



## Impact of Depth and Season on the Demersal Trawl Discard

Ali Cemal Gücü<sup>1\*</sup>

<sup>1</sup> Middle East Technical University, Institute of Marine Sciences, P.O.Box 28, Erdemli, 33731, Mersin, Turkey.

\* Corresponding Author: Tel.: +90.324 5212150; Fax: +90.324 5212327;  
E-mail: gucu@ims.metu.edu.tr

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### Abstract

Given that the discard has crucial impact on the coastal ecosystems, various countries around the world adopted various regulations to reduce the discard of non-commercial and undersized commercial species in the trawl catch, such as trawl exclusion depths and closed season. In this work discarded part of the catch of a trawl has been assessed to evaluate impact of depth and season. Monthly trawl-survey data, collected by the same research vessel operating all year round over the entire depth ranges of the same fishing ground, were used in order to minimize the sources of variation. By this mean, potential rather than absolute composition and quantity discarded by a trawl boat were estimated regardless of fishing regulations applied to the fleet. A generalized additive model was used to model the quantity of discarded catch as a function of depth and time. The model outputs were then used to quantify the impact of fishing regulations on the reduction in discard. The results suggested that the quantity of the catch returned to the sea is reduced 49% by trawl closure and 57% by trawling depth limitations. Overall, season and depth regulations reduce the discard by 77% at the expense of a 73% reduction in marketable catch. Finally, past trawl-survey data collected in the 1980s at the same site with the same research vessel and with the same net were used to evaluate possible impacts of regulations on the modification of fish composition

**Keywords:** Discard, depth, season, demersal trawl, GAM.

### Demersal Trollerde Mevsim ve Derinliğin İskarta Oranına Etkisi

#### Özet

Değişkenliğe sebep olabilecek kaynakların en aza indirilebilmesi için tüm yıl boyunca aynı avcılık sahasında tüm derinlik katmanlarında aynı araştırma teknesi ile toplanmış aylık trol örneklemesi sonuçları kullanılmıştır. Bu yolla, bölgede uygulanan balıkçılık düzenlemelerinden bağımsız olarak potansiyel iskarta miktarı ve kompozisyonu elde edilmiştir. İskarta edilen av miktarı Generalized Additive Model kullanılarak derinlik ve zamanın fonksiyonu olarak modellenmiştir. Bunun üzerine elde edilen model uygulanan balıkçılık düzenlemelerinin iskarta miktarını üzerindeki etkisinin sayısallaştırılmasında kullanılmıştır. Sonuçlar, trollere uygulanan ava kapalı dönem ile %49, derinlik (mesafe) yasakları ile ise %57 azaltılmaktadır. Bu düzenlemeler toplamda ise pazarlanabilir avda %73 azalmaya karşılık iskarta miktarını %77 azaltmaktadır. Ayrıca 1980'lerde aynı alanda aynı araştırma teknesi ile yapılan benzer bir çalışmanın sonuçları uygulanan söz konusu düzenlemelerin balık kompozisyonunun şekillenmesindeki olası etkilerinin değerlendirilmesinde kullanılmıştır.

**Anahtar Kelimeler:** İskarta, derinlik, mevsim, dip trolü, GAM.

#### Introduction

As yet unknown, however seemingly very high quantity of the marine animals, including mammals, sea birds and reptiles as well as non-target, low-value species and undersized fish of valuable commercial species killed in fishing operations never make them to market. As reported by the UN's Food and Agriculture Organization, the quantity of unwanted fish catch thrown back each year may be as high as 8

million tons (Kelleher, 2005). The percentage of discard is particularly high for some types of fishery, such as bottom trawling (Alverson *et al.*, 1994). In some areas characterized by multi-species complexity, such as in the Mediterranean Sea, the trawl discard is especially high since very narrow cod-end mesh size is used to catch diverse small sized commercial species (Machias *et al.*, 2001). The unwanted catch, in general, is a concern threatening the entire marine ecosystem. On the other hand,

unaccounted discard mortality causes significant bias in the fisheries regulation practices that are implemented to reduce fishing pressure on an ecosystem (Eayrs, 2007).

There are various measures enforced to reduce by-catch and discard, such as mesh size regulations, use of species exclusive or by-catch reduction devices (BRDs) etc. However effective implementation of these measures may sometimes be a cumbersome matter particularly in the multi-target fishing grounds. For instance, use of turtle exclusive devices (TEDs) or BRDs are claimed to reduce the catch and therefore protested by the fishermen community. Likewise, there is a consensus, among scientists that the discard rate is negatively related to cod-end mesh size and mesh geometry (Ordines *et al.*, 2006; Bahamón *et al.*, 2007). Several solutions based on selectivity experiments have been suggested to reduce the discard rate (Sacchi 2008). The selectivity studies enabled the quantification of the effectiveness on the target species of changing the shape and mesh size of a net (Sardà *et al.*, 2006). However, in practice it is impossible to enforce a unique cod-end mesh size for the entire range of species, especially in the tropics and subtropics, due to the multi-species nature of the catch and the highly variable size range of fish over the fishing grounds. Another important concern is the fate of animals escaping from the net. Although some studies suggest a high survival rate of fish escaping the trawl net, (Düzbastılar *et al.*, 2010) the factors such as net entrainment, wounding, sustained swimming until exhaustion, changes in pressure, biological attributes, immediate predation by attracted predators are still a matter of concern (Suuronen, 2005).

The rate of discard is altered by several factors. The depth of the fishing ground, total catch, tow speed, tow duration, species mix, year class strength and the season are among the critical factors contributing to the discard rate (Murawski, 1996). How strict the authorities are in monitoring the landings, the market demand for the species and other socio-economic aspects of fisheries were also shown to be important (Machias *et al.*, 2004). An important step in the solution of such a complex situation, which involves several sources of variation acting together, would be to discriminate each of the factors affecting the level of discard. The studies addressing the estimation of the discard of a fishing fleet operating in an area are generally and naturally based on sampling directly conducted onboard commercial fishing boats. On the other hand, this increases the sources of variance due to the varying capacities of fishing boats, fishing gear design, the skills of fishing crew, etc. and makes itemization of the factors harder. Also, an attempt to discriminate different factors may require data from the regions and seasons which are restricted to commercial fleet.

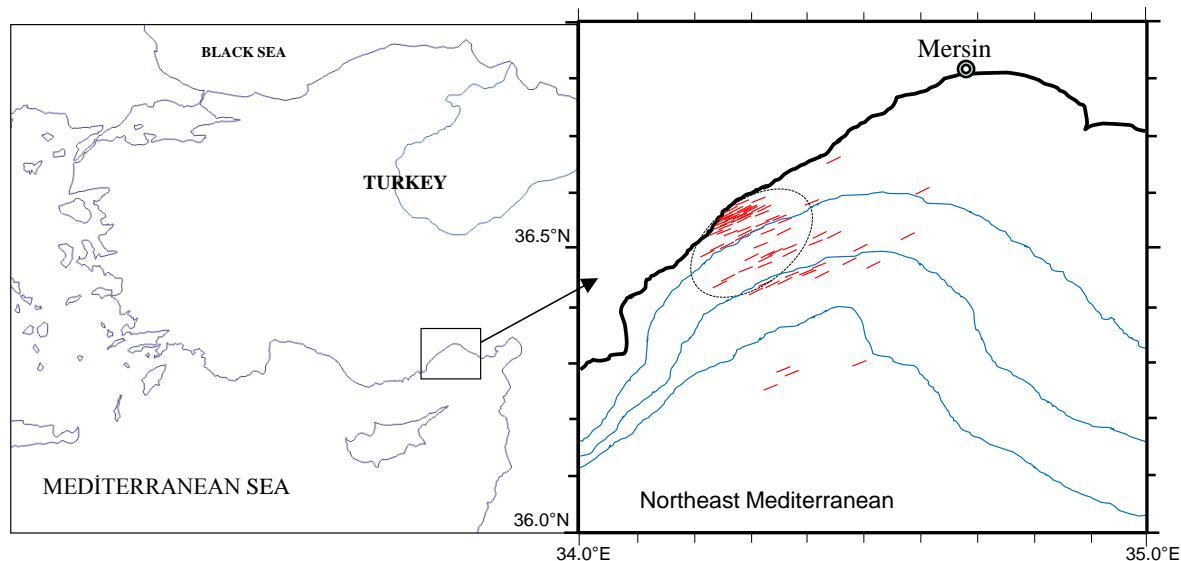
Another important aspect of this issue is, any attempt to reduce discard is essentially a manipulation

on ecosystem. Giving more chance to a part of the fauna to survive, would eventually alter the food web structure in the ecosystem, particularly when the differences in their natural productivity are considered. To better mitigate adverse ecological effects of fishing Garcia *et al.* (2012) suggested maintaining the size and species composition through a strategy aiming at balanced harvesting distributing mortality over the species, stocks, and size ranges in an ecosystem.

Thus in this study, instead of direct sampling onboard a commercial trawler, the discard was modelled and simulated using the data collected by a research vessel. The results were assessed to answer; i) the extent to which the implications of depth and time limitations may reduce the discarded catch individually; ii) how high the cost of these regulations may be; ii) if and how depth and time limitation enforced in an area alters the fish assemblages over a fishing ground.

## Materials and Method

Being a good example representing sites of high trawl discard rate, Mediterranean Sea is a suitable study area to understand the mechanism, controlling discard rate. Therefore, in this study, a location characterizing major peculiarities of the Mediterranean Sea (i.e. fish assemblages, size, spawning season and nursery characteristics of major species, high fishing pressure, etc) were selected. The data used in the analysis were collected every month by a research vessel, Lamas-1 between May 2007 and March 2010. The results were compared with the historical data, collected monthly with the same vessel between May 1980 and November 1982 over the same section of the same fishing ground. In all surveys, including those carried out in the 1980s, the same local design of trawl net (locally called the Ottoman) with a stretched cod-end mesh size of 22 mm was used. The trawl duration was kept constant at 30 minutes and the same sampling protocol was applied throughout the study; the samples were sorted into species; each species was weighed separately; the number of individuals was counted and the total length was measured to the nearest centimetre. Four trawl hauls covering different depth ranges (0–15, 15–30, 30–50 and >50 m) were carried out in the 1980s. Geographic Positioning System was not available in the early 1980s and the research boat was not equipped with an echo sounder. The course position and approximate depth of the trawl stations were determined by cross-bearings using a hand-held compass and by the skipper's insight; therefore depth was not used in the analysis. The area of sampling in the 1980s is represented by an ellipse in Figure 1. Time, depth and GPS coordinates of the station sampled in the 2000s were recorded at the beginning and at the end of each trawl operation. The arithmetic mean of the two measurements was used in the



**Figure 1.** Study area and the position of trawl stations sampled between 2007 and 2010; the ellipse is the region where trawl sampling was conducted between 1980 and 1982

analysis. Stations sampled between 2007 and 2010 are depicted in Figure 1.

Since the data was collected on a research vessel rather than a commercial trawl boat, the analyses were based on hypothetical quantities, here called the 'virtual discard', used as the surrogates of the quantities that would have been discarded in a commercial trawl boat. In a commercial boat of the region, the part of the catch to be retained is determined by the skipper of the boat who is usually guided by a wholesaler. Therefore, in order to simulate the sorting of the catch in a commercial vessel and to determine the species for retention and their minimum size, the skipper of a commercial trawler and a wholesaler (both employed by the research boat) were consulted. Later, it was assumed that the discard has two components and the weight of the discarded fraction of the samples was estimated using the following equation;

$$\text{Virtual\_discard} = NC + US; \quad US = \sum_{sp=1}^n \sum_{L=0}^{L_{ret}} a_{sp} L^{b_{sp}} f_{sp,L}$$

Where  $NC$  is total weight of the non-commercial species;  $US$  is the undersized categories of the commercial species;  $sp$  is the commercial species;  $L$  is the length class,  $L_{ret}$  is the minimum size retained (determined by the skipper/wholesaler),  $f_{sp,L}$  is the number of individuals in the catch at length class  $L$  of species  $sp$ ;  $a_{sp}$  and  $b_{sp}$  are the parameters of the length-weight relation of species  $sp$  estimated in the lab. The retained catch is estimated by subtracting virtual discard from the total catch. The loss of fishermen is calculated as follows;

$$\text{ret\_pot} = \sum_i \frac{\sum_j^{12} \text{ret}_{ij}}{d_i}$$

$$\text{loss\%} = 1 - \frac{\text{ret\_act} \times 100}{\text{ret\_pot}}$$

where;  $\text{ret\_pot}$  is the estimation of the quantity of the retained catch if a boat is operated all over the depth ranges and months disregarding the regulations;  $\text{ret}_{ij}$  is the retained catch at depth strata " $j$ " in month " $i$ "; " $d_j$ " is the number of hauls at depth strata " $j$ ";  $\text{loss\%}$  is the loss of fishermen in percent;  $\text{ret\_act}$  is the retained catch of a boat operating over the depth and months permitted by the regulations in question;

In the statistical analysis, one-way ANOVA was performed to test whether the discarded catch are statistically different for different periods (1980s and 2000s). To test the year to year variation, nested design ANOVA (months nested in years) was used. Two-way ANOVA was used for the initial evaluation of the interaction between discard, depth and time. The Kruskal-Wallis test for normality and Levene's test for the homogeneity of variances were used to check whether data agreed with the underlying assumptions of ANOVA (Zar, 1984). Data was normalized by log transformation where the raw data deviated from normality. Prior to further modelling, a Spearman's rank correlation test was carried out to check for co-linearity between these two factors.

For each species, the virtual discard was standardized (per trawling hour), the log transformed and the data used to populate a species-by-station (sample) matrix. Bray-Curtis similarity was calculated between samples and used for nearest-neighbour cluster analysis. Later, all samples collected in a month (disregarding the year and depth) were pooled to evaluate seasonality in the discard composition using the same test of similarity.

A generalized additive model (GAM) was used to examine the variation in the quantity of discard and to identify the extent to which the factors explain the

variability in discarded catch. The model allowed the additive non-linear effects of the factors depth and time without specifying a single equation for each factor. The virtual discard is log transformed as the continuous response variable with a LOG link function assuming a Gamma distribution. Explanatory variables were included as cubic spline smoothers. The model used in the study utilized two iterative processes, outer and inner loops. The former maximizes the overall fit of the model, by minimizing the likelihood of the data; while the latter refines the cubic spline smoother. The iteration estimation procedure terminated when the likelihood of the data, given the model, could not be improved (Schimek, 2000). Here the outer loop convergence threshold was set to 1.e-5, while the inner loop criterion was set to be less than 1.e-6. Estimated GAM parameters were then used to predict discard over a response array covering all depths (0–200 metres) and the entire calendar year (1–365 days). Each of the discard values, predicted for all possible combinations of depth and time pairs, were plotted on a 3D surface chart. The model predicted discard values were then sorted, from the lowest to the highest, and their cumulative sums of percentages plotted on a contour chart with respect to the corresponding depth and time coordinates.

## Results

### Composition of Discard

A comparison between the 1980s and the 2000s reveals a remarkable change in the discard composition, however not all taxonomic groups changed in the same manner; the lessepsian fish that migrated to the Mediterranean Sea after the opening of the Suez channel have increased remarkably, while the native teleosts have changed little. The increase in lessepsian fish is more noticeable at shallow depths. More importantly, invertebrates such as crustaceans and echinoderms, in particular, have almost disappeared in the 2000's (Table 1). The main contributor to the discard was *L. klunzingeri*, a lessepsian immigrant in the 1980s. Later in the 2000s, this species was still among the highest contributors of the discard generated on the upper continental shelf with the exception of the infralittoral zone (down to a depth of 30 metres). In this very shallow zone, it was replaced by a native species, *Bothus podas*. The second important contributor of discard at depths shallower than 100 metres was undersized red mullet, *Mullus barbatus*, which represented a relatively low involvement in the 1980's. Another noteworthy component of discard, which was abundant in the 1980s and later disappeared in the 2000s, is the tub gurnard, *Trigla lucerna*. The monthly appearances in the discard of this species and *M. barbatus* with respect to the trawl season enforced by the fisheries regulations are presented in Figure 2. The highest

value of *M. barbatus* discard was observed within the close trawl season. *T. lucerna* has a longer period of appearance in the discard compared with the former species and only a part of that period remains within the trawl closure.

The similarities in the species composition of discarded catch at stations sampled between 2007 and 2010 are given in Figure 3. At first sight, it is clear that there are two distinct groups of stations with respect to their discard composition. The stations located deeper than 120 metres were grouped as a single cluster. Among them, very deep stations located on the continental slope represent a dissimilar group, totally different than the rest. The cluster comprising shallower stations is further divided into two clusters below 25% similarity. The one on the right hand side represents the stations on the infralittoral zone. At a higher similarity value, the stations deeper than 60 metres are distinguished from the rest. The rest of the stations within this cluster are those located over the circalittoral zone. Within the circalittoral cluster, stations are grouped according to the season in which they were sampled. One group represents the discard in the samples collected between late summer and early winter and the other represents the rest of the year.

In summary, the samples are grouped under five main categories with respect to the discarded catch composition; infralittoral (9–30 m), upper circalittoral (30–50 m), lower circalittoral (50–120 m), lower shelf (150–220 m) and shelf break (>250 m) with further seasonal distinctions in the upper circalittoral zone. The data averaged over these bathymetric classifications are given in Table 1. Since the sampling in the 1980s was carried out only on the upper continental shelf (Figure 1) with no depth measurement, no meaningful clustering was found and the averaged data is given in the same column in Table 2. When the first three depth strata of the 2000s are taken into consideration, the discard composition has a very low resemblance to those of the 1980s (Spearman  $r=-0.042$ ;  $P=0.640$ ) indicating that there has been a significant change.

In a further analysis of the clustering, the stations are grouped under two clusters when the data were averaged over the months, disregarding the year of sampling. The summer months (June–October) and winter months (November–May) formed two dissimilar clusters (Figure 4).

The quantitative results are summarized in Table 2. Almost no change was observed in the quantities of retained fish per hour of trawling over the last 25 years; however the discard per trawling hour has doubled over the entire depth ranges sampled in the 2000s. The percentage of discarded catch has changed significantly ( $P<0.01$ ). The difference is even wider when only the samples from the depths shallower than 100 metres are considered. The remarkable increase was observed not only in the discarded quantity, but also in the number of species discarded (Table 2).

**Table 1.** The list of species that accounts for 90% of the discard (left: per h; right:%) by depth ranges (A=0–25 m; B=25–50 m; C=50–100 m; D=100–250 m and E=>250 m) and the depth range percentage within total

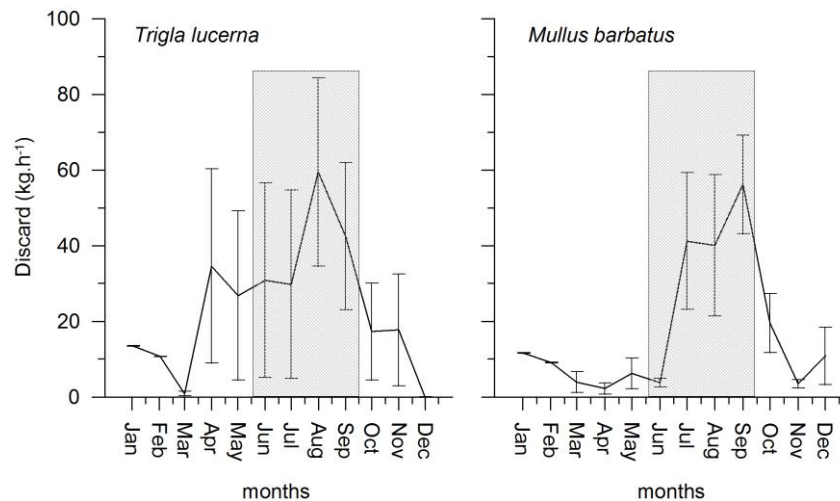
	1980s	A	B	C	D	E	1980s	A%	B%	C%	D%	E%
Lessepsian fish – total	3739	15189	12322	3190	-	-	28,3	26,3	47,3	24,7	0,1	-
<i>Lagocephalus sceleratus</i>	-	470	91	192	-	-	-	0,8	0,4	1,5	-	-
<i>Lagocephalus spadiceus</i>	255	354	650	108	-	-	1,9	0,6	2,5	0,8	-	-
<i>Lagocephalus suezensis</i>	-	2920	679	15	-	-	-	5,1	2,6	0,1	-	-
<i>Leiognathus klunzingeri</i>	3439	8129	9606	2237	-	-	26,1	14,1	36,9	17,3	0	-
<i>Upeneus moluccensis</i>	10	93	593	411	-	-	0,1	0,2	2,3	3,2	-	-
<i>Upeneus pori</i>	-	1681	232	0	-	-	-	2,9	0,9	-	-	-
Native fish – total	6783	39146	14916	8502	4847	14426	51,4	64,3	51,1	61,5	84,8	99,8
<i>Arnoglossus laterna</i>	1319	449	1192	286	34	-	10	0,7	4,3	2,1	0,6	-
<i>Arnoglossus thori</i>	-	4	4	531	30	-	-	0	0	3,9	0,5	-
<i>Bothus podas podas</i>	499	15288	171	1	0	-	3,8	24,1	0,6	0	-	-
<i>Capros aper</i>	-	-	-	-	120	-	-	-	-	-	2,1	-
<i>Chlorophthalmus agassizi</i>	-	-	-	-	59	9626	-	-	-	-	1	66,6
<i>Citharus linguatula</i>	1124	8	521	640	413	-	8,5	0	1,9	4,8	7,2	-
<i>Coelorhynchus coelorhynchus</i>	-	-	-	-	-	605	-	-	-	-	-	4,2
<i>Dasyatis pastinaca</i>	1547	6271	1446	660	75	-	11,7	9,9	5,2	4,9	1,3	-
<i>Dipturus oxyrinchus</i>	-	-	-	-	-	625	-	-	-	-	-	4,3
<i>Echelus myrus</i>	7	-	6	18	106	-	0,1	-	0	0,1	1,8	-
<i>Engraulis encrasicolus</i>	1	11	32	312	28	-	0	0	0,1	2,3	0,5	-
<i>Glossanodon leioglossus</i>	-	-	-	-	237	-	-	-	-	0	4,2	-
<i>Gobius niger jozo</i>	-	1	498	21	-	-	-	0	1,8	0,2	0	-
<i>Gymnura altevela</i>	179	1711	2830	-	-	-	-	2,7	10,2	-	-	-
<i>Lepidotrigla cavillone</i>	289	5	152	363	268	-	2,2	0	0,5	2,7	4,7	-
<i>Lepidotrigla dieuzeidei</i>	-	-	-	14	157	-	-	-	0	0,1	2,7	-
<i>Macrorhamphosus scolopax</i>	-	-	-	27	632	-	-	-	-	0,2	11,1	-
<i>Mullus barbatus</i>	258	8746	4432	1892	35	-	2	13,8	16	14,1	0,6	-
<i>Mustelus mustelus</i>	82	-	-	498	147	-	0,6	-	-	3,7	2,6	-
<i>Myliobatis Aquila</i>	288	-	616	56	-	-	2,2	-	2,2	0,4	-	-
<i>Pagellus erythrinus</i>	7	351	406	111	-	-	0	0,6	1,6	0,9	-	-
<i>Raja clavata</i>	-	-	76	104	1246	625	-	-	0,3	0,8	21,8	4,3
<i>Raja radula</i>	-	1662	72	112	393	1370	-	2,6	0,3	0,8	6,9	9,5
<i>Rhinobatus rhinobatus</i>	-	1738	70	0	-	-	-	2,7	0,3	-	-	-
<i>Sardina pilchardus</i>	-	46	161	257	55	-	-	0,1	0,6	1,9	1	-
<i>Scyliorhinus canicula</i>	-	-	-	35	459	464	-	-	-	0,3	8	3,2
<i>Scyliorhinus stellaris</i>	-	-	-	-	164	-	-	-	-	-	2,9	-
<i>Serranus hepatus</i>	36	5	64	923	13	-	0,3	0	0,2	6,9	0,2	-
<i>Trigla lucerna</i>	658	-	-	-	-	-	5	-	-	-	-	-
Crustacea – total	1686	172	354	304	2	-	12,8	0,2	1,3	2,3	0	-
<i>Carybdis longicollis</i>	746	92	295	282	-	-	5,7	0,1	1,1	2,1	-	-
<i>Erugosquilla massavensis</i>	940	80	59	11	-	-	7,1	0,1	0,2	0,1	-	-
Mollusca – total	-	5241	24	18	513	33	-	8	0,1	0,1	7,9	0,2
<i>Sepia elegans</i>	-	38	24	16	374	-	-	0,1	0,1	0,1	6,5	-
<i>Strombus persicus</i>	-	5198	-	-	-	-	-	8,2	-	-	-	-
Tunicata – total	1	-	40	1341	-	-	0	-	0,1	10,3	-	-
<i>Pennatula phosphorea</i>	1	-	40	1341	-	-	0	-	0,1	10,3	-	-
Echinoderm – total	973	22	9	56	364	0	7,4	0	0	0,4	4,8	-
<i>Antedon mediterraneus</i>	1	22	-	17	342	-	0	0	-	0,1	4,7	-
Asteroidae	558	-	-	-	-	-	4,2	-	-	-	-	-
<i>Cidaris cidaris</i>	338	-	-	42	5	-	2,6	0	0	0,3	0,1	-
Ophiuridae	76	-	-	-	-	-	0,6	-	-	-	-	-
Total / depth range %	13400	57700	26100	12900	5700	14500	100	49,4	22,3	11	4,9	12,4

The monthly averages of the discard in weight represented no statistical difference in the 1980s ( $P=0.226$ ); indicating the lack of a seasonal pattern. However, in the 2000s, a significant difference was found between months ( $P=0.005$ ) suggesting strong seasonality in discard similar to the pattern observed in the species composition of the discarded catch (Figure 5).

The monthly discard variations in the 2000s are disintegrated into non-commercial and undersized commercial components in Figure 6. The monthly averages of the non-commercial components do not differ statistically ( $P=0.135$ ), although the summer and autumn (July to November) averages are higher

than the rest. The undersized category of the commercial species, on the other hand, presented a very pronounced increase in July and August significantly higher than the rest ( $P=0.000$ ).

Figure 7 represents variations in quantity of discard by depth and by month between 2007 and 2010. The decreasing trend in the quantity of discard by depth is evident in almost all plots where the higher discard is observed at shallower depths (0–50 m). The same pattern applies to both categories of discard, non-commercial and undersized commercial species, and may be more so for the latter category which represents zero value except for a few winter months. The overall trend is not linear. The values



**Figure 2.** Monthly changes in the discarded quantities of tub gurnard (*Trigla lucerna*) and red mullet (*Mullus barbatus*) in the 1980s. Vertical bars indicate 95% confidence intervals of the monthly averages.

reach a minimum at depths of around 150 m and then increase again. The impact of depth and time of the year on the quantity of discarded catch were assessed applying two-way ANOVA analysis (Table 3). The results show that only one MS, representing the depth ranges classified in Figure 3, is highly significant, indicating that depth is the main factor determining the quantity of discard. The time and the combined effect of time and depth are not significant. The absence of interaction may mean that the trend is the same among the months. On the other hand, the MS for the main effect of time actually represented a probability figure very close to the critical level of 0.05. As can be seen from the figure, the discards between July and November are essentially higher than for the rest of the year.

The significance of season, which is probably masked by the effect of depth in the parametric test, is better represented by the GAM results although the impact of depth is still greater by far (Table 4). More specifically, the model predicts very high values at shallow depths down to 50 metres and the values are particularly high between July (180) and November (300) (Figures. 7 and 8). The results of the model prediction over the entire range of depths and for the entire span of a year are given in Figure 9. There is a noticeable agreement between this figure and Figure 7 indicating that the model grasped the general patterns. The analysis estimated discarded catch with an expectable accuracy ( $P=0.000$ ;  $\chi^2$  test).

The smoothed response to depth and time on a logarithmic scale displayed in Figure 9 is the combined effect of both predictors on the discard size. The impact of depth in shaping the chart can easily be seen. The effect of the seasons seems to enhance the effect of the depth above 50 metres in the second half of a calendar year.

The cumulative percentages of the discard values predicted over the depth and time array is presented on the contour chart (Figure 10). This chart may be used to estimate (or manage) the lowest

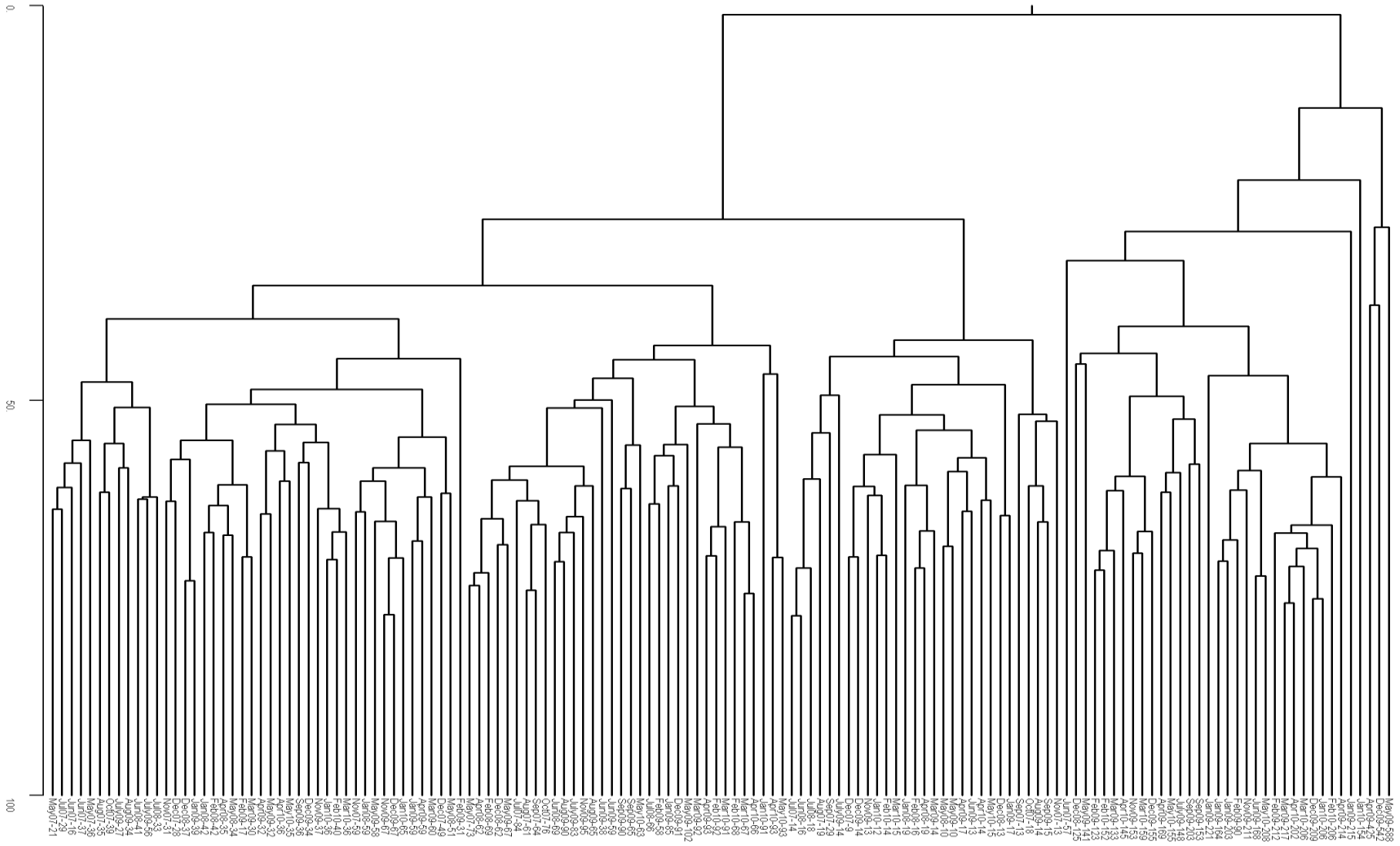
discard areas with respect to time and depth. That is, if a trawl boat is operated within the depth and time limits delineated by the 10% isobar (marked by '1') on Figure 10, the discard produced in a year would not exceed 10% of the maximum discard that could be produced without limitations.

The contour chart is used to evaluate the effectiveness of the depth and time regulations actually applied in the study area (the trawl fishery at a distance of two miles from the coast as this area is excluded for trawl fishery). The figure suggests that the catch returned to the sea is reduced by 48.61% by banning trawling from mid-April to mid-September and by 57.04% by the two-mile trawl exclusion which passes through 50 metres isobar on average.

The retained part of the catch is given in Table 2 and changes in its month- and depth-wise variations are displayed in Table 5. In general, the highest percentage of the catch is retained at the shallow stations and there is a decreasing trend towards the deeper parts. The percentages are low in winter. When both regulations are combined and the distribution of retained catch in Table 5 is considered, the discard is reduced by 77.28% by the existing discard regulations in the study area at the expense of a 73.4% reduction in the marketable catch.

## Discussion

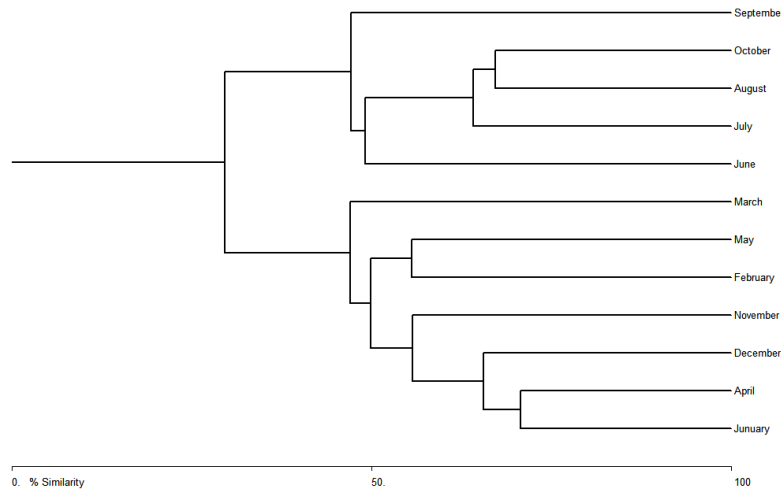
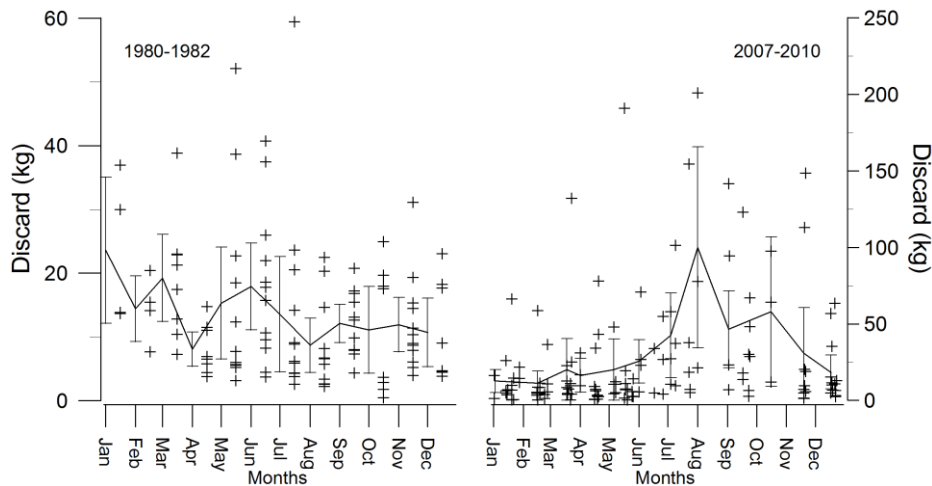
The factors determining the size and composition of discarded catch in trawl fishery are quite complex (Murawski 1996) and variations from one trawler to another contribute significantly to this complexity. In this study, the approach is to analyze and model the discard potential of a bottom trawler as a function of depth and time of the year, using monthly trawl survey data collected by a research vessel operating at the same set of depth strata in the same fishing ground collected in three successive years. So that it was aimed to minimize trawl specific



**Figure 3.** Percent similarities of the discarded catch (Bray & Curtis, Group Average Linkage) at all stations sampled between 2007 and 2010

**Table 2.** Summary of the results and comparison of 1980's and 2000's

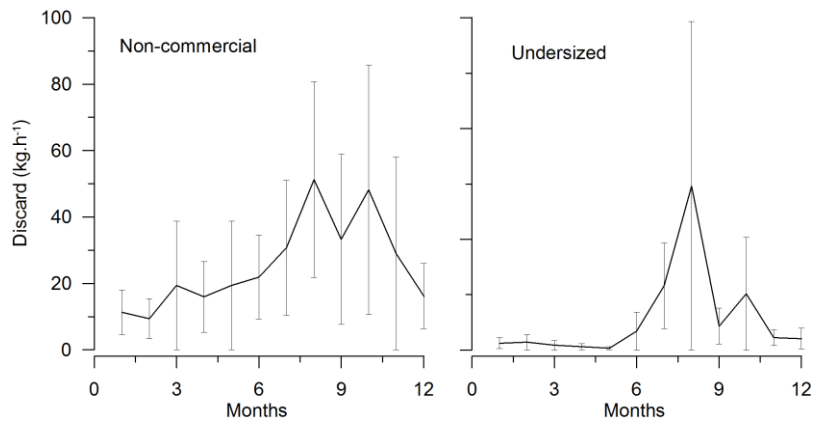
	1980-1982	2007-2010	2007-2010*	P (t-test)	P* (t-test)
Retained (kg.h <sup>-1</sup> )	20.9 ± 3.4	20.6 ± 3.9	22.8 ± 4.8	0,9007	0,5141
Discarded (kg.h <sup>-1</sup> )	13.4 ± 2.0	26.1 ± 6.6	31.6 ± 8.1	0.0005***	0.0000***
% discard	40.87 %	48.28 %	51.85 %	0.0051***	0.0001***
# of discarded species	48	115	88	-	-
# of retained species	51	73	64	-	-
# of hauls	110	118	92	-	-
min % discard	9.24 %	6.23 %	6.23 %	-	-
max % discard	85.88 %	93.45 %	93.45 %	-	-

**Figure 4.** Monthly similarities of discarded catch (Biomass, Bray & Curtis, Group Average Linkage) at all stations sampled between 2007 and 2010**Figure 5.** Monthly changes in the discarded quantities in the 1980s and the 2000s. Vertical bars indicate 95% confidence intervals of the monthly averages.

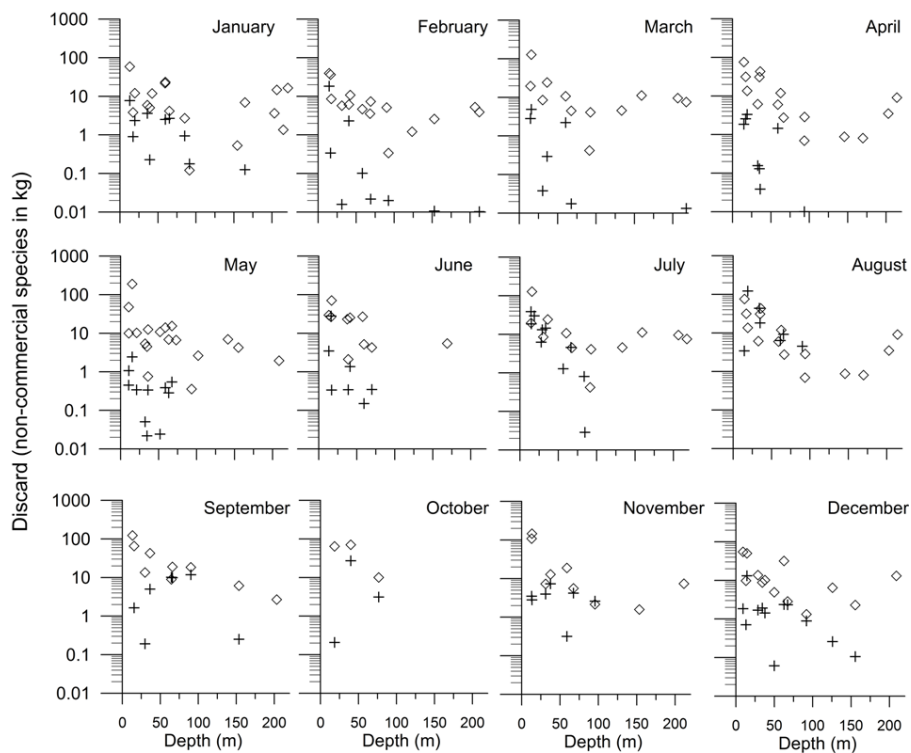
variability such as size, horse power, fishing gear specifications (design, mesh size, etc.), skill of the skipper, tow duration, geographic differences, bottom type, etc. The importance of Mediterranean Sea in the understanding the mechanisms of discard is that the fishing grounds like those in the Mediterranean, where commercial species are small and where the

catch comprises multi-species, the discard rate is alarmingly high (Alverson *et al.*, 1994; Tudela 2004). For instance, 13500 t to 22000 t per annum have been discarded at sea in the Aegean and Ionian seas (Machias *et al.*, 2001) which accounts for 44% (39–49%) of the total trawl catch. Although the vessel and the trawl net design used in the present study were





**Figure 6.** Monthly variations in the discarded non-commercial (left) and undersized (right) species



**Figure 7.** Variations in the discarded quantities by month and depth; '+' represents an undersized category of commercial species; '◇' represents non-commercial species.

**Table 3.** Two-way ANOVA results of discard (log transformed) by months and by depth ranges, and their interactions.

	SS	df	MS	F	P
Months	1,12	2	0.558	2,99	0.055
Depth range	11,31	2	5.654	30,31	0.000***
Month X Depth range	6,01	33	0.182	0,98	0.514
Error	17,35	93	0.187		

**Table 4.** Summary statistics of the generalized additive model (Log link function over Gamma distribution  $r^2=59.2\%$ )

Predictor	GAM coef.	s.e.	P
Intercept	1	1,4306	
Depth	3,996	-0,0012	0.0000***
Time of a year	4,0008	0,0003	0.0014***

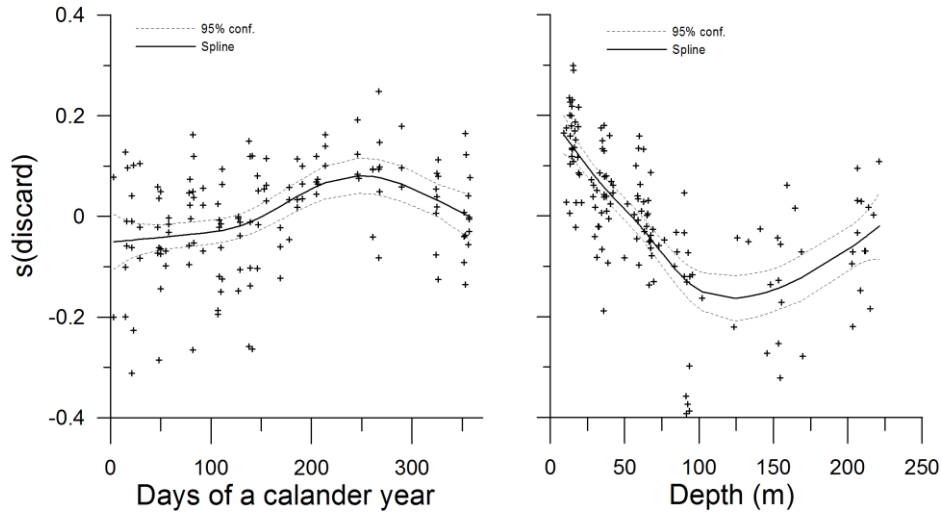


Figure 8. The smoothers given by generalized additive modelling

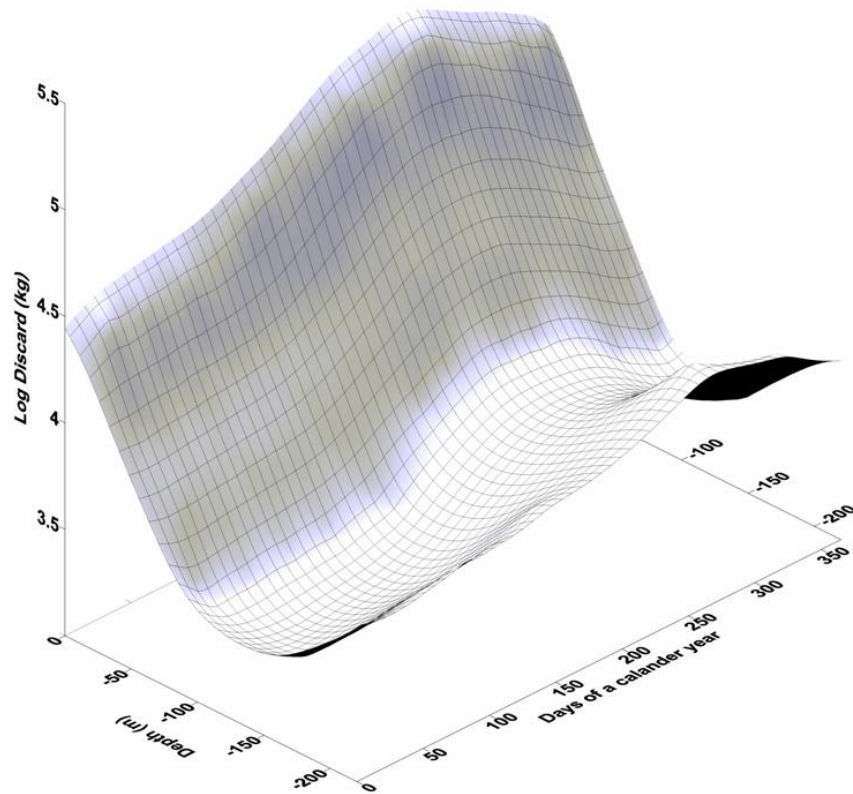
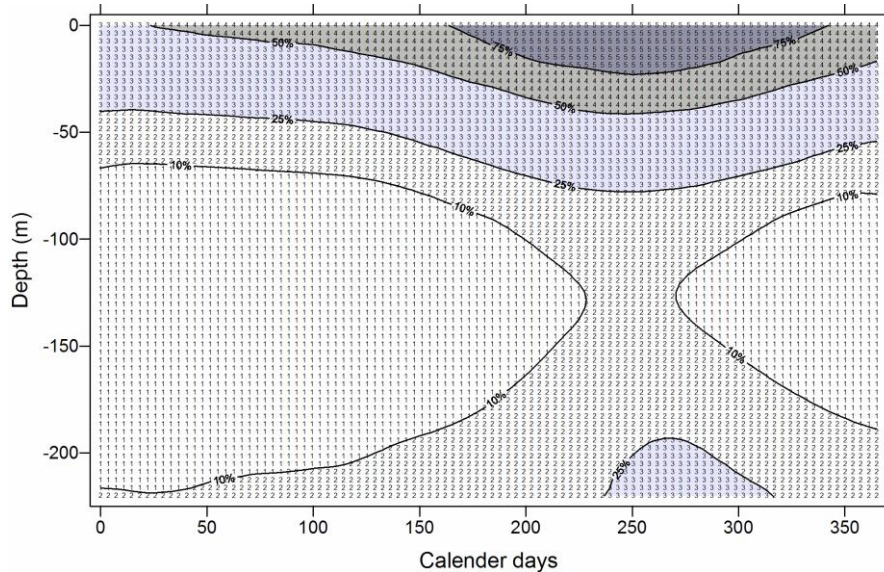


Figure 9. Predicted discard with regard to depth and time of the year

identical to those of the commercial fleet of the region, the absolute values of discard were not evaluated to estimate the discarded catch in the area. Nevertheless, it may be worthy to note that the virtual discard rate observed in the study is close to the upper margin of the trawling discard (20–50%) in other Mediterranean areas (Moranta *et al.*, 2000; Machias *et al.*, 2001; D’Onghia *et al.*, 2003; Sartor *et al.*, 2003;

Sanchez *et al.*, 2004, 2007).

As it has already been documented by Sanchez *et al.* (2004) by far the highest quantity of discard was generated at shallow depths (down to 35 m) and the depth was found to be a significant factor governing a great deal of variability in the quantity of discard. The both findings agree that the ecological use efficiency (retained/catch) at the shallow depths was the lowest.



**Figure 10.** Contour chart showing cumulative sum of percentages of discard.

It should be added that the time of a year has not been considered in Sanchez *et al.* (2004)'s work. However in another study, they observed seasonal patterns in the retained/discarded catch in the Adriatic and Catalan Seas in the Mediterranean, and they explained the seasonality as the result of the variation in the level of fishing intensities (Sanchez *et al.*, 2007). They observed slightly higher retention fractions in the periods of high fishing intensity, which does not agree with the findings of the present study. This study examines two different time periods; 1980's and present. In the 1980s the number of bottom trawlers was only one tenth of the size of the trawl fleet today (Anonymous, 2007). Yet, the retained fraction of the catch was significantly higher than present (Table 2). This may show that intensity of fishing has a lesser effect in the seasonality of discard, at least for this study. Seasonal variation in the discard was also noted in a study carried out in a Catalan port (Tudela, 2004) where the highest amount of catch was discarded in spring by the larger boats and in summer by the small ones operating on shelf bottoms shallower than 150 metres.

The monthly strength of recruitment of the target species (Figure 11) and almost identical pattern in the monthly discard variations (Figure 5) draw attention to the importance of the recruitment time of the fish in the determination of discarded quantity. This is not surprising because it is evident that the undersized commercial fish category would attain higher quantities during the peak time of recruitment. However, the similar, though not so pronounced, seasonality observed in the non-commercial category (Figure 6) is not necessarily linked to the recruitment period, especially when the composition of dissimilar species observed during the high discard period is considered (Figure 4). Therefore, in a statistical sense, there are 4 dissimilar populations within the data examined; two determined by season and two

determined by depth.

Mesh size and mesh shape regulation is a very useful tool to reduce discard of undersized fishes however when the multispecies complexity is concerned this may not be a concrete solution. The General Fisheries Commission for the Mediterranean (GFCM) has adopted the use of a minimum 40 mm square mesh codend or a diamond mesh size of at least 50 mm in the GFCM Area to achieve higher size selectivity (GFCM Recommendation, REC.CM-GFCM/33/2009/2). As demonstrated in the results of several studies, implemented mesh size regulation improves the selectivity of the trawl nets used in the Mediterranean. However it may not always be sufficient to reduce discard of undersized fishes (Özbilgin *et al.*, 2012) and to retain commercial size (Aydın *et al.*, 2011) of major target species.

As demonstrated by the results given above, fishery regulations based on depth and season limitations may be supplementary tools in significantly reducing the discard. However in return, the economic loss of a trawler, especially due to the close season, is a major concern raising resistance in the application. For instance, if no limitation is applied to the fishery and if the trawl fleet is operated over the entire depth ranges all year round, the model predicts a very high discard rate of almost 54%. In this case, the loss of the fleet would naturally be null. The local fisheries regulations applied in the area where the study is conducted includes a ban of trawl fishery from mid-April to mid-September and two mile trawl exclusion zone, which corresponds to an average depth of 50 meters. The results suggest that these regulations reduce the discard rate to 34% at an expense of about 73% economic loss to fishermen. As a considerable part of the discard in the banned season and at depth is composed of undersized commercial species, management may still regard the regulation as a reasonable trade-off.

**Table 5.** Percentage distribution of retained catch by month and by depth strata in the 2000s

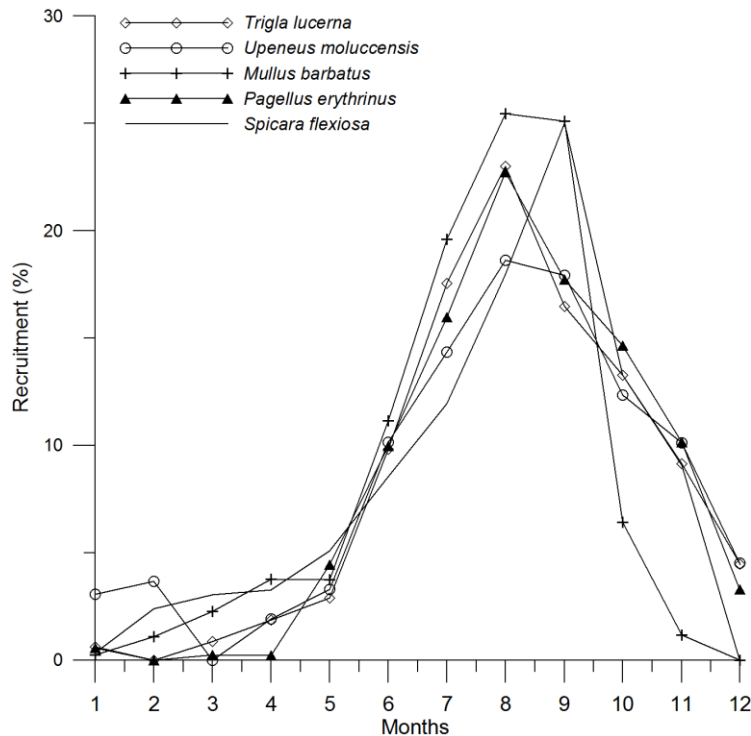
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Σ
0-25 m	2.2	3.2	4.9	2.8	5.4	1.2	3	4.4	1.1	1	4.3	2.4	35.7
25-50 m	1.5	1.2	2	1.1	1.1	2.9	3.1	3.1	5.8	3.7	1.4	1.2	28.1
50-100 m	0.9	0.8	0.8	0.6	3.7	1.1	1.7	4	4.7	2.2	1.3	1.9	23.6
100-250 m	0.8	0.6	1	0.6	1	1.4	0.8	0	2.3	0	2.3	1.9	12.6
Σ	5.4	5.8	8.7	5.1	11.1	6.5	8.6	11.5	13.8	6.9	9.3	7.4	

As another example, the closed trawl season in Greece is from June to the end of September (Presidential Decree n° 817/1966) and trawlers are allowed to operate at depths greater than 50 m or at a distance greater than 3 miles (EC Regulation n° 1626/1994). The GAM model developed in this study estimated that the depth and time regulations applied in Greece would reduce the discard to 40% discard rate which is slightly less than the figure given by Machias *et al.* (2001). In Spain, the same depth ranges are delimited; however two closed seasons are enforced in a year: May and October. The model suggests that the regulations reduce the trawl discard rate to 35% which is consistent with the general view proposed for that region (Moranta *et al.*, 2000; Sanchez *et al.*, 2004, 2007).

On the other hand, a comparison of the discard composition of the 1980s and the 2000s may answer the following question: what could have been the consequences of such a fisheries regulation on the fisheries ecosystem in the long run? The first answer is that the discard rate has increased from 40% to 51% within the last 30 years. The results also point to a significant change in demersal fish assemblages within the same period, as reflected in the discard composition. A part of the change is due to new species, not exploited and hence, not sampled in the 1980s, inhabiting the depths below the continental shelf. Another part is due to the introductions of new lessepsian species favoring warmer shallower depths (Golani, 1994; Gücü *et al.*, 2010). There are, however, some cases showing that the impact of selective fishery on these changes should not be overlooked. Lack of seasonality in the 1980s and strong seasonal patterns in the discard of the 2000s may be considered as a sign of fishery driven ecosystem modification. As Tudela (2004) stated earlier, fishery changes the biomass and demographic structure of different species by changing the balance between competitors and/or by increasing food availability for certain groups through discards, for instance by favoring scavengers (Moranta *et al.*, 2000). In the study area, each of the discard components actually had a pattern in the 1980s (Gücü, 1991). However these individual patterns were leveled out when combined. Throughout the years, each of the species observed in the discard was subjected to ever increasing and seasonally altered fishing pressure (Özbilgin *et al.*, 2009). Consequently, the composition of the species might have been sculptured by the uneven fishing pressure in the long run. An example of such a case is the disappearance

of tub gurnard in the catch as opposed to the rise of red mullet, *M. barbatus*. *T. lucerna* is a slow growing (Bingel, 1987), late maturing fish (Papaconstantinou, 1984); compared to the short lived *M. barbatus* which reaches maturity within the first year of its life (Gücü, 1991). Aging was not performed on discarded class sizes, however, extended occurrence of *T. lucerna* in the discard (Figure 2), as opposed to its relatively short and distinctive pattern of recruitment (Figure 11) indicates that not only young-of-the-year but probably also older sub adults were discarded by the commercial fleet. The longer occurrence of *T. lucerna* in the discard suggests higher fishing pressure over the early life stages of this fish. In contrast, *M. barbatus*, has a distinctive pattern of recruitment and an identical pattern of occurrence in the virtual discard. The discard regulations applied in the area bans trawl fishery from mid-April to mid-September (Anonymous, 2008; Figure 2). In this study, the data were collected throughout the year including the trawl close season. Recalling that the period of high *M. barbatus* discard occurs in the close season, the high *M. barbatus* discard figure given in Table 1 does not represent the actual quantity of *M. barbatus* discarded by the commercial fleet, which would evidently be lower in reality. In other words, undersized *M. barbatus* that would otherwise have been caught and been discarded by the fishery are protected by the fishing regulation. However, the same regulation protects only a part of the undersized *T. lucerna* (Figure 2). The unequal fishing pressure on the young has possibly provided better chances of recruitment for the former of the two competing species and this may be a factor responsible for the disappearance of *T. lucerna* in the 2000s. The endurance *M. barbatus* against a high level of exploitation has already been underlined by Demestre *et al.* (1997), however, they explained the success by the high turnover rate displayed by the species. Here, in addition to high turnover rate, the summer trawl closure, which applied in several Mediterranean countries, is a significant tool in the reduction in the discard of this species.

The quantity of retained catch, which has remained unchanged over the last 30 years despite a remarkable increase in the discard rate, indicates that discard might not be a critical issue from an economic point of view. The remarkable differences in the compositions of the species of the 1980s and the 2000s suggest that the retained catch has been stabilized, possibly through modifications in the fisheries ecosystem as was illustrated by the case of



**Figure 11.** Recruitment pattern of some selected species from NE Levant (re-drawn from Gücü 1991)

red mullet and tube gurnard. On the other hand, the disappearance of some sensitive sessile groups, which were represented in great quantities in the discard composition in the 1980's, such as echinoderms, could be an indicator of high fisheries pressure and may be a sign of the damage to the benthic and epibenthic biocoenosis which is considered to be an essential habitat for demersal target species, such as hake, *Merluccius merluccius* (Colloca *et al.*, 2004).

## Conclusion

Depth was verified as a significant factor affecting the size of the discard; very high discard at depths shallower than 30 metres. However, the discard does not follow a linear decrease towards deeper strata. The discarded quantity increases again towards the continental slope. The time of a year is found to be another important factor which may help in reducing the discard via appropriate regulations. It was demonstrated that, in the fishing grounds where the impact of these two factors are considered, the discard may be reduced remarkably. However, it was also demonstrated that enforcing seasonal closures to reduce the discard may cause significant changes in the fish assemblages in the long run; that the fast growing species having short recruitment periods achieve full advantage of the protection and gain advantage over the slow growing fish with extended recruitment patterns. It may be worthwhile to note that seasonal closures might have helped to maintain their resilience against leptocephalus immigrants; whereas protecting the infralittoral zone, particularly

in the areas where critically important sea-grass habitats, such as *Posidonia oceanica* meadows are absent, may favour the colonization of immigrants.

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