

Can a simple Pelagic-Demersal ratio explain ecosystem functioning?

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ABSTRACT

In quantity terms, the proportion of the total marine fish landings which is accounted for by pelagic fish has increased continuously, with large oscillations reflecting natural variations of resources productivity and fishing strategies. The aim of the present work is to assess this trend in different Mediterranean fishing areas from 1970 to 2005 using the Pelagic/Demersal ratio (P/D). The P/D ratio is a simple ecosystem indicator based on commercial landings and provides a measure of the status of the fish community also in data-poor fisheries situations. Simple statistical techniques were used to study fishery ecosystem through the collection and comparison of geographical parameters as chlorophyll-*a* (Chl-*a*) pigmentation intensity and rainfall. In all the Mediterranean the P/D ratio appears to be correlated with the mean Chl-*a* value and increased with time, this may depend both on a better availability of nutrients in the water column and the overexploitation of resources. The areas where there is a greater presence of zones of upwelling and nutrient inputs are the ones with the highest values of the index. Additionally, comparison with the analysis of the multispecies landings shows that the trend of the index is influenced by the landings of Clupeidae and Engraulidae, a fact showing that fisheries in these areas are increasingly relying on the smaller, short-lived fishes from the lower part of marine food webs.

KEY WORDS

Pelagic-Demersal ratio; Mediterranean Sea; Chlorophyll-*a*; Rainfall.

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INTRODUCTION

There is a growing understanding that exploited fish populations must be considered as integral components of ecosystem function, rather than units operating independently of their environment (Cury & Christensen, 2005). Internationally, there has been wide recognition of the need to move towards an ecosystem approach to fisheries, a development spearheaded by FAO through their Code of Conduct for Responsible Fisheries (Garcia, 2000), and supported by many regional and national institutions.

A special attention has been focused on fishing in the Mediterranean Sea, where significant ecosystem changes have become evident in recent de-

cades (Zaitsev, 1994; Caddy et al., 1995; Pauly & Watson, 2004).

FAO data show that landings from marine fish species (about 400,000 tonnes) has increased continuously, with large oscillations reflecting natural variations of resources productivity as well as probably boom and bust fishing strategies.

The modernisation of small- and large-scale fishing fleets (i.e., larger boats, higher tonnage and engine horsepower, improved fishing gears, use of high-technology equipment) led to the expansion of fishing in areas previously inaccessible (Stergiou et al., 1997).

As a result, new 'resources' started to be exploited, mostly at high trophic levels. Moreover, while

earlier studies suggest that the Mediterranean was originally very nutrient-limited (Murdoch & Onuf, 1972), recent researches show that the ecosystem is significantly affected by nutrient runoff over the last years.

Pelagic fishes are generally influenced by nutrient enrichment when it stimulates the plankton production (Caddy, 1993), while demersal fishes are influenced by the dynamics of benthic community, which generally responds negatively to the conditions of excessive enrichment (De Leiva Moreno et al., 2000).

The aim of the present work is to assess this trend in the Mediterranean Sea with the use of the ecosystem indicators. These indicators are to be estimated by fishery, environmental data and simple statistical techniques.

The Pelagic/Demersal index is a simple indicator that can be derived from commercial statistics. This ratio synthesizes the structure and functioning of the ecosystem in time and space and, in turn, how fisheries and eutrophication influence them (Libralato et al., 2004).

In fact, an increase in the P/D ratio of landings would seem to imply either an increase in forage fish abundance due to predatory release or environmental change. The decline of top predators stocks due overfishing leads to expansion in biomass of pelagic fishes. A similar result may occur with eutrophication, because the demersal resources are adversely affected by hypoxia resulting from excess primary production, which has less negative effects (or may even be positive) for pelagic species.

For this reason, the trend of the P/D index was compared with multispecies landings, with an independent index of primary production, namely the surface concentration of Chlorophyll-*a* (Chl-*a*), and with an index of potential land runoff impacts on marine fisheries such as precipitation to the sea surface.

The present study shows the potential of the Large Marine Ecosystem approach to examine these phenomena in the whole Mediterranean fishery ecosystem, in order to obtain an integrated insight of environmental and fishery issues.

The innovativeness of this approach is the consideration of the ecosystem as a whole including all the geographical, biological and ecological interactions, allowing the acquisition of new knowledge of coastal and marine ecosystems (Pennino et al., 2011).

MATERIALS AND METHODS

Fishery data was achieved from the GFCM (General Fisheries Commission for the Mediterranean) database (www.fishbase.org) that presents annual statistics allocated by countries, species items and statistical divisions, of capture production in the Mediterranean and Black Sea region for the period 1970-2005. For statistical purposes the Mediterranean GFCM region, which coincides with the FAO fishing "Area 37- Mediterranean and Black Sea", has been split into seven divisions (Fig. 1).

We have only analyzed the data of Mediterranean Sea, excluding those of the Black Sea. Landings data refer to nominal catches of 251 different species, not biomasses, and refer legal and reported large- and small-scale fisheries, excluding recreational or sport fishing.

These are collected by the national institution and reported to FAO by Member Countries. The data exclude production from marine aquaculture practices and statistics for marine mammals and seaweeds. The P/D index is estimated as the ratio between pelagic species and demersal species, that were defined by trophic information that classify the diet of adults of each commercial species, and were extracted from Stergiou & Vasiliki (2002) and fishbase website (<http://www.fishbase.org>). The P/D ratio was calculated for all 35 years of time series and for each division.

Subsequently, the index trend was compared with their multispecies landings grouped in 15 groups according to trophic level. The trophic level of each group is a mean of the different values that exist for a given species, obtained from Fishbase (www.fishbase.org) and from Stergiou & Vasiliki (2002). The environmental data used in this study were acquired using the "GES-DISC Interactive Online Visualization AND aNalysis Infrastructure (Giovanni), as part of the NASA's Goddard Earth Sciences (GES) Data and Information Services Center (DISC)" (<http://ocean-color.gsfc.nasa.gov/>).

An independent index of primary production, namely the surface concentration of Chlorophyll-*a* (Chl-*a*) was used based on remote sensing imagery from 1998 to 2005. Obviously primary production depends on a range of factors, including light, light penetration, temperature, which could not be taken into account here for the absence of comparable

quantitative data with a broad temporal and geographical coverage.

Nevertheless, the mean annual value of Chl-*a* is an index of primary production that represents the seasonal production of the marine area considered. To extract and analyze the Chl-*a* data we used the function “Lat-Lon Map, Time-averaged” that provides a time-averaged colour data plot for a specified area. The values plotted are the mean value of the data product calculated for year. After adjusting for different grid referencing systems, maps of the GFCM subdivisions were superimposed on images of mean Chl-*a* values, in order to obtain specific information for each fisheries subdivision.

We analyzed the data of rainfall to the sea surface to assess a nutrient input for every division and year of the series. The annual mean data are extracted with the same function “Lat-Lon Map, Time-averaged”, as mm/hr for rain rate for mm for accumulated rainfall. The source is TRMM and Other Satellite Monthly 0.25° x 0.25° Rainfall Data Product (3B43 Version 6).

RESULTS

Balearic

The area of Mediterranean Sea that has the highest values of P/D ratio is Balearic with a mean of 3.15 (Table 1). The trend of the index reaches the highest values in 1988 with 4.32 and in 1994 with 3.97 (Fig. 1). Comparing this P/D trend with the landings it can be seen that in those same years there have been increases in the landings of the class Clupeidae with respectively 146,704 and

Divisions	Chl- <i>a</i> (mg/mm ³)	Rainfall (mm/Km ²)	P/D index
Balearic	0.45	583	3.15
Gulf of Lions	0.79	618	2.80
Sardinia	0.31	624	0.45
Adriatic	0.95	911	0.90
Ionian	0.39	454	0.80
Aegean	0.27	559	1.23
Levant	0.68	356	0.80

Table 1. Mean of Chlorophyll-*a*, Rainfall and Pelagic/Demersal index for all Mediterranean divisions (1998-2005).

172,747 tonnes (Fig. 2). In the first half of the 80s landings of this class suffered a decline, while increasing those of the class Engraulidae (Fig. 2).

The analysis of the time series shows a negative relationship between these classes, i.e. any decrease in landings of Clupeidae is offset by an increase of landings of Engraulidae. These two categories are respectively 55% and 10% of total landings of Balearic. The most representative species in the class Clupeidae is the European sardine (*Sardina pilchardus*), while in the class Engraulidae is the European anchovy (*Engraulis encrasicolus*).

The index of primary production, calculated by the time series of 1998-2005, shows constant trend

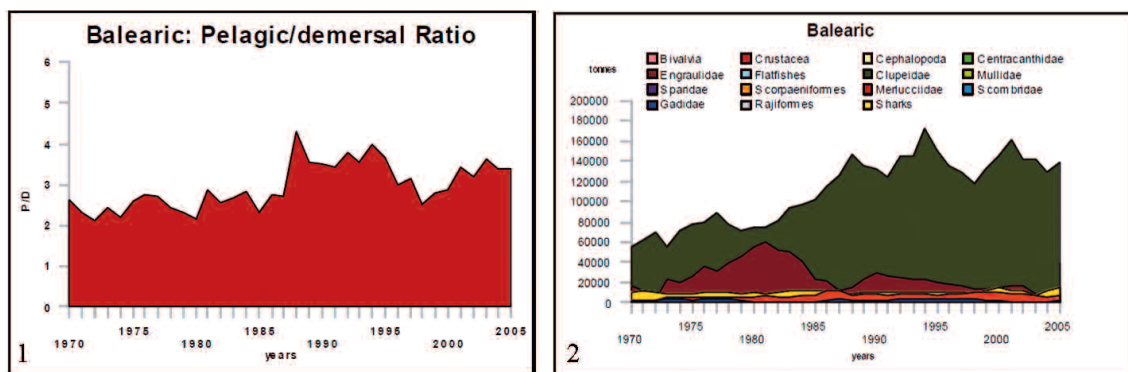


Figure 1. Pelagic/Demersal ratio of Balearic. Figure 2. Group's landings of Balearic.

with a minimum value of 0.41 (mg/mm³) in the first year of the series, and a maximum of 0.48 (mg/mm³) in 2001. The peak of Chl-*a* in 2001 is also found in the values of P/D index and corresponds to an increase in Clupeidae landings (Fig. 15).

The increased intake of nutrients in these years is not found in the trend of Chl-*a*, but the trend is reflected in the P/D ratio. In fact in 2003 the index recorded a value of 3.63, the highest in the last years series. At the species level in the same year class Scombridae landings increased of 11,000 tonnes.

The precipitation levels remain fairly constant across the years with values around 500 mm, except in 2002 and 2003, which recorded an average of 700 mm (Fig. 16). Another factor to take into account is that Balearic receives inflows of Atlantic water with significant inputs of nutrients with important upwelling occurring in the Alboran Sea and along the Algerian coast (Estrada, 1996; Caddy & Oliver, 1996).

Gulf of Lions

After the Balearic, the Gulf of Lions is the area with the highest average P/D, with a value of 2.80 (Table 1). The higher values of the time series are recorded in the early years, matching the biggest landings of the class Clupeidae and Engraulidae. The two classes are the 45% and 16% of the total landings. The minimum values are found in 1986 and 1982 (1.2 and 1.13) corresponding to an increase in the landings of the Bivalvia (Figs. 3 and 4). In 2003 there was a further decline in the P/D index, given the increased Merluccidae landings (Fig. 4).

In the same year the index of primary production shows its lowest value (0.69 mg/mm³). The year 2001 shows the highest peak in the trend of Chl-*a*, as in Balearic, and corresponds to an increase in the P/D index and in the Engraulidae landings (Fig. 15).

The index P/D shows a declining trend in 2005 correlated with a decrease in landings of small pelagic species, but not with the concentration of Chl-*a*. The average rainfall is one of the highest in the Mediterranean, taking into consideration that it is the smallest division, and also the area receives considerable inputs from the river Rhône.

In 2001, when the trend of Chl-*a* and the P/D ratio record the maximum value, the level of rainfall in the area is minimal (Fig. 16). The maximum value of precipitation is recorded in 2002 (834 mm), year when the landings of the class Engraulidae increase of 4,000 tonnes, while those of class Clupeidae decrease by 3,000 tonnes.

Sardinia

The lowest P/D index occurs in the Sardinia division and remains below unity for the entire time series, with a mean the 0.45 (Table 1). Only in its first decade in which landings of Engraulidae and Clupeidae are high, the values exceed the unit (Figs. 5 and 6). In recent decades they have been represented mainly by the class Bivalvia. Until 1986 the landings of small pelagic fish are between 20,000 and 30,000 tonnes.

In these years a negative relationship is apparent between the landings of Engraulidae and Clupeidae, i.e. a rise in landings of one group reflects a decrease in the other group. Since 1987 the landings show a sharp drop of 20,000 tonnes. Only in 1993 the Engraulidae class has a peak of 10,000 tonnes, while Clupeidae in 1999, 2003 and 2005.

The P/D index shows an increase only in 1999 and 2005. This is because the index is heavily influenced by the landings of Bivalvia starting in the mid 80s; when landings of this fall in 2005, the index increases up to a value of 0.82. Values of P/D index less than 1 indicate a prevalence of demersal fishes compared to pelagic species.

The landings of this area, unlike others that have a high prevalence in the total landings of pelagic species, have a uniform distribution in all classes (Fig. 6).

Furthermore, in this area most of the fishing boats are mainly of small-scale fishing, which corresponds to a different environmental impact. The index of primary production shows a constant trend with a maximum 0.36 (mg/mm³) in 2005, coinciding with the increase of the Clupeidae landings and the P/D ratio (Figs. 15 and 5).

The minimum value is recorded in 2001 (0.27 mg/mm³). It is surprising that maximum and minimum values are close in time, configuring a quite erratic trend in last years. The decrease of Chl-*a* in 2001 also finds its counterpart in the trend of rainfall. Indeed, the trend remains constant throughout the series with an average of 624 mm and records the minimum value in 2001 with 520 mm (Fig. 16).

Adriatic

De Leiva Moreno et al. (2000) found a mean value of P/D equal to 3.76 in the Adriatic for the historical series 1978-88. From our analysis, the mean P/D is 0.90; years from 1978-88 show the highest values of the index, but always less than 3 (Fig. 7).

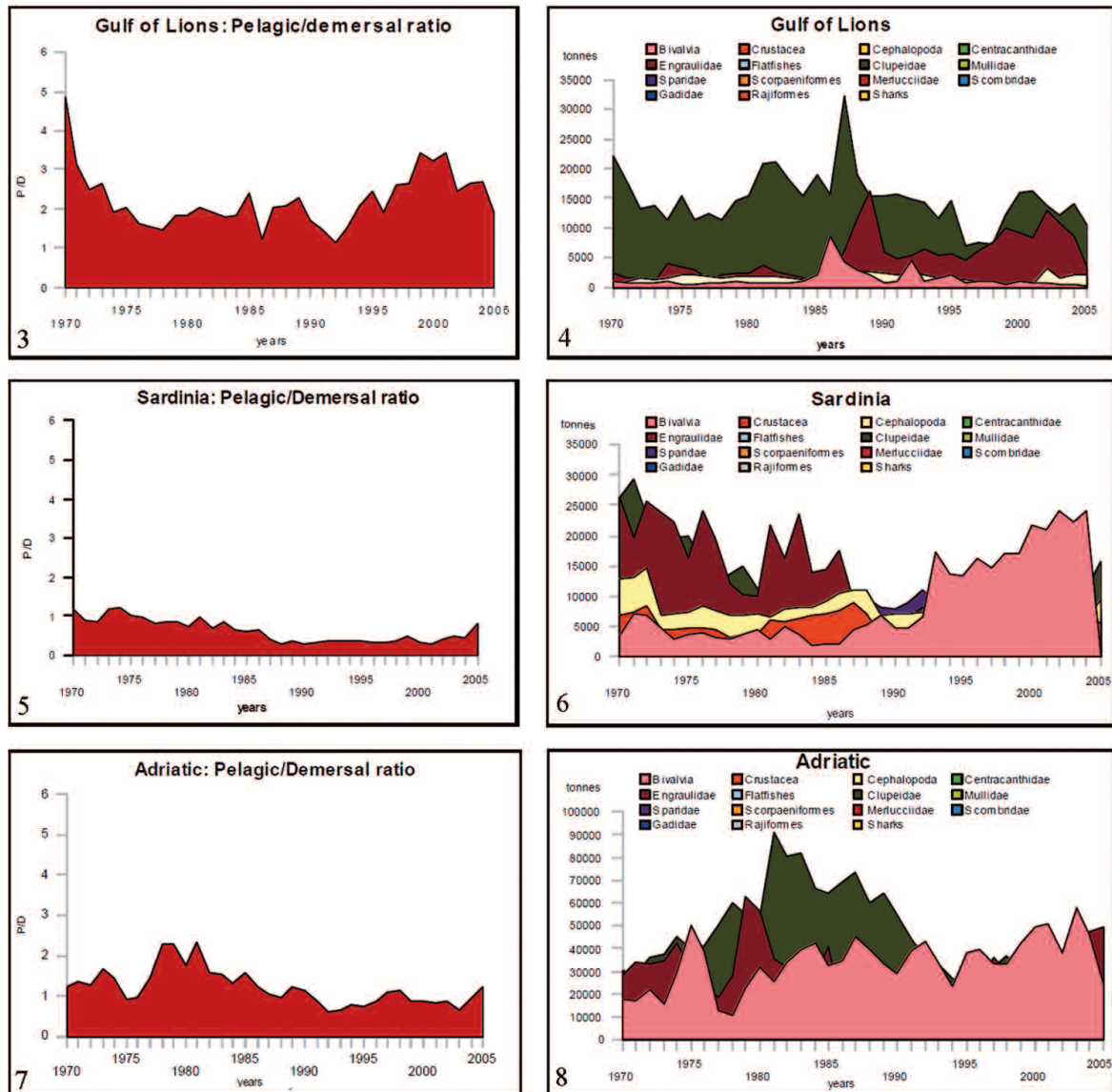


Figure 3. Pelagic/Demersal ratio of Gulf of Lions. Figure 4. Group's landings of Gulf of Lions.

Figure 5. Pelagic/Demersal ratio of Sardinia. Figure 6. Group's landings of Sardinia.

Figure 7. Pelagic/Demersal ratio of Adriatic. Figure 8. Group's landings of Adriatic.

It is known that the Adriatic is under the influence of the rather polluted river Po which brings in around 330,000 t of nitrogen and 28,000 t of phosphorus annually (Degobbis, 1989), and seasonally intense hypoxia of the upper Adriatic is caused by phytoplankton blooms (Legović & Justić, 1997).

Moreover, the analysis of the level of rainfall throughout the Mediterranean shows that the Adriatic has the highest average (911 mm), confirming the major nutrient input from this area. According with these reasons we would expect high values in the index; the analysis by species notes that large

quantities of landings of Bivalvia affect strongly the index (Fig. 8). This class represents 23% of the landings of the area and it is an important local fishery resources, especially in the lagoon of Venice, where the species of the genus *Tapes* are heavily exploited (Granzotto et al., 2003).

Indeed the index P/D, calculated without the landings of the Bivalvia reaches values equal to 4. The index records the highest values in 1979 (2.31), at the peak in landings of Engraulidae (90,000 tonnes), and in 1981 (2.32), at the peak landings in the class Clupeidae (62,000 tonnes).

Over the years 1986-1995 the class Clupeidae undergoes a sharp collapse in the landings and the index P/D shows a declining trend reaching a minimum value of 0.63 in 1992. Comparing the values of Chl-*a* with the other areas, it is clear that the Adriatic is the area with the highest mean (0.95 mg/mm³). Analyzing the time series in the primary production is noted that the minimum value was recorded in 2003 (0.64 mg/mm³) (Fig. 15).

The index P/D shows a positive relationship with the trend by highlighting the minimum value of 0.68 in the same year, reported probably with the highest peak of the whole series of class Bivalvia. In the same year the trend of rainfall records the minimum value (720 mm) (Fig. 16).

In 2002 and 2004 the level of rainfall and Chl-*a* reached the maximum value and the P/D ratio seems to follow these maximums, presenting P/D a slightly increase (Figs. 7 and 8). Landings by species show in 2002 a decrease of 7,000 tonnes in the Engraulidae class, while in 2004 increase of 16,000 tonnes. In 2002 also landings of Bivalvia suffered a collapse and, after a recovery in 2003, continue to decline (Fig. 8).

Ionian

The Ionian has a mean P/D ratio of 0.80, with values of less than 1 for the entire series (Table 1). The 19% of total landings is the Cephalopoda class with a sharp increase in 1988 of 20,000 tonnes. In this area the values of the index and the analysis of the landings do not seem to support that there is a clear predominance of pelagic fish on groundfish (Figs. 9 and 10). In fact, 12% of the landings belongs to the class Merluccidae that significantly reduces the value of the index (Fig. 10).

The Chl-*a* index in this area is generally in the range 0.20-0.30 mg/mm³ and remains constant for the entire time series. After Levant, Ionian shows the lowest average (454 mm) in the level of rainfall, despite being the largest division of the Mediterranean. The trend of rainfall remains constant over the years with values ranging between 500 and 400 mm, except in 2000 where it reached 300 mm (Fig. 16). In the same year also the Chl-*a* registered its lowest value (0.37 mg/mm³) (Fig. 15). In 2003, the values of Chl-*a* and rainfall reach the maximum, while the P/D ratio decreases and the trend of landings by species shows a joint decline in the landings of the class Clupeidae, Sparidae and Scombridae.

Aegean

The Aegean shows a mean P/D ratio of 1.23. The values are higher in the first four years and between 1979 and 1985, reflecting high landings of classes Clupeidae and Engraulidae (Fig. 11). The two categories account for 22% and 15% of the total landings. In correspondence of the years in which values of the index are rising, nutrient inputs increased under the influence of river run-off and Sea of Marmara inflows (Friligos, 1989). Although in recent decades the landings of Clupeidae and Engraulidae classes are significantly increased, values of P/D are less than 2, because there is also a large increase in landings of the class Bivalvia and Crustacea (Fig. 12). The Aegean is considered an oligotrophic area with biological production significantly nutrient-limited. Low levels of surface Chl-*a* pigmentation seem to confirm this feature. In fact the trend of Chl-*a* is constant with values ranging from 0.30 and 0.20 mg/mm³ (Fig. 15).

As far as concerns level of precipitation, the values fluctuate between 500 and 700 mm, with a minimum of 405 mm in 2000 (Fig. 16). In the same year the Chl-*a* shows a minimum value of 0.26 mg/mm³, and the P/D ratio declines. In this year landings of Engraulidae suffer a decline of 4,000 tonnes, while the class Clupeidae increase landings of 6,000 tonnes.

The level of rainfall reaches its peak in 1998 and 2002, respectively with 700 and 600 mm. During those same years, landings of Clupeidae show an increasing trend, while the Chl-*a* does not show values relatively high.

Levant

The P/D ratio for Levant is generally in the range 0-1 and has remained relatively constant, with a mean of 0.80 (Fig. 13). The highest values of the P/D index are between 1993 and 1997 (Fig. 13). Over the same period the landings of the class Clupeidae have suffered an increase of 30,000 tonnes (Fig. 14), and in fact is the category which represents the 30% of the total landings. The values of Chl-*a* in the Levant area are in the range between 0.63 and 0.74 mg/mm³ (Fig. 15).

The maximum value is recorded in 2002. In the same year P/D index reaches the minimum value, presumably due to an increase in landings of the Bivalvia, Mullidae and Crustacea.

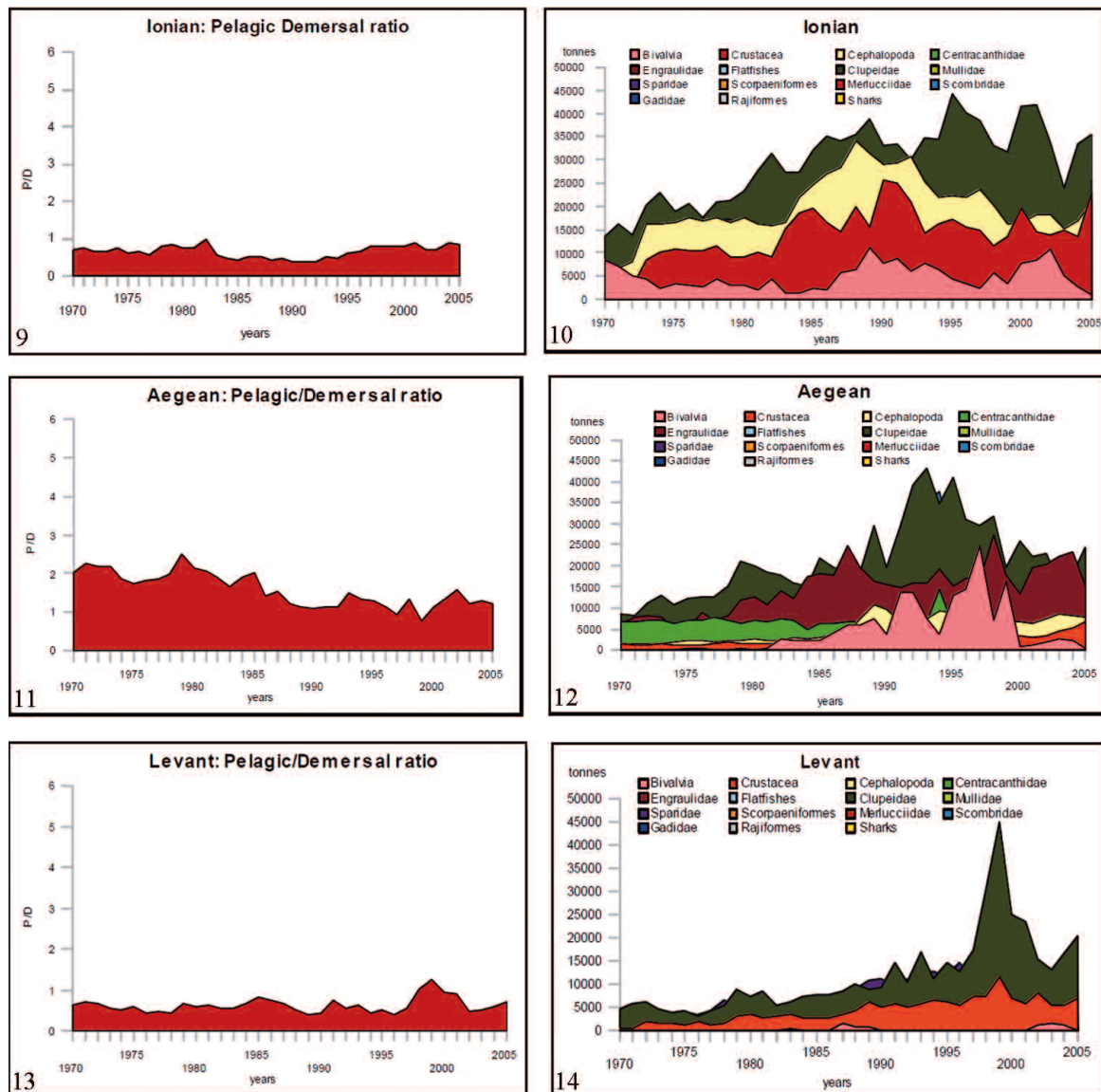


Figure 9. Pelagic/Demersal ratio of Ionian. Figure 10. Group's landings of Gulf of Ionian.

Figure 11. Pelagic/Demersal ratio of Aegean. Figure 12. Group's landings of Aegean.

Figure 13. Pelagic/Demersal ratio of Levant; Figure 14. Group's landings of Levant.

The class Clupeidae undergoes an increase in landings of 30,000 tonnes between 1993 and 1999. Later in 2001 show a decline of 20,000 tonnes, with a minimum of 16,000 tonnes in 2003. Only in 2005 the landings increased another time; the Levant is the area with the lowest average rainfall (356 mm).

In 2001 alone, the trend peak was at 400 mm. The minimum value is recorded in 1999 (251 mm) (Fig.16). In the same year landings of Clupeidae increase of 15,000 tonnes and the P/D index recorded the highest value (1.26).

DISCUSSION

This study supports the idea that analyses of the relationships between landings of pelagic and demersal marine fish are useful indicators of overall trends in fisheries; for example, since the demersal fish stocks are generally in higher demand, a rise in P/D ratio may be caused by a decline in demersal stocks due to overexploitation.

Hence, a positive trend over time in the P/D index may depend both on eutrophication and

overexploitation of resources (Libralato et al., 2004). Nutrient enrichment and overfishing have similar and synergistic effects: a decline in diversity, an initial increase in productivity of benthic/demersal and pelagic food webs, then the progressive dominance of the production system by short-lived, especially pelagic species (Caddy, 1993). In all the areas the ratio between the landings of pelagic and demersal species increased with time, a fact showing that fisheries in these areas are increasingly relying on the smaller, short-lived fishes from the lower part of marine food webs.

It is clear that the small pelagic fish are essential elements of marine ecosystems due to their significant biomass at intermediate levels of the food web, playing a considerable role in connecting the lower and upper trophic levels. Small pelagics are usually considered as forage fish (Tacon & Metian, 2009).

Therefore, fluctuations in small pelagic populations can modify ecosystem structure and functioning and have a major impact on the whole ecosystem. The data show a gradual transition in landings from long-lived, high trophic level, piscivorous bottom fish toward short-lived, low trophic level invertebrates and planktivorous pelagic fish. High exploitation rates have been applied to demersal stocks over the last few decades and particularly in the western Mediterranean. Comparison with the analysis of the multispecies landings shows that the trend of the index is influenced more by the landings of Clupeidae and Engraulidae, which in fact represent more than 60% of the total landings of the Mediterranean area. The analysis also revealed a divergent trend between species most representative

of these classes (*Sardina pilchardus* and *Engraulis encrasicolus*); when the first declines, the latter increases significantly and viceversa. In the last decade the increase in landings of small pelagic fish is probably compounded by increasing competition from the fish meal market due to increasing demands from the aquaculture industry for the production of carnivore fish and shrimps for the high value markets (Tacon & Metian, 2009).

The species considered demersals (although some of them show a pelagic behaviour) represent around 40% of total reported landings in the Mediterranean. In those areas there is an identifiable series of target species as hake (*Merluccius merluccius*), red mullets (*Mullus* spp.), blue whiting (*Micromesistius poutassou*), whiting (*Merlangius merlangus*), anglerfishes (*Lophius* spp.), *Pagellus* spp., bogue (*Boops boops*), picarels (*Spicara* spp.) striped venus (*Chamelea gallina*), *Octopus* spp., cuttlefish (*Sepia officinalis*) and the red shrimp (*Aristeus antennatus*).

Analysis shows that the two environmental variables examined influence the P/D ratio but does not fully explain its trend. The Chl-*a* and rainfall levels may be at least partly associated with nutrient run-off of the areas. In particular, the associations pointed out between the P/D ratio and the Chl-*a* index, suggest that the P/D ratio may be a useful indirect index of the level of nutrients available.

The Mediterranean has been globally considered as an oligotrophic sea (Margalef, 1985; Estrada, 1996; Stergiou et al., 1997). The satellite imagery of Chl-*a* shows a gradual decrease in nutrient which would result in a west to east decrease in productivity, with local exceptions resulting from a north to south productivity gradient due to incoming nutrients

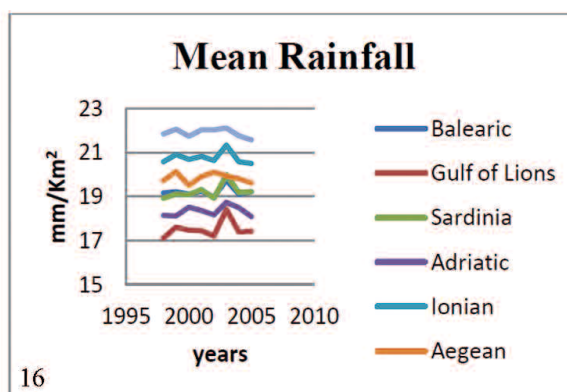
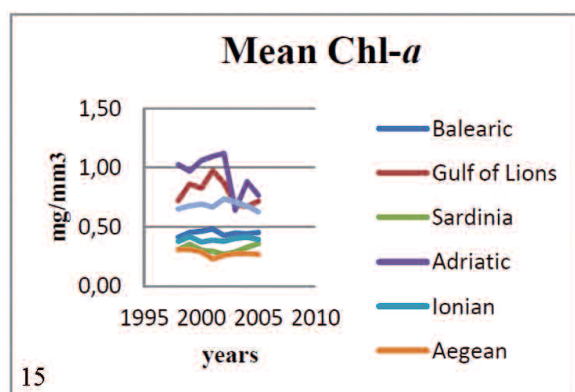


Figure 15. Mean Chlorophylla-*a* (1970-2005). Figure 16. Mean precipitation (1970-2005).

from rivers as the Rhône in the Gulf of Lions, the Po in Adriatic division and different inflows into the Aegean. In Sardinia division nutrient inputs from land are low and, in the south and east, Mediterranean nutrients have been severely depleted during the eastward flow of surface waters from the Straits of Gibraltar (Murdoch & Onuf, 1972; Caddy & Oliver, 1996).

In Ionian area there is a restricted water exchange across the shallow sill between the Adriatic basins, and this seems to reflect a trophodynamic regime efficiently removing nutrients from the coastal current moving southward from the northern Adriatic (Civitarese et al., 1998). Nutrient levels in the Levant are very low and Chl-*a* concentrations off the coast of Israel are between 1/2 and 1/10 of those for the Sargasso Sea, an area of very low primary productivity (Azov, 1990). Also, river run-off has been substantially reduced since blockage of Nile outflow by the Aswan Dam (Halim et al., 1995).

The lowest P/D ratios occur in the Sardinia, Ionian and Levant divisions and remain below unity for the entire time series. In these areas the fisheries are characterised by fragmented fleets, usually composed by relatively small vessels, use of a large number of landing sites and multi-species landings. The positive index indicates a dominance of pelagic on demersal fish, but values less than 1 suggest that the demersal stocks in these areas are not yet fully exhausted. Also areas where there is a greater presence of zones of upwelling and nutrient inputs, as Balearic and Gulf of Lions, are the ones with the highest values, except for the Adriatic where landings of the class Bivalvia greatly influence the trend of the P/D ratio.

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