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Spatial disentangling of Greek commercial fisheries landings by gear between 1928-2007

Dimitrios K. MOUTOPOULOS[1,2*] and Konstantinos I. STERGIOU[2]

[1] *Technological Educational Institute of Mesolonghi, Department of Aquaculture and Fisheries, Nea Ktiria, 30200 Mesolonghi, Greece*

[2] *Aristotle University of Thessaloniki, School of Biology, Department of Zoology, Laboratory of Ichthyology, BOX 134, 54124 Thessaloniki, Greece*

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In the present study, Greek marine fisheries landings per gear and subarea were reconstructed for the period 1928-2007. The reconstruction was based on the landing per species, gear (i.e., trawls, purse-seines, beach-seines and other small-scale gears operated from vessels with engine power ≥ 19 HP) and subarea during 1990-2007 that have been recorded by the Hellenic Statistical Authority but have never been published or presented before, and the landings from small-scale vessels (with engine power < 19 HP) by prefecture that have been recorded by Agricultural Statistics of Greece during 1970-2007. The results showed that the reconstructed total landings time series, as well as those of each gear separately, increased substantially from 1928 up to mid 1990's and then declined for the remaining years. The same trend was almost true for the vast majority of the total (i.e. all species combined) landings and of the most abundant species per gear and subarea, depending on each case. This indicates that the general trend identified were not the result of aggregating landings over different gears and subareas but rather a general pattern for most gears, subareas and dominant species. Apart from studying the historical development of the Greek fisheries, the main reason for reconstructing Greek fisheries landings was to use this series for applying various ecological indices/analyses on a gear/subarea basis and to develop ecosystem-based models for comparing different management scenarios for Greek waters.

Key words: fisheries landings, landings reconstruction, long-term trends, multi-gear fisheries, fisheries history, Mediterranean.

INTRODUCTION

Greek fisheries statistics for 1928-2007 have been collected by various organisations (for an extended discussion see Moutopoulos & Stergiou, 2011), and those of the Hellenic Statistical Authority (HELSTAT, previously known as National Statistical Service of Greece, NSSG) are more robust, reliable and consistent (for a discussion see: Stergiou *et al*. 1997; Papaconstantinou *et al*., 2002; Tsikliras *et al*., 2007).

HELSTAT marine fisheries statistics have been recorded and published in annual bulletins covering two different periods: 1928-1939 (GSSG, 1934-1940) and 1964 to present (HELSTAT, 1966-2009). The available data included, among others (see Stergiou *et al*., 1997 for a full description), fisheries landings per species and fishing subarea (i.e. Greek waters are spatially allocated to 16 fishing subareas, see Fig. 1) which have been presented elsewhere (for 1928-1939: Moutopoulos & Stergiou, 2011; for 1964-2003: Stergiou *et al*., 2007). During 1969-2007, fisheries landings were recorded for professional fishing vessels with engine power ≥ 19 HP (henceforth called large vessels), whereas during 1964-1969 landings were recorded from all engined-vessels. The landings from vessels with engine power < 19 HP (henceforth called small vessels) are recorded for 41 prefectures (Fig. 1) by a different branch of HELSTAT, namely Agricultural Statistics of Greece (ASG) (ASG, 1977-2009).

Tsikliras *et al*. (2007) reconstructed the total (i.e.

* Corresponding author: tel.: +30 26310 58202, fax: +30 26310 58202, e-mail: dmoutopo@teimes.gr

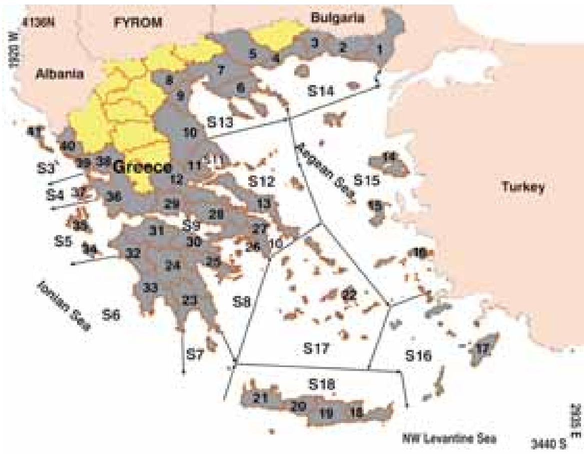

FIG. 1. Map of Greek waters showing the division of the fishing subareas allocated by the different fisheries statistical organizations; S3 to S18 indicate the 16 fishing subareas (each enclosed by lines) allocated by the Hellenic Statistical Authority of Greece; grey parts indicated the prefectures involved in the collection of fisheries statistics from vessels with engine power < 19 HP by the Agricultural Service of Greece during 1975-2007 (numbers follow Table S1, see online supplementary material). Subareas S1 and S2 are outside Greek waters (Atlantic Ocean and North African Mediterranean coasts, respectively).

all subareas combined) landings during 1964-2004 after the inclusion of landings from small vessels and estimates of landings from certain large pelagic species (i.e. *Auxis thazard*, *Euthynnus alletteratus*, *Thunnus* spp. and *Xiphias gladius*) that were taken from FAO. Moutopoulos & Stergiou (2011) presented the landings per species during 1928-1939, which were recorded by GSSG, re-allocated the spatial distribution of landings from 29 custom port authorities to 15 HELSTAT subareas and summarized the total landings from different sources for Greek waters during 1928-2007.

In the present study, the species landings by gear and subarea (including the landings from small vessels by subarea) were disaggregated in order to obtain a continuous reconstructed time series of marine fisheries landings per gear and subarea during 1928-2007. Our reconstructed landings refer only to commercial landings (i.e. they do not include discards, illegal and unreported catches as well as recreational fisheries landings).

The reconstruction was based on the landing per species, gear (i.e. trawls, purse-seines, beach-seines and other small-scale gears operated from vessels with engine power > 19 HP) and subarea during 1990-2007 that have been recorded by HELSTAT but have never been published or presented before (provided to us by Mrs A. Nasiakou, HELSTAT) in the annual bulletins and thus were not accessible to the scientific community at large. In addition, landings from small vessels by prefecture were disaggregated for each of the 16 HELSTAT subareas during 1970-2007 and were added to the reconstructed landings derived from large vessels during this period. We note that landings before 1970 already included those of the small vessels.

The above information will be a valuable repository of knowledge for studying the effects of fishing on marine ecosystems (Zeller & Pauly, 2006), useful for re-evaluating the state of Greek fisheries and for comparing with global fisheries trends (Pauly, 2008) and will be the basis for developing mass-balanced models (e.g. Pauly *et al*., 2000) for the Greek Seas and testing various management scenarios (Moutopoulos *et al*., unpublised data).

MATERIALS AND METHODS

Greek fisheries landings per species were disaggregated for each of the 16 fishing subareas (Fig. 1) and gear (trawls, purse-seines, beach-seines and small-scale gears) during 1928-1989 using the data shown in Tables 1 and 2 and based on the methodology described in Tables 3 and 4. The final reconstruction of the Greek fisheries landings during 1928-2007 was derived by summing the following final matrices (for symbols, see Tables 3 and 4):

Total landings = Landings per species/subarea (1970-2007) for small vessels (Q11) + Landings per species/subarea/gear (1990-2007) (K) + Landings per species/subarea/gear (1970-1989) (Z1) + Landings per species/subarea/gear (1964-1969) (Z2) + Landings for large pelagics/subarea/gear (1982-2007) (Z4) + Landings for large pelagics/subarea/gear (1964-1981) (Z6) + Landings per species/subarea/gear (1950-1963) (Z8) + Landings per species/subareas (15 subareas)/gear (1940-1947) (Z10) + Landings per species/subareas (16 subareas)/gear (1948-1949) (Z12) + Landings per species/subareas (15 subareas)/gear (1928-1939) (Z13).

Detailed landings per species/gear/subarea for 1928-2007 are presented in Table S5 (see online sup-

TABLE 1. Summary of the fisheries landing statistics recorded by the different statistical organizations for Greek waters (1928-2007)

Code	Period	Fishery type	Species resolution	Gear type	Spatial resolution (Fig. 1)	Source
A	1928-1939	Marine	33 fish species, 3 cephalopod species, 3 crustacean species and 1 other custacean-cephalopod group	All gear types (i.e. trawl, purse seine, beach seine and small scale) combined for all engined vessels	For 15 fishing subareas	GSSG (reconstructed by Moutopoulos & Stergiou, 2011)
B	1940-1949	All fisheries (i.e., marine[*], freshwater and lagoons) combined	Total landings (i.e. all species combined)	All gear types combined for all engined vessels	Total for Greek waters	Ananiadis (1968)
C	1950-1957	All fisheries combined (i.e., marine[+], freshwater, lagoons and overseas)	18 fish species, 1 cephalopod species and 1 crustacean species	All gear types combined for all engined vessels		FAO
D	1958-1963		27 fish species, 1 cephalopod species and 2 crustacean species			
E	1964-1969	Marine	17 fish species, 4 cephalopod species and 1 crustacean species	All gear types combined for all engined vessels	For 16 fishing subareas	NSSG
F	1964-1969		Total landings (all species combined)	Per gear type (i.e. trawl, purse-seine, beach-seine and other small-scale) for all engined vessels		
G	1964-2007		*Auxis thazard*, *Euthynnus alletteratus*, *Thunnus* spp. and *Xiphias gladius*	All gear types combined for all engined vessels	Total for Greek waters	ICCAT
H	1970-1981		17 fish species, 4 cephalopod species and 1 crustacean species	All gear types combined excluding small vessels	For 16 fishing subareas	NSSG
I	1970-1989		Total landings (all species combined)	Per gear type (i.e. trawl, purse-seine, beach-seine and other small-scale) excluding small vessels		
J	1982-1989		56 fish species, 5 cephalopod species and 5 crustacean species	All gear types combined excluding small vessels		
K	1990-2007			Per gear type (i.e. trawl, purse-seine, beach-seine and other small-scale) excluding small vessels		NSSG unplished data (Nasiakou A, pers. comm.)

[*] Marine landings were estimated by the proportion (equal to 0.735) of the Greek marine landings to the total (i.e. marine, lagoons and freshwater, excluded the landings from overseas) landings in 1939 (GSSG, 1934-1940)

[+] Marine landings were estimated by the proportion (equal to 0.840) of the Greek marine landings to the total (i.e. marine, lagoons and freshwater, excluded the landings from overseas) landings in 1956 from data published by Ananiadis (1968)

TABLE 2. Summary of the fishing statistics recorded for the small vessels by the different statistical organizations for Greek marine waters, (1964-2007)

Legend	Period	Data	Spatial resolution (Fig. 1)	Source
L	1975-1994	Mean total (i.e. for all fish, cephalopod, crustacean and bivalve species*) annual landings per vessel	Total for Greek waters	ASG
M	2002-2006	Total (i.e. for all fish, cephalopod, crustacean and bivalve species[i]) annual landings per vessel	For 41 prefectures	
N	1970-1974	Number of small vessels	Total for Greek waters	Tsikliras *et al*. (2007)
O	1975-2006		For 41 prefectures	ASG
P	1991-2007		For 178 fishing ports	Common Fisheries Registry-CFR (EC, 1998)

* Bivalve species were excluded from the reconstruction of the fisheries landings from both large-engined and small-engined vessels, from which a large proportion of the reported values are derived from intensive farming in coastal sea (Galinou-Mitsoudi *et al*., 2006)

TABLE 3. Methodology for the reconstruction of fisheries landings from vessels with engine power < 19 HP (1970-2007)

Method used
From matrix O (for the period 1975-1990) (Table 2), bootstrapped mean (1975-1990) proportions of the number of small vessels for each of the 41 prefectures were estimated, Q1
Number of small vessels for each of the 41 prefectures (1970-1974), Q2 = Q1 · N (Table 2)
Number of small vessels for each of the 41 prefectures (1970-1990), Q3 = Sum of the matrices Q2 and O (Table 2)
Number of small vessels for each of the 16 subareas (1970-1990), Q4, was derived from the spatial allocation of the online supplementary material, Table S3 to the 16 subareas as shown in the online supplementary material, Table S1
Number of small vessels for each of the 16 subareas (1991-2007), Q5, was derived from the spatial allocation of matrix P[1] (Table 2) to the 16 subareas as shown in the online supplementary material, Table S2
Number of small vessels for each of the 16 subareas (1970-1990), Q6, = Sum of the matrices Q4 and Q5
Mean annual landings of small vessels for each of the 41 prefectures (2002-2006), Q7 = bootstrapped mean (2002-2006) proportions of landings for all species combined for each of the 41 prefectures were estimated from matrix M (Table 2)
Landings of small vessels for each of the 16 subareas (2002-2006), Q8, were derived from the spatial allocation of Q7 to the 16 subareas according with the online supplementary material, Table S2
1970-1994: Mean total (i.e. all species combined) landings/subarea, Q9 = L (see Table 2) · Q6 (for the period 1970-1994) 1995-2007: Total (i.e. all species combined) landings/subarea, Q10 = Q8 · Q6 (for the period 1995-2007) 1970-2007: Total (i.e. all species combined) landings/subarea, Q11 = Q9 + Q10
Q11 was taxonomically disaggregated by species based on Anonymous (2001) using the mean (1996-2001) catch per unit of effort for 66 species[2] caught by all small-scale gears in five Greek sea regions (see online supplementary material, Table S1). The spatial disaggregation of S11 by species to the 16 subareas is based on the region-subarea relationship shown in the online supplementary material, Table S1

[1] For the estimation of the number of small vessels during 1991-2007, the number of small vessels registered in Common Fisheries Registry (CFR) was used instead of the those reported by ASG. This is due to the fact that CFR records all the officially registered vessels in Greek waters which derived from local custom port authorities (EC, 1998), whereas ASG uses a random sampling technique

[2] For large pelagics (i.e. *Auxis thazard*, *Euthynnus alletteratus*, *Thunnus* spp. and *Xiphias gladius*) derived from small vessels we multiplied the landings estimated in Anonymous (2001) with 0.454. This is because according with the official records of the Ministry of Agricultural and Food for 2006, the vessels with engine power < 19 HP and vessel length < 10 m licensed to catch large pelagic were 45.4% of the total number of licensed vessels involved in the large pelagics fisheries

TABLE 4. Methodology for the reconstruction of marine fisheries landings from vessels with engine power ≥19 HP from data recorded by the different organizations and periods for Greek waters (1928-2007) according to HELSTAT (Hellenic Statistical Authority)

Method used	Spatial-gear disaggregation
From matrix K (Table 1), bootstrapped[1] mean (1990-2007) proportions for each of 65 species landings per gear (i.e. trawls, purse-seines, beach-seines and other small-scale gears with engine power <19 HP) were estimated for each subarea, T1 From the sum of matrices K + Q11 (for 1990-2007) (Table 3), bootstrapped[1] mean (1990-2007) proportions for each of 65 species landings per gear were estimated for each subarea, T2	Landings for 65 species/subarea/gear (1990-2007), K (Table 1)
In matrix H (Table 1), species that were reported as aggregated groups for each of the 16 subareas, during 1964-1981 (see online supplementary material, Table S3) and were reported as individual species during 1982-1989, were disaggregated into individual species landings per subarea, during 1964-1981, according to Tsikliras *et al.* (2007), T3 In matrix H (Table 1), species that were reported as aggregated groups together with the landings of "other Osteichthyes group", during 1964-1981 (see online supplementary material, Table S4) and were reported as individual species landings, during 1982-1989, were disaggregated[2] into individual species landings for each of the 16 subareas, during 1964-1981, T4 Landings for 65 species/subarea for all gears combined (1964-1989), T5 = species landings of the matrices T3 and T4 were correspondingly conjuncted with matrices E, H and J (Table 1)	Landings for 65 species/subarea/gear (1970-1989), Z1 = T5 · T1 · I (Table 1) Landings for 65 species/subarea/gear (1964-1969), Z2 = T5 · T2 · F (Table 1)
Mean (1982-2007) proportion of landings of the large pelagics in each of the 16 subareas for all gears combined, T6 = was estimated from the matrices J and K (Table 1) Mean (1964-1981) proportion of landings of the large pelagics in each of the 16 subareas for all gears combined, T7 = was estimated from the matrices E and H (Table 1)	Landings for large pelagics/subarea for all gears combined (1982-2007), Z3 = T6 · G (for 1982-2007) (Table 1) Landings for large pelagics/subarea/gear (1982-2007), Z4 = Z3 · T1 Landings for large pelagics/subarea for all gears combined (1964-1981), Z5 = T7 · G (for 1964-1981) (Table 1) Landings for large pelagics/subarea/gear (1964-1981), Z6 = Z5 · T2
Mean (1964-1969) proportions for each of 65 species landings (as taxonomically disaggregated above) in each of the 16 subareas for all gears combined, T8 = were estimated from matrix E (Table 1) Mean (1964-1969) proportions of all species combined for each gear in each of the 16 subareas, T9 = were estimated from matrix F (Table 1)	

TABLE 4. continued

Method used	Spatial-gear disaggregation
In matrices C and D (Table 1), species (see online supplementary material, Table S3) that were reported as aggregated groups during 1950-1963 and were reported as individual species during 1964-2007, were disaggregated into individual species landings per 16 subareas, during 1950-1963 using the methodology of Tsikliras *et al*. (2007), T10 In matrix C (Table 1), species (see online supplementary material, Table S4) that were reported as aggregated groups together with the landings of "other Osteichthyes group", during 1950-1957 and were reported as individual species landings during 1958-1963 (matrix D: Table 1), were disaggregated[4] into individual species landings, during 1950-1957, T11 Landings for 43 species in all subareas and gears combined (1950-1963), T12 = the species landings of the matrices T10 and T11 were correspondingly conjuncted with matrices C and D (Table 1)	Landings for 43 species/subarea for all gears combined (1950-1963), Z7 = T12 · T8 Landings for 43 species/subarea/gear (1950-1963), Z8 = Z7 · T2 · T9
	Landings for 40 species/subarea (15 subareas) for all gears combined (1940-1947), Z9 = B (Table 1) · T13 Landings for 40 species/subareas (15 subareas)/gear (1940-1947), Z10 = Z9 · T2 · T9 Landings for 40 species/subarea (16 subareas) for all gears combined (1948-1949), Z11 = B (Table 1) · T8 Landings for 40 species/subareas (16 subareas)/gear (1948-1949), Z12 = Z11 · T2 · T9
From matrix A (Table 1) the mean (1936-1939) proportions of the marine landings for each of 40 species landings for all gears combined were estimated for each of the 15[5] subareas, T13	Landings for 40 species/subarea (15 subareas)/gear (1928-1939), Z13 = A (Table 1) · T2 · T9

[1] Iterative (100 times) bootstrap technique were used by removing the landings from each year at each time-step. Given that the produced means will be used to hindcast the landings, we assumed that the probability for data to be removed from each year at each time-step increased linearly with time (during 1990-2007) and the landings from more recent years, which overall weighted less, were most frequently eliminated

[2] The mean (1982-1986) proportion of landings for the species that were included in the "other Osteichthyes" group landings during 1964-1981 were estimated. This proportion was multiplied with the annual landings for the "other Osteichthyes" group during 1964-1981 (matrices E and H: Table 1) and with the proportion of the contribution of the "other Osteichthyes" group to the mean (1982-1986) contribution of landings from the "other Osteichthyes" group together with the species that were reported aggregated with this group during 1964-1981. The 1982-1986 period was selected because the landings of the "other Osteichthyes" group remained quite stable (Fig. 4a)

[3] Matrices F, I and T9 were used as weighted factors

[4] The mean (1958-1960) proportion of landings for the species that were included in the "other Osteichthyes" group landings during 1950-1957 were estimated. This proportion was multiplied with the annual landings for the "other Osteichthyes" group during 1950-1957 (matrix C: Table 1) and with the proportion of the contribution of the "other Osteichthyes" group to the mean (1958-1960) contribution of landings from "other Osteichthyes" group together with the species that were reported aggregated with this group during 1950-1957. The 1958-1960 period was selected because the mean proportion of the "other Osteichthyes" group remained quite stable (about 15%)

[5] HELSTAT subarea S16 (Dodecanese Islands) was annexed by Greece in 1948

plementary material, Table S5). Different types of time-varying regressions (i.e. linear, quadratic, exponential: trend analysis) (Stergiou & Christou, 1996) were fitted to the reconstructed landings time series of the different gears and for the dominant species per gear (i.e. those with the highest mean percentage contribution during 1928-2007). Best models were selected based on the value of the coefficient of determination (R^2) and regressions and slopes that were significantly different from 0 ($p < 0.05$) were identified. Finally, the pelagic/demersal ratio (P/D) was also estimated for total (i.e. all subareas and gears combined) landings during 1928-2007.

RESULTS

Total reconstructed landings

Greek total (i.e. all species/subareas/gears combined) reconstructed landings derived from all engined-vessels increased by 2206% between 1928 and 2007, ranging from 6073 tn (in 1928) to 133964 tn (in 2007), with a maximum of 193256 tn, in 1994 (Fig. 2A).

Reconstructed total annual landings for each gear (Fig. 2B) showed a gradual increase during 1928-1994, with small-scale vessels exhibiting a much steeper increase (slope values = 0.059) than those of the remaining 3 gears (slope values; trawlers: 0.031, purse-seiners: 0.039 and beach-seiners: 0.040). Since 1995, purse-seine, beach-seine and small-scale landings gradually decreased (by 48.1%, 23.9% and 18.5%, respectively). In contrast, trawl landings decreased during 1994-1999 and then increased again almost to the mid-1990s level.

The percentage contribution of each gear to the total landings during 1964-2007, the period during which landings were reconstructed (black circles in Fig. 2A), is shown in Figure 2C. The percentage contribution of purse-seiners and beach-seiners gradually decreased during 1964-2007 (from 46.6% and 13.4% to 19.5% and 2.7%, respectively), whereas those of trawlers decreased during 1964-1999 (from 20.7% to 11.9%) and then increased again to the mid-1960s level (20.2% for 2007). In contrast, the percentage contribution of small-scale landings gradual increased

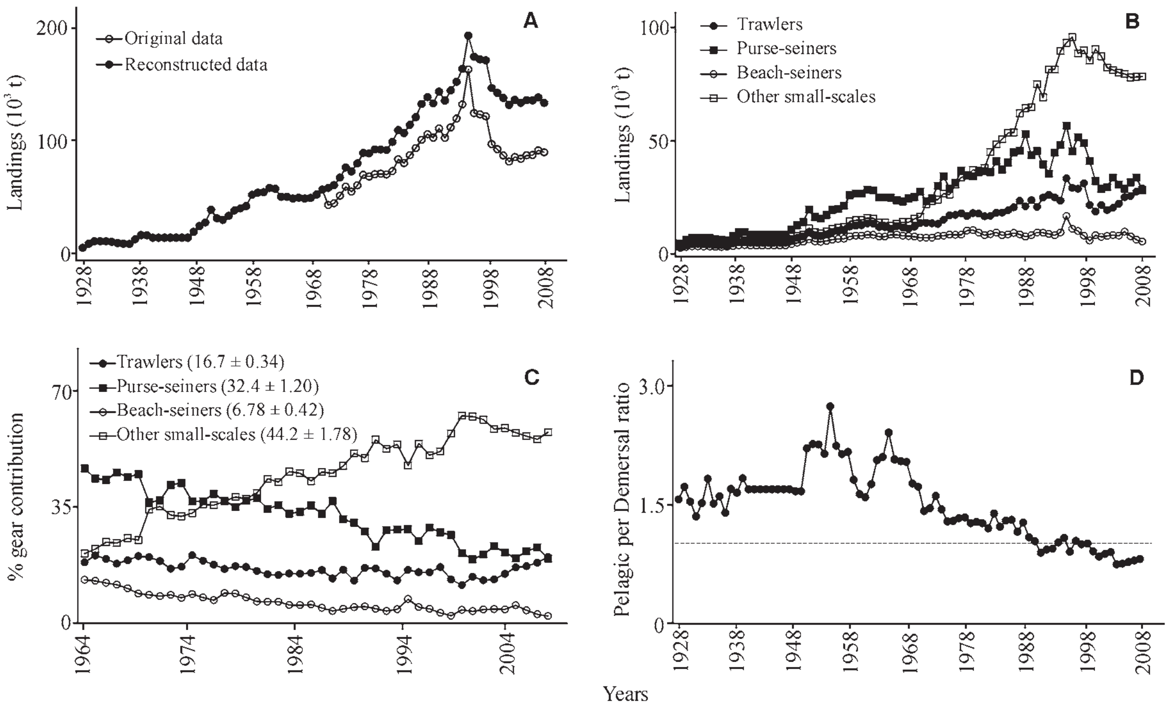

FIG. 2. Greek waters (i.e. all subareas combined). (A): annual original and reconstructed landings, 1928-2007; (B): annual reconstructed landings per gear (i.e. trawlers, purse-seiners, beach-seiners and small-scale vessels), 1928-2007; (C): annual gear contribution (%) of total (i.e. all species/subareas combined) landings per gear (i.e. trawlers, purse-seiners, beach-seiners and small-scale vessels) (mean ± s.e. gear contribution), 1964-2007; (D): Pelagic per Demersal ratio (1928-2007). Dashed line indicated the reference line for equal pelagic and demersal landings.

from 21.3% (in 1928) to 57.3% (in 2007), with a maximum of 62.3% in 1999 (Fig. 2C). The percentage contribution of the landings of small vessels (those recorded by ASG), increased from 25.6% (in 1970) to 32.5% (in 2007), with a maximum of 37.8%, in 2001.

The P/D ratio (Fig. 2D) remained stable during 1928-1949, fluctuating around 1.66, and increased to 2.76 in 1954 and then gradually decreased to 0.83, in 2007, with a minimum value of 0.76, in 2003.

Reconstructed landings per fishing subarea and gear

Annual total landings per subarea and gear during 1928-2007 are shown in Figure 3. More than 50% of the time-series exhibited an exponential positive trend (35 out of 64 time series), whereas 19 out of the 64 landings series exhibited a quandratic trend, nine landings series a linear increasing trend and one landings series a non-significant trend (that for subarea S9 for trawlers).

Landings from trawlers and other small-scale vessels generally peaked during 1990-1998 for most fishing subareas, whereas those from beach-seiners and purse-seiners peaked over an extended period (1965-1999), depending on subarea (Fig. 3).

In subarea S12, three out of the four fishing gears (i.e. trawlers, purse-seiners and small-scale vessels) landings contributed equally to the total landings, while, purse-seine landings dominated in subareas S8, S11, S13 and S14 and small-scale vessel landings in all the remaining subareas (Fig. 3).

Trends in the landings of the dominant species per subarea and gear

The species dominating the landings of each gear varied with subarea (Fig. 4). Thus, for trawlers, *Spicara smaris* was the dominant species in eight subareas (central-south Ionian and Aegean Seas: S5, S6, S7, S10, S12, S15, S17 and S18), *Merluccius merluccius* and *Mullus barbatus* each in two subareas, and *S. flexuosa*, *Trachurus mediterraneus*, *Engraulis encrasicolus* and Natantia each in one subarea (Fig. 4). For purse-seiners, *Sardina pilchardus* and *E. encrasicolus* dominated the landings each in six subareas (S3-S6/S14-S15 and S8-S13, respectively), *Boops boops* in three subareas (south Aegean: S7, S17, S18) and *Scomber japonicus* in S16. For beach-seiners, *S. smaris* dominated the landings in all subareas except in the Thracean Sea (S14), where landings where dominated by *S. pilchardus*. Finally, for small-scale vessels, *B. boops* was the dominant species in four subareas (south Ionian and central-south Aegean Seas: S7, S8, S12 and S17), Mugilidae, *S. pilchardus* and *M. merluccius* in three subareas each (S10, S11 and S15; S4, S13 and S14; S3, S5 and S9, respectively) and *Dentex macrophthalmus* and *X. gladius* in one subarea each (Cretan Sea: S18, and south Ionian: S6, respectively) (Fig. 4).

The landings of the most abundant species per subarea and gear exhibited variability and 61 out of 64 landings series displayed significant ($p < 0.05$) trends during 1928-2007 (Fig. 4). Species landings from trawlers and purse-seiners mostly exhibited significant ($p < 0.05$) exponential (for 6 out of 16 cases for each gear) and quandratic (for 9 and 8 cases, respectively) trends, whereas very few exhibited non significant trends (for 1 and 2 cases, respectively). Species landings from beach-seiners mostly exhibited significant ($p < 0.05$) quadratic trends (for 12 out of 16 cases), followed by exponential trends (in 4 cases). Species landings from small-scale vessels mostly exhibited significant ($p < 0.05$) exponential trends (for 12 out of 16 cases), in three cases linear increasing trends and in one case a quandratic trend.

DISCUSSION

In the present study, we reconstructed Greek commercial fisheries landings by gear and subarea for an extended period and built a time series of total commercial landings for 1928-2007. We also reconstructed the landings for 75 species, depending on the periods (see online supplementary material, Table S4), for four gears and 16 subareas during for 1928-2007 (i.e. overall 4800 time series), all available in the online supplementary material (see online supplementary material, Table S5). A similar compilation/reconstruction of fishing effort by gear is also in progress (Moutopoulos *et al*., unpublished data). The main reason for doing such a reconstruction was, apart from evaluating the historical development of the Greek fisheries (see also Moutopoulos & Stergiou, 2011), to: (a) evaluate the status of the Greek fisheries using various ecological indices/analyses on a gear/subarea basis (e.g. Marine Trophic Index: Pauly & Watson, 2005; Fisheries in Balance Index: Pauly *et al*., 2000; trophic spectra analysis: Libralato & Solidoro, 2010; pelagic/demersal ratios: Enin & Groger, 2004) and fisheries indices/analyses (e.g. catch-effort models: Hilborn & Walters, 1992) and (b) develop mass-balanced models (Ecopath with Ecosim; Pauly *et al*., 2000) in order to outline the potential effects of multi-species and multi-gear fisheries in a ecosystem-

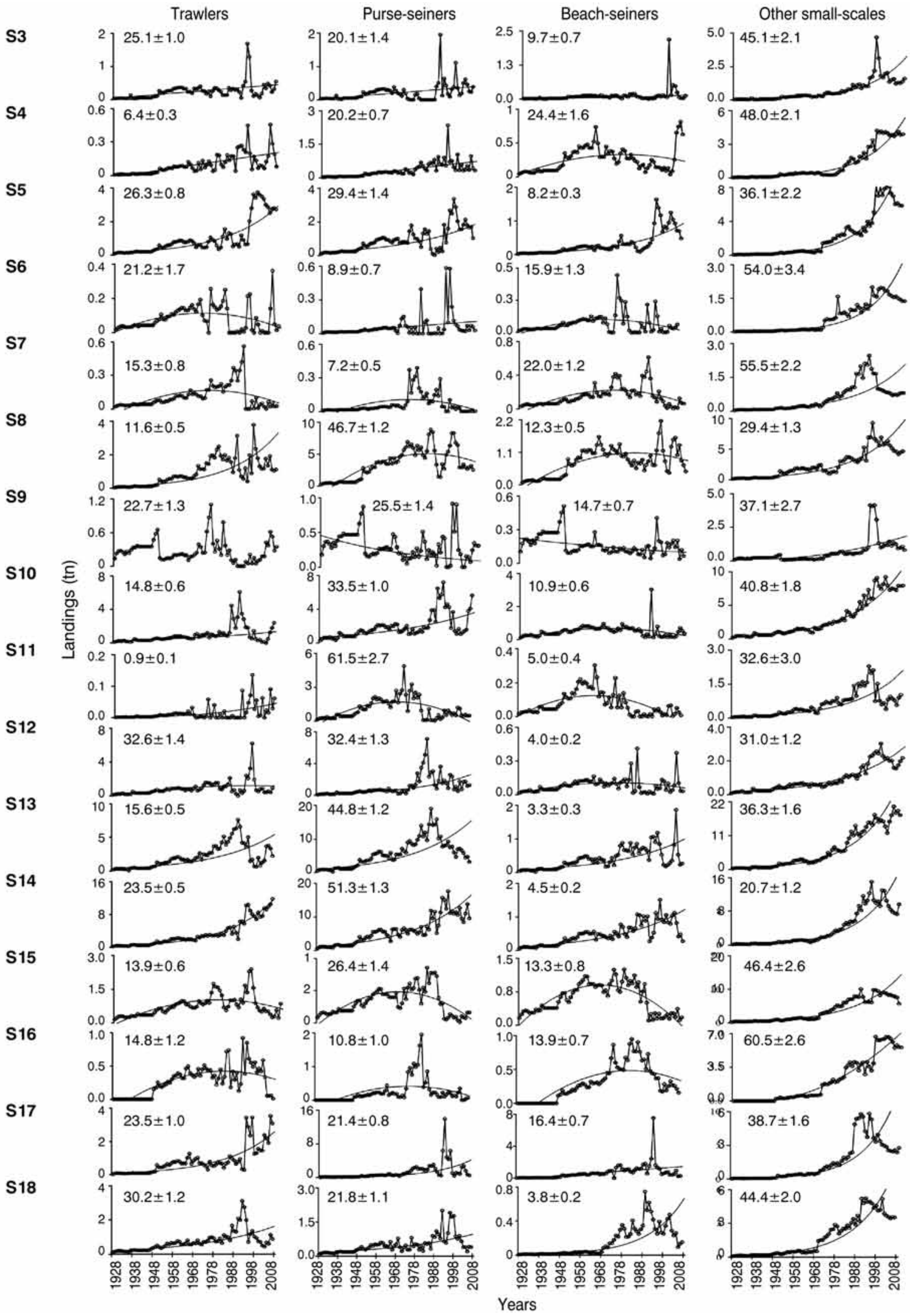

FIG. 3. Annual total (i.e. all species combined) landings per gear (i.e. trawls, purse- and beach-seines and small-scales) and fishing subarea (subarea numbers followed Fig.1), Greek waters, 1928-2007. Significant ($p < 0.05$) trends are also shown. Numbers indicated mean (± s.e.) % contribution of landings per subarea.

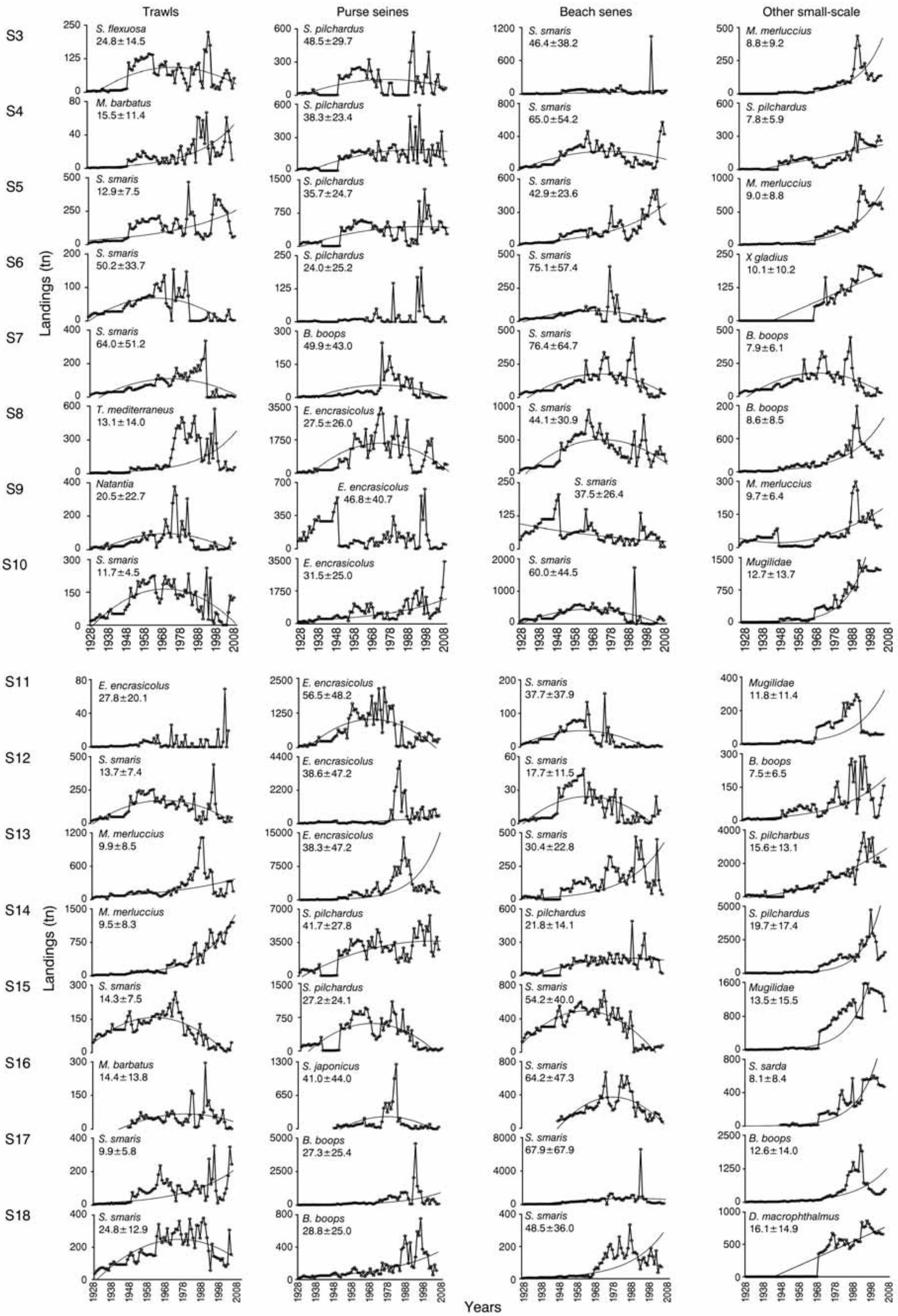

FIG. 4. Annual species landings for the most abundant species per gear-subarea, Greek waters, 1928-2007. Significant ($p < 0.05$) trends are also shown. Numbers indicated mean (± s.e.) % contribution of landings per gear-subarea.

based context and, thus, to evaluate different management scenarios for Greek waters. Disentangling landings by gear on fine spatial scales is important because it reduces the bias in estimates of various ecological indices (Pauly & Palomares, 2005) that might lead to false conclusions about the state of fisheries (Pauly, 2008).

The pattern of the total (i.e. all species/gears/subareas) reconstructed landings during 1928-2007 differs from the one presented in Moutopoulos & Stergiou (2011) in that it includes the landings of small vessels per subarea for the period 1970-2007. However, the reconstructed total landings time series (Fig. 2A) as well as those of each gear separately (Fig. 2B), parallels the pattern shown in Moutopoulos & Stergiou (2011). The latter authors identified four different phases in the development of the Greek fisheries: 1928-1946 (pre-development phase), 1947-1969 (growth phase), 1970-1994 (fully to over-exploited phase) and 1995-2007 (collapse phase). Our present analysis also showed that the general trend for the vast majority of the total (i.e. all species combined) landings per gear and subarea (Fig. 3) and of the most abundant species per gear and subarea (Fig. 4), was an increase from 1928 up to mid 1980s-mid 1990s followed by a decline for the remaining years, depending on each case, which generally agrees with that of the total landings.

This general pattern indicates that the different phases identified in Moutopoulos & Stergiou (2011) were not the result of aggregating landings over different gears and subareas but rather a general pattern for most gears, subareas and dominant species. Thus, the increasing trend of landings during the 'fully to over-exploited' phase (1970-1994), which is attributed to the fleet modernization and geographic/bathymetric expansion of the fisheries (Papaconstantinou & Farrugio, 2000; Anonymous, 2001; Moutopoulos & Stergiou, 2011) was followed by a general decline of landings because fisheries have become unsustainable, independently of gear type and subarea. It is interesting to note that the first sign of overexploitation in Greek waters seem to have already occurred in the early 1950's, especially in enclosed gulfs where most of fishing exploitation was concentrated during that period (Ananiadis, 1970). For instance, during 1949-1956 both the experimental landings and landings per fishing effort of trawlers for *M. barbatus* and *M. merluccius* decreased with time in the enclosed gulfs of subareas S8, S13 and S14 (Ananiadis, 1970). Later, several field studies have shown that some of the most commercially important demersal species in Greek waters (i.e. *M. merluccius*, *M. barbatus*, *Pagellus* spp.) are also overexploited (Stergiou *et al*., 1997; Politou, 2007). Small pelagic fish are also considered to be overexploited (i.e. *E. encrasicolus*: Machias *et al*., 2007 and *S. pilchardus*: Voulgaridou & Stergiou, 2003) and the same is true of large pelagic species (i.e. *X. gladius* and *Thunnus thynnus*: ICCAT, 2003). In addition, the overall mean trophic level of the landings of the species with trophic level >3.5 in Greek waters declined (fishing down) during 1995-2007 (Stergiou, 2005).

Notable exceptions to the above-mentioned pattern of landings evolution were the trawl landings in S14 and S17, where landings continued to increase, the purse-seine landings in S10, where landings increased in the last years, the beach-seine landings in S4, where landings sharply increased in the last years, and the small-scale landings in S10 and S13, where again landings continued to increase. With respect to the landings of the most abundant species per gear and subarea, the exceptions were *E. encrasicolus* (for purse-seiners in S10 and trawlers in S11), *M. merluccius* (for trawlers in S14), Mugilidae (for small-scale vessels in S10) and *S. smaris* (for beach-seiners in S4, for trawlers in S10 and S17), all of which increased during the collapse phase.

Such exceptions might be related to the effect of one or more of the following factors: (a) fisheries legislation changes (i.e. various technical measure most of which were established since 1953: Gonzalvo *et al*., 2011; Moutopoulos & Stergiou, 2011), (b) eutrophication changes (i.e. originated either from the Black Sea, influencing the northern-central Aegean waters: see Stergiou *et al*., 1997; Nikolaidis *et al*., 2005, or locally in enclosed gulfs with limited water renewal, in S4, S10: Stergiou *et al*., 1997; Ferentinos *et al*., 2010), which generally enhance fisheries productivity, especially for small-pelagics (Caddy & Garibaldi, 2000), (c) technological changes (Adamidou, 2007) and (d) climatic changes (Tsikliras, 2008; Corsini-Foka, 2009). However, the small number of such exceptions indicates that they are probably related to local fishing operations and/or other reasons. This is because the four general factors mentioned above would have affected many more cases of gear and species landings. This requires the analysis of the landings of each species participating in the landings per gear and subarea, which is outside the scope of the present paper. There are only two cases that need to be stressed here.

Firstly, the trawl landings in the enclosed and relatively shallow subarea S11 (depth < 100 m) increased, mostly because of the increase of *E. encrasicolus* landings, in the last years (Fig. 3). Trawl landings represented a very small part of the total landings in S11 because of the all year ban on trawling since 1967 (No 1 Royal Decree 50/67). Thus, trawl landings should have been zero because of this ban. The non-zero landings must be attributed to the multiple licensing system, according to which the same vessel operates as trawler outside S11 and as purse-seiner within S11, a fact that probably leads to local misreporting.

The second case refers to the increasing trend for beach-seine landings in S4, as opposed to all other subareas in which beach-seine landings decline because of the gradual withdrawal of this gear (see below). Trawl and purse-seine fishing is banned in a large part of S4 (i.e. the enclosed Amvrakikos gulf) since 1966 (No 8 Royal Decree 917/66) and 1953 (No A81 Royal Decree 23.3/8-4-53), respectively. In addition, the eutrophication of the Amvrakikos gulf has increased in recent years (Ferentinos *et al*., 2010). These two factors probably resulted in an increase in the populations of *S. pilchardus*, *S. smaris* and *B. boops* and this is probably reflected in the increase of the beach-seine landings for these species during recent years.

The low values of the percentage contribution per gear (Fig. 2C) stressed the fact that the parameters used for reconstruction are not varying a lot, thus reconstruction is feasible and robust. The decreasing contribution of beach-seine landings (Fig. 2C) is attributed to the gradual withdraw of beach-seiners from Greek waters, which started in 1980 (Papaconstantinou & Farrugio, 2000) and will end with the complete banning in 2013 (ER 1967/2006) as this gear is considered to be harmful for both the stocks (Stergiou *et al*., 1996) and habitats (Katsanevakis *et al*., 2010). Thus, through EU fundings, 30.6% of beach-seiners have been withdrawn from Greek waters during 1991-2007 (Katsanevakis *et al*., 2010). The increasing contribution of trawl landings during late 1980's is most probably attributed to the fleet modernization and geographic expansion of the trawl fisheries (Papaconstantinou & Farrugio, 2000; Anonymous, 2001). In addition, the gradual withdraw of beach-seiners, which exploit the same demersal and inshore species as trawlers do (Stergiou *et al*., 1996), left room for the 'expansion' of trawling.

The decreasing contribution of purse-seiners to the total landings during 1964-2007 might be attributed to the decline in the abundance of small and large pelagic species in recent years (as mentioned above) and mainly to the steep increase of the landings of small-scale vessels and trawlers, which both exploit demersal and inshore species (Stergiou & Petrakis, 1993). As a result, the P/D ratio declined considerably, illustrating the shift from pelagic to demersal dominance in landings (dashed line in Fig. 2D).

The very steep increase in the contribution of small-scale vessels to the total landings during 1964-1999 is attributed to their modernization (Papaconstantinou & Faruggio, 2000), which allowed vessels to fish in more distant and deep waters than before, that lead to a gradual engagement of small-scale vessels into fishing for large pelagic and benthopelagic species (Anonymous, 2001). The high percentage contribution of the small-scale landings as a total (Fig. 2C) as well as for most fishing subareas highlights their significant importance for Greece and is a factor differentiating Greece from other European countries (Tzanatos *et al*., 2006). Thus, the next step of future research should be the dissentagle of small-scale landings into their constituent gear components (i.e. netters and longliners).

It is important to note that a significant part of the small-scale landings usually are directed to the local market, hotels and restaurants (Tzanatos *et al*., 2006), without passing through the wholesale market. Thus, it is quite probable that small-scale landings are highly underestimated and the illegal, unreported and unregulated (IUU) (Tinch *et al*., 2008) part of the small-scale catches is probably very high. Thus, accurate estimates of IUU catches are very important for the management of Greek resources, and require urgent attention in terms of proper and regular estimation.

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ONLINE SUPPLEMENTARY MATERIAL

Supplementary data associated with this research paper are presented on the online version of this manuscript (www.jbr.gr).

REFERENCES

Adamidou A, 2007. Commercial fishing gears and methods used in Hellas. In: Papaconstantinou C, Zenetos A, Vassilopoulou V, Tserpes G, eds. *State of the Hellenic marine fisheries*. Hellenic Centre for Marine Research, Athens: 118-131.

Ananiadis KI, 1968. *Greek fisheries. Prospects and perspectives of development*. Centre of National Programme & Economic Research, Athens.

Ananiadis KI, 1970. The effects of trawl fishing on the stocks of different commercial species in Greek waters. *Proceedings of the Hydrological Institute of Athens Academy*: 493-497.

Anonymous, 2001. *Patterns and propensities in Greek fishing effort and catches*. Report to the EU (DGXIV), Project 00/018.

ASG (Agricultural Statistics of Greece), 1977-2009. *Statistical Year-Book. Thirty two issues (for the years 1975-2006)*. Athens, Greece.

Caddy JF, Garibaldi L, 2000. Apparent changes in the trophic composition of world marine harvests: the perspective from FAO capture database. *Ocean & Coastal Management*, 43: 615-655.

Corsini-Foka M, 2009. Uncommon fishes from Rhodes and nearby marine region (SE Aegean, Sea, Greece). *Journal of Biological Research-Thessaloniki*, 12: 125-133.

EC, 1998. Commission Regulation (EC) No 2090/98 of 30 September 1998 concerning the fishing vessel register of the Community.

Enin UI, Groger J, 2004. An assessment of the biomass production theory in the Baltic Sea using fish landings data. *Journal of Applied Ichthyology*, 20: 362-368.

Ferentinos G, Papatheodorou G, Geraga M, Iatrou M, Fakiris E, Christodoulou D, Dimitriou E, Koutsikopoulos C, 2010. Fjord water circulation patterns and dysoxic/anoxic conditions in a Mediterranean semi-enclosed embayment in the Amvrakikos Gulf, Greece. *Estuarine, Coastal and Shelf Science*, 88: 473-481.

Galinou-Mitsoudi S, Vlahavas G, Papoutsi O, 2006. Population study of the reported bivalve *Pinna nobilis* (Linnaeus, 1758) in Thermaikos Gulf (North Aegean Sea). *Journal of Biological Research-Thessaloniki*, 5: 47-53.

Gonzalvo J, Moutopoulos DK, Bearzi G, Stergiou KI, 2011. Fisheries mismanagement in a Natura 2000 area in western Greece. *Fisheries Management and Ecology*, 18: 25-38.

GSSG (General Statistical Service of Greece), 1934-1940. *Statistical Year-Books. Seven issues (for the years 1928-1939)*. Athens, Greece.

HELSTAT, 1966-2009. *Results of the sea fishery survey by motor boats. Forty four issues (for the years 1964-2004)*. Hellenic Statistical Authority of Greece, Athens.

Hilborn R, Walters CJ, 1992. *Quantitative fisheries stock assessment*. Chapman & Hall, New York.

ICCAT, 2003. Report of the Sixth GFCM-ICCAT meeting on stocks of large pelagic fishes in the Mediterranean. *ICCAT Collective Volume of Scientific Papers*, 55: 1-84.

Katsanevakis S, Maravelias CD, Vassilopoulou V, Haralambous J, 2010. Boat seines in Greece: Landings profiles and identification of potential metiers. *Scientia Marina*, 74: 65-76.

Libralato S, Solidoro C, 2010. Comparing methods for building trophic spectra of ecological data. *ICES Journal of Marine Science*, 67: 426-434.

Machias A, Giannoulaki M, Somarakis S, Siapatis A, 2007. Small pelagic fish. In: Papaconstantinou C, Zenetos A, Vassilopoulou V, Tserpes G, eds. *State of the Hellenic marine fisheries*. Hellenic Centre for Marine Research, Athens: 192-207.

Moutopoulos DK, Stergiou KI, 2011. The evolution of Greek fisheries during 1928-1939. *Acta Adriatica*, 52: 183-200.

Nikolaidis G, Koukaras K, Aligizaki K, Heracleous A, Kalopesa E, Moschandreou K, Tsolaki E, Mantoudis A, 2005. Harmful microalgal episodes in Greek coastal waters. *Journal of Biological Research-Thessaloniki*, 3: 77-85.

Papaconstantinou C, Farrugio H, 2000. Fisheries in the Mediterranean. *Mediterranean Marine Science*, 1: 5-18.

Papaconstantinou C, Kavadas S, Tsimenidis N, Economou AN, Bazigos G, 2002. Design of a system for the collection and compilation of basic fisheries statistics in the Mediterranean: a case study for Greece. *Fisheries Research*, 57: 155-167.

Pauly D, 2008. Global fisheries: a brief review. *Journal of Biological Research-Thessaloniki*, 9: 3-9.

Pauly D, Palomares ML, 2005. Fishing down marine food web: it is far more pervasive than we thought. *Bulletin of Marine Science*, 76: 197-211.

Pauly D, Watson R, 2005. Background and interpretation of the "Marine Trophic Index" as a measure of biodiversity. *Philosophical Transactions of the Royal Society B-Biological Sciences*, 360: 415-423.

Pauly D, Christensen V, Walters C, 2000. Ecopath, Ecosim and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES Journal of Marine Science*, 57: 697-706.

Politou C-Y, 2007. Current state of demersal fisheries resources. In: Papaconstantinou C, Zenetos A, Vassilopoulou V, Tserpes G, eds. *State of the Hellenic marine fisheries*. Hellenic Centre for Marine Research, Athens: 183-191.

Stergiou KI, 2005. Fisheries impact on trophic levels: Long-terms trends in Hellenic waters. In: Papathanasiou E, Zenetos A, eds. *State of the Hellenic marine environment*. Hellenic Centre for Marine Research, Athens: 326-329.

Stergiou KI, Petrakis G, 1993. Description assesment of the state and management of the demersal and inshore fisheries resources in the Hellenic seas. *Fresenius Environmental Bulletin*, 2: 312-319.

Stergiou KI, Christou ED, 1996. Modelling and forecasting annual fisheries catches: comparison of regression, univariate and multivariate time series methods. *Fisheries Research*, 25: 105-138.

Stergiou KI, Petrakis G, Politou C-Y, 1996. Small-scale fisheries in the South Euboikos Gulf (Greece): species composition and gear competition. *Fisheries Research*, 26: 325-336.

Stergiou KI, Christou ED, Georgopoulos D, Zenetos A, Souvermezoglou C, 1997. The Hellenic Seas: physics, chemistry, biology and fisheries. *Oceanography and Marine Biology: an Annual Review*, 35: 415-538.

Stergiou KI, Moutopoulos DK, Tsikliras AC, Papaconstantinou C, 2007. Hellenic marine fisheries: a general perspective from the national statistical service data. In: Papaconstantinou C, Zenetos A, Vassilopoulou V, Tserpes G, eds. *State of the Hellenic marine fisheries*. Hellenic Centre for Marine Research, Athens: 141-150.

Tinch R, Dickie I, Lanz B, 2008. *Costs of illegal, unreported and unregulated (IUU) fishing in EU fisheries*. Economics for the Environment Consultancy Ltd, London.

Tsikliras AC, 2008. Climate-related geographic shift and sudden population increase of a small pelagic fish (*Sardinella aurita*) in the eastern Mediterranean Sea. *Marine Biology Research*, 4: 477-481.

Tsikliras AC, Moutopoulos DK, Stergiou KI, 2007. Reconstruction of Greek marine fisheries landings, and comparison of national with the FAO statistics. In: Palomares MLD, Stergiou KI, Pauly D, eds. *Fishes in Databases and Ecosystems*. Fisheries Centre Research Reports, Vancouver, 14: 1-17.

Tzanatos E, Dimitriou E, Papaharisis L, Roussi A, Somarakis S, Koutsikopoulos C, 2006. Principal socio-economic characteristics of the Greek small-scale coastal fishermen. *Ocean & Coastal Management*, 49: 511-527.

Voulgaridou P, Stergiou KI, 2003. Trends in various biological parameters of the European sardine, *Sardina pilchardus* (Walbaum, 1792), in the Eastern Mediterranean Sea. *Scientia Marina*, 67: 269-280.

Zeller D, Pauly D, 2006. *Reconstruction of marine fisheries catches for key countries and regions (1950-2005)*. Fisheries Centre Research Reports 15, Vancouver.