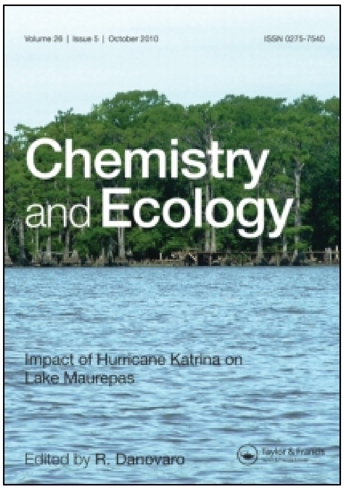

Chemistry and Ecology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713455114

Filtration pressure by bivalves affects the trophic conditions in Mediterranean shallow ecosystems

Antonio Manganaro[a]; Giuseppa Pulicanò[a]; Alessandra Reale[a]; Marilena Sanfilippo[a]; Gianluca Sarà[b]
[a] Dipartimento di Biologia Animale ed Ecologia Marina, Università di Messina, Italy [b] Dipartimento di Ecologia, Università di Palermo, Italy

Online publication date: 09 December 2009

To link to this Article: DOI: 10.1080/02757540903325120
URL: http://dx.doi.org/10.1080/02757540903325120

Chemistry and Ecology
Vol. 25, No. 6, December 2009, 467–478

Taylor & Francis
Taylor & Francis Group

Filtration pressure by bivalves affects the trophic conditions in Mediterranean shallow ecosystems

Antonio Manganaro[a], Giuseppa Pulicanò[a], Alessandra Reale[a], Marilena Sanfilippo[a] and Gianluca Sarà[b]*

[a]*Dipartimento di Biologia Animale ed Ecologia Marina, Università di Messina, Italy;* [b]*Dipartimento di Ecologia, Università di Palermo, Italy*

(*Received 14 June 2009; final version received 7 August 2009*)

Bivalve filtration may control the amount of seston in coastal waters, reducing local euthrophication and keeping degrading phenomena like hypoxia and anthropogenic pollution under control. Two Sicilian brackish-marine ponds (Ganzirri and Faro) present us with the opportunity to gain data on the effect of bivalve filtration on the amount of particulate organic matter in the field. The cultivation of bivalves has been carried out in both of the ponds since the early 1990s but stopped in Ganzirri in 1995. We tested whether the cessation of bivalve cultivation influenced features of organic matter available to suspension feeders (total suspended matter, its inorganic and organic fractions, chlorophyll *a*, carbohydrates, proteins and lipids). Since the bivalve cultivation was stopped in Ganzirri in 1995, chlorophyll *a* sharply and significantly increased compared to Faro, where, in contrast, they remained the same as in previous decades. Recent data shows that organic matter was significantly higher in Ganzirri than Faro and that differences were maintained throughout the study period. Using clearance rate data from the literature, we determined that bivalves can filter the available volume in Ganzirri by about 540 times and in Faro by 650 times per year. Thus bivalve farmed biomass (about 300 tonnes per year of fresh biomass) can exert a high filtration pressure to both (i) control the phytoplankton biomass and trophic dynamics in ponds, and (ii) reduce a possible role of natural-with-sea exchange and polluted waters coming from the hinterlands.

Keywords: bivalves; filtration; particulate organic matter; shallow waters; primary production; Mediterranean Sea

1. Introduction

Bivalve filtration may control the amount of seston in coastal waters [1], reducing local euthrophication and keeping degrading phenomena like hypoxia and anthropogenic pollution under control [2,3]. Indeed, bivalves rely on particulate matter of sizes ranging from 1 μm to 40–100 μm, including bacteria, nano-phytoplankton, small zooplankton and detritus of different origins [4,5]. They concentrate many toxic substances like heavy metals or polycyclic aromatic hydrocarbons [6] and on many occasions, bivalves have been used as organic recyclers, transforming sewage and surplus organic matter originating from fish culture [3,7] into secondary edible biomass.

*Corresponding author. Email: gsara@unipa.it

ISSN 0275-7540 print/ISSN 1029-0370 online

DOI: 10.1080/02757540903325120
http://www.informaworld.com

Bivalves are thus important parts of an ecosystem, often representing key species in their ability to control organic matter flux through coastal trophic webs (*sensu* [8]). The role of bivalves has often been evidenced in numerous areas of the Northern Hemisphere, where organic pollution is a severe problem. Lindhal et al. [3] propose the use of bivalves as an efficient tool for reducing the negative effects of eutrophication, while contrasting evidence shows that biodeposits and ammonia excretion of bivalves could promote phytoplankton growth [9]. However, the knowledge that phytoplankton may be controlled by bivalve filtration has mostly been derived from mesocosmal and laboratory experiments [10]; large field data are, to date, rather scant. In eastern Sicily, two brackish-marine ponds (Faro and Ganzirri) present us with the opportunity to gain data on the effect of bivalve filtration on the amount of particulate organic matter in the field. The cultivation of bivalves has been carried out in both of the ponds since the early 1990s, but was stopped in Ganzirri in 1995. Thus, based on the observation that the ponds had the same origin, receive the same type of waters (from both industrial sources and sewage, and seawaters from the Strait of Messina), we can assume that the unique, remarkable difference between them is the presence of bivalve cultivation. Consequently, the present paper aims to investigate: (i) whether the amount of chlorophyll *a* was different between the two ponds when bivalves were still cultivated; (ii) whether the interruption of bivalve cultivation resulted in different features of chlorophyll *a* and particulate organic matter; and (iii) what feature of particulate organic matter was most affected by bivalve cultivation.

2. Materials and methods

2.1. *Study areas*

The study was carried out in two brackish ponds located close to Capo Peloro (Eastern Sicily; 38° 15’57” N; 15° 37’ 50” E): Ganzirri and Faro (Figure 1). These share a similar geological origin, and are characterised by brackish waters of marine origin [11].

The Ganzirri pond is larger (surface 34 ha; entire volume 9.8×10^5 m^3) and shallower (6 m maximum depth) than Faro (surface 26 h, entire volume 2.5×10^6 m$^{3;}$; about 9.0×10^5 m^3 0–5 m

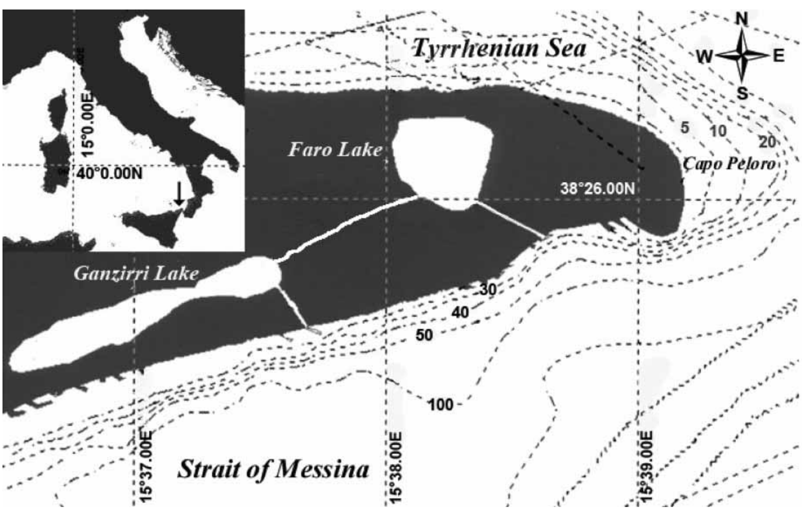

Figure 1. Map of the Ganzirri and Faro ponds.

layer and maximum depth 28 m). Ganzirri has the appearance of a long (1,670 m) and narrow (on average ~200 m) stream tube [12] parallel to the coast, and has slightly lower salinity (on annual average 31, ranging from 21–37; [13]) than Faro (annual average 33, ranging from 31–37; [14]) but similar water temperatures (annual average about 23.1 °C in both ponds).

The Ganzirri pond is characterised by two sub-basins: north and south. The southern basin (3 m average depth) has been extensively exploited for over a century for mollusc culture (mussels and clams), has muddy sediments, and primary production is sustained essentially by phytoplankton [13]. The north basin accounts for one quarter of the total surface area, is shallower (maximum depth 1 m) than the southern one, has sandy bottoms and mats of the green alga *Chaetomorpha linum*. Primary production in the north basin is due both to phytoplankton and green and red macroalgae [15]. The two Ganzirri basins, being partially separated from each other by a sand tombolo, are characterised by different hydrodynamic regimes [14,16].

Faro is a small meromictic marine pond (~26 ha), characterised by the presence of H_2S in the hypolimnion and a brownish water layer at the chemocline (at about 10 m depth) colonised by dense populations of phototrophic sulphur bacteria [13,17]. It is a circular basin with a 500 m diameter, and is deeper in its central part (~28 m), whereas its mean depth ranges from 0.5–5 m. The pond is characterised by sandy-muddy bottoms seasonally covered by green algal mats, although primary production here is mainly sustained by phytoplankton.

Both ponds exhibit similar fetches [11], are characterised by wind-driven circulation and frequent sediment resuspension events ([16], *sensu* [5]) and are connected to each other by the Margi channel (about 1 km long and 10–12 m large). Seawater entering the ponds through narrow channels plays an almost negligible role in the internal circulation and hydrodynamics [11,16]. Water turnover time is ~40 and ~27–30 days for Ganzirri and Faro, respectively [15] (Pulicanò, pers. comm.). The relatively long water residence times, coupled with relevant continental nutrient inputs, maintain constant eutrophic conditions and determine recurrent dystrophic crises [14]. The Ganzirri pond was used for shellfish culture until 1995, after which, because of heavy pollution and contamination by pathogenic prokaryotes, activity ceased [13]. The Faro pond, however, is still largely exploited for bivalve cultivation (mainly *Mytilus galloprovincialis*; [16,18–20]; estimated mean annual cultivated biomass: ~300 t).

2.2. *Experimental assumptions and hypothesis*

The basic assumption underlying the present study is that, throughout the last century, the temporal changes in the two ponds' trophic statuses have been quite similar [11]. During the first part of the 1990s, when both ponds were largely exploited for shellfish culture, their trophic conditions were rather similar (chlorophyll *a* concentrations $<10\,\mu g\,L^{-1}$; [17,21]) because of the large effect of shellfish cultivation and bivalve filtration pressure on water characteristics (*sensu* [22]; see Table 1). Since both ponds have experienced the same anthropogenic pressure throughout the last decade (after 1995–2000), it can be assumed that the temporal changes of their trophic conditions would have been the same with or without the presence of shellfish cultivation.

We hypothesised that, after the cessation of shellfish culture in the Ganzirri pond, the trophic regime would be significantly different from that in the Faro pond (which continued to be exploited for bivalve culture), and that most of the changes occurring were due to the different levels of bivalve filtration pressure.

To test this hypothesis, the two sub-basins within the Ganzirri pond (north and south) and the Faro pond as a whole were chosen to examine the effects of bivalve filtration pressure on quality and quantity of organic matter available for consumers. Before this, we also tested that differences between the two ponds were not significant before 1995, at which point shellfish farming was interrupted in the Ganzirri pond.

Table 1. Data of chlorophyll a ($\mu g\,L^{-1}$) collected across the current literature on Faro and Ganzirri ponds.

Year	Ganzirri	Faro	Adjacent Sea	Source	
Oct 1982		0.30		Tab. 1	Platt et al. 1985
1982			0.10	Tab. 1	Magazzù and Decembrini 1995
Mar–Dec 1986		5.03		Body text	Acosta Pomar et al. 1988
May 1986		16.4		Body text	Acosta Pomar et al. 1988
July 1986		1.00	0.21	Body text	Acosta Pomar et al. 1988
Oct 1986			0.22	Body text	Acosta Pomar et al 1988/Decembrini and Magazzù 1990
All 1986		5.00	0.20	Body text	Acosta Pomar et al 1988/Decembrini and Magazzù 1990
1987–1988	2.60	1.6		Tab. 1	Magazzù et al 1989b
1987–1988				Tab. 1	
1990			0.20	Body text	Azzaro et al. 2007
1992	10.60			Fig. 2f	Giacobbe et al. 1996
Mean before 1995	**6.60**	**4.90**	**0.20**		
±	**5.70**	**6.00**	**0.01**		
1996					
1998–1999	12.40	2.50		–	Present study
2000–2001	112.01			Tab. 1	Vanucci et al. 2005
2000–2001	126.32			Tab. 1	Vanucci et al. 2005
2000–2001	42.27			Tab. 1	Vanucci et al. 2005
1998–2007			0.22	EMIS	http://emis.jrc.ec.europa.eu/4_1_gismap.php
Mean after 1995	**73.25**	**2.50**	**0.22**		
±	**54.72**	**23.93**	**0.08**		

Thus, the ponds were assumed to be representative of putatively different conditions: a brackish water mass affected only by anthropogenic impact without shellfisheries (Ganzirri), and a brackish water mass with strong anthropogenic impact and shellfisheries (Faro).

2.3. *Sampling and laboratory analysis*

In each pond, water sampling was carried out in shallow sites with similar depth ($\sim$2.5 m) using Niskin bottles. Two sampling replicates of water were collected monthly from May 1998 to April 1999 from each of the sites (Ganzirri's north and south basins, and Faro). Water samples were screened through a 200 μm mesh net in order to remove large zooplankton and debris. Sub-samples (500–2000 mL) were filtered onto pre-washed, precombusted (450 °C, 4 h) and pre-weighed Whatman GF/F filters (0.45 μm nominal pore size). Filters were analysed for total suspended matter (TSM, $mg\,L^{-1}$), its inorganic (ISM, $mg\,L^{-1}$) and organic fractions (OSM, $mg\,L^{-1}$), chlorophyll a (CHL a, $\mu g\,L^{-1}$), carbohydrates (CHO, $\mu g\,L^{-1}$), proteins (PRT, $\mu g\,L^{-1}$) and lipids (LIP, $\mu g\,L^{-1}$). For the determination of TSM, Whatman GF/F filters (0.45 μm nominal pore size) were weighed after desiccation (60 °C, 24 h) using a Mettler M3 balance (accuracy $\pm 1\,\mu g$), while OSM was determined by loss on ignition (450 °C, 4 h; [23]). Particulate chlorophyll a, proteins, carbohydrates and lipids were determined using spectrophotometric assays according to [24]. Phytoplankton biomass was estimated from chlorophyll a concentrations using 40 μgC μg Chl a^{-1} as a conversion factor. Lipids, carbohydrates and proteins were converted into carbon equivalents using 0.75, 0.40 and 0.49 $\mu gC\,L^{-1}$ conversion factors, respectively [24], and their sum was reported as biopolymeric carbon (BPC; [25]). The food index (POM/TSM) of particulates was estimated as the percentage ratio between the sum of protein, carbohydrate and lipid concentrations (POM) and the sum of total suspended matter (TSM) [26,27].

2.4. *Statistical analyses and elaboration*

Data were analysed to test the null hypothesis that there is no difference in trophic concentrations between the pond without shellfisheries (i.e. absence of bivalve filtration pressure) and the pond with shellfisheries (i.e. presence of bivalve filtration pressure exerted by 300 t of cultivated organisms), using a two-way analysis of variance (ANOVA). The presence/absence of shellfisheries (Bivalve, 2 levels) and sampling time (Month, 12 levels) were treated as fixed and orthogonal factors. Two independent sites (Site, 2 levels) were treated as random factors and nested in the interaction of BIVALVE × MONTH. Two replicates ($n = 2$) were chosen randomly for each site. For all of the analyses, the heterogeneity of variance was tested using Cochran's C test prior to the analysis of variance, and the Student–Newman–Keuls (SNK) test allowed the appropriate means comparison. GMAV rel 5.0 (University of Sydney, personally licensed to G. Sarà) was used to perform ANOVAs. The Student t-test was used to verify differences between chlorophyll a means before 1990.

A distance-based permutational multivariate analysis of variance (PERMANOVA [28,29]) was used to quantify the effects of shellfish farming on the trophic conditions of the two ponds. The sampling design was the same as for the uni-variate analyses. Pairwise comparisons used 999 random permutations to obtain p-values. The p-values were calculated using 999 Monte Carlo draws from the asymptotic permutation distribution [29,30].

3. Results

3.1. *Temporal evolution of trophic state up to 1990*

Phytoplankton biomass in the two ponds as measured throughout the last four decades is reported in Table 1. Chlorophyll a values ranged between 2 and 5 $\mu g\ L^{-1}$ and biomass did not differ between

Table 2. ANOVA performed to test whether presence or absence of shellfisheries affected trophic variables of the water column in brackish waters in Sicily.

		TSM			ISM			OSM			ISM/OSM		
Source	df	MS	F	p	MS	F	p	MS	F	p	MS	F	p
Bivalve (BIV)	2	0.48	6.42	***	0.26	2.82	ns	2.16	29.55	***	0.9385	8.87	***
Month (MO)	11	2.45	32.64	***	1.95	20.9	***	2.66	36.39	***	0.3921	3.71	***
Site (BIV × MO)	36	0.07	1.24	ns	0.09	2.17	***	0.07	0.24	ns	0.1058	0.25	ns
BIV × MO	22	0.75	9.98	***	0.57	6.11	***	0.95	13.08	***	0.4508	4.26	***
Residuals	72	0.06			0.04			0.30			0.4292		
Cochran's C				ns (§)			ns (§)			ns (§)			ns (§)
		C-CHL *a*			C-CHO			C-PRT			C-LIP		
Bivalve (BIV)	2	20	37.78	***	12	116.24	***	19	125.29	***	4.5315	17.3	***
Month (MO)	11	9.6	17.79	***	4.4	42.78	***	6.5	42.76	***	3.4213	13.06	***
Site (BIV × MO)	36	0.5	0.49	ns	0.1	0.31	ns	0.2	0.51	ns	0.2619	0.61	Ns
BIV × MO	22	2.1	3.81	***	1.6	15.21	***	1.1	7.48	***	0.9878	3.77	***
Residuals	72	1.1			0.3			0.3			0.4311		
Cochran's C				ns (§)			ns (§)			ns (§)			ns (§)
		BPC			C-CHO/C-PRT			POM/TSM			C-CHL *a*/BPC		
Bivalve (BIV)	2	6.5	72.9	***	0.9	4.91	**	626	31.28	***	9.4327	22	***
Month (MO)	11	3.7	41.8	***	1	5.59	***	195	9.75	***	2.7739	6.47	***
Site (BIV × MO)	36	0.1	0.39	Ns	0.2	0.63	ns	20	0.49	ns	0.4287	0.52	ns
BIV × MO	22	0.8	9.10	***	0.6	3.13	***	109	5.43	***	0.795	1.85	*
Residuals	72	0.2			0.3			41			0.8212		
Cochran's C				ns (§)			ns (§)			ns (§)			ns (§)

Notes: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ns, no significant difference; §, data log-transformed [log (x + 1].

ponds in the years up to 1995 (Student t-test $p > 0.05$). Since the bivalve cultivation was stopped in Ganzirri, in just a few years (from 1992–1995 to 2000) chlorophyll a concentrations sharply and significantly increased ($p < 0.05$) in Ganzirri when compared with Faro, where, in contrast, they remained the same as in previous decades.

3.2. *Current differences*

The analysis of variance carried out on data collected between 1998 and 1999 revealed that concentrations of TSM and its organic fraction were significantly different between the two ponds

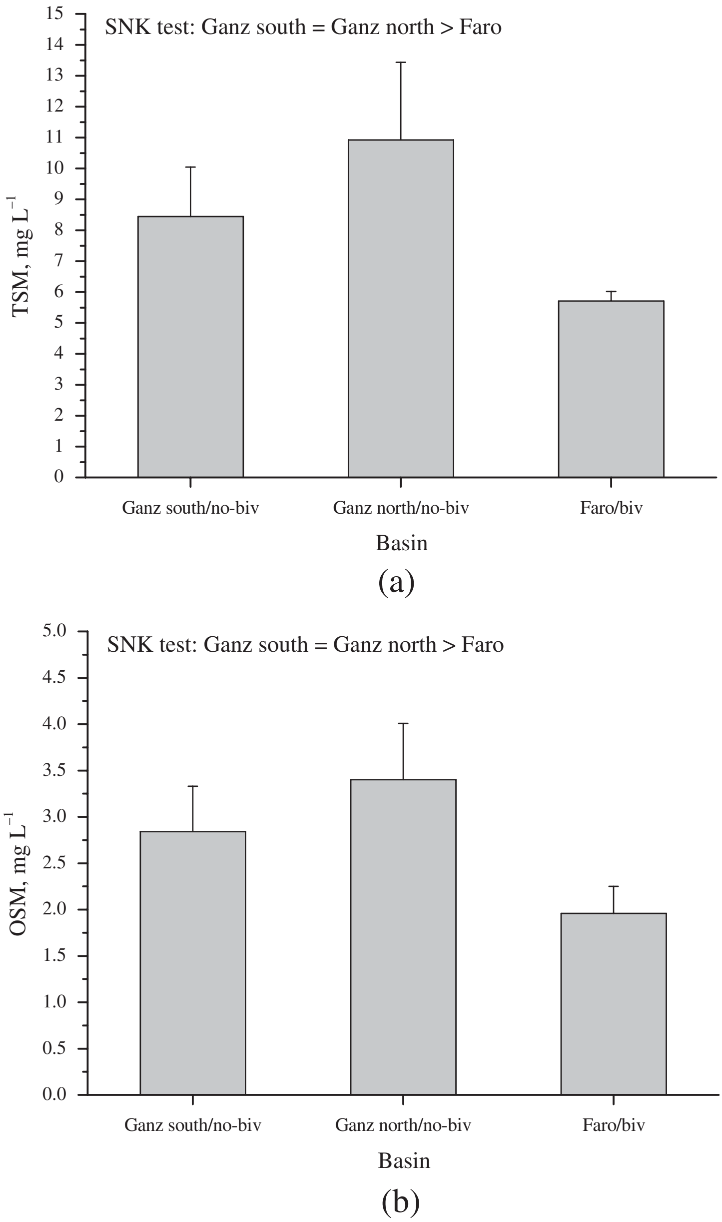

Figure 2. (a) Total suspended matter (TSM; mg L^{-1}) and (b) organic suspended matter (OSM; mg L^{-1}) as estimated in the two brackish ponds of Eastern Sicily (Ganz = Ganzirri).

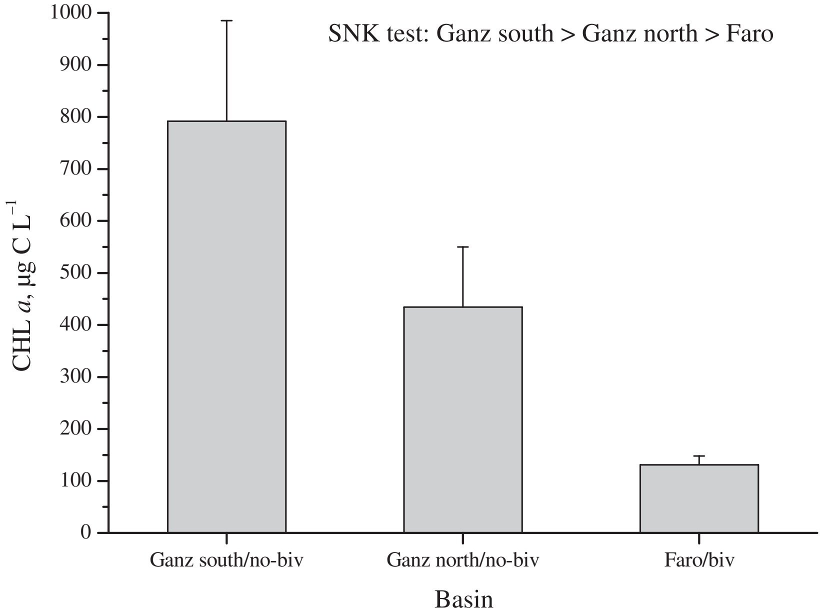

Figure 3. Carbon from suspended chlorophyll *a* (CHL *a*; μgC L^{-1}) as estimated in the two brackish ponds of Eastern Sicily (Ganz = Ganzirri).

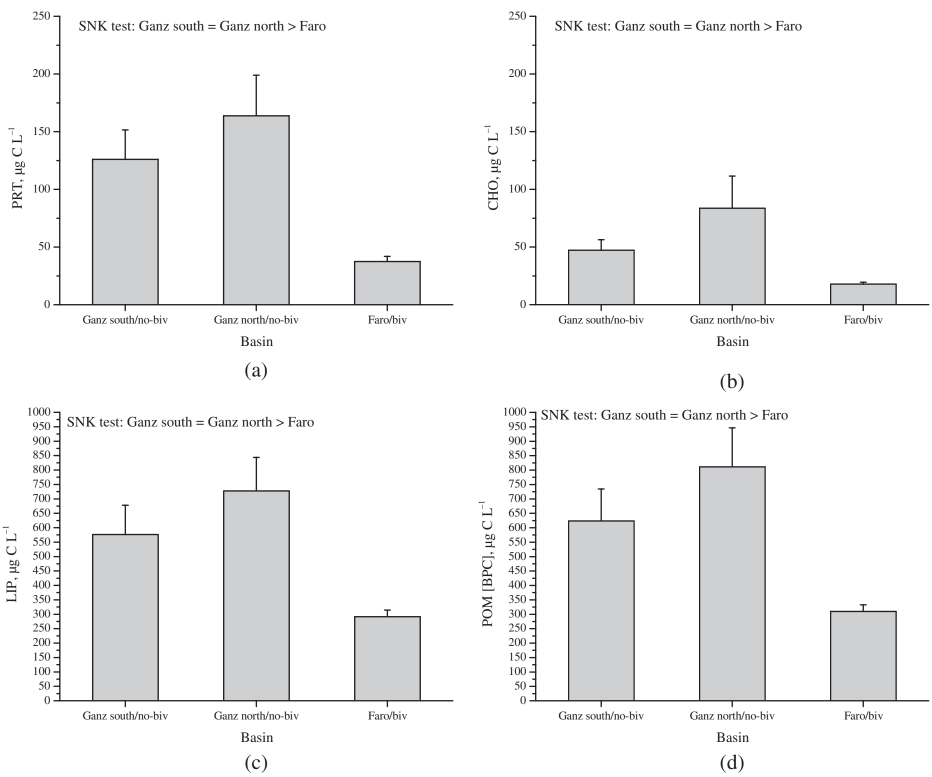

Figure 4. Carbon from (a) particulate carbohydrates (CHO; μgC L^{-1}), (b) particulate proteins (PRT, μgC L^{-1}), (c) particulate lipids (LIP; μgC L^{-1}), and (d) biopolymeric particulate carbon (BPC as a sum of C-CHO, C-PRT and C-LIP; μg L^{-1}) as estimated in the two brackish ponds of Eastern Sicily (Ganz = Ganzirri).

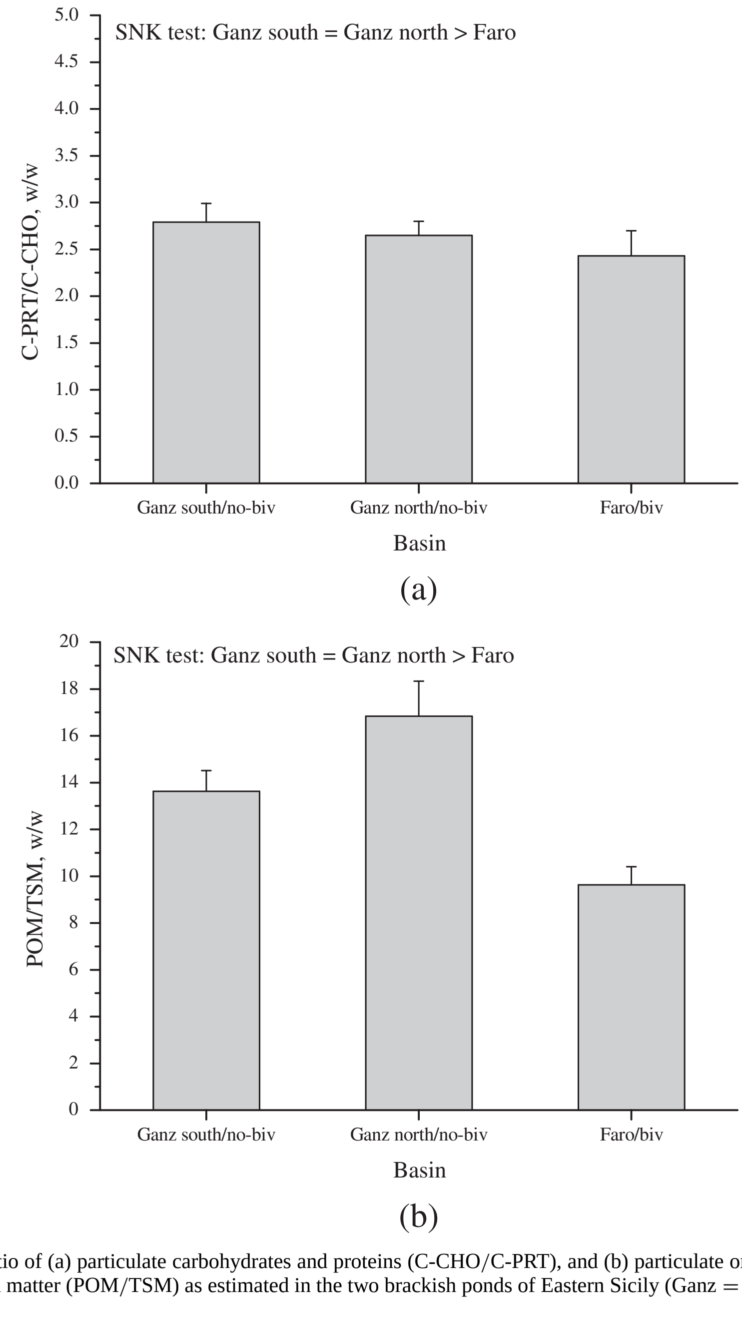

Figure 5. Ratio of (a) particulate carbohydrates and proteins (C-CHO/C-PRT), and (b) particulate organic matter and total suspended matter (POM/TSM) as estimated in the two brackish ponds of Eastern Sicily (Ganz = Ganzirri).

and that these differences varied significantly with time (months; Table 2). These differences were maintained throughout the study period and were particularly relevant in Spring and Summer, when TSM concentrations in the Ganzirri sites were up to 8–13 times higher than in Faro (Figure 2(a),(b)). Values of phytoplankton biomass differed significantly between the two sites in the Ganzirri pond. Phytoplankton biomass values in both were significantly higher (ca. 3-fold) than those measured in the Faro pond (ANOVA, $p < 0.05$) (Figure 3). Particulate proteins, carbohydrates, lipids and, consequently, biopolymeric carbon concentrations in the Ganzirri pond waters (both sectors) were significantly higher than in the Faro pond ($p < 0.05$; Figure 4(a)–(d)).

Table 3. (a) PERMANOVA performed on multivariate matrix to test whether presence or absence of shellfisheries affected trophic variables of the water column in brackish waters in Sicily; (b) pairwise comparisons.

(a)

Source	df	MS	Pseudo-F	P(perm)	Significance
Bivalve (BIV)	2	1202.00	76.31	0.0001	***
Month (MO)	3	914.40	58.05	0.0001	***
BIV × MO	6	294.89	18.72	0.0001	***
Site (BIV × MO)	12	15.75	0.23	0.99	ns
Residuals	120	68.55			

(b)

SPRING	t	P(perm)	Significance	SUMMER	t	P(perm)	Significance
noBiv-north vs noBIV-south	3.16	0.01	***	noBiv-north vs noBIV-south	1.88	0.17	ns
noBIV-north vs BIV	5.08	0.00	***	noBIV-north vs BIV	7.62	0.00	***
noBIV-south vs BIV	3.60	0.00	***	noBIV-south vs BIV	9.93	0.00	***

AUTUMN	t	P(perm)	Significance	WINTER	t	P(perm)	Significance
noBiv-north vs noBIV-south	1.33	0.28	ns	noBiv-north vs noBIV-south	2.62	0.06	ns
noBIV-north vs BIV	9.35	0.00	***	noBIV-north vs BIV	5.57	0.00	***
noBIV-south vs BIV	7.81	0.00	***	noBIV-south vs BIV	3.37	0.01	***

Notes: ***$p < 0.001$; ns, no significant difference.

Proteins represented about 16% of BPC in Ganzirri and about 10% in Faro; the percentage of carbohydrates was similar in both ponds (about 6.0% and 6.8%, respectively, in Ganzirri and Faro), while lipids represented about 77% in Ganzirri and 84% in Faro. Protein-to-carbohydrate ratios were rather high (up to 3.0), and significantly higher in Ganzirri than in Faro (Figure 5(a)). Values of the food index POM/TSM were similar in the two sectors of the Ganzirri pond (up to 15%) and were higher than in the Faro pond (consistently lower than 10%) (Figure 5(b)).

The results of PERMANOVA (Table 3(a),(b)) revealed that the two ponds displayed consistent differences in the trophic conditions and that, apart from in Spring, the trophic conditions in the two sectors of the Ganzirri pond were relatively constant.

4. Discussion

Results for the present study show that bivalve grazing pressure can control phytoplankton and particulate concentrations, which affects the trophic status of the two investigated ponds. Since 1982, when the first influential papers were published [31,32], benthic grazing has been considered the most important fate of primary production [22,33]. Thus, the paradigm ‘changes in benthic grazer biomass (i.e. bivalves) equals the changes in phytoplankton biomass’ seems well established across the literature [39]. Bivalve filtration pressure is thereby able to control concentrations of chlorophyll *a* in the water column, and different trophic conditions are produced in its absence. Thus, in these Sicilian brackish ecosystems, the cessation of shellfisheries appears to consistently influence the fate of primary production as expressed by chlorophyll *a* concentration before and after the 1990s, but it could also have an effect on the phytoplankton and bacterioplankton community structure [32]. Before the 1990s, our two ponds were quite similar from the trophic point of view; they had similar concentrations of most trophic variables, while after the 1990s their concentrations significantly deviated. In Faro, where the shellfishery is still active, concentrations remain constant or display natural annual/seasonal fluctuations. However, they always remain within the ranges of the last few decades. In contrast, in Ganzirri, concentrations after the 1990s increased enormously, which was probably due to the absence of bivalve grazing. On the other hand, any clearance data measured for any mussel species in the past and in any condition (mesocosm, wild or simulated; from [1,34–37]), may explain present findings. Considering the 0–5 m layer water volume in the ponds (about 900,000 m^3 and 800,000 m^3, respectively, for Ganzirri and Faro) and the consequent water exchanges, bivalve farmed biomass (about 300 tonnes per year of fresh biomass) would exert such a great filtration pressure that it would be able to both (i) control the phytoplankton biomass and trophic dynamics in ponds, and (ii) reduce a possible role of natural-with-sea exchange and polluted waters coming from hinterlands. Indeed, assuming a very conservative clearance value of about 1.0 $l\,h^{-1}$ DW g^{-1} of bivalve somatic matter [1,34], the water volume of both ponds (see above) and a total biomass of 300 t per year of wet somatic biomass (more or less 60 t of dry wet biomass; [1]), bivalve filtration pressure could be able to filter the available volume in Ganzirri by about 540 times and in Faro by 650 times per year (i.e. about or more than two times per day). These simple and gross calculi clearly show that filtration pressure exerted by farmed bivalves plays the most important role in determining the fate of primary production in the study area [38]. Filtration pressure can also mask any role played by anthropogenic sources in determining differences between ponds before and after the cessation of shellfisheries in one of the ponds. Thus, the higher the biomass of bivalves farmed in the ponds, the higher the control of trophic conditions in the ponds (*sensu* [33,38]). Bivalves affected almost all components of particulate matter, although the effect of pressure was more evident on chlorophyll and biochemical components of POM due to bivalve selective filtration [5,37]. Indeed, mussels mainly rely on living and dead material ranging from a few microns to about 20–40 microns, even though they realise their maximum efficiency of the filtration around 4–10 microns [39]. However, cells of this size include bacteria ($\sim$1 μm), nano-phytoplankton ($<$10 μm) and detritus of different origin [4,5,40]. Filtration by bivalves was particularly efficient but only on particles of the sizes cited above. Indeed, filtration had a slight effect on the total bulk of suspended matter (TSM), its organic (OSM) and inorganic fractions (ISM) as TSM was reduced in Faro by approximately 1.7 times with respect to Ganzirri, and as OSM of about 1.6. TSM and its fractions are not usually pre-filtered through 200 μm net size, the effect of filtration was negligible because bivalves rely solely on fractions of smaller dimensions. In contrast, if we consider the chlorophyll a, the level was about 4.7 times higher in Ganzirri than in Faro. This greater difference was likely due to selective filtration by bivalves on phytoplankton with regard to bulk detritus (as expressed by OSM). On the other hand, phytoplankton in the studied ponds is reported as usually composed of nano-sized phytoflagellates or diatoms [16]. Selective pressure on fractions lower than 200 μm was also supported by particulate biochemical differences between the two ponds. POM as a sum of proteins, carbohydrates and lipids differed between ponds by an average of 2.5 times. POM has been used across the recent literature as an efficient tool to describe food availability for filter feeders [41,5]. Indeed, in bivalve ecosystem studies like the present study, POM has always been a fraction of the total bulk, which is mainly influenced by filtration of bivalves [5]. POM fractions are often used to distinguish the selection ability of bivalves. Particulate proteins are usually considered as primary production indicators, hence the higher proteins, primary production and biomass in the marine water masses. Carbohydrates and lipids are considered to have originated from cellulose based organic matter and from cell heterotrophic walls. In the present study, particulate proteins and carbohydrates were higher in Ganzirri by about 3.8–4.0 times than in Faro, while lipids were only twice as high, which substantiates the experimental hypothesis. More than anything the difference in proteins, which is small compared to the difference in chlorophyll a, supported the experimental hypothesis.

In conclusion, our results suggest that bivalve molluscs can control water quality in brackish ecosystems, reducing the likelihood of eutrophication, and since coastal brackish waters provide essential ecosystem services to society [42], bivalves can play an important role in maintaining ecological equilibrium (*sensu* [3,43]).

Acknowledgements

We are indebted to Sig. Giovanni Maio, (technician of the Department of Animal Biology and Marine Ecology, Messina University) for his very important help during the collection of samples. We thank also Anna Lossman for the English correction.

References

[1] G. Sarà and A. Pusceddu, *Scope for growth of* Mytilus galloprovincialis (*Lmk.,* 1819) *in oligotrophic coastal waters* (*Southern Tyrrhenian Sea, Italy*), Mar. Biol. 156(2) (2008), pp. 113–126.

[2] H.J. MacIsaac, O.E. Johannsson, J. Ye, W.G. Sprules, J.H. Leach, J.A. McCorquodale, and I.A. Grigorovich, *Filtering impacts of an introduced bivalve* (Dreissena polymorpha) *in a shallow lake: Application of a hydrodynamic model*, Ecosystems 2 (1999), pp. 338–350.

[3] O. Lindahl, R. Hart, B. Hernroth, S. Kollberg, L.O. Loo, L. Olrog, A.S. Rehnstam-Holm, J. Svensson, S. Svensson, and U. Syversen, *Improving marine water quality by mussel farming: A profitable solution for Swedish society*, Ambio 34(2) (2005), pp. 131–138.

[4] R. Mann, *Field studies of bivalve larvae and their recruitment to the benthos: A commentary*, J. Shellfish Res. 7 (1998), pp. 7–10.

[5] G. Sarà, *Hydrodynamic effect on the origin and quality of organic matter for bivalves: An isotopic, biochemical and transplant integrated study*, Mar. Ecol. Progr. Ser. 328 (2006), pp. 65–73.

[6] H.P. Halldórsson, M. De Pirro, C. Romano, J. Svavarsson, and G. Sarà, *Immediate biomarker responses to benzo[a]pyrene in polluted and unpolluted populations of the blue mussel* (Mytilus edulis *L.*) *at high-latitudes*, Envir. Intern. 34 (2008), pp. 483–289.

[7] A. Mazzola and G. Sarà, *The effect of fish farming organic waste on food availability for bivalve molluscs* (*Gaeta Gulf, Central Tyrrhenian, MED*): *Stable carbon isotopic analysis*, Aquaculture 192 (2001), pp. 361–379.

[8] C.G. Jones, J.H. Lawton, and M. Shachak, *Organisms as ecosystem engineers*, Oikos 689 (1994), pp. 373–386.

[9] R.M. Asmus and H. Asmus, *Mussel beds: Limiting or promoting phytoplankton?* J. Expl. Mar. Biol. Ecol. 148 (1991), pp. 215–232.

[10] P.H. Doering, C.A. Oviatt, and J.R. Kelly, *The effects of the filter-feeding clam* Mercenaria mercenaria *on carbon cycling in experimental marine mesocosms*, J. Mar. Res. 44 (1986), pp. 839–861.

[11] A. Bottari, C. Bottari, P. Carveni, S. Giacobbe, and N. Spanò, *Genesis and geomorphologic and ecological evolution of the Ganzirri salt marsh* (*Messina, Italy*), Quater. Internat. (2005), pp. 140–141; 150–158.

[12] M.W. Denny, *Biology and the Mechanics of the Wave-Swept Environment*, Princeton University Press, Princeton, NJ, 1988, 329 pp.

[13] S. Vanucci, V. Bruni, and G. Pulicanò, *Spatial and temporal distribution of virioplankton and bacterioplankton in a brackish environment* (*Lake of Ganzirri, Italy*), Hydrobiologia 539 (2005), pp. 83–92.

[14] E. Gangemi, *Dinoflagellati nocivi nelle fitocenosi di un ecosistema litorale della Sicilia orientale* (*Pantano Grande – lagune di Capo Peloro – ME*), PhD Thesis, Messina University, Messina, 2000, 88 pp.

[15] A. Bergamasco, M. Azzaro, G. Pulicano, G. Cortese, M. Sanfilippo, and T. Maugeri, *Ganzirri Lake, north-eastern Sicily*, in *Nutrient Fluxes in Transitional Zones of the Italian Coast*, G. Giordani, P. Viaroli, D.P. Swaney, C.N. Murray, J.M. Zaldívar, and J.I. Marshall Crossland, eds, LOICZ Reports and Studies, No. 28. LOICZ IPO, Texel, The Netherlands, 2005, pp. 103–110.

[16] M.G. Giacobbe, F.D. Oliva, and G. Maimone, *Environmental factors and seasonal occurence of the dinoflagellate* Alexandrium minutum, *a PSP potential producer, in a Mediterranean lagoon*, Est. Coast. Shelf Sci. 42 (1996), pp. 539–549.

[17] M.L.C. Acosta Pomar, V. Bruni, F. Decembrini, G. Giuffrè, and T.L. Maugeri, *Distribution and activity of picophytoplankton in a brackish environment*, Progr. Oceanogr. 21 (1989) pp. 221–224.

[18] G. Canestri Trotti., E.M. Baccarani, and F. Paesanti, Nematopsis *spp. Schneider, 1892* (*Apicomplexa: Gregarinida: Porosporidae*) *in* Chamelea gallina *from Adriatic Sea* (*Italy*), Parassitologia 40 (Suppl. 1) (1998), p. 28.

[19] P. Licata, G. Di Bella, G. Dugo, and F. Naccari, *Organochlorine pesticides, PCBs and heavy metals in tissues of the mullet* Liza aurata *in lake Ganzirri and Straits of Messina* (*Sicily, Italy*), Chemosphere 52 (2003), pp. 231–238.

[20] P. Licata, D. Trombetta, M. Cristani, D. Martino, and F. Naccari, *Organochlorine compounds and heavy metals in the soft tissue of the mussel* Mytilus galloprovincialis *collected from Lake Faro* (*Sicily, Italy*), Envir. Int. 30 (2004), pp. 805–810.

[21] G. Magazzù and F. Decembrini, *Primary production, biomass and abundance of phototrophic picoplankton in the Mediterranean Sea: A review*, Aquat. Microb. Ecol. 9 (1995), pp. 97–104.

[22] N.F. Caraco, J.J. Cole, P.A. Raymond, D.L. Strayer, M.L. Pace, S.E.G. Findlay, and D.T. Fischer, *Zebra mussel invasion in a large, turbid river: Phytoplankton response to increased grazing*, Ecology 78(2) (1997), pp. 588–602.

[23] J.D.H. Strikland and T.R. Parsons, *A practical handbook of sea water analysis*, Bull. Fish. Res. Board Canada 167 (1992), p. 310.

[24] A. Pusceddu, A. Dell'Anno, R. Danovaro, E. Manini, G. Sarà, and M. Fabiano, *Enzymatically hydrolyzable protein and carbohydrate sedimentary pools as indicators of the trophic state of 'detritus sink' systems: A case study in a Mediterranean coastal lagoon*, Estuaries 26 (2003), pp. 641–650.

[25] M. Fabiano and A. Pusceddu, *Total and hydrolizable particulate organic matter (carbohydrates, proteins and lipids) at a coastal station in Terra Nova Bay (Ross Sea, Antarctica)*, Polar Biol. 19(2) (1998), pp. 125–132.

[26] J.M. Navarro, E. Clasing, G. Urrutia, G. Asencio, R. Stead, and C. Herrera, *Biochemical composition and nutritive value of suspended particulate matter over a tidal flat of Southern Chile*, Estuar. Coast. Shelf Sci. 37 (1993), pp. 59–73.

[27] G. Sarà, A. Manganaro, G. Cortese, A. Pusceddu, and A. Mazzola, *The relationship between food availability and growth in* Mytilus galloprovincialis *in the open sea (southern Mediterranean)*, Aquaculture 167 (1998), pp. 1–15.

[28] M.J. Anderson, *A new method for non-parametric multivariate analysis of variance*, Austral Ecol. 26 (2001), pp. 32–46.

[29] B.H. McArdle and M.J. Anderson, *Fitting multivariate models to community data: A comment on distance-based redundancy analysis*, Ecology 82 (1) (2001), pp. 290–297.

[30] M.J. Anderson and J. Robinson, *Generalized discriminant analysis based on distances*, Aust. NZ J. Stats. 45 (2003), pp. 301–318.

[31] J.E. Cloern, *Does the benthos controlphytoplankton biomass in South San Francisco Bay?* Mar. Ecol. Progr. Ser. 9 (1982), pp. 191–202.

[32] R.T. Wright, R.B. Coffin, C.P. Ersing, and D. Pearson, *Field and laboratory measurements of bivalve filtration of natural marine bacterioplankton*, Limnol. Oceanogr. 27(1) (1982), pp. 91–98.

[33] H. Asmus and R.M. Asmus, *Phytoplankton-mussel bed interactions in intertidal ecosystems*, in *Bivalve Filter Feeders in Estuarine and Coastal Ecosystem Processes*, R.F. Dame, ed., Springer-Verlag, Berlin, 1993, pp. 57–84.

[34] E.H. Schulte, *Influence of algal concentration and temperature on the filtration rate of* Mytilus edulis, Mar. Biol. 30 (1975), pp. 331–341.

[35] J. Widdows, B.L. Bayne, D.R. Livingstone, R.I.E. Newell, and P. Donkin, *Physiological and biochemical responses of bivalve molluscs to exposure to air*, Comp. Biochem. Physiol. 62(A) (1979), pp. 301–308.

[36] G. Sarà and A. Mazzola, *The carrying capacity for Mediterranean bivalve suspension feeders: evidence from analysis of food availability and hydrodynamics and their integration into a local model*, Ecolog. Model. 179 (2004), pp. 281–296.

[37] O. Maire, J.M. Amouroux, J.C. Duchêne, and A. Grémare, *Relationship between filtration activity and food availability in the Mediterranean mussel* Mytilus galloprovincialis, Mar. Biol. 152(6) (2007), pp. 1293–1307.

[38] J.L. Gutiérrez and C.G. Jones, *Physical ecosystem engineers as agents of biogeochemical heterogeneity*, BioScience 56(3) (2006), pp. 227–236.

[39] R.F. Dame, *The role of bivalve filter feeder material fluxes in estuarine ecosystems*, in *Bivalve Filter Feeders in Estuarine and Coastal Ecosystem Processes*, R.F. Dame, ed., Springer-Verlag, Heidelberg, 1993, pp. 245–269.

[40] G. Sarà, *Sedimentary and POM mixed sources for* Cerastoderma edule *in a Mediterranean shallow pond*, Aquat. Liv. Resour. 20 (2007), pp. 271–277.

[41] A.C. Smaal and H.A. Haas, *Seston dynamics and food availability on mussel and cockle banks*, Est. Coast. Shelf Sci. 45 (1997), pp. 247–259.

[42] A. Pusceddu, C. Gambi, E. Manini, and R.Danovaro, *Trophic state, ecosystem efficiency and biodiversity of transitional aquatic ecosystems: Analysis of environmental quality based on different benthic indicators*, Chem. Ecol. 23 (2007), pp. 505–515.

[43] G. Sarà, *Variation of suspended and sedimentary organic matter with depth in shallow coastal waters*, Wetlands (in press).