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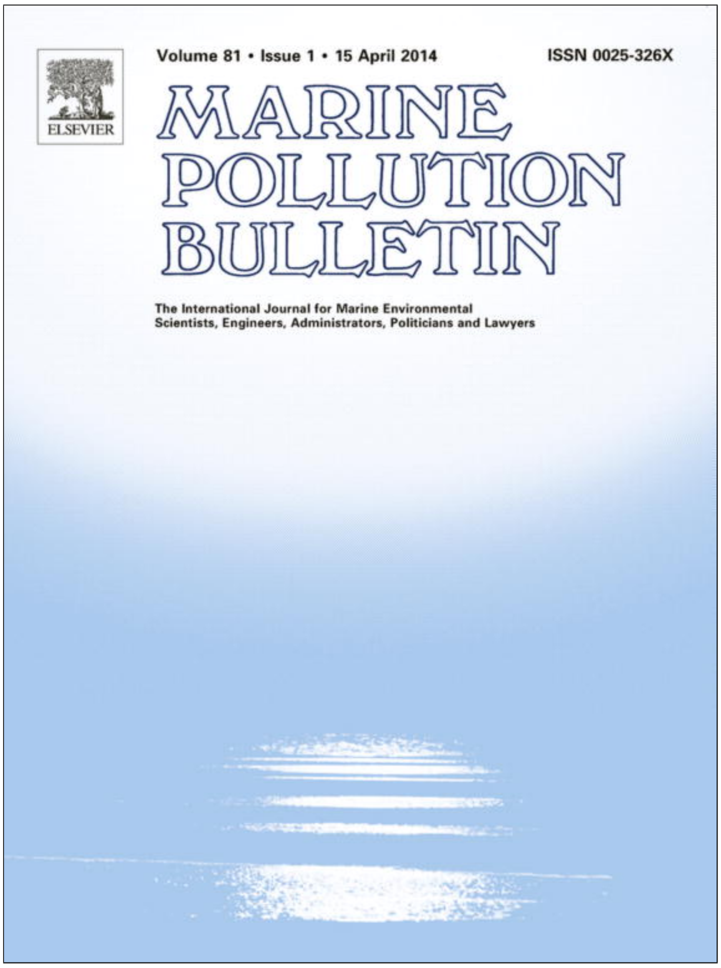

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Marine debris in bottom trawl catches and their effects on the selectivity grids in the north eastern Mediterranean

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A R T I C L E   I N F O

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A B S T R A C T

In this study composition of marine debris and their blocking potential on the selectivity grid systems deployed on demersal trawls were investigated in the north eastern Mediterranean. For this, a total of 132 hauls were examined in two fishing season between 20 September 2010 and 19 February 2012. Results showed that plastic items were the most abundant debris (73% in terms of weight) and they were followed by metals (10%). Because of plastics and packing debris, it is highly probable that grids may have been blocked in 85% of trawl hauls. The bathymetric and geographical variability in the quantity of debris were evaluated, and concluded that particularly in some areas where direction of currents and bottom topography favor deposition, such devices may easily be rendered ineffective by the plastics and packing debris in particular. To solve this problem, several solution proposals are submitted.

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1. Introduction

Marine debris consist of items that have been made or used by people and deliberately discarded or unintentionally lost into the sea or coastline including such materials transported into the marine environment from land by rivers, drainage or sewage systems or wind (Galgani et al., 2010). The pollution of the Mediterranean has been recognized internationally as a serious problem, and collective measures were planned to control an increasingly broad range of pollutions (Galil et al., 1995). Despite efforts made internationally, regionally and nationally, there are indications that the marine litter problem continues to worsen (UNEP/MAP, 2011).

Sources of marine debris are classified as land based or ocean based depending on how the debris enters the water (UNEP, 2008). At the global scale, estimates indicate that nearly 80 percent of marine litter originates from land-based sources (OSPAR, 2009). As a result of this, the abundance of marine debris is generally much greater in shallow coastal areas rather than deeper waters, with the exception of some accumulation zones in the open sea (Lee et al., 2006; Koutsodendris et al., 2008; Katsanevakis, 2008). These accumulation zones in Atlantic Ocean and the Mediterranean have very high debris concentration despite being far from coasts due to large-scale residual ocean circulation patterns or local water movements (Galgani et al., 2010).

The studies of marine debris in the Mediterranean have focused on beaches, floating debris and the seabed of the continental shelf or the deep sea (Katsanevakis and Katsarou, 2004). In most of these studies that investigated debris on seabed, sampling was conducted by using demersal trawls (Bingel et al., 1987; Galil et al., 1995; Galgani et al., 1996; Stefatos et al., 1999; Galgani et al., 2000; Yılmaz et al., 2002; Katsanevakis and Katsarou, 2004; Koutsodendris et al., 2008; Topçu and Öztürk, 2010; Güven et al., 2013). These studies clearly show that plastics comprise the largest source of marine debris. Due to resistance of plastic to degradation and its continuing discard into the sea, it is the largest polluting found in the marine environment (Derraik, 2002; Topçu and Öztürk, 2010). The most significant effects of plastics on the marine animals are entanglement in or ingestion that they kill more than a million seabirds and 100.000 marine mammals and turtles every year (UNEP/MAP, 2012).

Selectivity grids are proven to be effective tools to increase selectivity of trawl nets. They are vastly used for conservation of species (turtle excluder devices, TEDs, e.g. super shooter) or to reduce discard rate of juvenile fishes in particular (bycatch reduction devices, BRDs, e.g. nordmore grid). Although, they have been found very effective, there is a clogging or blocking risk in highly polluted marine areas.

There are two primary aims of this study. First is to determine debris composition according to material and use, and second is to evaluate the blocking possibility of selectivity grids to see whether grids will work because of debris in Mersin Bay.

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2. Materials and methods

This study was carried out in conjunction with a project titled "investigations to improve species and size selectivity in Mersin Bay trawl fisheries". A total of 132 hauls were carried out onboard commercial trawler 'Azim' (18 LOA, 350 HP/261 kW engine power) in two fishing season between 20 September 2010 and 19 February 2012. Hauls were performed between 19 and 178 m depth, and lasted 80–271 min. Towing speed varied between 2.3 and 2.8 knots.

After the trawl codend was dumped on deck, marine debris was sorted from the catch. Then, the bulk of debris was kept on deck for a while to remove the seawater. The plastic materials were wringed out by hand to filtrate the water. Subsequent to this process, all marine debris items caught in a haul were classified, and then weighed in groups. Although quantification methods vary, marine debris is mostly calculated as the number of items, by weight or size (Galil et al., 1995; Lee et al., 2006) and the choice of unit to quantify the debris is very important because variance of materials may cause distortion to the results (Galil et al., 1995; Spengler and Costa, 2008). Lastly, to determine the blocking possibility of selectivity grids, all items were brought together and surface area of plastic bags and packing debris was estimated in each haul, under three categories: less than 0.1 m^2, between 0.1 m^2 and 1 m^2, and larger than 1 m^2. Dimensions of super shooter (120×80 cm) and nordmore grids (80×60 cm) used in selectivity studies and tested in project mentioned above was taken into account to assess the blocking possibility. Debris components were initially classified according to their material in the following seven categories: plastic, wood, metal, glass, combined (consisting of more than one material) and others. They were also grouped into the following four categories according to usage: packaging, clothing, fishing gear, and others.

The concentration of debris on the seafloor was calculated with debris per unit effort (DPUE). DPUE was estimated using the following equation:

$$\mathrm{DPUE} = D/f$$

where D is weight of debris (kg) caught during the trawl operation and only those accumulated in the codend were taken in account and the others entangled on the wires, brindles etc. were disregarded. f denotes for effort and given that the trawling speed did not change remarkably during the operation the haul duration (hour) was assumed to be a good indicator to standardize the quantity of the debris.

The standardized quantities were statistically analyzed to explain the variability in the debris accumulation. Two explanatory variables, namely "depth" and "longitude" were chosen on the basis of their capacity, to examine the accumulation pattern of debris. Generalized additive models (GAMs) were applied to explain the variability in the debris accumulation. The "depth" was the average depth of the tracked line during the trawl haul, and "longitude" was the longitude of the midpoint of the haul track. Such approach was chosen due to non-linear relationships between predictor and response variables. In addition GAM allowed examining the relative influence of each parameter. Analyses were done using *mgcv* in R version 3.0.1 (R Development Core Team, 2013). The GAM was fitted assuming a quasi-Poisson error distribution in order to account for the overdispersion in the DPUE data (variance was greater than mean). All predictors in the model were included as smoothed terms. Thin plate regression splines were used as penalized regression smoothers. The smoothing level of the model, in other words balance between the model flexibility and generalization ability was determined based on the scoring as suggested by Wood (2006) available in the "*mgcv*" library (Wood, 2013). As the scale of the overdispersion of the data has not been known prior to analysis the "generalized cross validation" scoring method was selected (Wood, 2013). The goodness-of-fit was analyzed with regards to the percentage of explained deviance.

3. Results

Study area and middle points of each haul are shown in Fig. 1. In a total of 132 hauls conducted in Mersin Bay, total weight of marine debris entered the trawl codend was 227.34 kg. Debris density

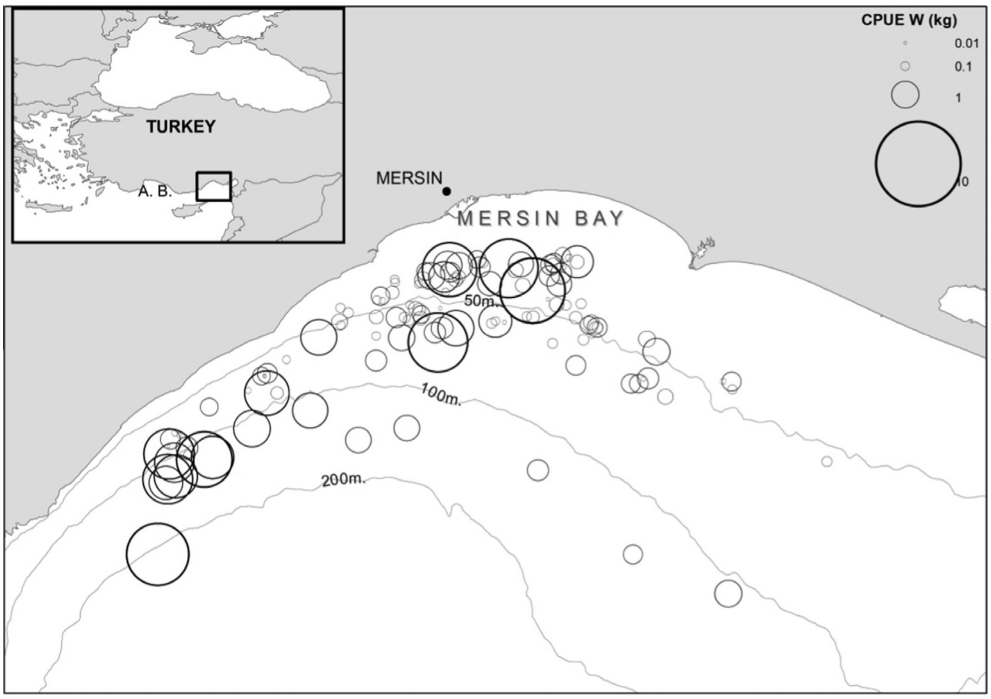

Fig. 1. Study area and middle points (each circle represents weight of debris pear hour) of hauls for two fishing season, 20 September 2010 – 19 February 2012 (A.B. shows Antalya Bay).

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ranged between 0.01 and 5.85 kg/h. Its average value per hour of trawling was calculated as 0.72 kg. Marine debris was mostly made up of plastic (73%), metal (10%), glass (5%), and others (5%) in terms of material they were made of (Fig. 2). According to use of the items, packaging material (plastic bags, bottle, containers, etc.) was the most abundant (56%), followed by others (wheel, phone, TV etc.) (32%), fishing gear (7%), and clothing (5%) (Fig. 3).

Results of surface area calculations of plastic bags and packing debris showed that only in 8% of the hauls, area of debris was less than 0.1 m^2. The items larger than 1 m^2 were found in 27% of the hauls. The medium size items between 0.1 m^2 and 1 m^2 were observed in the 58% of the hauls (Fig. 4). In 9 hauls (7%) no debris were found. As the items larger than 0.1 m^2 were sufficient to partially or fully block a selection grid, it was estimated that in almost 85% of the hauls the debris significantly affects the efficiency of the grids and may eventually render them useless.

The comparisons in respect to the percentage of deviance explained by GAM are given in Table 1 as univariate model (effect of the smoothers of each predictor over DPUE, in bold) and for bivariate model (effect of the pair of smoothers placed in the column and row). Only depth was found to be significant ($P < 0.05$). In univariate model, the highest percentage of DPUE deviance was explained by depth (34.5%), in bivariate model 39.3% of DPUE deviance was explained by the depth–longitude pair. Despite increased level of deviance explained by the latter model, the goodness-of-fit was low ($r^2 = 0.56$). The conditional effects of the predictors on DPUE obtained by GAM are shown in Fig. 5A and B in terms of their smoothing functions plotted with their best-fits and 95% confidence intervals. These results indicate an increasing trend in debris concentration with increasing depth (Fig. 5A). Effect of longitude suggests a reduction in debris concentration from west to east (Fig. 5B) except of longitude points between 34.6 and 34.7.

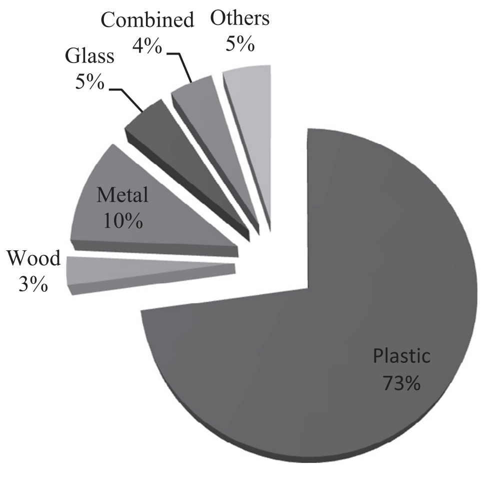

Fig. 2. Percentages of marine debris sorted in material types.

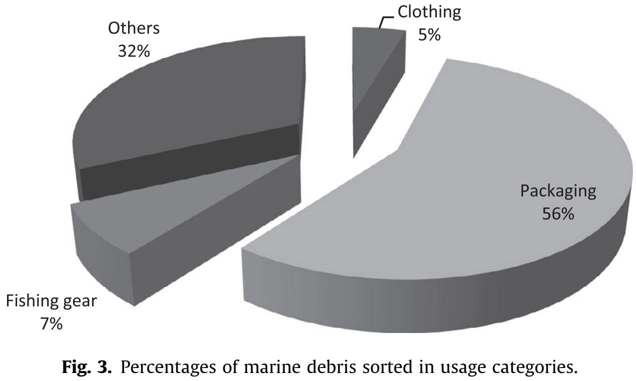

Fig. 3. Percentages of marine debris sorted in usage categories.

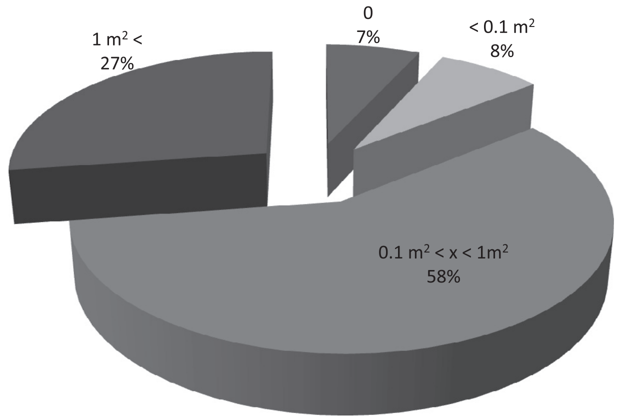

Fig. 4. Percentages of surface area of plastic bags and packing debris.

Table 1
Comparison of the effects of the predictors over DPUE in respect to univariate and bivariate models.

	Depth	Longitude
Depth	**34.5%**	
Longitude	39.3%	**23.6%**

4. Discussion and conclusions

To our knowledge, this is the first published study to demonstrate the blocking effect of plastics and packing debris on the selectivity grids. The results clearly show that grids may be easily rendered ineffective by especially plastics in majority of trawl hauls conducted in Mersin Bay. This finding is supported by many underwater video recordings obtained during a parallel study investigating fish behavior in relation to trawling operations (Özbilgin et al., 2013). Examples of selectivity grids being blocked by marine debris can be seen in Fig. 6. The state of blocking in selectivity grids may cause serious commercial loss. Therefore, any regulation implementing use of sorting grids to improve size and/or species selectivity in Mersin Bay demersal trawl fishery is likely to face a strong resistance by fishing industry.

Results of this study show that marine debris is composed of various types of materials and among these, plastics were the most dominant materials found in Mersin Bay. These results are parallel with those of other studies conducted by trawl in the Mediterranean (Galgani et al., 1996; Stefatos et al., 1999; Galgani et al., 2000; Koutsodendris et al., 2008; Topçu and Öztürk, 2010). However in a study carried out in the bathyal grounds in Antalya Bay, although the plastics were by far numerous compared to the other debris items, they did not form the heaviest part in the total (Güven et al., 2013). This discrepancy may be explained by various types of heavy items in the study area or might have been caused by differences in the definition of materials. When compared in terms of categories of use, the packaging materials are dominant debris among all. This finding of the present study is parallel with the other works conducted in the eastern Mediterranean by Stefatos et al. (1999) and Koutsodendris et al. (2008).

Results of GAM analysis indicate that the depth is a noticeable factor in the distribution of the debris in the area. In general, rate of debris deposition increased by depth except at a critical depth at around 50 m where a remarkable drop is recognized. This pattern is different than the Antalya Bay where no significant difference between depth ranges for debris abundance was found in

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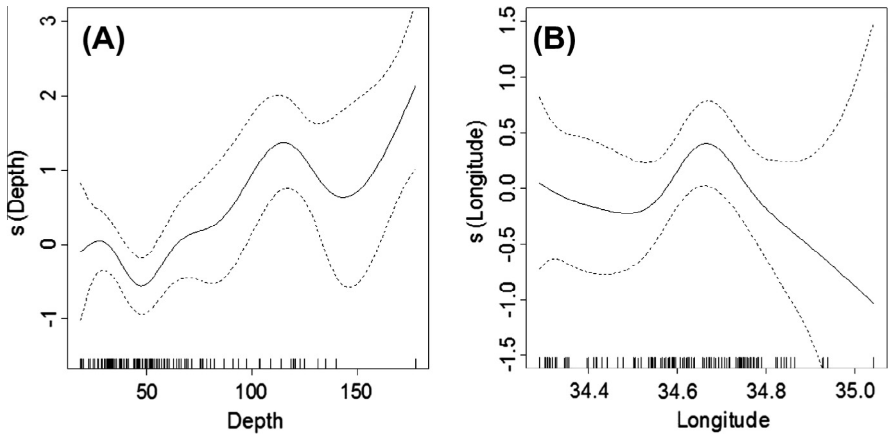

Fig. 5. Smoothing curves for partial effects of the predictors on DPUE derived by GAM. The contributions of each predictor are represented on the plots. Dotted lines indicate 95% confidence bands.

Fig. 6. Super shooter grid blocked by marine debris.

bathyal grounds (Güven et al., 2013). The majority of the debris found on the sea bottom are formed by light plastic material with large surface area-to-volume ratio and the specific gravity of the plastics likely to be found in the oceans varies between 0.91 and 1.38 (Andrady, 2005). Given that the gravity of the seawater is around 1.026 (@39.20 ppt) the sinking rate of such items are quite low (sometimes they need to be weigh down by fouling organisms to sink) and determined by the density of the surrounding water. Low sinking rate enables an item to be transported over a considerable distance before they reach the seabed. As can be seen from the direction and velocity of the currents in October 2011 (Fig. 7), the area is flushed by the currents running through Israel and Lebanon coast. Therefore it is very likely that the currents may be an important vector of transport for the light material and a considerable part of the plastics might have an origin outside of the bay. This idea is confirmed by Arabic labels on the packaging materials observed on the western part of the bay may be a proof for the transport. Similar trans-boundary problem was underlined by Yılmaz et al. (2002) in the south eastern part of Iskenderun Bay. They reported that approximately 1/3 of plastic debris at the 0–50 m depth range was of foreign origin and most of them were labeled in Arabic. Almost 40% of the trawl hauls were carried out during the period when there is a strong stratification in the water column. Fig. 8 displays monthly vertical density profiles throughout the fishing season. The depth of the pycnocline coincides with the depth layer with remarkably low debris accumulation (Fig. 5A). It is quite likely that the strong density gradient at 50 meters depth forms a barrier for the sinking plastics and increases their suspension time. The drop in the quantity of debris at that depth may therefore be a shadow effect of the pycnocline.

The longitude seems to be a secondary factor by its importance ($p = 0.4895$). The smoothed data suggested multimodal distribution which may point to sub regional irregularities (Fig. 5B). In essence, the eastern part is an important anchorage area used extensively by

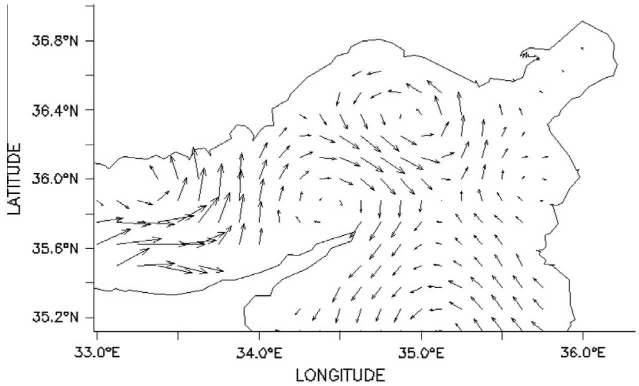

Fig. 7. Direction and velocity of geostrophic currents in the NE Mediterranean (the chart was produced and distributed by *Aviso* (<http://www.aviso.oceanobs.com/>), as part of the S SALTO ground processing segment).

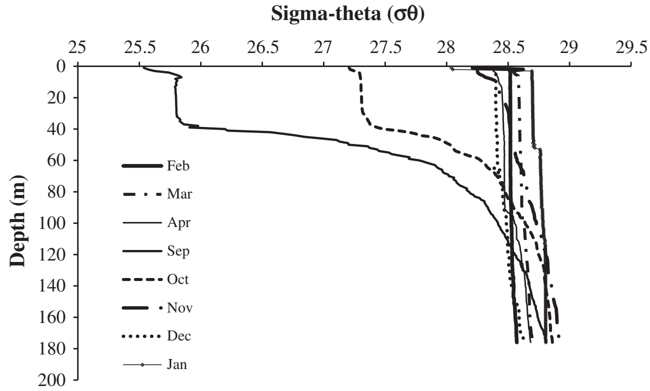

Fig. 8. Monthly vertical density (sigma theta) profiles measured in the Mersin Bay (taken from METU-IMS archive, http://www.ims.metu.edu.tr/IMS_Inventory/).

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international ships in the region. The high deposition observed on the east is probably a consequence of accidental or intentional dumping from the ships and underlines the importance of shipping as a source of debris. Essentially, currents in the eastern Mediterranean and shipping activity have already been reported as the origin of foreign debris in the south eastern Iskenderun Bay (Yılmaz et al., 2002). Similar results were also reported by Güven et al. (2013) in bathyal grounds in Antalya Bay.

Trawling is considered as the most effective way to collect marine debris from the seabed across vast areas (Lee et al., 2006) and at substantial depths (Spengler and Costa, 2008). The DPUE along with an estimate of area swept by the trawl net on the bottom could be used to extrapolate the results over the basin and so that foreseen the magnitude of marine debris deposited on the seafloor. However since the mouth opening of the trawl net could not be measured accurately, such estimation was not provided in the present study. On the other hand based on 40 active demersal trawlers operating in the area (Özbilgin et al., 2009) and assuming that they use the same conventional gear for 12 h a day and 180 days per fishing season, it may be postulated that almost 61 tons of marine debris could have been removed from the sea by the fleet, if the debris had not been discarded at sea. Given that the 73% of the debris is composed of plastics, the trawl fleet in Mersin alone has a potential to clean up 45 tons of highly resistant marine litter posing a serious hazard to marine environment (Derraik, 2002).

In conclusion, plastics are the most common marine litter and there are large numbers of plastics and packing debris in commercial fishing area in Mersin Bay. Therefore, it seems that selectivity grids are not suitable for bottom trawl fishing (especially in the western part of the bay). If grids are wanted to be used in highly polluted marine areas for bycatch reduction, further studies on the grid designs are needed for eliminating debris. Another important suggestion is that to clean up the accumulated debris on the seabed, especially trawlers should be encouraged to collect debris, and solid waste collection services must be established in ports.

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