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INTRODUCTION

As a growing number of reports indicate, man-made pollutants of many kinds are finding their way into the oceans of the world. The widespread occurrence of large numbers of plastic particles (Carpenter and Smith, 1972), oil tar lumps (Oceans, 1969), pesticides (Seba and Corcoran, 1969), toxic metals (Chow, Brudland, Bertine, Soutar, Koide and Gouldberg, 1973) and sewage (Kouyoumjian, 1972) indicate that oceanic pollution is reaching global proportions.

Marine algae form the autotrophic base of marine food webs. Thus detrimental effects of pollution on algae could be of utmost importance to fisheries and indeed to all life in the sea. Studies of the effects of marine pollutants on algae have been largely restricted to the phytoplankton. However, recent evidence indicates that marine macroalgae (seaweeds) play a larger role in coastal productivity than previously suspected (Mann, 1973). The few studies done on macroalgae in relation to pollution deal primarily with the effects of coastal sewage nutrient enrichment on individual species or populations (Rueness, 1973; Tewari, 1972; Waite and Mitchell, 1972).

Synecological studies of the quantitative changes in abundance or diversity of particular benthic algal species can serve as sensitive indicators of the influence of waste waters (Gamulin-Brida, Giaconne and Golubić, 1967) but such studies are rare. Borowitzka (1972) found a reduction in intertidal algal species diversity and a reduction in total number of algal species, particularly of Rhodophyta and Phaeophyta, in the vicinity of sewage outfalls. His study represents possibly the only quantitative synecological study of benthic macroalgae in relation to pollution.

Types of potential pollution along the Mediterranean coast of Lebanon include untreated sewage (Gowing and Hulings, 1975; Kouyoumjian, 1972), chemical enrichment from a fertilizer plant, oil refineries, heated water effluent from electric power generating plants, and freshwater runoff carrying lead (Shiber and Ramsey, 1972) and a variety of uncharacterized industrial pollutants. This study is the first synecological study of macroalgae in relation to pollution in the Eastern Mediterranean. It was undertaken to determine the effects of different potential pollutant sources on the species composition, standing crop biomass, and taxonomic diversity of communities of benthic macroalgae along the coast of Lebanon.

METHODS AND MATERIALS

Six non-random sampling stations were chosen along the coast of Lebanon from approximately 71 km north to 20 km south of Beirut (Figure 1). The stations were: 1 — Aaramane, about 400 m north of the Tripoli oil refinery; 2 — Selaata, about 100 m north of the Esso chemical fertilizer plant; 3 — Berbara, with no evident potential pollution source; 4 — Zouk Mkayel, a rocky island reef about 100 m north of the Jounieh electric power generating plant; 5 — Khalde, 200 m south of a major untreated sewage effluent; and 6 — Doha, with no evident potential pollution source and used as a control. All stations were typical coastal limestone platforms in the subtidal to wave-wash zone. The stations were sampled at two seasons (April 30 — May 1, May 20 and August 20 — 22) during 1973. A marked transect line up to 26 m in length, was laid out approximately perpendicular to the shoreline from the upper infralittoral to the outer edge of the rock platform. A 0.01 m^2 quadrate was placed at 1 to 2 m regular intervals along the transect line. All algae within each quadrate were collected and placed in plastic bags for transport to the laboratory. The heigth of each quadrate with respect to sea level was determined with a transit level. Seawater samples were collected in polyethylene bottles for laboratory nutrient and salinity analysis.

In the laboratory, the algae were separated from small invertebrates, sand grains, etc. The taxa in each sample were determined in a preliminary way; the samples blotted dry, and the wet weight algal biomass for each quadrate recorded. Representative samples from each quadrate were preserved in 6:3:1 formalin: ethanol: acetic acid for further detailed taxonomic study. The taxonomic diversitiy in relation to the standing crop biomass was determined by:

$$D = \frac{t - 1}{\text{Ln } B}$$

where t = number of species in the quadrate
B = algal biomass of quadrate in g/m^2
Ln = natural logarithm

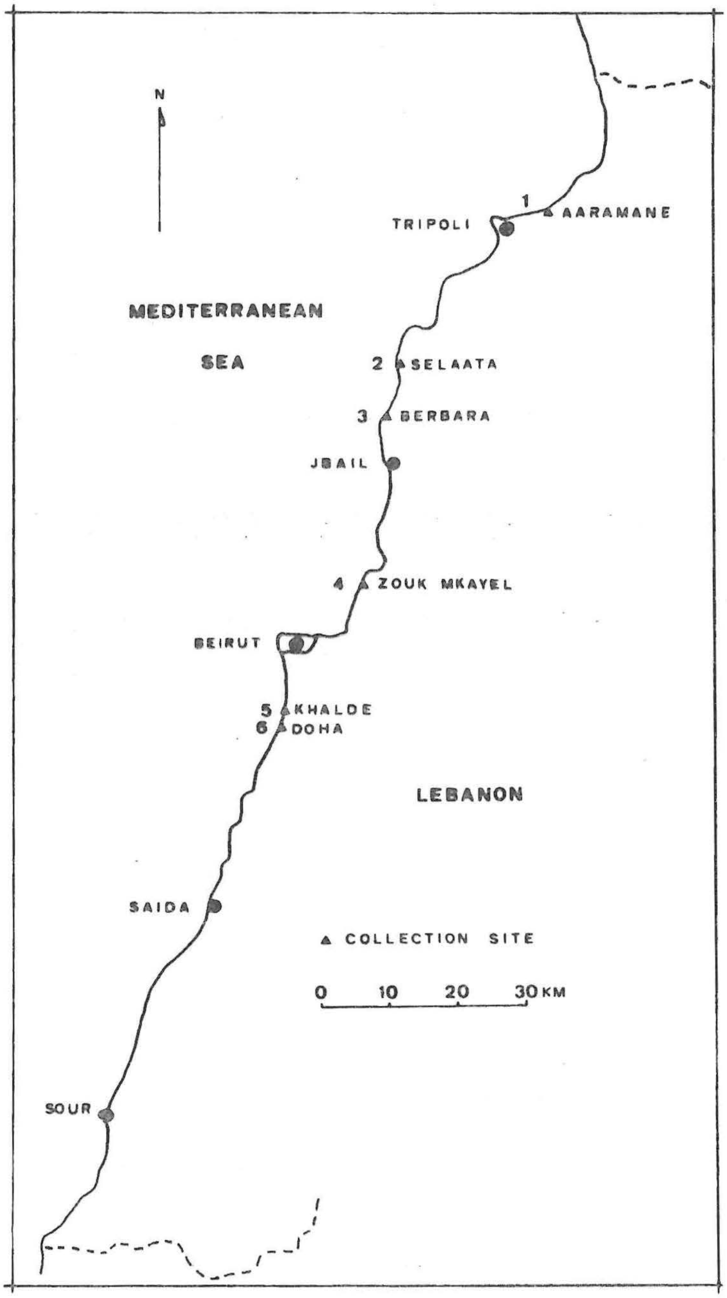

Fig. 1 — Mediterranean coast of Lebanon showing collection sites. 1, oil refinery; 2, chemical fertilizer plant; 3, no potential pollution source; 4, power plant; 5, sewer outfall; 6, control.

This index indicates the degree of taxa dominance in relation to the biomass.

Nutrients were analyzed colorimetrically. Reactive phosphorus, nitrate, and nitrite were determined following the procedures of Strickland and Parsons (1968), and ammonia was analyzed following Solorzano (1969). The lower limits of detectibility using these methods are 0.03 μg at PO_4-P/L, 0.05 μg at NO_3-N/L, 0.01 μg at NO_2-N/L, and 0.5 μg at NH_4-N/L. Linear regression analysis was carried out on a Hewletet-Packard Model 10 desk computer.

RESULTS

A total of 190 taxa of benthic algae have been identified including representatives from all the major algal divisions. Many of these taxa have not been previously recorded in the Eastern Mediterranean Sea (Table 1).

Table 1. Occurrence of algal species at collection sites along the coast of Lebanon (+ = present in sampled quadrates; M = outside quadrates).

Species (1973) (Date)	Ap 30	Aug 22	Ap 30	Aug 22	May 1	Aug 22	May 1	Aug 22	May 20	Aug 20	May 20	Aug 20
Station	1		2		3		4		5		6	
Cyanophyta												
Anabaena sp.				+		M						
Brachytrichia balani (Lloyd) Born. et Flah.										+		+
C. aeruginea (Kütz.) Thur.												+
C. crustacea Thur.								+				+
C. nidulans Setchell et Gardner												+
Calothrix sp.												+
Chroococcus turgidus (Kütz.) Näg.												+
Hormathonema sphaericum Erceg.												+
Hydrocoleus lyngbyaceus (Kütz.)				+						+		
Hyella caespitosa Born et Flah.						+						
Lyngbya aestuarii Liebm.					+							
L. confervoides C. Ag.			+				+					
L. lutea Gom.								+				
L. martensiana Menegh.								+				+
Lyngbya sp.				+								
Mastigocoleus testarum Lagerh.								+				

Table 1. Cont'd.

Species	(1973) (Date)	Ap 30	Aug 22	Ap 30	Aug 22	May 1	Aug 22	May 1	Aug 22	May 20	Aug 20	May 20	Aug 20
Station		1		2		3		4		5		6	
Microchaete sp.							+						
Microcoleus chthonoplastes Thur.											+		
Oscillatoria formosa Bory							+						
O. nigroviridis Thwaites				+	+				+		+		
O. tenuis C. Ag. var. *tergestina* Rabenh.						+							+
Oscillatoria sp. pl.						+				M			
Rivularia mesenterica Thur.							M						
Xanthophyta													
Vaucheria sp.		+											
Chlorophyta													
Acetabularia moebii Solms.			+										
Anadyomene stellata (Wulf.) C. Ag.						+	+					+	
Bryopsis adriatica Kütz.		+								M			
B. cupresina Lamour.										M			
B. cupressoides Kütz.				+									
B. disticha (J. Ag.) Kütz.										M			
B. hypnoides Lamour.										M			
B. pennata Lamour.										+			
B. plumosa (Huds.) C. Ag.		+	+										
Bryopsis sp.		M								+			
Caulerpa racemosa (Forsk) J. Ag.		+	+										
C. prolifera (Forsk.) Lamour		+	+										
Chaetomorpha linum (Müll.) Kütz.		+	+			+	+	+	+	+	+		
Cladophora coelothrix Kütz.		+		+	+								
C. dalmatica Kütz.				+	+								
C. echinus (Bias.) Kütz.		+	+	+									
C. hutchinsiae (Dill w.) Kütz.		+		+						M			
C. laetevirens (Dilw.) Kütz.		+	+	+	+	+	M	+		+	+	+	+
C. nigrescens Zanard.				+									
C. pellucida (Huds) Kütz.				+	+		M						
C. pellucida (Roth) Kütz.				+	+		M					+	
C. rupestris (L.) Kütz.		+	+						+				

Table 1. Cont'd.

Species (1973) (Date)	Ap 30	Aug 22	Ap 30	Aug 22	May 1	Aug 22	May 1	Aug 22	May 20	Aug 20	May 20	Aug 20
Station	1		2		3		4		5		6	
C. sericea (Huds.) Kütz.		+										
C. vagabunda (L.) C. Van den Hoek			+	+	+	+						
Cladophora sp.							+			+	+	
Cladophoropsis modonensis (Kütz.) Borg.					+	+		+		M		+
Dasycladus vermicularis (Scop.) Krass.	+	+									+	+
Derbesia tenuissima (De Not.) Crouan				+	+							
Endoderma viride (Reinke) Lagerh.						+				+		+
Enteromorpha aragoensis Blid.				+						+		
E. flexuosa (Wulf.) J .Ag.		+	+					+		+		
E. flexuosa (Wulf.) G. Ag. subsp. *flexuosa* Blid.												
E. flexuosa (Wulf.) G. Ag. subsp. *paradoxa* (Dill w) Blid.						M	+		+			
E. hendayensis Dang. et parr.								+				
E. *intestinalis* (L.) Link. var. *intestinalis* Blid.	+		+	+		M	+		+		+	
Enteromorpha prolifera (Müll.) J. Ag. subsp. *prolifera* Blid.	+		+				+		+			
E. ralfsii Harv.		+										
E. torta (Mert.) Reinb.			+									
Enteromorpha sp.										+		
Halimeda tuna (Ell. et Sol.) Lamour.		+									+	+
Phaeophyla dendroides (Crouan) Batt).						+					+	+
Rhizoclonium kochianum Kütz.		+										
Ulva olivascens Dang.			+									
U. rigida C. Ag.	+	+	+				+	+	+	+		
U. rotundata Blid.		+	+	+						+		
Ulva sp.	+											
Ulvella lens Crouan.		+				+			M	+		
Valonia utricularis (Roth) C. Ag.			+		+	+						
Phaeophyta												
Colpomenia sinuosa (Mert.) Derb. et Solier	+		+				+		+			
Cystoseira												

Table 1. Cont'd.

Species	(1973) (Date)	Ap 30	Aug 22	Ap 30	Aug 22	May 1	Aug 22	May 1	Aug 22	May 20	Aug 20	May 20	Aug 20
Station		1		2		3		4		5		6	
ercegovicii Giacc.													+
C. fimbriata (Desf.) Bory						+	+					+	+
C. medeiterranea Sauv.							+						
C. spinosa Sauv.						+							+
Cystoseira sp.							+					+	+
Dictyota dichotoma (Huds.) Lamour						M							
Dilophus fasciola (Roth) Howe						M							
Ectocarpus sp.			+								+		
Feldmannia irregularis (Kütz.) Hamel								+					
Giffordia mitchelliane (Harv.) Hamd			+		+		M	+		+	+		
Giffordia sp.				+						+	+		
Halopteris scoparia (L.) Sauv.						+						+	
Padina pavonica (L.) Thivy		+				+	+	+				+	+
Sargassum vulgare C. Ag.						+	+						
Scytosiphon lomentaria (Lyngbye) Endl.						M		+					
Sphacelaria furcigera Kütz.			+										
S. tribuloides Menegh.		+							+	+			
Sphacelaria sp.		+	+				+				+		+
Taonia atomaria (Wood w.) J. Ag.		+											
Rhodophyta													
Acrochaetium caespitosum (J. Ag.) Näg.			+										
A.crassipes Börges.		+		+	+								
A. daviesii (Dill w.) Näg.												+	
A. leptonema (Rosenv.) Börges.													M
A. microscopicum Näg.					+		M						
A. parvulum (Kylin) Hoyt											+		M
A. savianum (Menegh.) Näg.									+				
A .subpinnatum Born.				M									
A. subtilissimum (Kütz) Hamel							M						
A. thuretii (Born.) Coll. et Harv.											+		
A. trifilum (Buff.) Batt.												+	+
A. virgatulum (Harv.) J. Ag. f. *luxurians* (J. Ag.) Rosen v.					+								

Table 1. Cont'd.

Species	(1973) (Date)	Ap 30	Aug 22	Ap 30	Aug 22	May 1	Aug 22	May 1	Aug 22	May 20	Aug 20	May 20	Aug 20
Station		1		2		3		4		5		6	
Acrochaetium sp. pl.		+	+	+	+		M				+		
Alsidium corallinum C. Ag.		+	+	M	M		+						
A. helminthochorton (La Tour.) Kütz.						+	+				+	+	+
Algaothamnion neglectum G. Feldm.							M						
A. scopulorum (C. Ag.) J. Ag.										M			
A. tenuissimum (Bonnem.) Kütz.										+			
Aglaothamnion sp.											+		
Amphira rigida Lamour						+	+						
Antithamnion sp.							M						
Asterocytis ornata (C. Ag.) Hamel					+							+	+
Botryocladia botryoides (Wulf.) J. Feldm.						+							
Centroceras clavulatum Mont.				+	+		M			+	M	M	
Ceramium ciliatum (Ellis) Ducl. var. *robustum* (J. Ag.) G. Feldm.							+			+	+	+	+
C. codii (Rich.) G. Feldm.		+											
C. comptum Börg.		+	+							M			
C. diaphanum (Roth) Harv.		+	+			+	+			+	+	+	+
C. gracillimum Harv. var. *byssoideum* (Harv.) G. Feldm.		+	+			+	+						
Champia parvula (C. Ag.) Harv.						+	+			+			
Chondria coerulescens (Crouan) Falk.		+											
C. tenuissima (Good. et Wood w.) C. Ag.						+							+
Chondria sp.							+						
Chylocladia pelagosae Erceg.													
Corallina granifera Ell. et Sol.		+	+				M		+	+		+	+
C. mediterranea Aresch.						+	+			+		+	+
Crouania attenuata (Bonnem.) J. Ag.													
Dasya arbuscula (Dill w.) C. Ag.					+					+			+
D. ocellata (Gratel.) Harv.							M						
Dermatolithon litorale Sun.							+		+		+		+

Table 1. Cont'd.

Species	(1973) (Date)	Ap 30	Aug 22	Ap 30	Aug 22	May 1	Aug 22	May 1	Aug 22	May 20	Aug 20	May 20	Aug 20
Station		1		2		3		4		5		6	
D. pustulatum (Lamour) Fosl.							+						
Erythrocladia subintegra Rosenv.			+				M						M
Erythrotrichia carnea (Dillw). J. Ag.		+		+	+								
E. reflexa (Crouan) Thur.			+				+		+		+		
Falkenbergia hildenbrandii (Born.) Falk.				+			+				+		
Fosliella farinosa (Lamour) Howe							+		+		+		+
F. lejolisii (Rosan.) Howe							+					+	
Furcellaria fastigiata (Huds.) Lamour.								M	+				
Gelidiella tenuissima (Thur.) J. Feldm. et Hamel													M
Gelidiella sp.							+						
Gelidium crinale (Turn.) Lamour.				+	+								
G. pulchellum (Turn.) Kütz.			+					+		M			
G. pusillum (Stackh.) Le Jol.					+	+				+			
G. spathulatum (Kütz.) Born.				+				+		+			
Gelidium sp.			+				+			+	+		
Gigartina acicularis (Wulf.) Lamour.				M	+		M			M			
Goniotrichum alsidii (Zanard.) Howe			+				+						
Gymnogongrus griffithsiae (Turn.) Mart.				+	+		M	M		+			
Halopithys incurvus (Huds.) Batt.		+	+							+			
Herposiphonia secunda (C. Ag.) Ambr.			+			+				+			
H. tenella (C. Ag.) Ambr.		+	+			+	+			+	+	+	+
Herposiphonia sp.													M
Hypnea cornuta (Lamour.) J. Ag.					+		M						
H. musciformis (Wulf.) Lamour.				+		+	+		+	M	+		+
Hypnea sp.				+	+		+					M	+
Jania rubens (L.) Lamour.		+	+			+	+	+	+	+	+	+	+
Laurencia obtusa (Huds.) Lamour.		M				M	+						+
L. papillosa (Forsk.) Grev.		+	+			+	+			M	+	+	+

Table 1. Cont'd.

Species (1973) (Date)	Ap 30	Aug 22	Ap 30	Aug 22	May 1	Aug 22	May 1	Aug 22	May 20	Aug 20	May 20	Aug 20
Station	1		2		3		4		5		6	
L. perforata Mont.												+
Laurencia sp.					M						+	
Litholepis mediterranea Fosl.		+										
Lithothamnium sp.						+						
Lophocladia lallemandii (Mont.) Schmitz.						M						
Lophosiphonia cristata Falk.												+
L. obscura (C. Ag.) Falk.												+
L. subadunca (Kütz.) Falk.												+
Nemalion helminthoides (Vell.) Batt.					M		M		M			
Peyssonnelia inamoena Pilger		+										
P. rubra (Grev.) J. Ag.	+											
Peyssonelia sp.	+				+							
Polysiphonia atra Zanard.	+											
P. breviarticulata (C. Ag.) Zanard.						+						
P. dichotoma Kütz.					+	M					+	+
P. montagnei Zanard.						M						
P. opaca (C. Ag.) Zanard					M	+			+	+	+	+
P. parvula Suhr.						+						
P. sertularioides (Gratel.) J. Ag.					+							
P. subtilissima Kütz.												+
P. tenerrima Kütz.		+				M						
P. tripinnata J. Ag.	+				+	+						
Polysiphonia sp. pl.	+				+					+		
Porphyra sp.									+			
Pterocladia pinnata (Huds.) Papenf.								+				
Rytiphloea tinctoria (Clem.) C. Ag.	+	+	M	M		M						
Spermothamnion sp. pl.	+	+										
Spyridia filamentosa (Wulf.) Harv.					+	+					+	+
Taenioma macrourum Born. et Thur.					+							
Tenarea undulosa Bory					+							
Wurdemannia miniata (Drap.) J. Feldm. et Hamel					M							

Station 6 (control) was lower in nutrients than other stations (Table 2). This station was more remote from both potential pollution sources and river inflow than other stations. Phosphate, nitrate and nitrite, were undetectable. Ammonia (mean, 2.7 μg at/L) was lower than at any other station and only about one-half the average value for all other stations. Both biomass (mean, 2519 g/m^2) and taxonomic diversity (mean, 1.27) were high.

Station 5, south of the Khalde sewer outfall, was high in phosphate, and highest in nitrate and ammonia compared to other stations. Total nitrogen averaged 3.6 times greater than at the control station. This apparent sewage nutrient enrichment was accompanied by a marked reduction in biomass to only 24 percent of the control and a slight reduction in species diversity to 80 percent of the control level (Table 2).

Station 4, near the Jounieh power plant, showed no significant phosphate or nitrogen enrichment, but temperature at least in August, was much higher than at other stations. The 36.0°C August reading was considerably higher than either the control or the mean value (29.7°C) for all other stations at that time of year. The rise in temperature was apparent on a smaller scale as one approached the cooling water effluent of the power plant. Biomass was markedly reduced at station 4 to 39 percent of the control value. Taxonomic diversity was likewise greatly reduced and in fact averaged the lowest (0.31) of all six stations (Table 2).

At station 3, with no proximate pollution source, phosphate and ammonia were relatively high, while nitrate and nitrite were low. Biomass was high, averaging somewhat more than the control. Although the total number of taxa present (54) was higher than at any other station including the control, the average diversity was somewhat reduced from the control. This was largely a reflection of the greater biomass and hence lower biomass: taxa ratio.

At station 2, near the chemical fertilizer plant, phosphate was extremely high reaching an average of 19.6 μg at/L of seawater. In fact, the relatively high phosphate values found at station 3 may have reflected the fact that the two stations were only about 7 km apart. Biomass was reduced to only 42 percent and taxonomic diversity to only 69 percent of the control station.

At station 1, north of the Tripoli oil refinery, phosphate was low, but nitrogen relatively high. Biomass was only 41 percent of the control, but diversity (1.50) was higher than at other stations including the control (1.27) (Table 2).

In general, it can be said that, from a center of low diversity near station 4, algal diversity tended to increase in either a north or south direction along an extensive portion of the Lebanese coast (Figure 2). In fact, linear regression of 143 values indicated a significant positive correlation between taxonomic diversity and distance from station 4 (Figure 3). This indicates the probability that pollution, which is most concentrated in the urban Beirut area, may, when carried north by the prevailing currents, have widespread effects along much of the Lebanese coast.

Table 2. Algal population and environmental data at Stations 1 trough 6 along the coast of Lebanon. (* = mean of all quadrates taken, E = extrapolated value higher than range of standard analysis curve; — = not measured; X = below range of detectability; Tr = not within confidence limits of assay).

Station and type of pollution	1. Aaramane (Refinery)			2. Selaata (Esso Chemical)			3. Berbara (unpolluted)			4. Zouk Mkayel (Power Plant)			5. Khalde (Sewer)			6. Doha (Control)		
Distance from Sta 4.	57 km N			29 km N			22 km N			0			32 km S			34 km S		
	30 Ap to 1 May	20 Aug to 22 Aug	Mean	30 Ap to 1 May	20 Aug to 22 Aug	Mean	30 Ap to 1 May	20 Aug to 22 Aug	Mean	30 Ap to 1 May	20 Aug to 22 Aug	Mean	30 Ap to 1 May	20 Aug to 22 Aug	Mean	30 Ap to 1 May	20 Aug to 22 Aug	Mean
Biomass (g/m^2)	1234	832	1033	1997	1000	1048	2874	3650	3262	1419	538	978	548	683	615	2785	2254	2519
Total no. of taxa	45	44	45	35	31	33	46	61	54	21	21	21	45	39	42	30	53	42
Mean taxa diversity*	1.21	1.78	1.50	0.67	1.07	0.87	0.62	1.27	0.95	0.24	1.38	0.81	0.65	1.39	1.02	0.88	1.66	1.27
Temperature (°C)	22.0	31.0		20.0	29.5		19.8	28.5		22.0	36.0		22.0	29.5		22.8	30.0	
Phosphate (μg at PO_4-P/L)	1.22	X	0.6	16.5 (E)	23.7 (E)	19.6	1.00	2.63	1.82	—	1.08	1.08	1.67	1.34	1.51	X	X	X
Nitrate (μg at NO_3-N/L)	1.2	2.5	1.9	0.8	0.6	0.7	0.7	X	0.4	—	X	X	2.1	1.8	2.0	X	X	X
Nitrite (μg at NO_2-N/L)	Tr°	0.3	0.2	X	0.2	0.1	Tr	X	X	—	0.4	0.4	X	Tr	X	X	X	X
Ammonia (μg at NH_4-N/L)	6.1	1.9	4.0	6.7	1.2	4.0	11.9	1.2	6.6	—	4.3	4.3	9.5	5.7	7.6	0.8	4.5	2.7
Total nitrogen - mean		5.1			4.8			7.0			4.7			9.6			2.7	

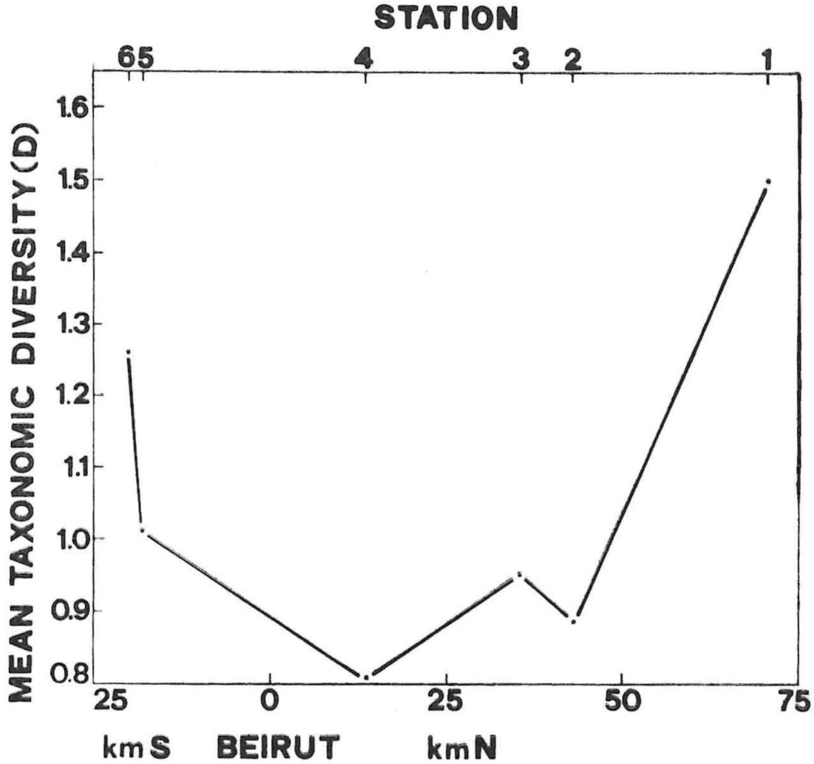

Fig. 2 — The mean diversity of algal samples (D).

In addition to the general reduction in diversity, major realignments in the species composition of algal communities in response to pollution were found. Species of Phaeophyta averaged 12 percent of the control population and 11.5 to 14 percent of the total species at other stations, except at station 2 where light concentrations of PO_4 were present. At station 2, they dropped to only 4.8 percent (Figure 4). Furthermore, the reduction in percentage of Phaeophyta in response to higher PO_4 levels appeared to be a general and significant phenomenon (Figure 5). Nutrient enrichment at stations 2 and 4 also appeared to lead to a decrease in the percentage of Rhodophyta and an increase in the Chlorophyta species.

A series of 2-factor linear regression analyses were performed on species diversity, biomass, and Phaeophyta percent against environmental and nutrient factors. Only two relationships, as discussed above, proved significant. Species diversity is positively correlated with distance from station 4 and Phaeophyta percent is negatively correlated with increasing PO_4 concentration (Figures 3 and 5). The percent of Rhodophyta increased with distance from station 4 (slope 0.57, $r = 0.38$, $n = 12$) and decreased with increasing PO_4 concentration

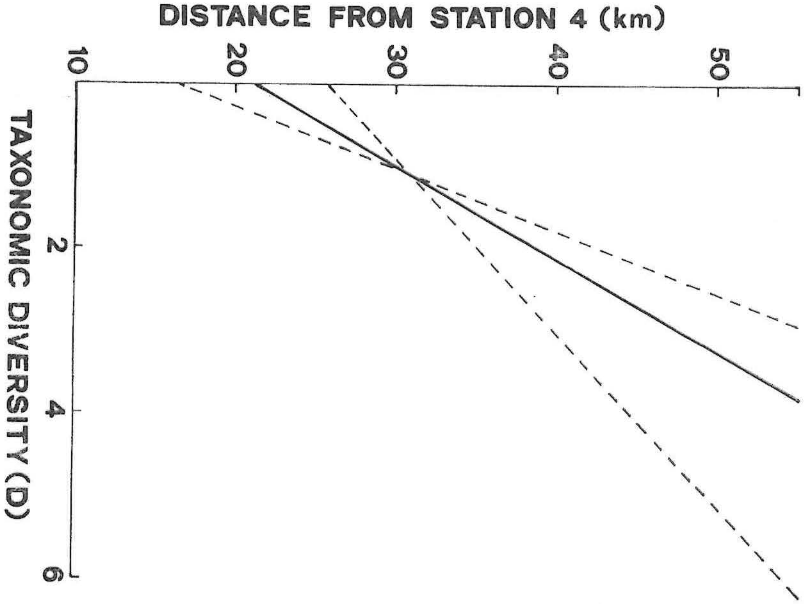

Fig. 3 — Algal diversity (D) showing a significant positive correlation with distance from station 4 (slope = 9.09, r = 0.33, n = 143). Dotted lines indicate the 95 percent confidence limits for the slope.

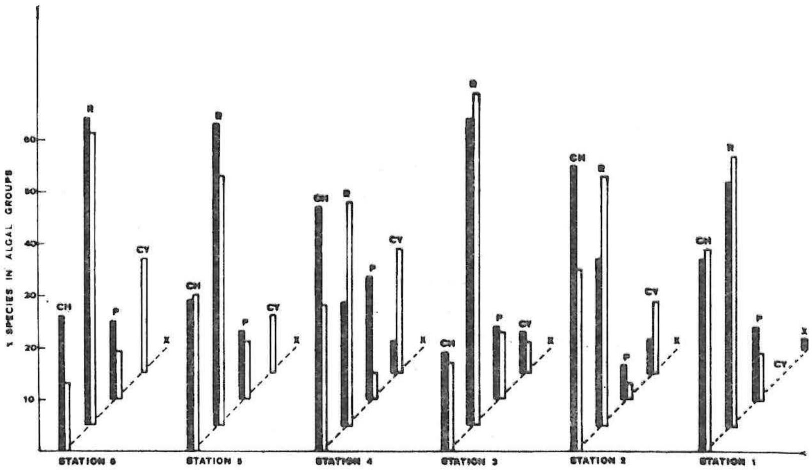

Fig. 4 — Percent of species belonging to major taxonomic groups at stations 1 to 6. (CH = Chlorophyta, R = Rhodophyta, P = Phaeophyta, CY = Cyanophyta, X = Xanthophyta).

(slope — 0.45, r = —0.51, n = 11; Chlorophyta percent tended to increase with increasing nitrate (slope 0.03, r = 0.43, n = 11) and PO_4 (slope 0.36, r = = 0.45, n = 11) concentrations; and species diversity tended to decrease with

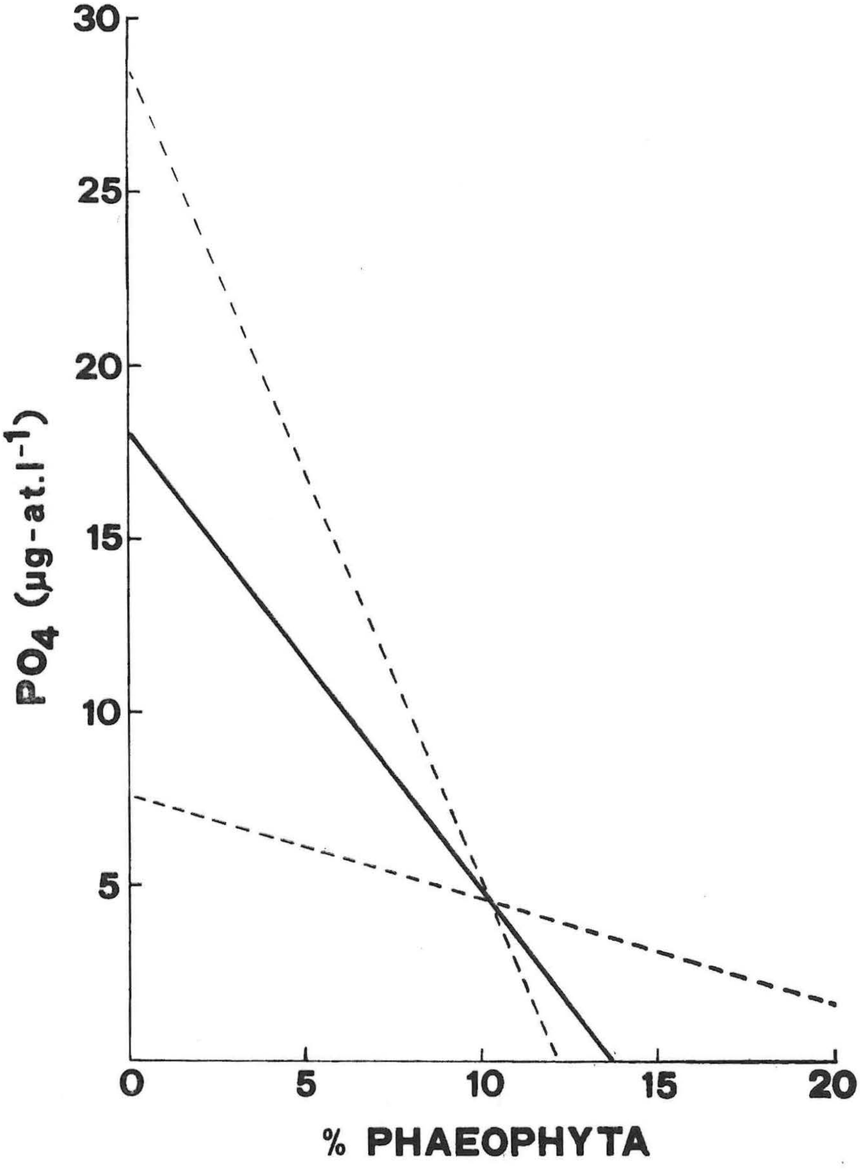

Fig. 5 — The percent of species of Phaeophyta (shows a significant negative) correlation with PO_4 concentration (slope = —1.33, r = 0.68, n = 11). Dotted lines indicate the 95 percent confidence limits for the slope.

increasing distance from the seaward edge of rock platforms (slope = —0.12, r = —0.10, n = 152), but none of these latter relationships were significant at the 95 percent confidence level.

DISCUSSION

The results indicate that different types of marine pollution produce significant and widespread changes in communities of benthic macroalgae along the coast of Lebanon. The widespread changes in taxonomic diversity, biomass, and species composition, reported above, extend from a »center« a few km north of Beirut over approximately an 80 km stretch of coastline. In fact pollution, reflected in degradation or simplification of the macroalgal communitiy, appears so widespread that one may question the validity of the »control« station 6. The predominant current along the coast is northward and pollutants generated in the vicinity of Beirut would presumably be carried slowly north along the coast. If the sampling were extended further to the south of Beirut, the algal community might show even greater diversity and represent an even less-polluted control. The greatest concentration of urban pollutants from Beirut is probably on the north side of the city and in Jounieh Bay which acts as an »epicenter« from which pollutants spread outward (predominately northward).

These results agree with Borowitzka (1972) who found a negative correlation between the species diversity of Australian macroalgae and proximity to pollution (sewage) sources. The reduction in taxonomic diversity and in the pollutant-indicationg Phaeophyta appears to be due to a variety of pollutant sources. At station 2, and perhaps at station 3, the reduction results from high PO_4 levels from a fertilizer plant. At station 4, the reduction is due to heated effluent water from a power plant and at station 5 from sewage nutrient enrichement. The effects of power plants on algal communities may result not only from heated water but from chlorine or other toxic chemicals added to the cooling water (Hamilton, Flemer, Keefe and Mihursky, 1970).

Phosphate appears to be the important nutrient pollutant affecting the macroalgal community. Nitrogen is of less importance. Relatively high levels of NO_3 and PO_4 at the sewer (station 5) have significant effects in reducing diversity, whereas a comparable level of NO_3 at station 1 with only low PO_4 has little effect upon diversity (Table 2). Furthermore, reduction in the percent of pollutant-indicating Phaeophyta is significantly correlated with increasing PO_4 (Figure 5), but not with NO_3 concentrations. These results confirm the findings of others (Jacques, Cahet, Fiala et Panouse, 1973) that PO_4 is often the limiting factor for algal growth in the Mediterranean Sea.

The findings here agree in general with Borowitzka (1972) who also found that the Phaeophyta and, secondarily, the Rhodophyta, were sensitive and cannot survive in polluted areas, whereas the Chlorophyta, particularly *Enteromorpha* spp. and *Ulva* spp. thrived in sewage polluted waters. A high dominance of green algae (Chlorophyta), particularly of the genera *Enteromorpha* and *Ulva*, seems to be a reliable indicator of pollution. On rock platforms surrounding major sewer outfalls in and around Beirut, practically the entire biomass is composed of *Enteromorpha* spp. and *Ulva* spp. Rueness (1973) noted the disappearance of the brown alga *(Ascophyllum nodosum)* from the inner Oslofjord of Norway in response to increased sewage pollution. At the higher nutrient levels, *Ascophyllum* cannot apparently compete successfully with the green alga, *Enteromorpha* spp. Other investigators have shown that nutrient fertilization with ammonia or phosphate increases the photosynthetic productivity of *Ulva lactuca* (Waite and Mitchell, 1972) and that *Enteromorpha prolifera* attains a larger size and contains a greater amount of protein when growing in sewage polluted rather than in non-polluted waters (Tewari, 1972). This increased competitive advantage of some *Ulva* spp. and *Enteromorpha* spp. at increased nutrient levels thus appears to be a general phenomenon indicative of nutrient enrichment pollution.

Several species serve as good indicators of clean water and appear intolerant of nutrient enriched or polluted water. Four species of *Cystoseira* occurred at unpolluted stations 3 and 6 and not at other stations (Table 1). Bellan-Santini and Armoux (1972) likewise found *Cystoseira* to be sensitive to pollution. *Cystoseira stricta*, once abundant around Marseilles, is disappearing in response to increased (sewage) pollution. *Corallina mediterránea* was found by Molinier (1960) to be inhibited by a high degree of nitrogen enrichment in harbors of Corsica. This species was found at unpolluted stations 3 and 6 and only incidently at one other station (5). The absence of *Laurencia obtusa* and *L. papillosa* at stations 2 and 4 also appeared to be indicative of pollution.

Several species, on the other hand, appeared to thrive in nutrient enriched waters. *Colpomenia sinuosa* appeared at polluted stations, but not at stations 3 and 6 (Table 1). *Pterocladia pinnata* occurred at polluted stations 4 and 5 only. As mentioned above *Ulva* spp. and *Enteromorpha* spp. often dominated the polluted stations. This confirms the description by Molinier (1960) of a »*Pterocladia-Ulvetum*« association characteristic of high nitrogen-enriched harbors in Corsica.

A general trend at all stations was an increase in taxonomic diversity and a decrease in the percent of Phaeophyta species between spring and summer as temperature, salinity, and solar energy increase. Studies are continuing to determine the effects of seasonal changes and other factors on algal communities and their response to pollutants. As more data are gathered the preliminary relationships discussed here will be more clearly defined.

In conclusion, a variety of types of marine pollution along the Lebanese coast, including significant phosphate enrichment, results in a geographically extensive coastal zone (more than 50 km) of reduced macroalgal diversity, a decrease in algal biomass at polluted stations, a shift in the taxonomic composition of algal populations with a decrease in the percentage of Phaeophyta species, and an increase in the percentage of Chlorophyta species at polluted stations.

SUMMARY

Marine macroalgae were collected at six stations representing different pollution sources along the Mediterranean coast of Lebanon. Samples within 0.01 m^2 quadrates were collected at 1 to 2 m intervals along transects in the wave-wash zone of limestone platforms in spring and summer. The number of species, wet weight biomass, and environmental factors were recorded, and the taxonomic diversity determined according to $D = \frac{t - 1}{Ln\ B}$, where t = total number of taxa in a quadrate, and Ln = natural log of the wet weight biomass (g/m^2).

A total of 190 species were identified. A number of pollutant sources including chemical plant PO_4 enrichment, power plant thermal enrichment, sewage nutrient enrichment, and a possible variety of other urban pollutants resulted in reduced algal diversity over an extensive coastal zone of more than 50 km, a decrease in algal biomass, and a decrease in the percentage of Phaephyta and icrease in Chlorophyta species at polluted stations. The presence of *Cystosiera* spp., *Carallina mediterranea,* and *Laurencia* spp. indicate clean water, while *Ulva* spp., *Enteromorpha* spp., *Colpomenia sinuosa,* and *Pterocladia pinnata* appeared to thrive in nutrient-enriched waters.

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EKOLOGIJA MORSKIH VIŠIH ALGI U ODNOSU NA POLUCIJU UZDUŽ LIBANONSKE OBALE

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KRATAK SADRŽAJ

Više morske alge su bile sakupljane na šest postaja izloženim različitim izvorima zagađenja uzduž libanonske obale. Uzorci su uzimani unutar kvadrata od 0.01 m^2 na udaljenosti od 1 do 2 m uzduž transekata u zoni prskanja valova na vapnenačkim platformama u proljeće i ljeti. Određivan je broj vrsta, vlažna težina biomase, faktori sredine i različitost vrsta prema formuli $D = \frac{t - l}{ln\ B}$, gdje je t totalni broj vrsta na jednom kvadratu, a $ln\ B$ prirodni logaritam vlažne težine biomase (g/m^2).

Identificirano je 190 vrsta. Izvori polucije kao kemijski (PO_4), termalni (elektrane), gradske kanalizacione i druge otpadne vode se očituju u smanjenoj različitosti vrsta u zoni od 50 km, u opadanju biomase i smanjenju učešća vrsta feofita, te porastu vrsta klorofita. Prisustvo *Cystoseira* spp., *Corallina mediterranea* i *Laurencia* spp. ukazuje prisustvo čiste vode, dok *Ulva* spp., *Enteromorpha* spp., *Colpomenia sinuosa* i *Pterocladia pinnata* uspijevaju u vodama obogaćenim hranjivim tvarima.