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Spiny lobster (*Palinurus elephas* Fabricius 1787) fishery in the western Mediterranean: A comparison of Spanish and Tunisian fisheries

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Abstract

The present work compares trammel net fisheries for the lobster *Palinurus elephas* by Spanish and Tunisian fleets, both situated in the Western Mediterranean. Fleet characteristics, lobster structure, yields, landings and by-catch and discarding practices are examined. The lobster catch was divided into three categories: commercial (individuals over the legal size), undersized (specimens under the legal size that were returned to the water) and ''rotten' (individuals killed by predation or stress when entangled in the net). Fleets from both countries are composed of artisanal boats with technical characteristics which reflect the distance from their homeports to the fishing grounds. The fleets fish over the same type of habitats, since the majority of the hauls were performed at 75–80 m depth over 'maërl' substrates. Tunisian exploited populations have a greater proportion of large lobsters than populations exploited by the Spanish fleets. However, the higher proportion of fishing set containing lobster catch, together with the higher catch rates in the Spanish fishery, are indicative of greater lobster density in the Spanish grounds. The seasonal change of lobster yields showed opposite trends in the two fisheries studied, decreasing in Spain but increasing in Tunisia as the season progressed. Although the proportion of commercial lobster to total lobster was not significantly different between areas, the proportion of 'rotten' and undersized categories differed: individuals under the legal landing size were more frequent in Spanish than in Tunisian catches, while the 'rotten' fraction were more common in Tunisia than in Spain. Tunisian total annual landings showed an abrupt increase from 1990 to 1993, but decreased afterwards. Catches from the Spanish Columbretes Islands peaked in 1991–1992, after which they showed a downward trend that fluctuated considerably from year to year. A total of 48 and 28 different by-catch species were caught in the Spanish and Tunisian fisheries respectively. The discarded fraction of the total by-catch and the discard practices were similar in both fisheries, where the rejected fraction included: 1) damaged and undersized commercial species; 2) species without commercial value; and 3) commercial species which are targeted by other fisheries but are not of interest owing to the low quantities of individuals captured.

Keywords: *Palinurus elephas*, trammel nets, artisanal fishery, Mediterranean Sea.

Introduction

The European spiny lobster *Palinurus elephas* is a large, benthic decapod crustacean from temperate waters occurring in the Atlantic from the Hebrides to the northwest African coast, and in the Mediterranean Sea from the western and central basins to the coasts of Greece, the Aegean Sea and Libya (Gamulin, 1955; Moraitopoulou-Kassimati, 1973; Ceccaldi & Latrouite, 1994). In the Mediterranean *P. elephas* is now most abundant around islands that have suitable rocky substrates because their relative isolation has provided refuge to exploited populations. In recent decades the most productive Mediterranean lobster fisheries occurred around islands in the Eastern Adriatic (Soldo *et al*., 2001), Corsica (Campillo, 1982; Marin, 1987), Sardinia (Secci *et al*., 1995, 1999), Sicily (Gristina, 2002), the Balearics (Iglesias *et al.,* 1994), and off northern Tunisia (Zarrouk, 2000).

In the western Mediterranean *P. elephas* commands high prices and its fisheries have great socio-economic importance, supporting a large number of small-scale artisanal vessels. In the past lobster was caught using baited traps, but now this gear has practically disappeared to be replaced almost exclusively by trammel nets (Goñi *et al*., 2003a). With the replacement of traps by trammel nets, fishing effort on *P. elephas* has increased fuelled by the growing tourist market around the Mediterranean coast and its high unit price (40–50 euros·kg^{-1} first sale). The low resilience of the species (it reaches sexual maturity at 4–5 years and lives up to 25 years; Marin, 1985; Goñi *et al*., in preparation), along with the intense exploitation to which it has been submitted for decades, have led to overfishing of most Mediterranean populations (Petrosino *et al.,* 1985; Marin, 1985; Latrouite & Noel, 1997; Soldo *et al*., 2001).

A variety of regulations are used to manage *P. elephas* fisheries in the Western Mediterranean: 1) fishing is allowed from March to August and forbidden the rest of the year, when females bear eggs; 2) there is a minimum landing size of 20 cm of total length (~80 mm of carapace length), which coincides with the size at first maturity; 3) it is not permitted to take berried females; and 4) both the mesh size and the total length of trammel nets per boat are regulated.

Despite the economic importance of *P. elephas* in the Mediterranean, the species has not been well studied. Most works cover its biology (Gamulin, 1955; Campillo & Amadei, 1978; Campillo, 1982; Marin, 1985, 1987; Goñi *et al.,* 2001a, 2001b, 2003b), while the fishery aspects have scarcely been analysed (Secci *et al.,* 1995, 1999; Soldo *et al*., 2001; Goñi *et al.,* 2003a) or are outdated (Santucci, 1926, 1928; Campillo, 1982; Marin, 1987). This study constitutes a first attempt to examine current *P. elephas* fisheries in the western Mediterranean by presenting updated information from the most productive Spanish (around the Balearic and Columbretes Islands) and Tunisian (northern coast especially, around La Galite and the Esquerquis Islands) fisheries. The purpose of the study is to determine and compare yields, exploitation patterns, and by-catch and discarding practices in the two fisheries. Because lobster yields have dwindled, by-catch species are increasingly relied upon to maintain the viability of these fisheries. Historical lobster landings are also reconstructed to the extent possible in an attempt to assess the current status of the populations.

Material and methods

Study areas and data collection

Two study areas are considered in this study: 1) the fishing grounds of islands in the Spanish Mediterranean (Balearics and Columbretes), and 2) the fishing grounds of islands in northern Tunisia (La Galite and the Esquerquis) (Figure 1). The Columbretes and La Galite Islands are marine reserves where lobster fishing is forbidden but fisheries occur on the boundaries and nearby areas.

Data for this study come from two different sources. The first data set originates from a sampling programme undertaken on board commercial lobster boats in the Spanish and Tunisian fisheries. A total of 130 hauls (87 from Spain, 43 from Tunisia) were sampled during May and August-October 2001. The following data were collected from each haul: date, depth, habitat type (information derived from the by-catch of structure forming species), position, net length and mesh size. Sex and size (carapace length –CL– and total length –TL–, in mm) of all lobsters caught were noted. Species composition and individual size (CL in crustaceans, TL in fishes and mantle length –ML– in cephalopods) of the non-lobster catch were also registered. The lobster catch was divided into three categories: commercial (individuals over the legal size), undersized (specimens under the legal size that were returned to the water) and ''rotten' (individuals killed by predation or stress when entangled in the net). Due to the impossibility of measuring precise individual weights on board commercial boats, length-weight (total weight, TW) relationships were calculated from research surveys conducted in the Columbretes Islands (for the Spanish data) and from Tunisian lobster ponds (for the Tunisian data).

Differences in lobster catch composition (N and W per haul) by categories (commercial, undersized, 'rotten') between the two areas where tested by t-tests. The percentage of each category in relation to the total lobster catch and the percentage of total lobster catch vs. total catch (lobster and by-catch) were compared using t-tests after arcsine transformation (Zar, 1999).

The second data set comes from logbooks distributed among lobster fishermen in the two fisheries. Logbook data cover the 2002 fishing season and fishermen noted the haul characteristics (as above) and the lobster catch (number and weight) for each fishing set. A total of 1149 hauls (468 from Spain, 681 from Tunisia) were registered.

Fleet characteristics and fishing grounds

Fleet size and characteristics (number of boats, gross tonnage –GT–, horse power –HP–, boat age and crew size) were obtained from official statistics. Fishing grounds (location, distance to the homeport, bathymetry, bottom type) and gear characteristics (length of nets, mesh size) were gathered during the onboard sampling trips and through interviews with fishermen.

Size and sex structure of lobster catches, yields and landings

The size structure of lobster catches and the morphometric relationships (CL–TW and CL–TL) were separated by sex and area and compared using Kolmogorov-Smirnov and ANCOVA tests respectively.

Yields were calculated as number and weight of lobsters per standard trammel net set (500 m length approximately) per fishing day. Differences in mean lobster yields (total and by category) in the two fisheries were evaluated by t-test. Spatial (study zones) and temporal (monthly) differences in yield (number and weight) were analysed by orthogonal analysis of variance (ANOVA), with zone and month as fixed factors. To attain a balanced design, the data from months that were coincident in the two zones studied (May, June, July and August) were selected. In order to have equal sampling effort for each month-zone combination, 90 samples were randomly selected from each combination. Prior to the analysis, the assumption of homogeneity of variances was checked by Cochran's test. This test indicated that variances were heterogeneous even after the ln(x+0.1) transformation and therefore one of the assumptions of the analysis was violated. However, ANOVA is robust to departures from this assumption, especially in the case of a balanced design with a large number of samples (Underwood, 1997). After ANOVA, mean yields were compared with the Student-Newman-Keuls and t- tests.

Finally, monthly lobster landings from 1990 to 2002 were collected from official Spanish and Tunisian fishery statistics.

By-catch and discards

During the onboard sampling on commercial lobster boats, the non-lobster catch (by-catch) was assigned to one of two categories: commercial by-catch (non-target commercial species which were landed) and discard (non-commercial and unprofitable commercial species that were returned to the sea). By-catch and discard rates were calculated as the mean number of each species caught per standard set and day. The discarded fractions (% discard/total by-catch) in Spain and Tunisia were compared using a t-test after arcsine transformation (Zar, 1999).

Results

1. Fleets, gear characteristics and fishing grounds

Three different fleet types operate in the studied fisheries depending on the distance from the homeports to the fishing grounds (Table I):

1-The Balearic Islands fleet: composed of over 250 artisanal boats operating from 16 ports. These boats are small, have low power and gross tonnage, and fish in grounds that lie 2–3 nm from their homeports. Such short distances allow boats to return to port daily to sell their catch. These boats are crewed by 1-3 fishermen. Nets are usually soaked for 2 days.

2-The Spanish mainland fleet fishing off the Columbretes Islands: This is a small fleet of about 5 boats based in ports on the east coast of the Iberian Peninsula. They fish grounds off the Columbretes Islands and adjacent areas that lie 30–40 nm from their homeports. Owing to such distances, the boats have technical characteristics intermediate between those of the Balearic and the Tunisian fleets and fishing trips last 2 or 3 days. The crew of these boats usually consist of 3–4 men. Although nets are usually soaked for 2 days, the mean soak time is raised to 4.5 days because at times nets remain at sea for long periods due to bad weather conditions.

3-The Tunisian fleet: composed of 56 vessels based in 2 ports. The vessels are larger and have greater power and tonnage than the Spanish ones, this being related to the long distances from the homeports to the fishing grounds (La Galite: 40 nm, the Esquerquis: 60 nm). As a consequence, the boats remain at sea for an average of 5–6 days per trip. The number of fishermen per boat is also greater than in the Spanish fleets (4–7). Nets are soaked for 2 days.

In the Spanish fisheries the nets are not taken ashore at the end of each fishing trip, remaining at sea through the season. Conversely, Tunisian fishing boats always take nets ashore at the end of each fishing trip thus avoiding nets remaining at sea in bad weather.

Trammel nets were used to catch lobsters in all the fishing operations studied. Trammel nets are made of three rectangular nets, two outer, large-mesh panels and one inner, smaller mesh panel. The mean size of the mesh in the inner panel was 70 mm in Spain and 75 mm in Tunisia (Table I). Net pieces of about 50 m were combined to make gangs averaging 650 and 725 m in length.

Both fisheries take place in the bathymetric range of 20 to 170 m and at a mean depth of 75–80 m. The onboard analysis of the benthic by-catch entangled in the nets indicated that lobster were caught over similar grounds in both study areas, which consisted predominantly of 'maërl' habitats (free living coralline algae and associated zoobenthos) often associated with the brown algae *Laminaria rodriguezii*.

2. The target species: the red spiny lobster

A total of 749 (408.4 kg) and 172 (161.3 kg) lobsters were caught and examined in the 87 and 43 fishing sets sampled onboard Spanish and Tunisian lobster vessels, respectively (Table II). In both areas the species represented 41–48% of the total catch in both number and weight. However, lobster was more frequent in Spanish (it appeared in 94.2% of the hauls) than in Tunisian (72.1%) catches. The mean number of commercial lobsters per haul was significantly higher in the Spanish (5.9) than in the Tunisian (2.8) fishery, but no significant difference was found when the weight of the catch was considered. The proportion of commercial lobsters to the total lobster catch was similar in the two fisheries, ranging from 70–80% (number and weight). The proportion of 'rotten' lobsters lost due to predation or other causes, was significantly higher in Tunisian (23–24%) than in Spanish (7–7.5%) fisheries (number and weight). Conversely, undersized lobsters were more frequent in Spanish (11–21%) than in Tunisian (3.5–6%) catches.

2.1-Size and sex structure of the lobster catch

The modal size of lobster caught in the Tunisian fishery (110 mm CL) was larger than in the Spanish fishery (90 mm CL) (Figure 2). Lobsters caught by Tunisian vessels ranged from 60–180 mm CL for females and 60–200 mm CL for males, while in the Spanish catches female and male sizes ranged from 30–150 and 30–170 mm CL respectively. The size structures of the female and male catch, as well as the size structure of the combined catch, were significantly different in the two study areas (KS test, $p<0.01$). Significant between-sex differences in size structure were only found in Tunisian catches (KS test, $p<0.01$).

The length-weight relationships of lobsters from the Spanish and Tunisian fishing grounds differed significantly for both males and females (Table III). These differences indicated that at a given size lobsters of either sex in the Tunisian fishing grounds were heavier than in the Spanish grounds but that the increase in weight relative to the size was faster in the latter. When length-weight relationships were compared between sexes for each area separately, significant differences appeared only for the intercepts both in Spain and Tunisia, confirming that males are heavier than females of equal size.

Significant differences were found in the CL–TL relationships between sexes and between areas (Table III). In both areas females had larger abdomens than males of the same size and the difference increased with size. The data also indicate that Spanish populations had greater slopes than Tunisian ones, suggesting that abdomen size grows at a faster rate relative to the carapace in the Spanish grounds.

2.2-Lobster yields

Monthly lobster yields (number and weight) in the 2001 fishing season differed in the two areas studied, as indicated by the significant area x month interaction (Tables IVa,b). Therefore, spatial and temporal patterns were examined separately. Lobster yields differed between months in the two areas in both number (Spain: df=3, F=7.35, p=0.0001; Tunisia: df=3, F=7.88, p<0.0001) and weight (Spain: df=3, F=9.03, p<0.0001; Tunisia: df=3, F=6.05, p=0.0005).

Spanish yields decreased in number and weight decreased throughout the fishing season (Figure 3). From March to May mean yields were 7.5–9 lobsters/500 m (~5 kg/500 m), while from June to August yields ranged from 4–6.5 individuals/500 m (2.5–4 kg/500 m). Yields were significantly lower (in number and weight) at the end of the season (August).

Yields showed an opposite trend in the Tunisian fishery. Yields in number remained the same in May and June (3 lobsters/500 m), then increased significantly through the rest of the season to 5 and 7 lobsters/500m in July and August respectively (Figure 3). Mean yields in weight were lowest in June (2kg/500 m) and highest in August (4 kg/500 m) and showed a prominent drop between May and June not observed in the yield in numbers.

Significant differences in yields between zones were found both in number and weight, showing that, except in August, the productivity of the Spanish fishery was higher than the Tunisian fishery (p< 0.05 in all cases).

2.3-Landings

Tunisia has a reliable series of lobster statistics because the species is exported for foreign consumption, which encourages good control of lobster landings. This is not the case for Spain, where production is for domestic use and a significant proportion of the catch is sold directly to restaurants or individuals, resulting in greatly underestimated landings. During the sampling period we observed that the fraction sold directly to consumers/restaurants was minimum for the Columbretes fleet but potentially very high for the Balearics. For this reason we decided to show only the official landing statistics from the Columbretes fishing grounds. However, taking into account the number of vessels and the catch per boat deduced from the sampling programme and interviews with fishermen, the lobster annual catch from the Balearic Islands may be estimated at approximately 100 tons.

The fishing effort of the Tunisian fleet is reflected by the change in the number of boats and the number of fishing days during the 1990–1999 period (Figure 4). The fleet grew rapidly between 1990 and 1995, when over 80 vessels fished lobster, and declined to 60 boats in 1998–1999. The number of days at sea also increased from 1990 to 1994 (with a peak in 1993 when extremely good weather conditions prevailed) and have remained relatively constant since then. Tunisian annual landings in the period 1990–2002 (Figure 5) showed a peak in 1993 where the maximum of the series was achieved (74 tons). Since then, lobster catches have decreased progressively to a minimum in 2002 when only about 33 tons were landed.

The number of vessels working in the Columbretes Islands fishing grounds ranged from 3–5 in the period 1990–2002. Total annual landings show a declining trend with marked fluctuations during the period considered. The maximum was reached in 1991–1992 when over 10 tons were landed (Figure 5).

The change of mean monthly landings averaged over the 12 year period showed different patterns in Tunisian and Spanish (Columbretes) fisheries (Figure 6). While in Tunisia the landings increased progressively through the season until the maximum of 11.5 tons in July and August, Spanish Columbretes landings grew from 1 to 1.3 tons from March to May and decreased afterwards.

3. By-catch and discards

A total of 48 and 28 different species were caught along with lobster in the Spanish and Tunisian fisheries respectively (Table V). The most common by-catch species in the Spanish lobster fishery were all fishes of high commercial value such as *S. scrofa, L. piscatorius, Z. faber* and *P. phycis*, in declining order. In the Tunisian fishery, the most frequent by-catch species were *S. canicula, S. scrofa, R. montagui, S. acanthias* and *T. marmorata,* which have (except the second one) low commercial value.

There was a much greater incidence of *S. scrofa* in the Spanish catches (F=72%) than in Tunisian (F=30%). Other coincident species of high commercial value that significantly differed in frequency between the two areas were *L. piscatorius, P. phycis* and *Z. faber.* Some species such as *S. umbra, R. naevus* and *S. cantharus* were rather frequent in Spanish samples but did not appear in Tunisian catches. Conversely, the shark *S. acanthias* was common in Tunisian catches but it never appeared in Spanish catches.

The mean number of specimens of commercial value taken per standard haul was very similar in the two study areas (~4 ind·haul^{-1}), but the discarded fraction was higher in Spain (4.9 ind·haul^{-1}) than in Tunisia (2.4 ind·haul^{-1}). However, no significant differences were found between the two areas when the percentage of discarded individuals related to the total by-catch were compared ($p>0.05$). The number of discarded individuals that were returned to the sea alive and in good condition was negligible in the two fisheries because the discarded commercial specimens were almost exclusively damaged individuals that could not be marketed, and this applied to the majority of the commercial species in Table V. Only the tougher species such as *Scyliorhinus spp., Raja spp.* or *E. marginatus* were returned to the water in good condition when undersized. The least resistant species were soft-bodied fishes such as *P. phycis, M. merluccius* and *M. surmuletus,* which decayed quickly and thus their discarded fraction was very high compared to the commercialised fraction. Commercial species targeted by other important fisheries such as *S. scombrus, A. rochei* and *S. aurita* were always discarded due to the low number of individuals captured. Finally, there was a group of species without commercial interest that were always discarded such as *T. marmorata, L. bimaculatus* and *M. mola*.

Discussion

The spiny lobster *Palinurus elephas* is a high-value commercial species that supports socio-economically important fisheries in the western Mediterranean. Currently, annual landings in the Tunisian and Spanish (Columbretes and Balearic Islands) fisheries studied amount to some 30 and

105 tons respectively, with a first sale value of $1.1 \cdot 10^6$ € and $5.3 \cdot 10^6$ € respectively. Although limited, the available information indicates that these landings are among to the lowest in documented history, despite indications of growing fishing effort in recent decades. The fleets from Spain and Tunisia are composed of artisanal boats with technical characteristics closely related to the distance from their homeports to the fishing grounds. This pattern of small-scale fishery applies to all the Mediterranean fleets directed to *P. elephas* (Marin, 1985; Secci *et al*., 1995, 1999; Latrouite & Noel, 1997; Gristina *et al.,* 2002). Over 250 boats and around 600 fishermen participate in the Spanish Balearic and Columbretes islands fisheries during the fishing season. Lobster has an enormous importance in the Balearic Islands, where around 75% of the artisanal vessels are directed to this species during the fishing season. The Tunisian fishery of La Galite and the Esquerquis involves about 50 boats and employs over 300 fishermen. In both countries, the commercialisation process –for foreign consumption in Tunisia and for domestic use in Spain– provides additional employment and an added value that may surpass the first sale price.

Tunisian exploited populations have a greater proportion of large lobsters than populations exploited by the Spanish fleets, as revealed by both the size range (60–200 vs. 30–170 mm CL) and the modal size (110 vs. 90 mm CL) of the catch. This is not related to fishing grounds because both fisheries work over the same type of habitats (75–80 m depth over 'maërl' substrates). There is a difference in the mesh size of the inner panel, which is larger (75 mm) in Tunisia than in Spain (70 mm), but we believe this difference is not sufficient to explain the different size structures of the lobster catches in the two areas. Lobsters taken by the Corsican fleet ranged from 40–140 and 40–120 mm CL in males and females respectively, being the modal size of 60–80 mm CL for both sexes (Ceccaldi & Latrouite, 1994). Sardinian populations ranged from 13–126 mm CL and had a modal size of 63–67 mm CL (Secci *et al.*, 1999). The greater proportion of small lobsters in Sardinian and Corsican fisheries than in the Spanish and Tunisian ones could indicate greater exploitation rates in the former. However, the higher proportion of fishing set containing lobster catch in the Spanish than in the Tunisian fisheries (94.2% vs. 72.1%), together with the higher catch rates in the Spanish fishery, is indicative of greater lobster density in Spanish grounds. Conversely, the greater modal and maximum sizes of lobsters in Tunisian catches suggest that the lower densities are not the result of greater fishing pressure, and that other factors may be in play. Optimal lobster habitats (mainly shelter size; see Caddy, 1986 and Planes *et al.,* 2000) could be more patchily distributed in Tunisian grounds, resulting in fewer positive sets. Moreover, because large lobsters, in particular males, tend to be solitary and display agonistic interactions with congeners (Goñi *et al.,* 2003a), the density may be lower in areas where large individuals abound. However, on the basis of the information available it is impossible to determine the relative importance of the different factors considered.

The proportion of lobster catch to total catch was similar in both fisheries (41–48% in number and biomass), as was the proportion of commercial lobster to total lobster (70% in number, 73–81% in biomass). However, the percentage of 'rotten' (damaged individuals caused by stress or predation) and undersized categories differed between zones. In accordance with what was explained in the last paragraph, the individuals under the legal landing size were more frequent in Spanish than in Tunisian catches (21.5% vs. 6%), though the proportion of undersized individuals from these zones was far lower than the 80% found by Secci *et al.* (1999) in Sardinian catches. Conversely, 'rotten' lobsters were more common in Tunisian than in Spanish catches (24% vs. 7.5% of total lobster catch). 'Rotten' lobsters are almost exclusively the result of predation (mainly by octopuses) and increases with the number of days that the nets remain at sea, and with rising temperature. In this study, soak time could not be the explanation because it was higher in Spain (2.3 and 4.5 days) than in Tunisia (2.5 days). Neither could the presence of predators because those species that could be potential consumers of entangled lobsters, such as *O. vulgaris, D. dentex* or *S. pagrus*, were even more frequent in Spain than in Tunisia. Temperatures at the depth where the majority of lobsters were caught did not differ between the two areas, and thus the higher proportion of 'rotten' lobsters in Tunisia than in Spain remain unexplained.

The seasonal evolution in lobster yields showed opposite trends (clearer for numerical than for biomass data) in the two fisheries studied, decreasing in Spain and increasing in Tunisia (where data were only available from May) as the season progressed. Mean monthly landings between 1990 and 2002 showed a similar pattern, increasing progressively through the season in Tunisia and increasing from March to May with a subsequent decline in Spain. This may be due to the different pattern of exploitation of the fishing grounds existing in each area. While Spanish vessels work on the same grounds the entire season, the Tunisian fleet fishes close to the homeports at the beginning of the season and moves offshore as the weather improves. Thus, the effect of the 6-month closed season is more conspicuous in Spanish than in Tunisian fisheries. In a study on the dynamics of the protected population from the Columbretes Islands Marine Reserve, Goñi *et al.* (2003a) found that temporal changes in relative abundance followed different patterns inside the reserve and in nearby unprotected areas. While catch rates in the reserve were not significantly different in the three studied periods (February, June and August), the abundance in the unprotected zones was highest in February, just before the fishing season began. Marin (1985) found that lobster yields in Corsica were highest in summer but that frequently decreased in late July–August. The author assigned this reduction to reproductive behaviour (mating and egg laying) since many lobsters disappeared from the fishing grounds in late summer.

Tunisian total annual landings showed an abrupt increase from 1990 to 1993 (where the maximum of the series was reached, 74 tons), but decreased afterwards. The increase in the early nineties was due to several factors, such as the growth of the fleet and unusually good weather conditions, but mainly to the discovery of new fishing grounds like the Esquerquis Islands (Zarrouk, 2000). Catches from the Columbretes Islands fluctuated during the documented period, peaking in 1991–1992 (10 tons) to decrease afterwards. Landings from Sardinia showed a peak in 1984–1985 (more than 10 tons) but an abrupt fall occurred afterwards and the annual captures since 1987 have been under the 5 tons (Secci *et al*., 1999). Similar declines are reported for all *P. elephas* fisheries for which some data exist (Petrosino *et al.,* 1985; Marin, 1985; Latrouite & Noel, 1997; Soldo *et al*., 2001), including the Atlantic fisheries (e.g., Hunter *et al.* 1996). These data demonstrate the depletion with time of all the documented lobster fisheries, and it would simply reflect an intense exploitation over a marine resource with low resilience.

A total of 48 and 28 different by-catch species were caught in the Spanish and Tunisian fisheries respectively. The discarded fraction of the total by-catch was not significantly different between the two areas. Discard practices were also similar, where the rejected fraction included: 1) damaged and undersized commercial species; 2) species without commercial value; and 3) commercial species which are targeted by other fisheries but are not of interest owing to the low quantities of individuals captured. The serious damage produced by getting entangled in a trammel net (stress, predation) makes the proportion of specimens discarded in good condition negligible and the probability of death increases with soak time (Quetglas *et al*., unpublished data). Similar findings were made in south Portugal where the discarded fraction from trammel netters was found to be relatively insignificant on a trip basis and was also largely caused by the poor condition of the catch, *S. japonicus* and *S. pilchardus* being the more abundant discarded species (Borges *et al*., 2001). Trammel net 'ghost fishing' experiences showed that predation (octopuses, cuttlefishes, conger eels, moray eels) was very important on entangled fishes, which disappeared completely after 24 h (Erzini *et al*., 1997). The discarded fraction in Spain and Tunisia was not as low as that reported by Borges *et al*. (2001) in Portugal, since the numerical importance of rejected specimens per standard haul was rather high (higher than the commercial fraction in Spain, half this fraction in Tunisia). However, Borges *et al.* (2001) did not specify the species targeted by the trammel netters studied and it must be taken into account that the discarded fraction could vary depending on it (mesh size, season, depth, soak time).

To conclude, the findings of the present work show the existence of a common pattern of exploitation for the lobster *P. elephas* in the Mediterranean, consisting of small, artisanal boats fishing almost exclusively with trammel nets. Analysis of historical landings also suggest serious levels of over exploitation in most of the areas studied, indicating that measures of protection should be improved in order to sustain the fisheries of this species which has high economical importance to small-scale Mediterranean fisheries.

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Table I. Characteristics of the fleets and fishing operations in the Spanish and Tunisian *P. elephas* fisheries studied. Values are means, standard errors and ranges.

	Spain		Tunisia
	Balearic Islands	Columbretes Islands	La Galite & Esquerquis Islands
Number of ports	16	4	2
Number of boats	257	5	56
Gross tonnage (GT)	2.0 ± 0.1 (0.2–11.2)	10.7 ± 3.4 (7.6–15.1)	18.9 ± 1.3 (6.8–47.0)
Horse power (HP)	37.5 ± 1.5 (3–261)	119.0 ± 35.1 (85–170)	149.4 ± 11.3 (45–330)
Boat length	7.2 ± 0.1 (3.2–12.8)	12.9 ± 1.3 (11.2–14.6)	14.0 ± 0.3 (10.6–18.8)
Boat age	34.8 ± 1.0 (1–98)	16.8 ± 14.1 (3–37)	13.4 ± 0.8 (2–28)
Nº fishermen·boat^{-1}	2.0 ± 0.0 (1–3)	3.2 ± 0.0 (3–4)	6.1 ± 0.1 (4–7)
Soak time (days)	2.3 ± 0.0 (2–5)	4.5 ± 0.1 (2–14)	2.5 ± 0.9 (2–10)
Net length (m)	662 ± 7.1 (450–1250)	726 ± 11.1 (350–1900)	653 ± 41.2 (300–850)
Mesh size (mm)	71 ± 0.5 (40–100)	69 ± 0.6 (40–80)	75 ± 0.0 (70–80)
Depth (m)	74.3 ± 1.3 (15.0–170.0)	79.3 ± 0.9 (26.0–172.0)	78.1 ± 12.4 (23.0–185.0)

Table II. Summary statistics of *P. elephas* catches (total and by categories) from fishing sets sampled during May and August-October 2001 in Spanish (N=87 hauls) and Tunisian (N=43 hauls) fisheries. F: frequency of appearance (%); N, W: total number and weight (in g); %N, %W: percentage in number and in weight (± standard error) referred to the total catch or to the total lobster catch; $N \cdot haul^{-1}$, $W \cdot haul^{-1}$: number and weight per standard haul (± standard error). (* $p<0.05$; ** $p<0.01$; NS: not significant at a=0.05).

		Spain	Tunisia	Student´s t-test
Total	F	94.2	72.1	
	N	749	172	
	W	408431.9	161312.9	
	$\%N_{total\ catch}$	47.8 ± 2.50	41.4 ± 5.34	NS (p=0.230)
	$\%W_{total\ catch}$	41.3 ± 2.63	47.4 ± 5.80	NS (p=0.277)
Commercial catch	$N \cdot haul^{-1}$	5.9 ± 0.67	2.8 ± 0.49	**(p=0.003)
	$W \cdot haul^{-1}$	3873.7 ± 422.9	2846.6 ± 625.7	NS (p=0.149)
	$\%N_{lobster\ catch}$	70.9 ± 2.87	69.7 ± 4.80	NS (p=0.649)
	$\%W_{lobster\ catch}$	81.4 ± 2.39	72.9 ± 4.95	NS (p=0.111)
Undersized	$N \cdot haul^{-1}$	2.0 ± 0.29	0.1 ± 0.05	**(p<0.001)
	$W \cdot haul^{-1}$	420.5 ± 65.4	26.6 ± 12.21	**(p<0.001)
	$\%N_{lobster\ catch}$	21.5 ± 2.47	6.1 ± 3.35	**(p<0.001)
	$\%W_{lobster\ catch}$	11.5 ± 1.81	3.8 ± 3.22	**(p=0.002)
'Rotten'	$N \cdot haul^{-1}$	0.8 ± 0.15	1.0 ± 0.19	NS (p=0.313)
	$W \cdot haul^{-1}$	400.4 ± 83.2	879.6 ± 209.2	**(p=0.006)
	$\%N_{lobster\ catch}$	7.5 ± 1.43	24.2 ± 4.29	**(p<0.001)
	$\%W_{lobster\ catch}$	7.2 ± 1.41	23.3 ± 4.42	**(p<0.001)

Table III. Carapace length-total weight (CL–TW) and carapace length-total length (CL–TL) relationships of *P. elephas* from Spanish and Tunisian exploited populations. Results of the ANCOVA tests are also shown. CL: carapace length, mm; TW: total weight, g; TL: total length, mm. (* p<0.05; ** p<0.01; NS: not significant at a=0.05).

		Spain				Tunisia				Spain vs. Tunisia	
		F		M	F+M	F		M	F+M	F	M
CL–TW	a	0.0016	***	0.0012	0.0016	0.0069	***	0.0029	0.0046	***	***
	b	2.834	NS	2.882	2.825	2.486	NS	2.667	2.571	***	***
	r	0.991		0.997	0.993	0.968		0.966	0.968		
	N	442		370	812	65		75	140		
CL–TL	a	12.511	***	32.041	43.080	32.536	***	38.361	45.295	***	***
	b	2.878	***	2.507	2.490	2.481	***	2.344	2.312	***	***
	r	0.991		0.986	0.964	0.918		0.963	0.949		
	N	441		370	811	89		91	180		

Table IVa. Results of ANOVA tests of factors Zone (Spain, Tunisia) and Month (May, June, July, August) on *P. elephas* yields in number ($N_{lobster}$/500 m) in trammel net fisheries. Data were ln(x+0.1) transformed; transformations reduced but did not eliminate heterogeneous variances. Untransformed data: Cochran's Test=0.33, p<0.001; Transformed data: Cochran's Test=0.17 p=0.03.

Source of variation	SS	DF	MS	F-ratio	Probability
Zone	28.87	1	28.87	21.5	0.000
Month	6.88	3	2.29	1.71	0.160
Zone x Month	54.79	3	18.26	13.61	0.000
Residual	955.85	712	1.34		
Total	1046.39	719			

Table IVb. Results of ANOVA tests of effects of Zone (Spain, Tunisia) and Month (May, June, July, August) on the lobster yields in weight ($W_{lobster}$/500 m) from trammel net artisanal fisheries. Data were ln(x+0.1) transformed; transformations reduced but did not eliminate heterogeneous variances. Untransformed data: Cochran's Test=0.30 p=0; Transformed data: Cochran's Test=0.18, p=0.009.

Source of variation	SS	DF	MS	F-ratio	Probability
Zone	34.90	1	34.90	26.24	0.000
Month	4.62	3	1.54	1.16	0.330
Zone x Month	52.41	3	17.47	13.13	0.000
Residual	947.01	712	1.33		
Total	1038.93	719			

Table V. Composition (mean and standard deviations) of the by-catch commercial and discarded fractions in catches from the trammel net *P. elephas* Spanish (N=87 hauls) and Tunisian (N=43 hauls) fisheries. The percentage of the discarded fraction related to the total by-catch capture along with the significance of the statistical test used for comparison (t-test after arcsine transformation) are also shown. F: frequency of appearance (%); N: total number; %N: percentage in number. Species are arranged in alphabetical order.

Species	Spain					Tunisia				
	F	N	% N	Commercial by-catch	Discarded by-catch	F	N	%N	Commercial by-catch	Discarded by-catch
Auxis rochei						2.33	18	7.93	0.529 ± 3.087	
Centracanthus cirrus						2.33	1	0.44	0.029 ± 0.171	
Dasyatis pastinaca	2.30	2	0.26		0.023 ± 0.152					
Dentex dentex	6.90	7	0.90	0.046 ± 0.212	0.034 ± 0.24					
Diplodus vulgaris	2.30	2	0.26	0.011 ± 0.108	0.011 ± 0.108					
Eledone moschata						2.33	1	0.44	0.029 ± 0.171	
Engraulis encrasicolus						2.33	1	0.44	0.029 ± 0.171	
Epinephelus marginatus	2.30	3	0.39	0.011 ± 0.108	0.023 ± 0.216					
Homarus gammarus	5.75	5	0.64	0.057 ± 0.235						
Labrus bimaculatus	5.75	5	0.64		0.057 ± 0.235	2.33	1	0.44		0.029 ± 0.171
Lophius budegassa	13.79	22	2.82	0.207 ± 0.596	0.046 ± 0.262	4.65	2	0.88	0.059 ± 0.239	
Lophius piscatorius	44.83	70	8.99	0.391 ± 0.816	0.414 ± 0.847	4.65	2	0.88	0.029 ± 0.171	0.029 ± 0.171
Lophius sp.						2.33	1	0.44		0.029 ± 0.171
Merluccius merluccius	4.60	7	0.90		0.069 ± 0.369					
Mola mola	2.30	2	0.26		0.023 ± 0.108					
Mullus surmuletus	9.20	16	2.05	0.057 ± 0.281	0.126 ± 0.562	2.33	1	0.44		0.029 ± 0.171
Muraena helena	1.15	1	0.13		0.011 ± 0.108					
Mustelus mustelus						2.33	1	0.44	0.029 ± 0.171	
Octopus vulgaris	3.45	3	0.39	0.023 ± 0.152	0.011 ± 0.108	2.33	1	0.44	0.029 ± 0.171	
Pagellus acarne	11.49	12	1.54	0.069 ± 0.299	0.069 ± 0.299	11.63	14	6.17	0.294 ± 0.97	0.118 ± 0.537
Pagellus erythrinus	20.69	21	2.70	0.080 ± 0.315	0.161 ± 0.43	9.30	5	2.20	0.147 ± 0.436	
Phycis phycis	37.93	66	8.47	0.310 ± 0.579	0.448 ± 1.143	9.30	4	1.76	0.088 ± 0.288	0.029 ± 0.171
Raja asterias	1.15	1	0.13		0.011 ± 0.108					
Raja clavata	2.30	2	0.26	0.023 ± 0.152		11.63	13	5.73	0.206 ± 0.729	0.176 ± 0.869
Raja miraletus	11.49	16	2.05	0.011 ± 0.108	0.172 ± 0.557	9.30	6	2.64	0.118 ± 0.409	0.059 ± 0.343
Raja montagui	2.30	3	0.39	0.011 ± 0.108	0.023 ± 0.152	18.60	18	7.93	0.382 ± 1.015	0.147 ± 0.436
Raja naevus	11.49	16	2.05		0.184 ± 0.584					
Raja sp.						6.98	5	2.20		0.147 ± 0.500
Raja undulata	2.30	2	0.26	0.011 ± 0.011	0.011 ± 0.108					
Sardinella aurita	3.45	12	1.54		0.138 ± 1.086					
Sciaena umbra	17.24	38	4.88	0.108 ± 0.108	0.322 ± 1.648					
Scomber japonicus	1.15	4	0.51		0.046 ± 0.431	4.65	2	0.88	0.059 ± 0.239	
Scomber scombrus	2.30	2	0.26	0.011 ± 0.108	0.011 ± 0.108					
Scophthalmus rhombus	1.15	1	0.13		0.011 ± 0.108					
Scorpaena notata	1.15	1	0.13		0.011 ± 0.108	2.33	1	0.44		0.029 ± 0.171
Scorpaena scrofa	72.41	200	25.67	1.540 ± 1.719	0.759 ± 1.207	30.23	18	7.93	0.353 ± 0.734	0.176 ± 0.387
Scyliorhinus canicula	20.69	31	3.98	0.023 ± 0.152	0.333 ± 0.806	34.88	31	13.66	0.618 ± 1.256	0.294 ± 0.579
Scyliorhinus stellaris	5.75	5	0.64	0.057 ± 0.235		9.30	7	3.08	0.176 ± 0.716	0.029 ± 0.171
Scyllarides latus	2.30	2	0.26	0.023 ± 0.152						
Seriola dumerilii	1.15	1	0.13	0.011 ± 0.108						
Serranus cabrilla	8.05	11	1.41	0.023 ± 0.216	0.103 ± 0.299					
Serranus scriba	1.15	1	0.13		0.011 ± 0.108					
Solea sp.	1.15	1	0.13		0.011 ± 0.108	2.33	1	0.44	0.029 ± 0.171	
Sparus pagrus	11.49	13	1.67	0.034 ± 0.185	0.115 ± 0.389	4.65	2	0.88	0.029 ± 0.171	0.029 ± 0.171
Spondyliosoma cantharus	11.49	17	2.18	0.103 ± 0.435	0.092 ± 0.424					
Squalus acanthias						16.28	37	16.30	0.765 ± 2.686	0.324 ± 1.093
Symphodus sp.	1.15	1	0.13		0.011 ± 0.108					
Torpedo marmorata	14.94	17	2.18		0.195 ± 0.505	16.28	9	3.96		0.265 ± 0.618
Trachinus draco	6.90	10	1.28		0.034 ± 0.185					
Trachinus radiatus	20.69	46	5.91	0.080 ± 0.558	0.310 ± 0.830	6.98	4	1.76	0.029 ± 0.171	0.088 ± 0.379
Trachurus mediterraneus	1.15	1	0.13		0.011 ± 0.108					
Trigla lucerna	2.30	2	0.26	0.011 ± 0.108	0.011 ± 0.108					
Trigla lyra	1.15	1	0.13		0.011 ± 0.108					
Trisopterus minutus	2.30	2	0.26	0.011 ± 0.108	0.011 ± 0.108	2.33	1	0.44	0.029 ± 0.171	
Uranoscopus scaber	9.20	8	1.03	0.057 ± 0.235	0.034 ± 0.185					
Zeus faber	40.23	65	8.34	0.345 ± 0.851	0.402 ± 0.886	11.63	6	2.64	0.147 ± 0.436	0.029 ± 0.171
Total		779		4.023 ± 3.060	4.931 ± 5.424		227		4.235 ± 5.614	2.441 ± 2.642
% Discarded/Total by-catch			Spain	53.6 ± 2.6	NS (P=0.539)			Tunisia	44.3 ± 6.3	

Figure captions

Figure 1. Map of the western Mediterranean showing the main red lobster *Palinurus elephas* fishing grounds of the Spanish and Tunisian fisheries.

Figure 2. *P. elephas* size-frequency distributions (males, females, total) of the catches from the Spanish (black) and Tunisian (white) fisheries.

Figure 3. Monthly *P. elephas* yields (A: number; B: weight) from the Spanish (black dots) and Tunisian (white dots) fisheries. Means and standard errors are shown.

Figure 4. Number of boats (solid line) and the number of days at sea (broken line) of the Tunisian lobster fleet during 1990-1999.

Figure 5. Monthly (solid line) and annual (broken line) landings of *P. elephas* in (A) Tunisian and (B) the Columbretes Islands (Spain) fisheries during 1990–2002.

Figure 6. Mean monthly (mean and standard error) landings of *P. elephas* in the Columbretes Islands (Spain) and Tunisian fisheries during 1990–2002.

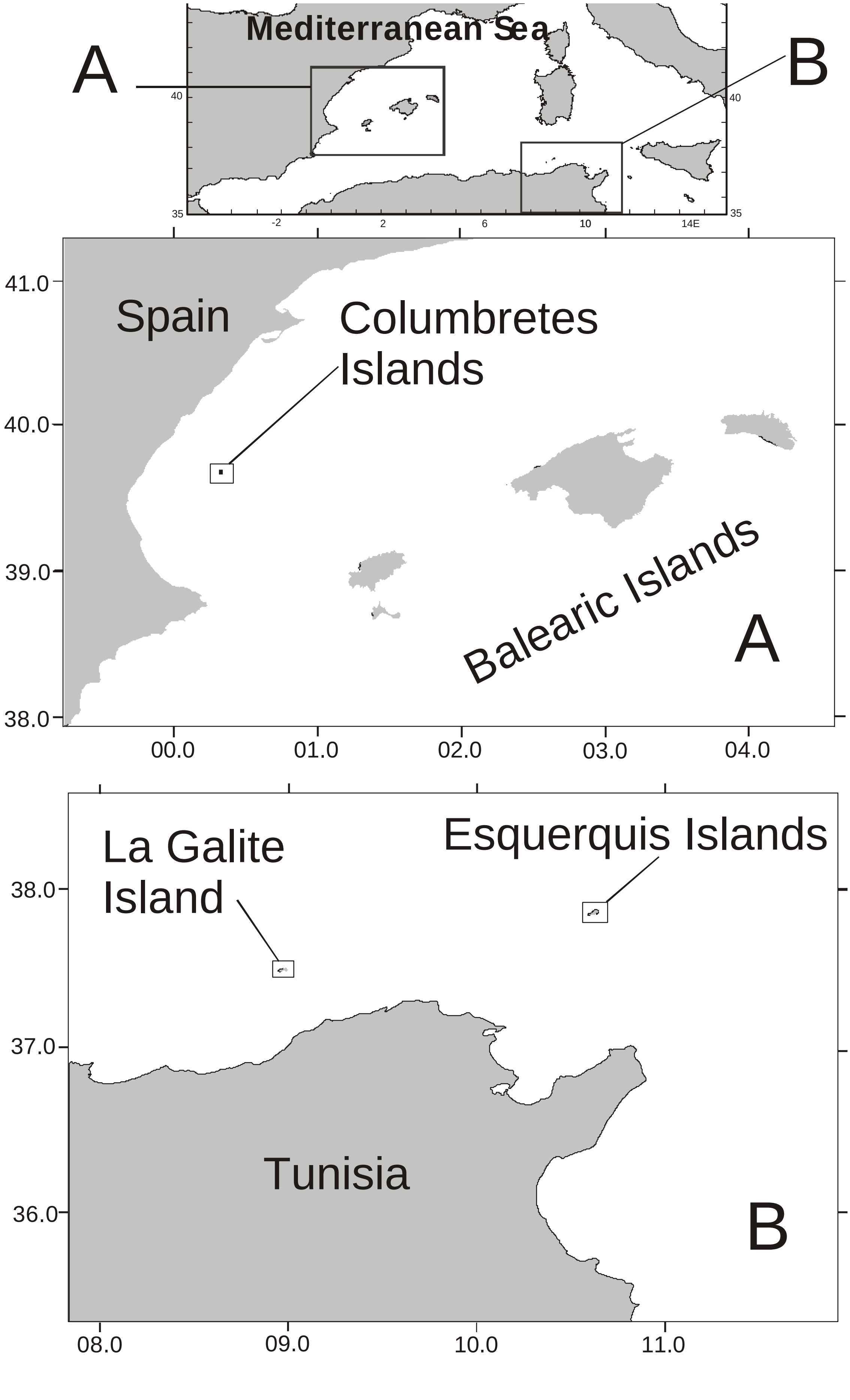

Mediterranean Sea
A
B
40
35
-2
2
6
10
14E
41.0
40.0
39.0
38.0
Spain
Columbretes
Islands
Balearic Islands
A
00.0
01.0
02.0
03.0
04.0
38.0
37.0
36.0
La Galite
Island
Esquerquis Islands
Tunisia
B
08.0
09.0
10.0
11.0

Figure 1

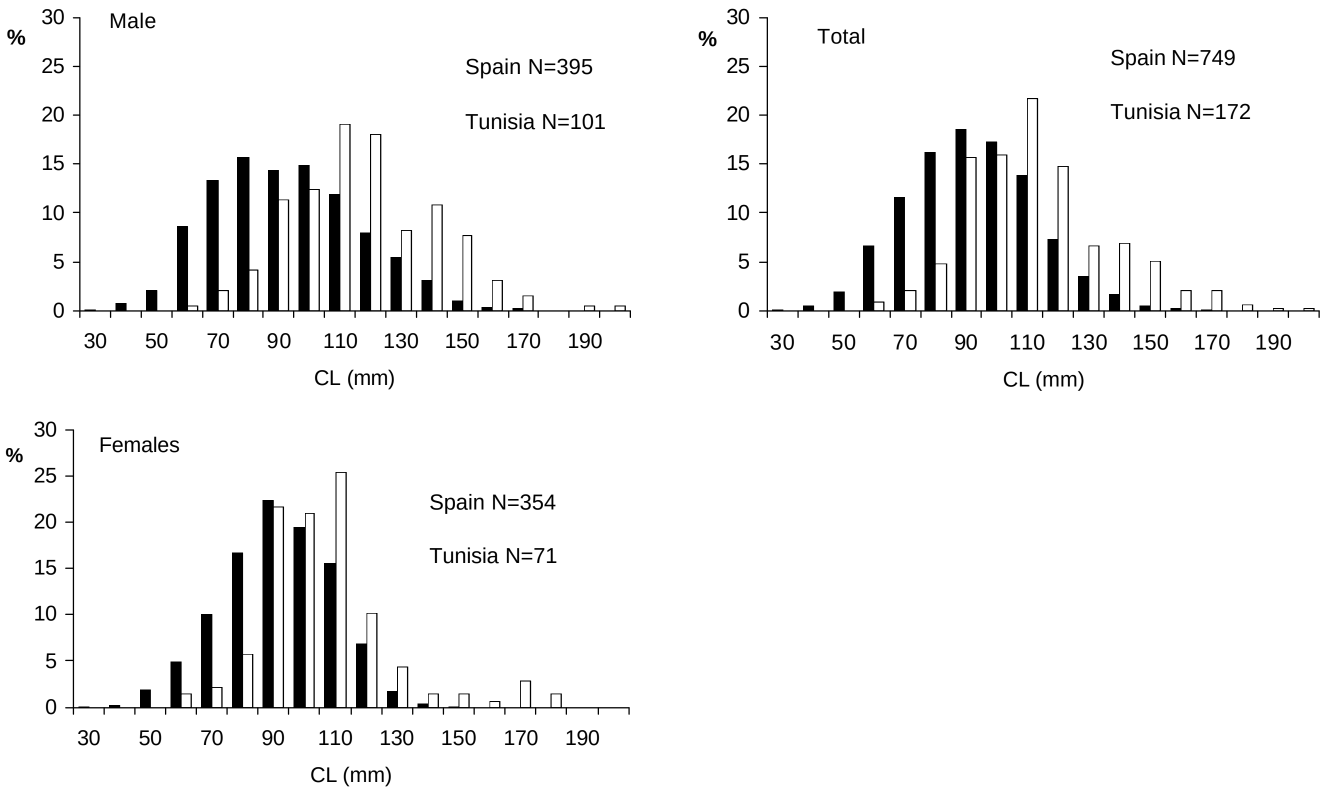

%
30
25
20
15
10
5
0
Male
Spain N=395
Tunisia N=101
30 50 70 90 110 130 150 170 190
CL (mm)
%
Total
Spain N=749
Tunisia N=172
30 50 70 90 110 130 150 170 190
CL (mm)
%
Females
Spain N=354
Tunisia N=71
30 50 70 90 110 130 150 170 190
CL (mm)

Figure 2

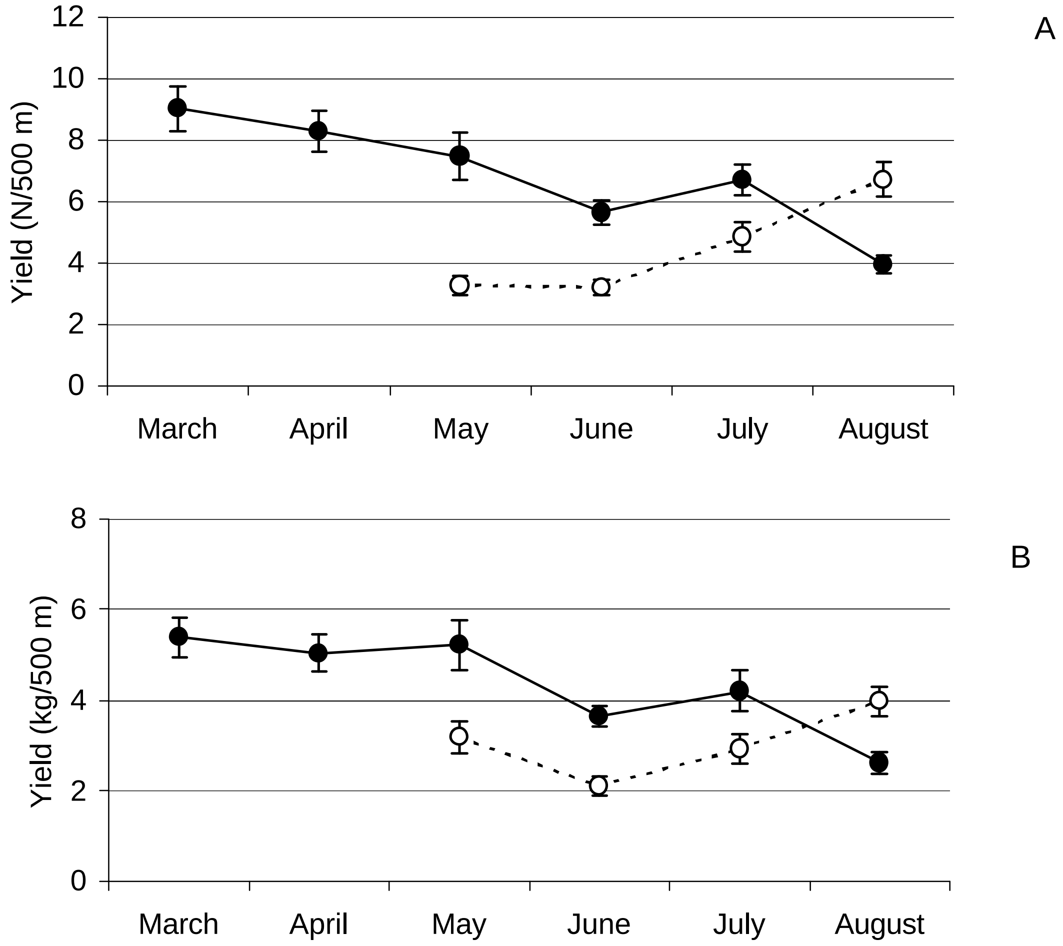

12
10
8
6
4
2
0
Yield (N/500 m)
A
March
April
May
June
July
August
8
6
4
2
0
Yield (kg/500 m)
B
March
April
May
June
July
August

Figure 3

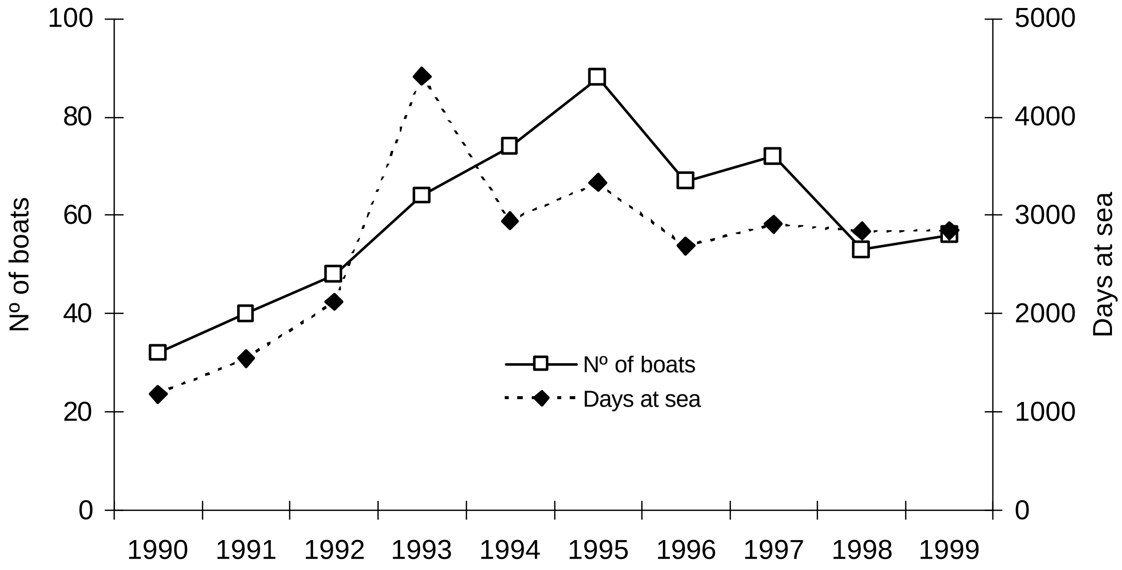
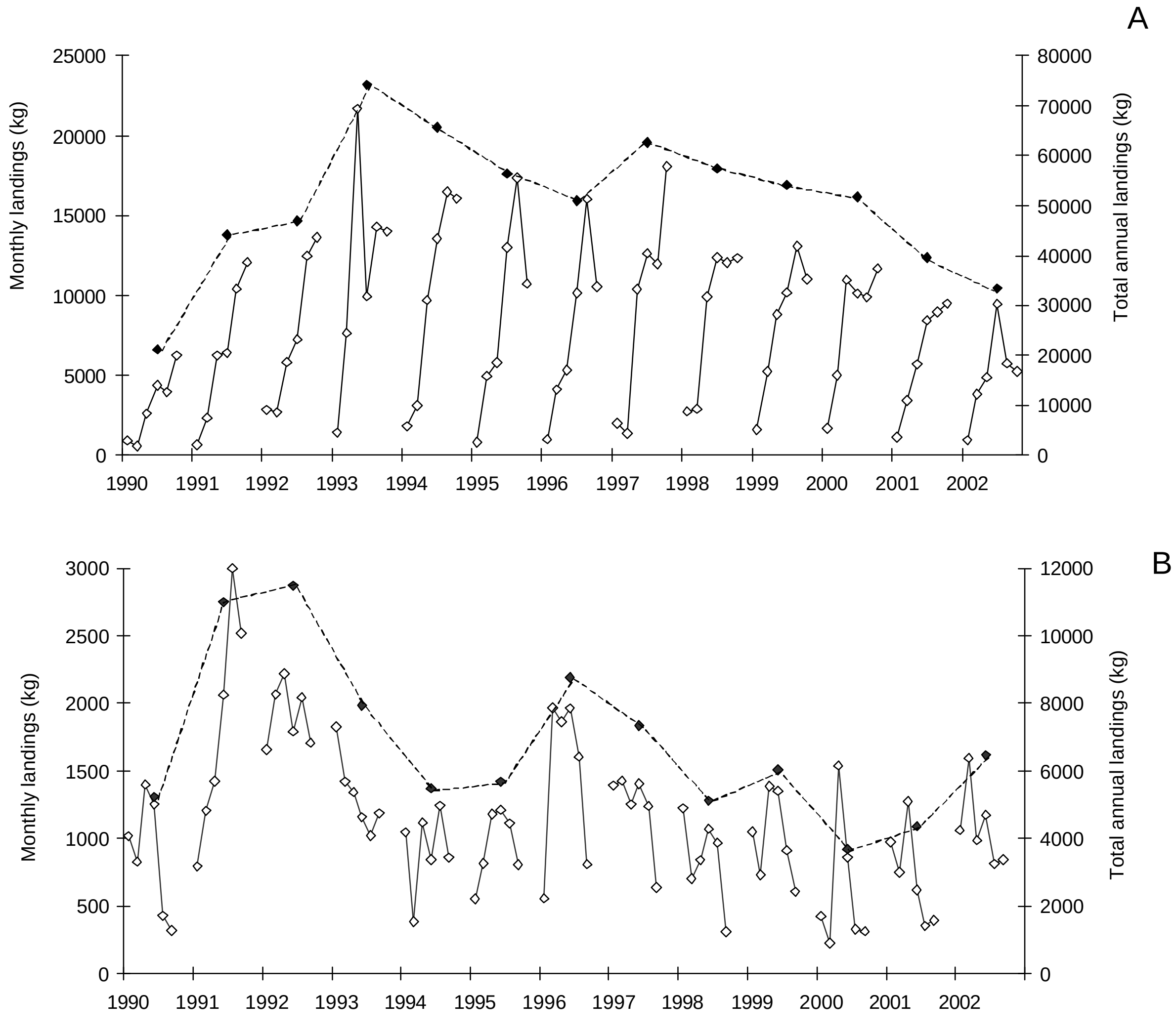

100
80
60
40
20
0
Nº of boats
5000
4000
3000
2000
1000
0
Days at sea
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
Nº of boats
Days at sea

Figure 4



A
Monthly landings (kg)
Total annual landings (kg)
25000
20000
15000
10000
5000
0
80000
70000
60000
50000
40000
30000
20000
10000
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002
B
Monthly landings (kg)
Total annual landings (kg)
3000
2500
2000
1500
1000
500
0
12000
10000
8000
6000
4000
2000
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002

Figure 5

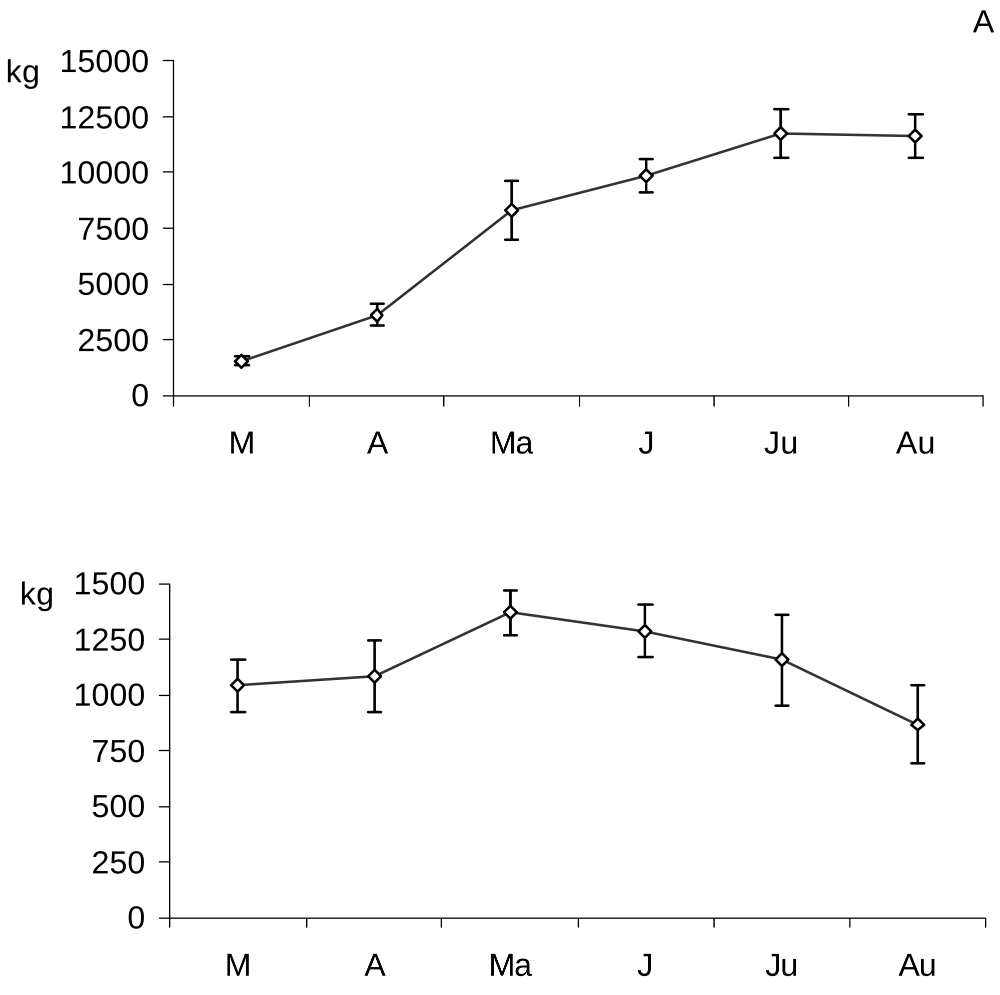

A
kg
15000
12500
10000
7500
5000
2500
0
M
A
Ma
J
Ju
Au
kg
1500
1250
1000
750
500
250
0
M
A
Ma
J
Ju
Au

Figure 6