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Eutrophication and Gastrotrich Diversity in the Northern Adriatic Sea

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Marine Gastrotricha of littoral and sublittoral sands at nine locations along the northern Adriatic coast were sampled during July, 1991. Three locations on barrier islands near the Laguna Veneta (Alberoni, San Nicolò, and Punta Sabbioni) supported a higher number of species in the littoral and shallow sublittoral zones (six each) than were reported by Hummon *et al.* (1990), who found no species at the same sites in 1989. The increased number of species may be related to colder temperatures during the winter previous to our study, which delayed formation of algal mats in the littoral zone, preventing the depletion of oxygen in the littoral sediments that can lead to gastrotrich mortality. Locations in the northeastern Adriatic, Bibione (13 species) and Foce Isonzo (15 species), evidenced a more diverse gastrotrich fauna than the more northwestern locations, and may serve as a source for colonizing species, moved with longshore currents, to westward populations subject to extinction due to local anoxic events.

In recent decades, benthic communities in the northern Adriatic Sea have come under increasing stress from acute dystrophic events such as anoxic bottom conditions, aggregates of mucous algae, and red tides resulting from eutrophication in the region (Crema *et al.*, 1991; Ghiardelli & Specchi, 1989; Justic, 1987). Such events can lead initially to mass mortalities in benthic populations and ultimately to reduced species diversity for macrofaunal (Brenco-Hrs, 1980; Crema *et al.*, 1991; Justic *et al.*, 1987) and meiofaunal (Gray, 1971; Hummon *et al.*, 1990) components of bottom communities. Hummon *et al.*, (1990) described a drastic reduction in the number of species of Gastrotricha in beaches and shallow, nearshore sublittoral sands of the northern Adriatic since Schrom first sampled there more than 20 years ago (Schrom, 1966a,b, 1972). Where Schrom had found 25 species of Gastrotricha, Hummon *et al.* reported only two, with an additional four species from an adjacent nearshore bar that was not sampled by Schrom.

We decided to resample the locations common to Schrom and Hummon *et al.* and several additional locations to determine: *1.* if the decline in gastrotrich diversity at the original locations continues to the present, *2.* if new locations nearby exhibit similar levels of diversity, *3.* if nearshore sublittoral sands serve as a diversity refugium for littoral habitats as Hummon *et al.* have hypothesized, and *4.* if richer habitats in the northeastern Adriatic such as the Foce Isonzo (Hummon *et al.*, 1990) could potentially supply species to more impoverished habitats near the Laguna Veneta via the westward longshore transport of sediments. Comparison with Schrom's data might also illuminate current diversity patterns within (littoral vs. sublittoral) and among locations.

We also wanted to assess the relationship between

gastrotrich diversity and sediment characteristics, such as mean grain size and organic content, and to evaluate the potential of marine Gastrotricha as indicators of environmental change.

Materials and Methods

During July, 1991 both littoral and shallow sublittoral sites at nine locations along the north Adriatic coast were sampled (Fig. 1). Alberoni (AL), San Nicolò (SN), Punta Sabbioni (PS), and Càorle West (CW) are locations common to both Schrom and Hummon *et al.* Additional locations included Lido del Faro (LF), Eraclea Mare (EM), Bibione (BI), Grado (GR), and the Foce Isonzo (FI). Littoral samples were obtained by scooping sediments from the bottom and sides of a 0.5 m deep hole in the beach and placing the sand in plastic bags. Sublittoral samples were taken similarly from sediments scooped out of the bottom with a hand-held dredge at 1.5 m water depth; samples were taken from nearshore bars when present. Gastrotrichs were extracted from the sediments by narcotization with isosmotic $MgCl_2$, and then by subsequent rinsing of sediments with seawater and decantation into 60 mm plastic Petri dishes. Individual living gastrotrichs were located by examining the supernatant fluid at 50× magnification under a dissecting microscope and then removed by pipette to a glass slide. Further examination and identification of specimens was done under Nomarski differential interference contrast optics. Granulometric analysis consisted of dry-sieving 100 gm of sediment using 1 phi interval sieves (−2 to +4 phi) and calculating mean phi size and sorting coefficient. The organic content of the sediments was determined by percent weight loss after combustion of 25 gm of sediment at 550°C for 1 h (Cummins, 1962).

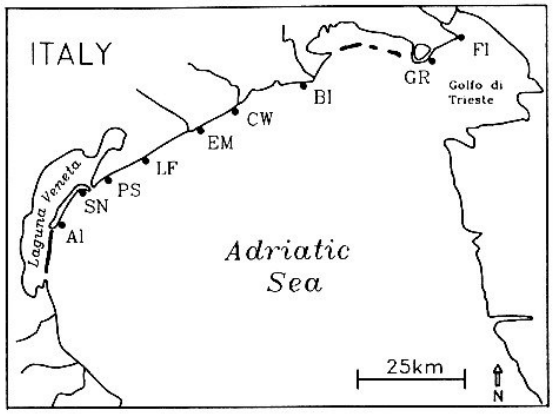

Fig. 1 Sampling locations in the northern Adriatic Sea. Alberoni (AL), San Nicolò (SN), Punta Sabbioni (PS), Lido del Faro (LF), Eraclea Mare (EM), Càorle West (CW), Bibione (BI), Grado (GR), and Foce Isonzo (FI).

TABLE 1

Gastrotrich species by location and site.

Locations:	Al	SN	PS	LF	EM	CW	BI	GR	FI
Species:									
Order Chaetonotida									
Aspidiophorus mediterraneus					LS				
*Aspidiophorus paramediterraneus**									L
Aspidiophorus polystictos	S	LS							
*Chaetonotus atrox**									L
Chaetonotus lacunosus†							S		
*Draculiciteria tesselata**	L				L		L		
Halichaetonotus aculifer	S		LS	L	L		LS	S	LS
Halichaetonotus jucundus†									L
*Halichaetonotus spinosus**	L				LS	S	L		LS
Halichaetonotus margeretae									LS
Heterolepidoderma loricatum							S	LS	S
Heterolepidoderma sp. I*								S	
Heteroxenotrichula pygmaea†							L		
Xenotrichula intermedia					S		S		
Xenotrichula lineata							L		
Xenotrichula punctata†									S
Order Macrodasyida									
Acanthodasys aculeatus									L
*Cephalodasys turbanelloides**	S								S
Dolichodasys elongatus	S		S				S		
Macrodasys caudatus	LS			L	LS	L	L		
Macrodasys sp. I*								S	
Macrodasys sp. II*						L			
Paraturbanella dohrni			S		S		S	LS	
*Paraturbanella pallida**									LS
*Tetranchyroderma esarabdophorum**	L								
Tetranchyroderma papii†									L
Tetranchyroderma sp. I*									S
Tetranchyroderma sp. II							S	L	S
Tetranchyroderma sp. III*									L
*Turbanella ambronensis**							L		
Total Species	8	1	3	2	7	3	13	6	15

AL—Alberoni, SN—San Nicolò, PS—Punta Sabbioni, LF—Lido del Faro, EM—Eraclea Mare, CW—Càorle West, BI—Bibione, GR—Grado, FI—Foce Isonzo, L—Littoral Site, S—Sublittoral Site. Sublittoral sites include nearshore bars where present. *Previously unreported from the northern Adriatic coastline. †Unreported but previously recorded from the region by Hummon *et al.* in 1989.

Results

A total of 30 species of Gastrotricha were identified during the course of the present study (Table 1). Sixteen species in seven genera of Chaetonotida were divided between two families (Chaetonotidae—10 and Xenotrichulidae—6) and 14 species in seven genera of Macrodasyida were distributed among four families (Lepidodasyidae—2, Macrodasyidae—3, Thaumastodermatidae—6, and Turbanellidae—3). Twelve species were unique to the littoral, eight species occurred only in the sublittoral (including nearshore bars), and 10 species were common to both zones. Eighteen of the species have been heretofore unreported from the northern Adriatic coast, though five of these had previously been found by Hummon *et al.* in 1989 (Table 1). We recorded a total of 10 species from Alberoni, San Nicolò, Punta Sabbioni, and Càorle West (the littoral site only), those sites we shared with Schrom (25 species) and Hummon *et al.* (two species). Four of the species were also reported by Schrom. Seven of the 10 species were found in the littoral zone at the sites where Hummon *et al.* had found none. Of our additional locations, Bibione and the Foce Isonzo were the richest, with 13 and 15 species respectively.

The littoral and sublittoral sediments at all locations were composed of medium to fine, moderately well-sorted sands (Table 2). The organic content of the sediments was variable, but littoral sediments always contained less organic matter than the sublittoral sediments at the same location. Multiple regression analysis revealed no significant ($P=0.07$) relationship between the number of gastrotrich species and sediment parameters.

Discussion

The number of species per site at common sampling sites during the present study (mean of 2.4 and range of 1–5) were intermediate between those found by Hummon *et al.* (0.6 and 0–2) and by Schrom (6.7 and 3–19). Thus, the communities we sampled were not as impoverished as Hummon *et al.* had found, particularly the littoral sites. However, Hummon *et al.* did find five additional species in a nearshore bar at Càorle, a site not sampled by Schrom. While the level of diversity found by us is far from that reported by Schrom, many of his species came from an intensive study of one site (19 species at Alberoni littoral). The number of gastrotrichs at Schrom's remaining sites ranged from three (San Nicolò sublittoral) to six (Càorle West littoral).

The number of gastrotrich species at sites in addition to Schrom and Hummon *et al.* ranged from zero (Lido del Faro sublittoral) to 10 (Foce Isonzo littoral) with a mean of 5.3 species per site. As a point of reference, the number of gastrotrichs at nine sites from five locations sampled during the same summer on the Gargano peninsula of Italy in the southern Adriatic Sea ranged from one (littoral) to eight (sublittoral) species with a mean of 4.4. The data exhibited considerable variability.

This increase in diversity in beaches located on the barrier islands south of the Laguna Veneta since 1989 could be explained by short-term abatement of organic inputs to the northern Adriatic Sea, although this is unsubstantiated and not likely. A second explanation for these results is suggested by the yearly variability in regional weather patterns. Mild weather and high temperatures in the nutrient-rich northern Adriatic basin are known to be important factors in initiating algal blooms, red tides, and gelatinous algal aggregates (Marchetti, 1985; Najdek *et al.*, 1989; Regione Emilia Romagna, 1989). The winter and spring of 1989 prior to the field work of Hummon *et al.* were relatively mild (Todaro, personal observation). This promoted early warming of seawater and may have resulted in the accelerated growth of phytoplankton populations, leading to early "blooms" of algae (Rinaldi & Montanari, 1988; Simons, 1989; Vukadin, 1991). The algae and their mucilaginous by-products then wash upon the shoreline, often forming dense mats. Such mats can prevent oxygen from diffusing into the sediments resulting in anoxic conditions beneath the mats. Gastrotrichs usually are not found in this milieu (Todaro, 1992). This could explain the absence of gastrotrichs in the littoral zone during the study of Hummon *et al.* (the presence of algal mats in the littoral zone at San Nicolò during this period was confirmed by the authors of that paper). Nearshore sublittoral sediments may be less susceptible to this type of event due to the agitation of bottom surface sediments by wave and current action, which could prevent the formation of algal mats. The sublittoral is where Hummon *et al.* found the most species. By contrast, the winter and spring prior to our field work

TABLE 2

Sediment parameters by location and site.

Locations:		AI	SN	PS	LF	EM	CW	BI	GR	FI
Mean Phi	(L)	1.70	1.62	1.60	1.44	0.94	1.55	1.62	1.76	0.63
	(B)	1.57	1.93	1.59	1.58	2.12	1.64	1.58	—	—
	(S)	1.62	1.64	1.95	1.60	1.59	1.73	1.68	1.91	1.62
Sorting Coeff.	(L)	1.14	0.70	0.49	0.64	0.99	0.50	0.44	0.56	0.57
	(B)	0.59	0.61	0.45	0.46	0.79	0.48	0.41	—	—
	(S)	0.62	0.49	0.61	0.48	0.98	0.55	0.49	0.61	0.48
Organic Matter (%)	(L)	4.27	5.11	3.74	2.92	2.82	4.45	4.62	3.49	3.40
	(B)	4.58	6.63	4.50	4.11	4.43	5.03	5.32	—	—
	(S)	6.12	6.18	5.31	5.69	4.39	4.74	4.65	3.58	3.47

(L)—Littoral Site. (B)—Nearshore Bar. (S)—Sublittoral Site. Nearshore bars were not present at Grado and Foce Isonzo. Location abbreviations as in Table 1.

in the summer of 1991 were much colder than normal (M. Balsamo, personal communication), preventing an early rise in seawater temperature. Blooms of mucilaginous algae were not reported in the northern Adriatic Sea until late July, 1991. Thus, the littoral sediments in the present study were free from the stresses imposed by overlying algal mats, and we found a correspondingly more diverse gastrotrich community than did the recent investigators.

If this explanation is true, then gastrotrichs demonstrate a sensitivity to long-term environmental change sufficient to make them good indicators of the general health of marine benthic communities that live in sandy sediments. Moreover, gastrotrichs have been shown to be affected by high levels of organic effluents (Hummon & Hummon, 1977; Raffaelli, 1982), exhibit a rapid response to environmental change (Hummon, 1975; Potel & Riese, 1987), and be taxonomically manageable (i.e., sufficient species to detect changes in diversity patterns yet not too speciose for the non-specialist).

Such year to year fluctuations in the diversity of benthic taxa such as the Gastrotricha point out the desirability of intensive, long-term sampling at intervals of 1 to 2 years when attempting to determine causal relationships between pollution and diversity, and when seeking to predict the recovery or degradation of marine environments.

If sublittoral sediments act as refugia for interstitial gastrotrichs during periods of high stress in the littoral zone, then one would expect that littoral communities would be comprised largely of species from nearby sublittoral sands, allowing for the ecological differences between these habitats. When considering all nine of our sampling locations in aggregate, we found that 10 of the 22 species (45%) recorded from littoral sites were also present in the sublittoral sites; this increased to seven of eight (88%) when including only those species found at two or more locations, and to seven of seven (100%) when including only those species found at three or more locations. Schrom found similar patterns at his Venetian sites (Alberoni, San Nicolò, and Punta Sabbioni) where six of 22 species (27%) in the littoral were also found in the sublittoral; this increased to five of seven (71%) when considering species found at two or more locations and to two of two (100%) when including species found at all three sites. Our data for the same locations show three of seven (43%), two of two (100%), and zero of zero (0%) respectively. However, the more common species with wider geographic distributions might also have broader ecological niches, allowing them to exist in both littoral and sublittoral habitats. It is possible that littoral species with limited distributions may also occur in the sublittoral, but either at such low densities or for such short periods of time as to go undetected by the sampling intensities employed in this study. These patterns lend support to the refugium theory of Hummon *et al.*, but it must be pointed out that similar spatial patterns have been observed by us elsewhere in the Adriatic, Tyrrhenian, and Ligurian Seas, at both polluted and unpolluted locations (Evans, Todaro, & Hummon, unpublished data).

Surface currents in the northern Adriatic Sea flow in an anticlockwise direction, forming longshore bars and generally moving sediments from east to west along the northern coastline (Frascari *et al.*, 1988). Our additional locations of Bibione, Grado and the Foce Isonzo (eastern region) contained 26 species of gastrotrichs as compared to 12 for the remaining six locations (western region). Eight species were common to both regions. Grado and the Foce Isonzo locations are clearly more isolated from the western region than is Bibione due to their position in the Golfo di Trieste, which lies outside of the major current circulation pattern in the northern Adriatic Sea. Bibione is a more likely source of colonizers for locations to the west due to its geographical proximity and its location within the principal circulation system. Seven of the 13 species present at Bibione were also found in the western region (54%), while only four of the 18 species present at Grado and the Foce Isonzo were found there (22%). Moreover, when considering an additional 12 species found by Hummon *et al.* in 1989 at the Foce Isonzo (unpublished data), the latter figures change to five of 30 species in common (17%). These distribution patterns differ significantly ($P < 0.05$) from patterns generated by assigning species to locations at random. Thus, species rich locations such as Bibione are more likely to replenish more impoverished locations to the west when environmental conditions permit new communities to become established there.

It is clear that the locations in the eastern region represent ecologically important habitats that support the most diverse gastrotrich fauna in the northern Adriatic Sea and, as such, are worthy of preservation.

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Brenco-Hrs, M. (1980). Preliminary survey of populations of the bivalve Noah's Ark (*Arca noae* Linné) in the northern Adriatic. *Aquaculture* **21**, 357–353.

Crema, R., Castelli, A. & Prevedelli, D. (1991). Long term eutrophication effects on macrofaunal communities in the northern Adriatic Sea. *Mar. Pollut. Bull.* **22**, 503–508.

Cummins, K. W. (1962). An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. *Amer. Midl. Natur.* **67**, 477–504.

Frascari, F., Frignani, M., Guerzoni, S. & Ravaioli, M. (1988). Sediments and pollution in the northern Adriatic Sea. *Ann. N. Y. Acad. Sci.* **534**, 1000–1020.

Ghiardelli, E. & Specchi, M. (1989). Gli episodi di "mare sporco" nell'Adriatico dal 1789 ai giorni nostri. p. 178. Regione Autonoma Friuli Venezia Giulia. Trieste.

Gray, J. S. (1971). The effect of pollution on sand meiofauna communities. *Thalassia Jugoslav.* **7**, 79–86.

Hummon, W. D. (1975). Seasonal changes in secondary production, faunal similarity and biological accommodation, related to stability among the Gastrotricha of two semi-enclosed Scottish beaches. *10th European Symposium on Marine Biology.* **2**, 309–336.

Hummon, W. D. & Hummon, M. R. (1977). Meiobenthic subcommunity structure: Spatial versus temporal variability. In *Biology of Benthic Organisms* (Keegan, Ciedigh & Boaden, eds), Pergamon, Oxford.

Hummon, W. D., Todaro, M. A., Balsamo, M. & Tongiorgi, P. (1990). Effects of pollution on marine Gastrotricha in the northwestern Adriatic Sea. *Mar. Pollut. Bull.* **21**, 241–243.

Justic, D. (1987). Long-term eutrophication of the northern Adriatic Sea. *Mar. Pollut. Bull.* **18**, 281–284.

Justic, D., Legovic, T. & Rottini Sandrini, L. (1987). Trends in the oxygen content 1911–1984 and the occurrence of benthic mortality in the northern Adriatic. *Sea Estuar. Coast. Shelf Sci.* **25**, 435–445.

Marchetti, R. (1985). Quadro analitico complessivo dei resultati delle indagini condotte negli anni 1977–1989 sul problema dell'eutrofizzazione nelle acqua costiere dell'Emilia Romagna: Situazione ed ipotesi di intervento. Regione Emilia Romagna. Bologna.

Najdek, M., Puskaric, S., Batel, R., Bihari, N., Devescovi, M., Ozretic, B., Precali, R. & Zavodnik, N. (1989). Extraordinary manifestation of eutrophication in the Adriatic during 1988. I. Mechanism of the event. *Conf. on Water Protection.* Opatija, YU, 431–438.

Potel, P. and Reise, K. (1987). Gastrotricha Macrodasyida of intertidal and subtidal sandy sediments in the northern Wadden Sea. *Microfauna Marina.* **3**, 363–376.

Raffaelli, D. (1982). An assessment of the potential of major meiofauna groups for monitoring organic pollution. *Marine Environ. Res.* **7**, 151–164.

Regione Emilia Romagna (1989). *Eutrofizzazione dell'Adriatico. Richerche e Linee d'Intervento.* Patron Editore, Bologna.

Rinaldi, A. & Montanari, G. (1988). Eutrophication in the Emilia-Romagna coastal waters in 1984–1985. *Ann. N. Y. Acad. Sci.* **534**, 959–977.

Schrom, H. (1966a). Gastrotrichen aus Feinsanden der Umgebung von Venedig. *Boll. Mus. Civico di Storia Naturale di Venezia.* **17**, 31–45.

Schrom, H. (1966b). Verteilung einiger Gastrotrichen im oberen Eulitoral einiges nordadriatischen Sandstrandes. *Veroff. Inst. Meeresforsch. Bremerhaven.* Sonderband II, 95–104.

Schrom, H. (1972). Nordadriatischen Gastrotrich. *Helgolander wiss. Meeres.* **23**, 283–351.

Simons, M. (1989). Adriatic fouled by vast sea of algae. *New York Times*, August 16, p. A6.

Todaro, M. A. (1992). Contribution to the study of the Mediterranean meiofauna: gastrotrichs from Ponza Island. *Boll. Zool.* **59**, 321–333.

Vukadin, I. (1991). Impact of nutrient enrichment and their relation to the algal bloom in the Adriatic sea. *Mar. Pollut. Bull.* **23**, 145–148.