EFFECTS OF THE 1976 NEW YORK BIGHT OXYGEN DEPLETION PHENOMENON ON THE BENTHIC INVERTEBRATE COMMUNITY

by

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Introduction

Oxygen depletion, or anoxia, and toxic concentrations of hydrogen sulfide have been reported in marine waters from many parts of the world (Richards, 1965; Deuser, 1975). In anoxic areas, there are usually dramatic changes in the bottom life. Where bottom oxygen concentrations remain chronically low, with a persistent presence of hydrogen sulfide, the benthic fauna is absent or low in species diversity and abundance, e.g. the Black Sea and areas of the Baltic Sea (Tulkki, 1965; Theede et al., 1969). In other situations, when anoxic conditions develop sporadically or seasonally, a "normal" fauna can develop between anoxic occurrences but anoxia reoccurrence results in mass mortalities of the intolerant species, e.g. Conception Bay, Chile (Falke, 1950); Walvis Bay, South Africa (Brongersma-Sanders, 1957); the Adriatic Sea (Fedra et al., 1976); and Mobile Bay, Alabama (May, 1973).

Reports of anoxic water along the east coast of North America are relatively rare. However, a few anoxic or semi-anoxic basins and estuaries are known, e.g. along the Gulf of Maine and Canadian coasts (Folger et al., 1973; Gaines and Pilson, 1972; and Hoos, 1973). Oxygen deficient conditions were unobserved in the waters of the New York Bight, an open coastal area bounded by Long Island, New York, and the New

Jersey shore, until 1968. During September of that year sport divers observed dead and dying fish and benthic invertebrates around wrecks off central New Jersey. The area where these mortalities were reported was between Sea Bright and Surf City, New Jersey (a distance of about 65 km) and between 3 and 15 km offshore, covering a total area of less than 800 km^2. Investigation by the NMFS Sandy Hook Laboratory found dissolved oxygen (D.O.) concentrations below 1.0 ml/l (Ogren and Chess, 1969). Additional reoccurrences of this situation were observed during October, 1971 and August, 1974 (Young, 1973; 1974). These reoccurrences were much more limited in spatial distribution (less than 100 km^2) and in impact to marine life.

The latest observation of anoxic conditions in the N. Y. Bight occurred between July and October, 1976. The occurrence included the mass mortalities of benthic invertebrates within a 165 km corridor of oxygen depleted bottom water paralleling the New Jersey coast, between 5 and 85 km from shore. This paper describes and discusses this event.

Methods

Assessment of benthic invertebrate impacts is based on: 1) *in situ* diver observations; 2) incidental collections of benthic invertebrates in finfish trawling and shellfish dredging surveys; and 3) benthic grab collections.

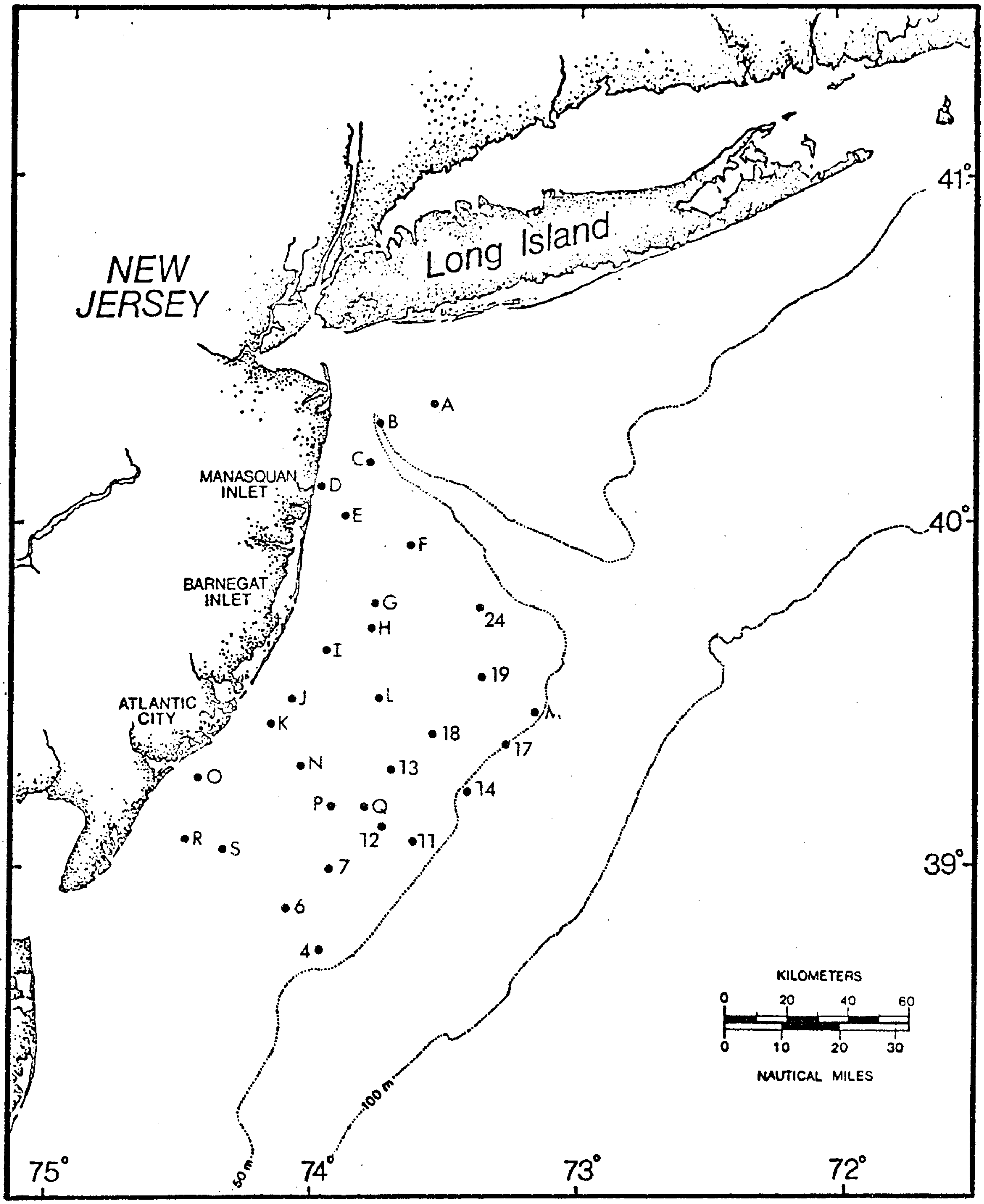
The diver observations comprised reports from reliable sport divers, as well as from NMFS divers, of the species and relative numbers which were observed to be affected around wrecks in the New York Bight. They included observations on the behavior of organisms which appeared to be affected and other conditions which appeared relevant to the phenomenon, e.g. the presence of a dark organic flocculent layer on the bottom.

Trawl surveys, assessing the effect on resource finfish and shellfish, began within a few days of the initial reports of mortalities; dredge surveys began a few weeks later. Although valuable resource species were the primary targets of the surveys, many non-resource benthic invertebrates were also collected which could be used to assess impacts, especially for the larger invertebrate species.

Five benthic surveys were conducted to examine the effects on the infauna. Whenever possible, the surveys reoccupied stations from which pre-anoxic data were available, however, many stations were sampled for the first time. Thirty stations were examined between July and November, 1976. Three 0.1 m^2 Smith-McIntyre grab samples were collected at each station, with each washed through a 0.1 mm mesh size screen, fixed in 10% buffered formalin and later transferred to 70% ethanol for storage. At least one of the triplicate samples, or a total of 46 samples, has been processed (Figure 1) with species identified and enumerated. The stations were chosen as being those for which the greatest impact would be expected, i.e., in the area of the most severe anoxic and hydrogen sulfide conditions, as well as some control stations. The processed data were analyzed for H' diversity (Shannon and Weaver, 1963), and J' equitability (Pielou, 1969).

Additional samples were collected during June and July 1977 to examine recolonization and long term impacts. Only preliminary data are available for these later samples.

Figure 1. Station locations for the benthic grab collections. The numbered stations are part of the OCS series used in the inter-year comparisons.



Results

Diver observations:

The benthic fauna was one of the first groups of organisms observed to be affected by the development of anoxic water. Initial clues to a developing problem came during the weekend of June 27, 1976. Sport divers visiting wrecks off central N. J. observed lobsters (*Homarus americanus*) and rock crabs (*Cancer* sp.) congregated on the highest parts of wrecks, indicative of stressful but not yet lethal conditions at the bottom of the water column below the 20 meter deep thermocline. They also observed surf clams (*Spisula solidissima*) lying on their sides on the sediment surface, a condition also considered an indication of stress, e.g., hypoxia (Savage, 1976). The initial reports of actual mortalities to marine life came following the July 3-5, 1976, weekend (Bullock, 1976; E. Geer, American Littoral Society, Highlands, N. J., pers. comm.). Sport divers reported many dead fish and invertebrates on or near wrecks and other diving spots off the north-central New Jersey coast in a zone extending from Long Branch to Barnegat Inlet and from approximately 5 to 40 km offshore. The invertebrate mortalities consisted mostly of rock crabs, starfish (*Asterias forbesi*), blue mussels (*Mytilus edulis*), and lobsters. Lobsters were also observed alive but very sluggish, lying exposed, out of their shelters, with some sharing holes or dens. As the area of oxygen depletion increased, mortalities were reported by sport divers on wrecks as far south as Atlantic City by July 17. Continued accounts of mortalities were received throughout the summer off the central New Jersey coast.

In September, sport divers reported partial recovery and recolonization of some affected wrecks, northeast of Manasquan Inlet. The recolonizers were mostly finfish but a few rock crabs and lobsters were also found, where previously all were dead or had left the area.

During March of 1977, NOAA divers reexamined an area near the center of the 1976 anoxia zone S.E. of Manasquan Inlet. They observed dense aggregations of the tube-dwelling polychaete, *Asabellides oculata* (Figure 2).

Incidental benthic data from trawl and dredge surveys:

The results for July surveys (Azarovitz, 1976; Ropes, 1976a) indicated that the benthic fauna at stations in a small area 5-10 km east-northeast of Barnegat Inlet (Figure 3), were severely impacted (greater than 50% total mortalities for all invertebrates collected). The surf clam suffered the greatest impacts; other mortalities included: crustaceans - rock crabs, mud shrimp (*Axius serratus*), lobsters, and mantis shrimp (*Platysquilla enodis*); echinoderms - starfish, sand dollars (*Echinarachnius parma*), and sea cucumbers (*Caudina arenata*); molluscs -

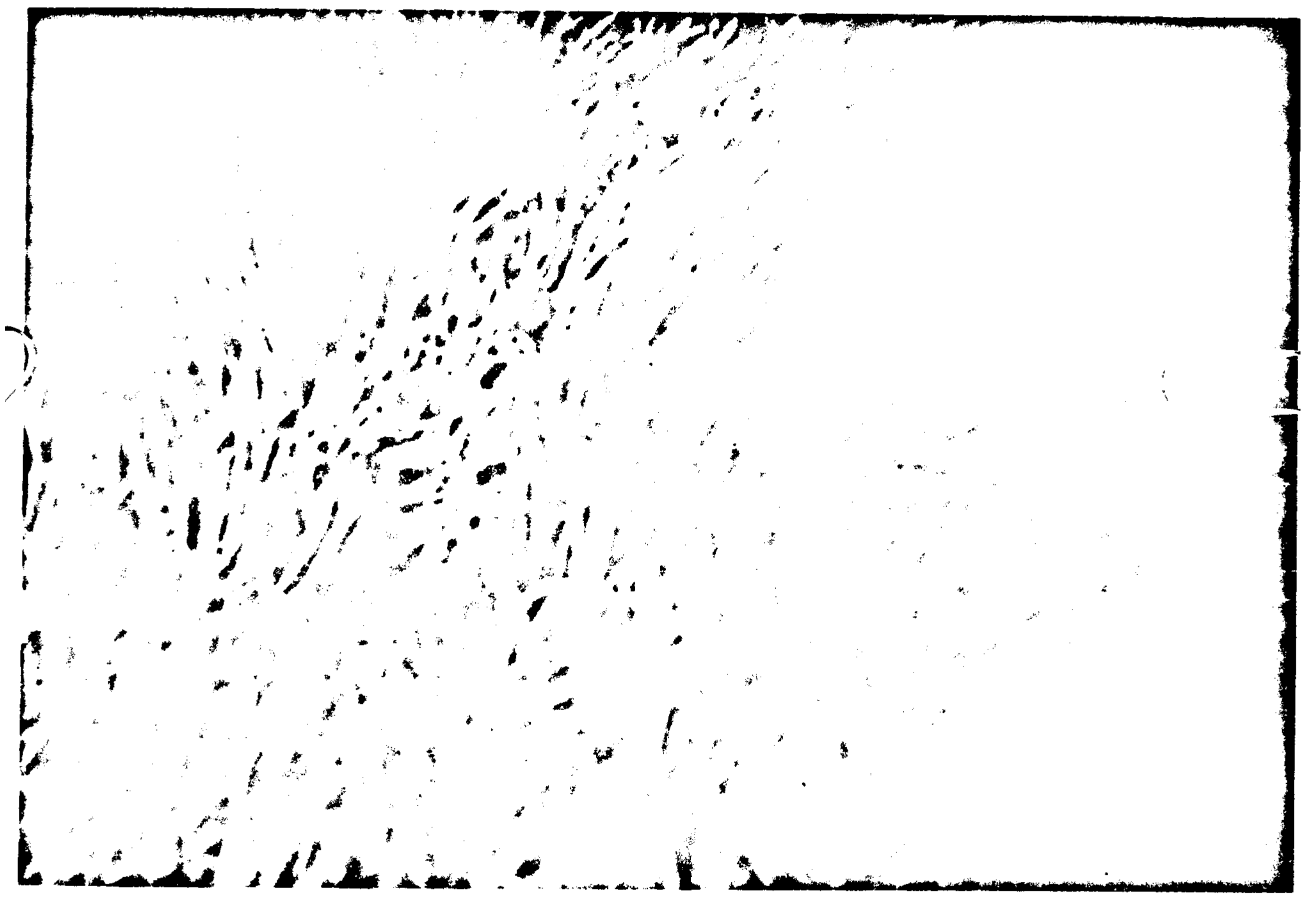
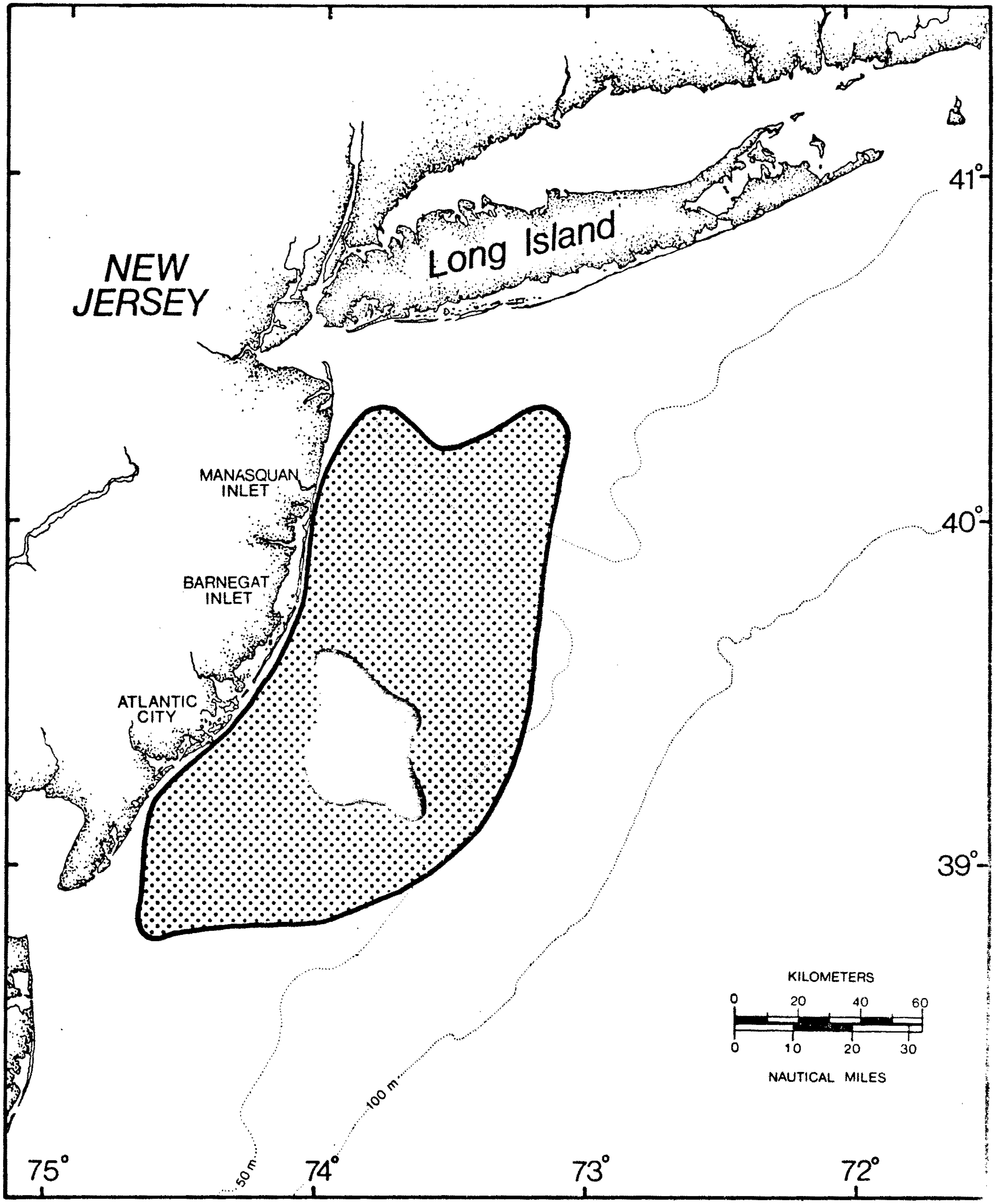


Figure 2. Example of the dense clumps of Asabellides oculata tubes located by NOAA divers off Manasquan Inlet during March, 1977. Each tube ranges between 5-10 cm in length. (Photograph courtesy of E. Geer, American Littoral Society, Highlands, N. J.).

Figure 3. The distribution of observed benthic mortalities July-November '76. Black portion denotes area of greatest impact.



sea scallops (*Placopecten magellanicus*), razor clams (*Ensis directus*), moon snails (*Lunatia heros*), and ocean quahogs (*Arctica islandica*); unidentified sipunculids; burrowing anemones (*Ceriantheopsis americanus*), and polychaete worms (mostly *Sigalion arenicola* but including *Aglaophamus circinata*, *Orbinia swani*, *Glycera dibranchiata*, *Lumbrineris fragilis* and *Nephtys longosetosa*). Moderate impacts (10 to 50% total mortalities) involving the same species were found over a wider area, from Long Branch to Beach Haven, N. J., and between 5 and 35 km offshore. Other species, many which normally burrow in the sediments below the penetration of grabs, trawls or dredges, i.e., larger polychaetes, mud shrimp, mantis shrimp, sea cucumbers, sipunculids, and surf clams, were collected in finfish trawls alive, but in an obviously stressed state (Figure 4). Very little impact was observed within 3 km of the shore except during two short periods when suspected upwellings of anoxic bottom water occurred in the surf zone; this resulted in large numbers of dead calico crabs (*Ovalipes ocellatus*), rock crabs and lobsters, as well as some finfish, washing on the beaches near Manasquan and Beach Haven.

Surveys in August (Ropes, 1976b, c; Azarovitz, 1976) through November found the impacted area to expand to that outlined in Figure 3. Moderate impact was found as far south as

Cape May and, as in July, the surf clam mortalities were the most extensive in terms of relative numbers and biomass of dead animals collected. Putrifying surf clam meats were found in trawls at several stations during August's collections.

The surveys in October and November found continued scattered evidence of mortalities; mostly "clapper"* razor clams and ocean quahogs were found. There was also some re-colonization by cancroid crabs and starfish in this area.

A summary list of affected invertebrate macrofaunal species collected by trawls or dredges is presented in Table 1; detailed listings of impacts are available (Steimle, 1977).

Smith-McIntyre grab collections:

Data from eleven OCS stations are compared to pre-anoxic conditions (Table 2). The earlier samples were collected during April, 1975 (Pearce et al., in press); resampling was done during October and November, 1976. To simplify analysis and interpretation of impacts, only species which occurred at three or more stations are included in the tables. The results from the remaining 19 processed stations are presented in Table 3.

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* Clappers are meatless bivalve shells, stilled joined at the ligament; considered to indicate tha animal's death was recent, within several weeks in the case of the surf clam (A. Merrill, NMFS, Woods Hole, Mass., pers. comm.).

Figure 4. Examples of the normally deep burrowing benthic species which were collected in trawl nets, included are (clockwise from upper right): Nereis longosetosa, Sigalion arenicola, Axius serratus, Spisula solidissima (meats only), Ensis directus, Caudina arenata, Cancer irroratus (not a burrower), more Caudina and near center Platysquilla enodis. A nickel coin is included for size comparison.

Table 1. List of affected benthic invertebrate species collected in trawl or dredge samples with observations on extent of impact.

Species	Common name	Comments
Ceriantheopsis americanus	burrowing anemone	a few dead observed by divers and collected by trawl surveys
various polychaetes (mostly *Siglion arenicola*)	marine worms	100's were collected hanging dead from trawl net mesh
Axius serratus	mud shrimp	a few were collected in trawl collections
Platysquilla enodis	mantis shrimp	"
Libinia emarginata	spider crab	"
Cancer irroratus	rock crab	100's were reported dead by divers and collected in surveys
Cancer borealis	Jonah crab	dozens were reported dead by divers and collected in surveys
Homarus americanus	American lobster	"
Mytilus edulis	blue mussel	1000's were reported dead on wrecks by divers
Placopecten magellanicus	sea scallop	dozens dead and recent empty clappers were collected in surveys
Astarte castanea	chestnut astarte	a few were collected in surveys
Arctica islandica	ocean quahog	100's were collected dead or as recent empty clappers in surveys especially in the fall and offshore

Table 1. (continued)

Spisula solidissima	surf clam	1000's of dead clams, and clappers and bushels of unattached meats were collected during surveys
Ensis directus	razor clam	dozens of dead or recent clappers found in surveys
Lunatia heros	moon snail	several were collected dead in surveys
Asterias forbesi	starfish	hundreds were reported dead by divers and collected in surveys
Echinarachnius parma	sand dollar	100's were collected dead in surveys
unidentified holothurian	sea cucumber	a few were collected dead in surveys
Sipunculoids	no common name	a few were collected in trawl surveys

Table 2. A comparison of benthic data at stations occupied prior to (April, 1975) and after (October-November, 1976) the oxygen depletion.

	Station occurrences		STATION AND YEAR													
			4		6		7		8		11		12	
	75	76	75	76	75	76	75	76	75	76	75	76	75	76
Archiannelida	8	8		1	266			4	21		4	22	2	1
Ceriantharia:	1	10												
Ceriantheopsis americanus				6						1	1	13		1
Rhynchocoela	7	11	4	4	2	4	2	4		1		30	1	2
Polychaeta:														
Phyllodoce arenae	3	3	1							12				
Sthenelais limicola	3	3	1						1			3		
Glycera dibranchiata	8	6	4	2	2						2			1
Goniadella gracilis	4	5			45				28					
Nephtys picta	2	3						3				2	1	3
Aglaophamus circinata	10	5	11	16		1	2		2	4	1		2	
Exogone hebes	5	8			2			2	1	21		1		
Nereis grayi	3	3	1		4					2				
Scalibregma inflatum	2	3		2										
Macroclymene zonalis	6	5	10		8	8	1		33	17				1
Leiochone dispar	10	0	3		1		1		2				2	
Spiophanes bombyx	9	11	272	199		3	1	3	1	193	34	321	10	
Aricidea cerruti	4	10		7	1	10	1		7	9		6		
Aricidea wassi	4	6				3		4		1		1	2	3
Lumbrinerides acuta	4	5			2				35	1				2
Lumbrineris fragilis	5	3	1	1	2	1				3				
Lumbrineris tenuis	3	3	4		2				1					
Drilonereis magna	4	3			1				5		1		2	
Dorvillea caeca	0	6		7						5		1		
Tharyx acutus	6	5		2	264		1		4	14				
Tharyx annulosus	3	5			3					1			2	
Caulleriella killariensis	4	4						1	5	9				
Ampharete arctica	5	7	5	6				1		6		17		
Euchone rubrocincta	6	0	3						1		1			
Mollusca:														
Cyclocardia borealis	1	4	2											
Ensis directus	5	3	1		2			1	1					
Crustacea:														
Leptognatha caeca	4	1							1				2	
Ptilanthura tricarina	1	5		1										
Cirolana polita	6	2	2				1	4	3		14			
Edotea triloba	4	1								1	2			
Ampelisca vadorum	2	3	3	1						5				
Ampelisca agassizi	3	3			1									
Byblis serrata	10	5	4		2		17	1	5	6	25			
Unciola irrorata	6		4	10			3	1		17	1	29		
Unciola inermis	3	4			1									
Pseudunciola obliquua	4	4	1	5			46					1	3	7
Protohaustorius wigleyi	4	4				14	8	1			1		2	3
Acanthohaustorius spinosus	2	3						1					1	
Leptocheirus pinguis	2	3												
Phoxocephalus holbolli	4	1			1				1					
Trichophoxus epistomus	8	8	16	21		24	17	5	3	2	8	1		13
Cancer irroratus	2	4			1	1		1						
Phoronida:														
Phoronis architecta	0	9		149						1		90		2
Echinodermata:														
Echinarachnius parma	10	5	3			8	9		6	4	14		15	22
Total # Species			27	31	25	19	16	19	23	35	19	17	19	13
Total # Individuals			370	472	624	93	113	40	168	387	118	543	52	61
H' Diversity			1.34	1.81	1.34	2.43	1.93	2.73	2.38	2.21	2.18	1.46	2.40	2.00
J' Equitability			0.41	0.53	0.42	0.82	0.89	0.93	0.76	0.62	0.74	0.51	0.83	0.78

Table 2 (continued).

	13		14		17		18		19		24	
	75	76	75	76	75	76	75	76	75	76	75	76
Archiannelida		4	15	293	13	105.5	1			5	102	
Ceriantharia:												
Ceriantheopsis americanus		30.5		3		7.5		2		7		21
Rhynchocoela	3	55	1	2.5		16	1			3		2
Polychaeta:												
Phyllodoce arenae			1	2.5	2	9						
Sthenelais limicola		3		2	1							
Glycera dibranchiata	1		1	.5	5	.5	1	1			3	2
Goniadella gracilis		13.5				4		.5	10	10	5	3
Nephtys picta	1											
Aglaophamus circinata	2		3	5.5	2	3.5	1				1	
Exogone hebes		1		5.5	1	21		1	1	1	5	
Nereis grayi		.5				2.5						
Scalibregma inflatum				.5	2	19	1					
Macroclymene zonalis		.5	1			90			1			
Leiochone dispar	1		3		3		4				1	
Spiophanes bombyx	2	62	40	356	24	46	1	4		138		64
Aricidea cerruti		11		1.5		.5					1	
Aricidea wassi			1			16.5		2.5		2	6	1
Lumbrinerides acuta				3	1		1			1		
Lumbrineris fragilis			1			2.5			4		18	15
Lumbrineris tenuis		6							1		1	
Drilonereis magna				1.5		10				13		
Dorvillea caeca				12							1	2
Tharyx acutus	1	1				21.5						4
Tharyx annulosus		2			1	92.5					16	2
Caulleriella killariensis			1	7		12.5		.5			1	1
Ampharete arctica		12	6	12.5	2	10					1	
Euchone rubrocincta			39		2	4	1				1	
Mollusca:					27		1					
Cyclocardia borealis		.5										
Ensis directus		6.5	1			1						
Crustacea:					1							
Leptognatha caeca			1									
Ptilanthura tricarina		.5		.5		1.5						
Cirolana polita	1		1			2						
Edotea triloba							1		1			
Ampelisca vadorum								1				1
Ampelisca agassizi						.5						
Byblis serrata	6		9	1.5		5.5						
Unciola irrorata		1.5	13.5		8	6						
Unciola inermis			6			52.5	2				1	
Pseudunciola obliquua						75						
Protohaustorius wigleyi				3								
Acanthohaustorius spinosus	1			.5								
Leptocheirus pinguis				1				1			1	
Phoxocephalus holbolli						.5						
Trichophoxus epistomus								1			4	
Cancer irroratus	5		7	7.5	3	7.5	1					
Phoronida:												
Phoronis architecta		13		8		14.5		10		26		
Echinodermata:												
Echinarachnius parma	10		14	8	10	3	9					1
Total # Species	14	27	24	26	25	50	23	6	10	14	21	15
Total # Individuals	37	636	157	793	116	1045	40	26	23	210	174	125
H' Diversity	2.28	1.41	2.31	1.51	2.50	2.61	2.75	0.95	1.83	1.31	1.67	1.68
J' Equitability	0.86	0.43	0.73	0.56	0.77	0.69	0.88	0.90	0.79	0.49	0.55	0.62

Table 3. Abundance and distribution of macrofaunal species occurring at three or more stations for the 19 non-OCS stations, including replicate grab data for station B, D, I, L, N and P.

	A	B 1	B 2	B 3	C	D 1	D 2	D 3	E	F	G	H	I 1	I 2	I 3	J	K
Ceriantheopsis americanus	1			12	2	5	9	2			2	6					
Sthenelais limicola	1			1				1			1					2	
Sigalion arenicola	1				1					1							
Phyllodoce arenae				1													2
Exogone hebes							1		2	2							
Nephtys picta	5						16	12	7		1					2	
Goniadella gracilis						3	6			5	8	16	3	9	6		14
Capitella capitata																	4
Macroclymene zonalis																	
Aricidea cerruti				4					1		10	8					
Aricidea wassi	2					1	4	5		3							
Scolelepis squamata												3				1	3
Spiophanes bombyx	1			3		41	17	2		17	1	9	2		1	63	92
Lumbrineris tenuis		128	14	27			1										
Lumbrineris fragilis					1	3	1	1	3			1					
Lumbrinerides acuta						1				1	4	5					
Magelona rosea	1					1	1	1								65	
Tharyx annulosus		62	2	5					6	2	7						7
Tharyx acutus	1	1	2	40			2			2	3	1					
Caulleriella killariensis								3				1					
Asabellides oculata						1	4			2		1				6	120
Ampharete arctica	1					9	18	2				1					
Nassarius trivittatus						1										2	
Ensis directus												1					17
Nucula proxima		32	3	88	1	2	3	3	1								
Astarte castanea					3		2				3	3					4
Tellina agilis	9			2	1	31	11	13	21	2		4					6
Spisula solidissima					3	4					2						1
Unid. copepod				6					58		19		1		1	1	8
Oxyurostylis smithi												1					4
Cirolana polita												1					
Pseudunciola obliquua	1					5	1										1
Unciola irrorata	1			43	2	4											
Trichophoxus epistomus	7				8	1	2	2									
Platysquilla enodis															1	1	
Cancer irroratus	1			2	2			1									
Phoronis architecta				1		13	25	10	9		9						1
Asterias forbesi							1										
Echinarachnius parma	2					3						4					8
Total # Species	19	27	24	56	16	24	30	20	12	13	18	30	3	4	5	11	23
Total # Individuals	43	530	152	705	39	136	173	70	72	61	95	1139	10	22	12	164	305
H' Diversity	2.57	2.40	2.77	3.06	2.47	2.33	2.87	2.56	1.97	1.95	2.43	0.72	1.03	0.99	1.31	1.43	1.89
J' Equitability	.873	.728	.872	.760	.891	.732	.844	.856	.792	.761	.841	.211	.937	.717	.817	.595	.602

Table 3 (continued).

	L 1	L 2	L 3	M	N 1	N 2	N 3	O	P 1	P 2	P 3	Q	R	S
Ceriantheopsis americanus				3			1	1		1	3		2	4
Sthenelais limicola													1	1
Sigalion arenicola								3		1		1		
Phyllodoce arenae				5										
Exogone hebes				5										
Nephtys picta										1			1	
Goniadella gracilis	9	6	18	4	1	14	5	13					2	4
Capitella capitata				10					31	2		9	1	
Macroclymene zonalis				17						2			7	1
Aricidea cerruti				1					1			1		
Aricidea wassi									5	4			23	
Scolelepis squamata					1					2				
Spiophanes bombyx				288	1									
Lumbrineris tenuis								20		1			2	1
Lumbrineris fragilis				1										
Lumbrinerides acuta				12									5	
Magelona rosea												1		
Tharyx annulosus	10	1	2					496						2
Tharyx acutus										2		1	1	1
Caulleriella killariensis				1				3		1	1		2	
Asabellides oculata								1		1				
Ampharete arctica				1				1						
Nassarius trivittatus														2
Ensis directus								1						2
Nucula proxima														6
Astarte castanea													2	
Tellina agilis						3	6							
Spisula solidissima								10	1	2				26
Unid. copepod													4	
Oxyurostylis smithi						1							X	
Cirolana polita		1	3											
Pseudunciola obliquua												1		
Unciola irrorata								1		1	1			
Trichophoxus epistomus			11									1	1	
Platysquilla enodis			13											24
Cancer irroratus											1			
Phoronis architecta			2					9	3	20	48		3	6
Asterias forbesi			2										5	
Echinarachnius parma			3											
Total # Species	4	4	5	31	4	4	4	20	7	20	8	9	32	20
Total # Individuals	33	25	33	421	30	30	22	608	57	54	63	17	529	93
H' Diversity	1.19	0.86	1.08	1.56	0.43	1.07	1.19	0.91	1.30	2.31	0.92	1.67	1.44	2.28
J' Equitability	.858	.622	.670	.454	.314	.768	.858	.304	.670	.770	.445	.760	.416	.760

Table 4 . Observations of mortalities or clappers in grab samples.

Date	Station	Grab #	Observations
Aug.	E	1	Clappers: 7 Tellina, 1 Astarte, 1 Cyclocardia
Oct.	A	1	Clappers: 4 Tellina
Oct.	I	1	Clappers: 5 Tellina, 1 Spisula, 1 Pitar
			" 7 Tellina
			" 2 Tellina, 5 Astarte, 1 Nucula
Nov.	J	1	Clappers: 5 Tellina
Oct.	L	1	Clappers: 2 Spisula, 1 Cyclocardia
Oct.	m	2	Clappers: 1 Spisula
			" 2 Spisula, 2 Tellina
Nov.	N	1	Clappers: 6 Tellina
Oct.	O	2	Clappers: 2 Ensis, 7 Tellina, 1 Spisula 1 Cerastoderma
			" 1 Tellina, 1 Nucula
Oct.	R	1	Clappers: 1 Tellina, 2 Pitar, 1 Ensis
Oct.	OCS4	1	Clappers: 2 Cyclocardia, 1 Astarte
Oct.	OCS6	1	Clappers: 2 Tellina
Oct.	OCS14	2	Clappers: 1 Ensis
Oct.	OCS18	1	Clappers: 5 Tellina, 3 Ensis, 1 Spisula
Oct.	OCS19	1	Clapper: ?# Spisula
Oct.	OCS24	1	Clapper: 2 Ensis; Dead: many Echinarachnius and 1 Sthenlais limicola

Discussion

The benthic invertebrate fauna of the New York Bight is dominated by organisms which are adapted to inhabiting relatively clean porous sands (Pratt, 1973; Pearce and Radosh, in prep.). This fauna does not normally experience extended periods of anoxia or significant levels of hydrogen sulfide, thus most species have a low tolerance level to these conditions (Theede et al., 1969; Davis, 1976; Shick, 1976). When the bottom waters of the New York Bight became depleted of oxygen and significant hydrogen sulfide concentrations subsequently developed, it could be anticipated that extensive mortalities within the benthic community would occur. Diver observations and results of biological surveys, utilizing various sampling equipment during this period, support this hypothesis.

The best evidence of impacts to the benthic community are the results of trawl and dredge collections. These impacts were summarized in Table 1, and indicate that extensive mortalities occurred to a wide variety of benthic species in the area of oxygen depletion. These impacted organisms include over twenty species of invertebrates, most being incidental to survey target species. Both epifaunal, e.g. crabs and lobsters, and macroinfaunal species, e.g. polychaete worms and other, deep-burrowing organisms, *Axius*, *Platysquilla*, *Caudina*, and sipunculans were noted. Of interest were deep-burrowers which have been rare in most previous New York Bight benthic collections, mainly because they are generally below the sampling range of most standard benthic equipment. For a few species, especially surf clams, the impacts were massive in terms of numbers and biomass of animals affected. For other species, e.g. lobsters, the response was mainly one of avoidance and disruption of normal seasonal migrations. The impacts to commercially valuable species have been previously discussed in detail in this volume (Ropes, et al.; Azarovitz, et al.), emphasizing a fishery management point of view.

Unfortunately, Smith-McIntyre grab collections resulted in mostly circumstantial evidence of impacts on the macrofauna. Actual mortalities were observed in only two samples, OCS 24, including some sand dollars and one polychaete (*Sthenelais limicola*), and station B, near the apex of the Hudson Channel, where dead holothuroideans (*Thyone* sp.) were found in one of the three samples taken. Also available from our grab samples are data on numbers of clapper bivalves in the samples, indicating recent mortalities. However, due to inadequate data on pre-anoxia clapper abundance, it is difficult to assess their significance at this time.

What appear to be the best indications of impacts on the infauna are the low numbers of species, individuals and diversities (H') which were found at many stations: E, F I, J, L, N, P, Q and 18 (Tables 2 and 3). Again, this evidence has its limitations, because of variability and inadequate baselines for the majority of the area influenced by the oxygen-depleted water mass. However, triplicate samples have been processed for several of the stations, and where numbers of species and individuals were consistently low, we believe this indicates an impact from anoxia. Stations I, L and N appeared to be particularly affected. P and Q may also have been impacted but the data are less convincing due to variability (P) or lack of replication (Q).

A possible alternate approach to assessing impacts on the infauna is to concentrate on population changes in species which are known to be fairly ubiquitous in the sandy sediments off New Jersey. Such species have been identified in several studies (Boesch et al., 1977; Radosh et al., 1978). Based on these studies and on numbers of station occurrences in Table 2, these species include _Ceriantheopsis americanus_, _Aglaophamus circinata_, _Leiochone dispar_, _Spiophanes bombyx_, _Byblis serrata_, _Cirolana polita_ and _Echinarachnius parma_. _Spiophanes_ and _Ceriantheopsis_ which are known to be tolerant species, occurring in stressed environments e.g., sewage disposal areas (Pearce, 1972), showed marked increases in abundance. Boesch et al., (1977) also found these two species to be resistant to the anoxia and found

Spiophanes to be opportunistic as well. We know the low tolerances of *Echinarachnius* and crustaceans (Boesch et al., 1977) to anoxia. Based on increases in *Spiophanes* and *Ceriantheopsis* and decreases in the other species listed above, there were probably severe anoxia impacts at stations 11 and 13, moderate effects at 4, 18 and 24, and little or no impact at 6, 7, 8, 12, 14, 17 and 19. The area of greatest impact to the benthic macrofauna based on Tables 2 and 3 is shown in Figure 3.

The substantial post-anoxia increases in populations of *Spiophanes* and *Ceriantheopsis* may be due to rapid recolonization as well as to anoxia and sulfide tolerance. The polychaete, *Goniadella gracilis*, was abundant at the heavily impacted stations I, L and N, implying high tolerance to oxygen depletion. This was unexpected, since *Goniadella* is characteristic of ridge environments (Boesch, Kraeutner and Serafy, 1977; Radosh et at., 1978) in which anoxic episodes must be relatively rare. There is slight evidence that the polychaetes, *Aricidea cerruti* and *Tharyx acutus*, and bivalve, *Astarte castanea*, may also be tolerant to anoxia. The increased occurrence in our samples of the deep-burrowing mantis shrimp, *Platysquilla enodis*, is undoubtedly a sign of stress rather than of resistance.

The absences of any appreciable impacts to the benthic fauna at stations G and H, which were near the center of the anoxic water mass, can be attributed to the fact that these two stations are located on an elevated sand-gravel ridge. The height of this ridge is near the depth of the thermocline, 25-30 m, and it would be expected that more oxygen was available here, at least intermittently, than in the surrounding deeper waters.

Two other benthic studies conducted in the area during the anoxia situation also found impacts to the benthic invertebrate community. Boesch, Kraeuter and Serafy (1977) and Boesch et al. (1977) reported heavy impacts to megabenthos at one station approximately 30 km east of Atlantic City during a benthic collection in August 1976 and limited impact to another station further east in November (Boesch et al., 1976). They found drastic reductions in the populations of the sand shrimp Crangon septemspinosus; the rock crab Cancer irroratus; the small peracaridean crustaceans Tanaissus liljeborgi, Protohaustorius wigleyi and Pseudunciola obliquua; the starfish Asterias forbesi; and the sand dollar Echinarachnius parma. They also noted large quantities of decayed surf clam meats in trawl nets and dead or moribund specimens of other species, e.g. the polychaetes Glycera dibranchiata and Sigalion arenicola, the sipunculan Phascolopsis gouldii, the mantis shrimp Platyquilla enodis and unidentified burrowing anemones. They also observed that the bivalve Astarte castanea and the gastropod Nassarius trivitatus appeared unaffected.

Another study, at an inshore area off Little Egg Harbor, New Jersey, also observed benthic and epibenthic mortalities during the late summer; the species affected were similar to those reported here (Milstein, Garlo and Jahn, Ichthyological Associates, Inc., Absecon, N.J., unpubl. ms).

The mortalities caused by the anoxia are only the immediate manifestation of the total impact to the benthic invertebrate community. There is a latent aspect of the impacts which includes the recovery time of the benthos. After the 1968 fish kill, Ogren and Chess (1969) reported that the megafauna appeared to have completely recovered the following summer. The preliminary results, so far, of present recolonization studies suggest that recovery had not occurred by the summer of 1977. This is evidenced by the occurrence of "blooms" of some opportunistic organisms and continued low numbers of other species. The abundant species were small, tube-dwelling polychaetes, Asabellides oculata, Polydora socialis, and Spiophanes bombyx which were collected in the oxygen depleted area during March, June and July of 1977. The last two species belong to the family Spionidae, which contains many species which have been classified as opportunistic (Ziegelmeier, 1970; and Grassle and Grassle, 1974). Asabellides, although not previously regarded as an opportunistic species, has been reported in large numbers in an earlier unpublished study, at an ocean sewer outfall off Deal, New Jersey (J. Pearce and J. Caracciolo, NMFS, Highlands, N.J., pers. comm.). Stressed, unstable areas, such as sewer outfalls, are commonly dominated by opportunists. Boesch et al. (1977) also reported a population increase of Spiophanes in their November 1976 and February 1977 collections off Atlantic City. Some recolonization by juvenile surf clams and sand dollares was also reported.

The total recovery of the affected benthic community may take several years because of the extensive dimensions of the affected area. Recolonization by some species can be expected to be rapid, especially those species whose eggs or larvae are dispersed planktonically. The population expansion of *Asabellides*, *Spiophanes* and *Ploydora* and the appearance of juvenile sand dollars and surf clams are probably expressions of this mode of dispersal. For other species, without a planktonic phase, the recovery will be slower, e.g., many species of amphipods which brood their young. In the end we may not even be able to definitely determine when recovery is complete because of such factors as the heterogeneity of the environment and the dynamic aspects of the inshore benthic community. The stabilization of certain indicator species may be helpful in determining recovery.

In summary, the oxygen depletion phenomenon of 1976 resulted in extensive mortalities to many benthic invertebrate species; some species, mostly polychaetes, exhibited tolerance. Preliminary analysis of subsequent samplings one year later indicate that the ecosystem has not yet recovered.

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