* L. N1758) from the Mediterranean Sea. *Journal of Applied Ichthyology*, **21**, 483-486.

De Metrio, G., Arnold, G.P., de la Serna, J.M., Block, B.A., Megalofonou, P., Lutcavage, M., Oray, I., Deflorio, M. and Gunn, J. (2005) Movements of bluefin tunna (*Thunnus thynnus* L.) tagged in the Mediterranean Sea with pop-up satellite tags. *Collective Volumes of Scientific Papers of ICCAT*, **58**, 1337-1340.

Desse, J. and Desse-Berset, N. (1994) Stratégies de pêche au 8èmemillénaire: les poisons de Cap Andreas Kastros (Chypre). In: Fouilles récentes à Khirokitia (eds A. Le Brun). Editions Recherche sur Civilisations, Paris, pp. 335-360.

Dicenta, A. (1977) Zonas de puesta del atún (*Thunnus thynnus*) y otros túnidos del Mediterráneo occidental y primer intento de evaluación del "stock" de reproductores de atún. *Boletin del Instituto Español de Oceanografía*, **234**,109-135.

Dicenta, A. and Piccinetti, C. (1978) Desove de atún (*Thunnus thynnus* L.) en el Mediteráneo Occidental y evaluación directa del stock de reproductores basado en la abundancia de sus larvas. *Collective Volumes of Scientific Papers of ICCAT*, **7(2)**, 389-395.

Dicenta, A., Piccineti, C., Sara, R. (1979) Recherches sur la mortalité des œufs et larves de thonidés. *Rapports Comission International Mer Mediterraneé*, **26**, 191-192.

Dicenta, A., Franco, C. and Lago de Lanzós, A. (1983) Distribution and abundance of the families Thunnidae and Mullidae in the Balearic waters. Rapports Comission international Mer Mediterraneé, **28**, 149-153.

Dicenta, A., Piccinetti, C. and Piccinetti-Manfrin, G. (1975) Observaciones sobre la reproducción de los túnidos en las islas Baleares. *Boletín Instituto Español de Oceanografía*, **204**, 27-37.

Dieuzeide, R. (1951) Campagne en Méditerranée du navire océanografique de l' Office Scientifique et Technique des Pêches Maritimes "President Theodore Tissier". *Bulletin des Travaux Publíes par la Station d´Aquiculture et et de Pêche Castiglione, Alger,* **3**, 85-138.

Dittman A. and Quinn T. (1996) Homing in Pacific salmon: mechanisms and ecological basis. *Journal of Experimental Biology*, **199**, 83-91.

Dodson, J.J. (1988) The nature and role of learning in the orientation and migratory behavior of fishes. *Environmental Biology of Fishes,* **23**, 161-182.

Doty, M. S. and Oguri, M. (1956) The island mass effect. *Journal du Conseil*, **22**, 33-37.

Doumenge, F. (1998) L'historie des pêches thonnières. *Collective Volumes of Scientific Papers of ICCAT*, **50**, 783-802.

Duclerc, J., Sacchi, J., Piccinetti, C., Piccinetti-Manfrin, G., Dicenta, A. and Barrois, J-M. (1973) Nouvelles données sur la reproduction du thon rouge (*Thunnus thynnus* L.) et d´autres espèces de thonidés en Mediterranée. *Revue Travaux Pêches maritimes*. **37(2)**, 163-176.

Ehrembaum, E. (1924) Scombriformes. *Reports Danish Oceanographic Expeditions*, *1908-1910*, **2(A11)**, 1-42.

Fromentin, F.M. and Fonteneau, A. (2001) Fishing effects and life history traits: a case-study comparing tropical versus temperature tunas. *Fisheries Research*, **53**, 133-150.

Fromentin, J.M. and Powers, J.E. (2005) Atlantic bluefin tuna: population dynamics, ecology, fisheries and management. *Fish and Fisheries*, **6**, 282-306.

Garcia, A., Alemany, F., Velez-Belchi, P., Lopez Jurado, J.L., de la Serna, J.M., Gonzalez Pola, C., Rodriguez, J.M., Jansá, J. (2003a) Bluefin tuna and associated species spawning grounds in the oceanographic scenario of the Balearic archipielago during June 2001. *Collective Volumes of Scientific Papers of ICCAT*, **55(1)**, 138-148.

García A., Alemany, F., Vélez-Belchy, P., Rodriguez, J.M., López Jurado, J.L., González Pola, C. and de la Serna, J.M. (2003b) Bluefin and frigate tuna spawning off the Balearic Archipelago in the environmental conditions observed during the 2002 spawning season. *Collective Volumes of Scientific Papers of ICCAT*, **55 (3)**, 1261-1270.

García, A., Alemany, F., Velez-Belchí, P., López Jurado, J.L., Cortés, D., de la Serna, J.M., González Pola, C., Rodríguez, J.M., Jansá, J., Ramírez, T. (2005) Characterization of the bluefin tuna spawning habitat off the Balearic archipelago in relation to key hydrographic features and associated environmental conditions. *Collective Volumes of Scientific Papers of ICCAT*, **58(2)**, 535-549.

García, A., Quintanilla, L.F., Alemany, F., Bernal, M., Cortés, D., Rodríguez, J.M., and Vélez-Belchi, P. (2007) Assesing spatio-temporal changes of bluefin (*Thunnus thynnus*) larval distribution applying GAMs with geographic, hydrographic and biiological variables. 1st GLOBEC/CLIOTOP Symposium, La Paz, December 2007.

Graham, J.B. and Dickson, K.A. (2001) Anatomical and physiological specializations for endothermy. In: Tuna. Physiology, Ecology, and Evolution (eds B.A. Block and E.D. Stevens). Academy Press, San Diego, CA, pp. 121-165.

Gunn, J. and Block, B.A. (2001) Advantages in acoustic, archival and satellite telemetry. In: Tuna: Physiliogy, Ecology and Evolution, pp. 167-224 (B.A. Block and E.D. Stevens Eds.). New York: Academis Press.

Hanski, I. (1999) Metapolution Ecology. Oxford University Press, Oxford.

ICCAT (1999) 1998 SCRS detailed report on bluefin tuna. *Collective Volumes of Scientific Papers of ICCAT*, **49**, 1-191.

ICCAT (2002) ICCAT workshop on bluefin tuna mixing. *Collective Volumes of Scientific Papers of ICCAT*, **54**, 261-352.

ICCAT (2003) Report of the 2002 Atlantic Bluefin Tuna Stock Assessment Session. *Collective Volumen of Scientific Papers ICCAT,* **55**, 710-937.

ICCAT (2006) Report of the ICCAT Planning Meeting for Bluefin Tuna Research (Madrid, Spain, June 27-30, 2005). *SCRS*, **011**, 717-749

ICCAT (2007a) Report of the 2006 Atlantic bluefin Tuna Stock Assessment. *Collective Volumes of Scientific Papers of ICCAT*, **60(3)**, 652-880

ICCAT (2007b) Report of the 2006 Atlantic Bluefin Tuna Stock Assessment Session (Madrid, June 12 to 18, 2006). *SCRS*, **013**, 652-880.

ICCAT (1997) 1996 SCRS detailed report on bluefin tuna. *Collective Volumes of Scientific Papers of ICCAT*, **46**, 1-301.

Karakulak, S., Oray, I., and Correiro, A. (2004) First information on the reproductive biology of the bluefin tuna (*Thunnus thynnus*) in the eastern Mediterranean. *Collective Volumes of Scientific Papers ICCAT,* **56**, 1158-1162.

Kritzer, J.P. and Sale, P.F. (2004) Metapopulation ecology in the sea: from Levins´model to marine ecology and fisheries science. *Fish and Fisheries*, **5**, 131-140.

Leis, J. M., Trnsky, T., Harmelin-Vivien, M., Renon, J. P., Dufour, V., El Moudni, M. K. and Galzin, R. (1991) High concentration of tuna larvae (Pisces: Scombridae) in near-reef waters of French Polynesia (Society and Tuamotu Islands). *Bulletin of Marine Science*, **48**, 150-58.

Lioka, C., Kani, K. and Nhhla, H. (2000) Present status and prospects of technical development of tuna sea-farming. *Cahiers Options Mediterranéennes,* **47**, 275-285.

López-Jurado, J.L., Garcia Lafuente, J. and Cano, N. (1995) Hydrographic conditions of the Ibiza Channel during November 1990, March 1991, July 1992. *Oceanologica Acta*, **18(2)**, 235-243.

Lutcavage, M.E., Brill, R.W., Skomal, G.B., Chase, B.C. and Howey, P.W. (1999) Results of pop-up satellite tagging of spawning size class fish in the gulf of Maine: Do North Atlantic bluefin tuna spawn in the mid-Atlantic? *Canadian Journal of Fisheries and Aquatic Sciences*, **56**, 173-177.

Magnuson, J.J., Block, B.A., Deriso, R.B., Gold, J.R., Grant, W.S., Quinn, T.J., Saila, S.B., Shapiro, L. and Stevens, E.D. (1994) An assessment of Atlantic bluefin tuna. Washinton D.C., National Academy Press.

Mather, F. J. III (1962) Distribution and migrations of North Atlantic bluefin tuna. Proccedings of the Seveth International Game Fish Conference, Galveston, Texas, November 15, 1962.

Mather, F.J., Mason Jr, J.M. and Jones, A. (1995) Historical document: life history and fisheries of Atlantic bluefin tuna. NOAA Technical Memorandum NMFS-SEFSC-370, Miami, Florida, 165 pp.

McGowan, M.F. and Richards, W.J. (1989) Bluefin tuna, *Thunnus thynnus*, larvae in the Gulf Stream off the southeastern United States: Satellite and shipboard observations of their environment. *Fisheries Bulletin*, **87**, 615-631.

Medina, A., Abascal, F.J., Aragón, L., Mourente, G., Aranda, G., Galaz, T., Belmonte, A., de la Serna, J. M. and García, S. (2007) Influence of sampling gear in assessment of reproductive parameters for bluefin tuna in the western Mediterranean. *Marine Ecology Progress Series*, **337**, 221-230.

Medina, A., Abascal, F.J., Megina, C. and Garcia, A. (2002) Stereological assessment of the reproductive status of female Atlantic northern bluefin tuna during migration to Mediterranean spawning grounds through the Strait of Gibraltar. *Journal of Fish Biology*, **60**, 203-217.

Miller, J.M. (1979) Nearshore abundance of tuna (Pisces : Scombridae) larvae in the Hawaiian Islands. *Bulletin of Marine Science*, **29**, 19-26.

Miyake, P.M., De la Serna, J.M., Di Natale, A.,Farrugia, A., Katavic, I., Miyabe, N., Ticina, V. (2003) General review of Atlantic bluefin tuna farming in the Mediterranean area. *Collective Volumes of Scientific Papers of ICCAT*, **55(1)**, 114-124.

Nishida, T.S. Tsuji and Segawa, K. (1998) Spatial data analyses of Atlantic bluefin tuna larval surveys in the 1994 ICCAT BYP. *Collective Volumes of Scientific Papers of ICCAT*, **48**,107-110.

Oray, I. K. and Karakulak, F.F. (2005) Further evidence of spawning of bluefin tuna (*Thunnus thynnus* L., 1758) and the tuna species (*Auxis rochei*., 1810, *Euthynnus alletteratus* Raf., 1810) in the eastern Mediterranean Sea: preliminary results of TUNALEV larval survey in 2004. *Journal of Applied Ichthyology,* **21**, 226-240.

Pavesi, P. (1887) Le migrazione del tonno. *Rendiconti dell´Istituto Lombardo di Scienze e Lettere, Milano, Ser*, **2(20)**, 311-324.

Piccineti, C., Piccineti-Manfrin, G. and Soro, S. (1997) Résultats d'une campagne de recherche sur les larves de Thonidés en Méditerranée. *Collective Volumes of Scientific Papers of ICCAT*, **46(2)**, 207-214.

Piccinetti, C. and Piccinetti Manfrin, G. (1970) Ossrvazioni sulla biologia dei primi staid giovanili del tonno (*Thunnus thynnus* L.). *Bollettino di Pesca, Piscicoltura e Idrobiologia, Roma,* **25(2)**, 223-247.

Piccinetti, C. and Piccinetti, M. (1978) Tavola Rotonda: Problemi del plankton del mar Adriatico. Larvae di tunnidi in Adriatico. Trieste, 14-15 Aprile, 1978.

Piccinetti, C., Piccineti-Manfrin, G. and Soro, S. (1996a) Larve di tunnidi in Mediterraneo. *Biologia Marina Mediterranea*, **3(1)**, 303-309.

Piccinetti, C., Piccineti-Manfrin, G., Soro, S. (1996b) Résultats d'une campagne de recherche sur les larves de thonidés en Mediterranée. *SCRS,* **57**.

Piccinetti, C., Piccinetti-Manfrin, G. and Dicenta, A. (1977a) Premieres peches quantitatives de larves de thonides en Adriatique. *Rapports Comission International Mer Mediterraneé*, **24(5)**.

Piccinetti, C., Piccinetti-Manfrin, G. and Tellai, S. (1977b) Donnes sur les larves des thonides d´Algerie. *Rapports Comission international Mer Mediterraneé*, **24(5)**.

Piccinetti, C., Piccinetti-Manfrin, G., Barrois, J.M., Lalami, Y. and Tellai, S. (1976) Résultats d´une campagne d´étude sur les oeufs et larvaes de thonidés d´Algérie. *Rapports Comission international Mer Mediterraneé*, **23(8)**, 55-56.

Pinot, J. M., Tintoré, J., López-Jurado, J. L., Fernández de Puelles, M. L. and Jansá, J. (1995) Three-dimensional circulation of a mesoscale eddy/front system and its biological implications. *Oceanologica Acta*, **18**, 389-400.

Potoschi, A., Cavallaro, G., Sturiale, P. and Lo Duca, G. (1994) Uova e larve di pescespada (*Xiphias gladius* L. 1758) tonno (*Thunnus alalunga* Bonn. 1788) pescate nello Ionio della Sicilia orientale. *Biologia Marina Mediterranea*, **1(1)**, 119-124.

Ravier, C. and Fromentin J.M. (2001) Long term fluctuations in the eastern Atlantic and Mediterranean Atlantic bluefin tuna population. *ICES Journal of Marine Science*, **58**, 1299-1317.

Ravier, C. and Fromentin, J.M. (2004) Are the long-term fluctuations in Atlantic bluefin tuna (*Thunnus thynnus*) population related to environmental changes? *Fisheries Oceanography*, **13(3)**, 145-160.

Richards, W.J. (1976) Spawning of bluefin tuna (*Thunnus thynnus*) in the Atlantic Ocean and adjacent seas. *Collective Volumes of Scientific Papers of ICCAT*, **5**, 267-336.

Rodriguez-Roda J. and Dicenta, A. (1981) Areas de puesta del atún, melva y bonito en las costas de España y Marruecos. *Collective Volumes of Scientific Papers of ICCAT*, **15(2)**, 278-283.

Rodríguez-Roda, J. (1964) Biología del atún, *Thunnus thynnus* (L.), de la costa sudatlántica de España. *Investigación Pesquera, Consejo Superior de Investigaciones Científicas, Barcelona*, **25**, 33-146.

Rodríguez-Roda, J. (1967) Fecundidad del atún, *Thunnus thynnus* (L.), de la costa sudatlántica de España. *Investigación Pesquera, Consejo Superior de Investigaciones Científicas, Barcelona*, **31(1)**, 33-52.

Rodriguez-Roda, J. (1975) Expedición científica para la identificación de zonas de puesta del atún, *Thunnus thynnus* (L.) (Campaña "Maroc-Iberia, 1" del Cornide de Saavedra). *Resultados Expediciones Científicas B/O Cornide*, **4**, 113-130.

Rooker, J.R. and Secor, D.H. (2004) Stock structure and mixing of Atlantic bluefin tuna: evidence for stable C and O isotopes in otholits. *Collective Volumes of Scientific Papers of ICCAT,* **56**, 1115-1120.

Rooker, J.R., Alvarado, J.R., Block, B.A., Dewar, H., De Metrio, G., Corriero, A., Kraus, R.T., Prince, E.D., Rodriguez-Marín, E. and Secor, D.H. (2007) Life History and Stock Structure of Atlantic bluefin Tuna (*Thunnus thynnus*). *Reviews in Fisheries Science*, **15**, 265-310.

Rooker, J.R., Secor, D.H., de Metrio, G. and Rodrigez-Marin, E. (2006) Evaluation of population structure and mixing rates of Atlantic bluefin tuna from chemical signatures in otholits. *Collective Volumes of Scientific Papers of ICCAT,* **59**, 813-818.

Rooker, J.R., Secor, D.H., Zdanowicz, V.S., De Metrio, G. and Relini, L.O. (2003) Identification of northern bluefin tuna stocks form putative nurseries in the Mediterranean Sea and Western Atlantic Ocena using otolith chemistry. *Fisheries Oceanography*, **12**, 75-84.

Roule, L. (1914) La biologie et la pêche du thon dans la Mediterranée occidentale. *Revue genérale des Sciences pures apliqueés, Paris*, **25**, 808-814.

Roule, L. (1917) Etude sur les aires de ponte et les déplacements périodiques du thon commun (*Orcynus thynnus* L.) dans la méditerranée occidentale: conséquences quand à l´extension rationnelle de la pêche de ce poisson. *Annals Institut océanographique, Paris*, **7(7)**, 1-26.

Sabatés, A. and Recasens, L. (2001) Seasonal distribution and spawning of small tunas (*Auxis rochei* and *Sarda sarda*) in the northwestern Mediterranean. *Scientia Marina*, **65(2)**, 95-100.

Sanzo, L. (1929a) Uova a larve di tonno (“*Orcinus thynnus* Ltkn.”). *Rendiconti, Atti della Reale Academia Nazionale dei Lincei, Roma, Serie 6*, **9(1)**, 104-106.

Sanzo, L. (1929b) Uova e primi stadi larvali di tonno (“*Orcinus thynnus* Ltkn.”). *Memori, R. Comiato Talassografico Italiano, Venecia*, **189**, 1-16.

Sanzo, L. (1933) Uova e primi stadi larvali di Alalonga (*Orcynus germo* Ltk.). *R. Com. Talas. Ital.,Mem. CXCVIII,* 10 pp.

Sarà, R. (1964) Data, observations and comments on the occurrence, behaviour, characteristics and migrations of tunas in the Mediterranean. *Proceedings and Technical Papers, General Fisheries Council for the Mediterranean , Rome,* **7(37)**, 371-388.

Sarà, R. (1973) Sulla biología dei tonni (*Thunnus thynnus* L.) modelli di migrazione e di comportamento. *Bolletino di Pesca, Piscicultura e Hidrobiología, Roma*, **28**, 217-243.

Scordia, C. (1938) Per la biología del tonno (*Tunnus thynnus* L.) XV. Le migrazioni dei tonni entro il Mediterraneo. *Memorie di Biología Marina e di Oceanografia, Messina*, **5(8)**, 1-50.

Secor, D.H. (1999) Specifying divergent migrations in the concept f stock: the contingent hipótesis. *Fisheries Research*, **43**, 13-34.

Sella M. (1924) Caratteri differenziali dei Giovanni stadi di *Orcynus thynnus* Lunk., *O. alalonga* Risso, *Auxis bisus* Bp. *Rendiconti, Tai Della Reale Academia Nazionale dei Lincei, Roma, Serie 5*, **33(1)**, 300-305.

Sella, M. (1927) Les migrations des thons étudiées par le moyen des hamecons. *Bulletin des Travaux Publiés par la Station d´Aquiculture et de Pêche de Castiglione, Alger*, **2**, 101-136.

Sella M. (1929a) Migrazione e habitat del tonno (*Tunnus thynnus* L.) studiati col metodo degli am, con osservazioni su láccresscimento, sul regime delle tonnare ecc. *Memorie, R. Comitato talassografico Italiano*, **156**, 1-24 (translations into English: Sella 1930, Van Campen 1952).

Sella, M. (1929b) Bilología y pesca del tonno (*Tunnus tynnus* L.). *Atti Convengo di Biología Marina applicata alla pesca, Messina, giugno 1928*, 1-32.

Sella, M. (1932a) Sulle migrazione del tonno (Thunnus tynnus L.) Convegni Biologici, 1° Convengno: Biología Marina, Napoli, December 1931, 103-136.

Sella, M. (1932b) Il tonno. Conferenza Note dell´Istituto Italo-Germanico di Biología Marina di Reovigno d´Istria 3:1-24.

Sparta, A. (1953) Uova e larve di Tetrapturus belone Raf. *Aguglia Imperiale. Boll. Pesca e Idrobiol*, **VIII(1)**, 58-63.

Stokesbury, M.J.W., Teo, S.L.H., Seitz, A., O´Dor, R.K. and Block, B.A. (2004) Movement of Atlantic bluefin tuna (*Thunnus thynnus*) as determinated by satellite tagging experiments initiated off New England. *Canadian Journal of Fisheries and Aquatic Sciences*, **61**, 1976-1987.

Teo, S.L.H., Boustany, A., Dewar, H., Stokesbury, M., Weng, K., Beemer, S., Seitz, A., Farwell, C., Prince, E.D. and Block, B.A. (2007) Annual migrations, dining behaviour and thermal biology of Atlantic bluefin tuna, *Thunnus thynnus*, to breeding grounds in the Gulf of Mexico. *Marine Biology*, **151**, 1-18.

Thomazi, A. (1947) Historie de la pêche des âges de la pierre à nos jours. Ed. Payot, Paris, 645 pp.

Tsuji, Nishikawa, S.Y., Segawa, K. and Hiroe, Y. (1997) Distribution and abundance of Thunnus larvae and their relation to the oceanographic condition in the gulf of Mexico and the Mediterranean Sea during may through august of 1994 (draft). *Collective Volumes of Scientific Papers of ICCAT*, **46(2)**, 161-176.

Vélez-Belchí P. and Tintoré J. (2001) Vertical velocities at an ocean front. *Scientia Marina*, **65**, 301-304.

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