Effect of marine pollution with litter on the benthic megafauna of coastal soft bottoms

Katsanevakis Stelios, Verriopoulos George, Nicolaidou Artemis, Thessalou-Legaki Maria

Department of Zoology-Marine Biology, School of Biology, University of Athens, 15784 Athens, Greece

Introduction

Marine anthropogenic debris, defined as any manufactured or processed solid material that enters the marine environment, is a greatly underestimated component of marine pollution. The threat of debris for the marine environment has been ignored for a long time and only in the last decades has serious attention been given to it (see Derraik (2002) for a review). The entanglement of marine species (turtles, mammals, fishes, and birds) has been frequently described as a serious mortality factor. Ingestion of debris (mainly plastics) is frequent and often has many harmful effects. PCB's and other contaminants enter marine food webs (mainly through ingested plastics) with yet unknown, but potentially very negative effects. In addition, drift debris can assist in the dispersal of 'alien' species.

Marine debris may concentrate on the seafloor reaching very high densities. In shallow coastal areas of Greece the density of marine debris ranged from 0 to 251 items per 1000 m^2, with a mean density of 15 items per 1000 m^2 (Katsanevakis & Katsarou, 2004). The potential effect on benthic communities of high marine debris densities on benthic communities has not been evaluated till now. In the present study, the effect of marine pollution with litter on the abundance, biodiversity, and community structure of benthic megafauna in soft-bottom areas was investigated.

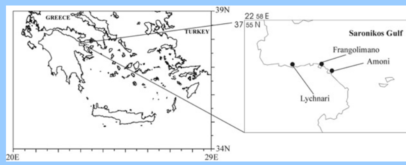

Figure 1: The three sites of the present experiment

Materials & Methods

In each of three different sites (Amoni, Frangolimano, and Lychnari) (**Fig. 1**), two square 100-m^2 surfaces (10 m x 10 m), ~ 50 m apart, were defined on the seafloor with nylon line, at similar depths (16 - 20 m) (**Fig. 2**). In all areas, the bottom was soft, with medium, fine or very fine sand. On one of the surfaces at each site, 16 items of litter (plastic bottles and glass jars) were placed uniformly, while the other surface remained 'clean' and acted as a control area. Apart from the square outline, 5 corridors (2 m x 10 m) were defined inside each square to facilitate the visual census of the surface. The benthic megafauna was quantitatively censused, during SCUBA dives, on all surfaces, once before littering the surfaces (in June 2005) and then monthly for 1 year, till June 2006.

The time-series of the difference in total abundance between the impacted surface and the control ($\Delta N = N_{impact} - N_{control}$) and difference in the total number of species ($\Delta S = S_{impact} - S_{control}$) were fitted to 7 models (with non-linear least squares, using Marquardt's algorithm): the constant model (g_1), the linear model (g_2), the parabolic model (g_3), the exponential model (g_4), the von Bertalanffy growth model (g_5), the Gompertz growth model (g_6), and the logistic model (g_7) (**Table 1**).

Model selection was based on the Information Theory approach (Burnham & Anderson, 2002). The small-sample, bias-corrected form AIC_c (Hurvich & Tsai, 1989) of the Akaike's Information Criterion (AIC) (Akaike, 1973; Burnham & Anderson, 2002) was used for model selection. The model with the smallest AIC_c value ($AIC_{c,min}$) was selected as the 'best' among the models tested.

To obtain more robust inferences, the final results were based on model averaging the response variable using Akaike weights, rather than simply on the 'best' model (Burnham & Anderson, 2002). The 'Akaike weight' w_i of each model g_i was calculated as $w_i = \frac{\exp(-0.5\Delta_i)}{\sum_{j=1}^{7}\exp(-0.5\Delta_j)}$, where $\Delta_i = AIC_{c,i} - AIC_{c,min}$.

Non-metric multidimensional scaling (MDS) was also performed on benthic community data to establish before/after impact differences at each site. Similarity matrices were based on Bray-Curtis similarity coefficients of square-root transformed data (Clarke and Warwick, 2001).

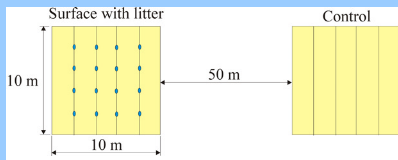

Figure 2: The experimental setup in each of the three sites of the study. Blue ellipses stand for the litter items that were placed in the impacted surface.

Table 1: The set of candidate models for modelling the time-series of $\Delta N = N_{impact} - N_{control}$ and $\Delta S = S_{impact} - S_{control}$ in the three sites of the study.

Set of Candidate Models		
g_1	Constant	$Y = a_0$
g_2	Linear	$Y = a_0 + a_1 t$
g_3	Quadratic	$Y = a_0 + a_1 t + a_2 t^2$
g_4	Exponential	$Y = Ae^{kt}$
g_5	von Bertalanffy	$Y = Y_\infty(1 - e^{-k(t-t_0)})$
g_6	Gompertz	$Y = Y_\infty \exp(-\lambda e^{-kt})$
g_7	Logistic	$Y = Y_\infty(1 + e^{-k(t-t_0)})^{-1}$

Results

The best model for ΔN on all three experimental surfaces was the logistic model. The second best model was the Gompertz equation, which was substantially supported by the Amoni data but considerably less supported than the logistic equation at the other two sites (**Table 2**). No other model had substantial support. The 'no impact' assumption (which was expressed by model g_1) had essentially no support by the data. The 'average' models for ΔN at the three sites are given in **Fig. 3**. For all three bays, the litter effect of increased megafauna abundance appeared six months after debris deposition, in late winter, while it seemed to reach a plateau towards the end of the experiment.

The best model for ΔS was g_2 (positive linear trend) for Amoni and Frangolimano, and Gompertz (as well as logistic) for Lychnari; other models also had substantial support (**Table 3**). The 'no impact' assumption (which was expressed by model g_1) had essentially no support by the data. The 'average' models for ΔS at the three sites are given in **Fig. 4**.

All three MDS plots demonstrated a marked gradual deviation of the impacted surface from the control (**Fig. 5**)

Table 2: Modelling the time-series of the difference in total abundance between the impacted surface and the control ($\Delta N = N_{impact} - N_{control}$). For each site and for each candidate model of the set, AIC_c, Akaike differences Δ_i, and Akaike weights w_i are given. k is the number of model parameters plus one. The 95% confidence set of models is printed red and the best model bold.

Model	k	Amoni			Frangolimano			Lychnari		
		AIC_c	Δ_i	w_i	AIC_c	Δ_i	w_i	AIC_c	Δ_i	w_i
g_1	2	148.9	24.3	0.0%	165.6	35.8	0.0%	169.0	38.5	0.0%
g_2	3	130.9	6.3	2.6%	145.7	15.9	0.0%	148.8	18.3	0.0%
g_3	4	133.0	8.4	0.9%	140.4	10.6	0.4%	138.3	7.8	1.7%
g_4	3	133.4	8.8	0.8%	141.3	11.5	0.3%	139.1	8.6	1.2%
g_5	4	135.7	11.0	0.2%	150.1	20.3	0.0%	153.1	22.7	0.0%
g_6	4	125.8	1.1	34.5%	134.5	4.7	8.6%	134.4	4.0	11.8%
g_7	4	124.6	0.0	**61.0%**	129.8	0.0	**90.7%**	130.5	0.0	**85.3%**

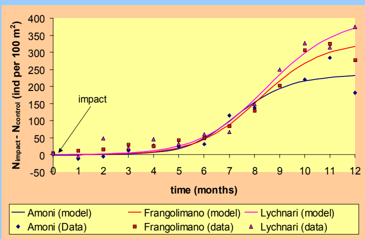

Figure 3: The time-series of the difference in total abundance between the impacted surface and the control, $\Delta N = N_{impact} - N_{control}$, in the three sites. The 'average' models are also given as solid lines.

Table 3: Modelling the time-series of the difference in the total number of species between the impacted surface and the control ($\Delta S = S_{impact} - S_{control}$). For each site and for each candidate model of the set, AIC_c, Akaike differences Δ_i, and Akaike weights w_i are given. k is the number of model parameters plus one. The 95% confidence set of models is printed red and the best model bold.

Model	k	Amoni			Frangolimano			Lychnari		
		AIC_c	Δ_i	w_i	AIC_c	Δ_i	w_i	AIC_c	Δ_i	w_i
g_1	2	71.7	15.7	0.0%	81.4	20.8	0.0%	79.9	14.5	0.0%
g_2	3	56.1	0.0	**42.0%**	60.6	0.0	**47.3%**	67.6	2.1	13.6%
g_3	4	58.9	2.8	10.2%	64.9	4.3	5.4%	71.4	6.0	2.0%
g_4	3	62.0	6.0	2.1%	64.2	3.6	7.8%	69.9	4.4	4.3%
g_5	4	59.2	3.1	8.8%	64.9	4.3	5.4%	71.9	6.5	1.6%
g_6	4	57.5	1.4	20.8%	63.0	2.5	13.8%	65.4	0.0	**39.4%**
g_7	4	58.0	1.9	16.0%	62.3	1.7	20.3%	65.5	0.0	39.1%

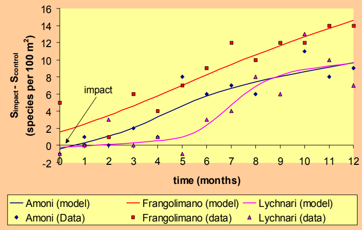

Figure 4: The time-series of the difference in the total number of species between the impacted surface and the control ($\Delta S = S_{impact} - S_{control}$) in the three sites. The 'average' models are also given as solid lines.

Discussion

Both the number of individuals and the number of species showed an upward trend at the impacted surfaces (in relation to the control). Two reasons were mainly responsible for that:

1. hard-substratum sessile species settled on the surfaces of the litter increasing both number of species and total abundance,
2. the litter provided refuge for mobile species (fishes, crustaceans, sea-urchins etc.) either by direct use of their cavities or by digging in the sediment beneath them (**Figs 6, 7).**

Acknowledgements

The project was co-funded by the European Social fund and National Resources (Hellenic Ministry of National Education and Religious Affairs: EPEAEK II: Pythagoras II).

References

Akaike H, 1973. Information theory and an extension of the maximum likelihood principle. In *Proceedings of the Second International Symposium on Information Theory, Akademiai Kiado, Budapest* (ed. B.N. Petrov and F. Csàaki), pp. 267-281.

Burnham KP, Anderson DR, 2002. *Model selection and multimodel inference: a practical information-theoretic approach*, 2nd edn. New York: Springer.

Clarke K, Warwick R, 2001. Change in marine communities: An approach to statistical analysis and interpretation, 2nd edition. Plymouth Marine Laboratory, UK.

Derraik JGB, 2002. The pollution of the marine environment by plastic debris: a review. *Marine Pollution Bulletin* 44, 842-852.

Hurvich CM, Tsai CL, 1989. Regression and time series model selection in small samples. *Biometrika* 76, 297-307.

Katsanevakis S, Katsarou A, 2004. Influences on the distribution of marine debris on the seafloor of shallow coastal areas in Greece (Eastern Mediterranean). *Water, Air and Soil Pollution* 159, 325-337.

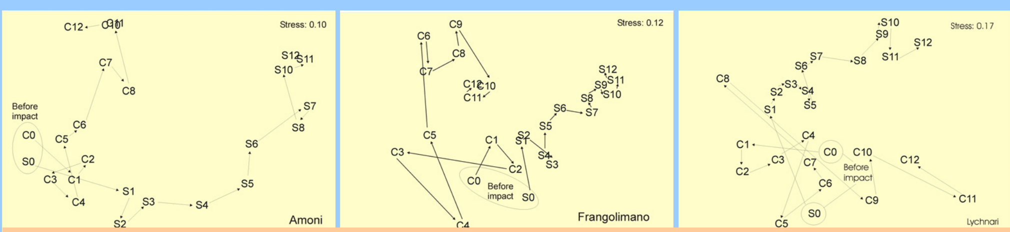

Figure 5: MDS plots of epibenthic megafauna monthly samples at the three sites of the study. S: impacted surface, C: control surface, index: months after impact (0 is before impact)

Figure 6: A sea-urchin (*Sphaerechinus granularis*) found refuge in the cavity of a plastic bottle. The photo was shot in the experimental surface in Lychnari.

Figure 7: Some gastropods (*Trunculariopsis trunculus*) laid their eggs in the cavity of a plastic box. The photo was shot in the experimental surface in Lychnari.