Analysis of fishery resources: potential risk from sewage sludge dumping at the deepwater dumpsite off New Jersey

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Abstract.—Analytical and statistical procedures were applied to bottom trawl survey data in tests of hypotheses about potential effects of sewage sludge dumping at a 106-mile dumpsite (106-MDS) off New Jersey on fishery resources assessed on the continental shelf and upper slope. Sludge dumping, even in deep ocean waters, was not discounted as one of several ecological and environmental perturbations influencing these resources measured as temporal, spatial, and seasonal differences in abundance. Species abundances of silver and red hakes (*Merluccius bilinearis* and *Urophycis chuss*), summer flounder (*Paralichthys dentatus*), goosefish (*Lophius americanus*), and black sea bass (*Centropristis striata*) declined significantly over temporal and spatial scales during the disposal of contaminant-laden sewage sludge at the deepwater 106-MDS. There was also a decline in the array of all aggregated species, but to a lesser degree. Results of these analyses of assessment data are considered in relation to effects of ocean dumping in shallow waters at the southern California sewage outfalls and in the New York Bight apex, and in relation to increased contamination of the ecosystem around the 106-MDS. Further, large-scale coordination of environmental research surveys with fishery resource assessments would allow tests of more specific hypotheses and allow a more definitive interpretation of offshore resource population data as presented here.

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Sewage sludge and a variety of other wastes have been disposed of in coastal waters of the New York Bight for over 50 years (Squires, 1983). Offshore deepwater waste disposal of sewage sludge, however, is a relatively new activity of the last 20 years. With legally mandated closure of the coastal water 12-mile dump site (12-MDS) in the New York Bight apex (Ocean Dumping Ban Act of 1988), a deepwater dumpsite, 106 miles off New Jersey (106-MDS), was selected as a temporary alternative site for disposal of sewage sludge from the New York and New Jersey metropolitan area (O'Connor, 1983; O'Connor et al., 1983, 1985; Pearce et al., 1983; Norton, 1989; NOAA[1,2]; Battelle[3]).

The 106-MDS had been used previously for disposal of industrial wastes as well as sewage sludge (O'Connor, 1983; Bisagni[4]; Anderson[5]). Phased relocation of New York-New Jersey sewage disposal began in March 1986, and by December 1987 all sewage sludge disposed at sea was being barged to the 106-MDS site. At the 106-MDS, an average of 6.0 million metric tons (t) wet weight sewage sludge (range 1.2–9.9 million t) was dumped between 1986 and 1992. This mean is similar to an average of 5.8 million t of sewage sludge (range 4.0–8.3 t) dumped at the 12-MDS from 1973 to 1987. New Jersey ceased disposal at 106-MDS in March 1991. New York City phased out 20% of its ocean dumping in December 1991, and the remainder by the end of June 1992.

The fishing industry, citizens groups, state governments, and federal agencies all voiced concerns about potential effects of heavy sewage sludge dumping at the 106-MDS on the surrounding marine environment and fisheries. Dumping of sewage sludge and industrial waste in

[1]NOAA. 1975. May 1974 baseline investigation of deepwater dumpsite 106. NOAA Dumpsite Evaluation Report 75-1. U.S. Dep. Commer., Natl. Oceanic Atmospheric Admin., Natl. Ocean Survey, Rockville, MD, 388 p.

[2]NOAA. 1977. Baseline report of environmental conditions in deepwater dumpsite 106. NOAA Dumpsite Evaluation Report 77-1. U.S. Dep. Commer., NOAA, Natl. Ocean Survey, Rockville, MD, 798 p.

[3]Battelle. 1990. 106-miles deepwater municipal sludge site monitoring, research and surveillance plan. Battelle Memorial Institute, Duxbury, MA, 90 p.

[4]Bisagni, J. J. 1977. A summary of the input of industrial waste chemicals at deepwater dumpsite 106 during 1974 and 1975. NOAA Dumpsite Evaluation Report 77-1. U.S. Dep. Commer., NOAA, Natl. Ocean Survey, Rockville, MD, 487–497 p.

[5]Anderson, P. W. 1983. Current status—ocean dumping in the New York Bight. Paper presented on 6 April 1983 in Atlantic City, NJ at the 15th National Conference and Exhibition on Municipal and Industrial Sludge Utilization and Disposal, 6 p.

the comparatively pristine deep-water ocean environment has been considered to have an adverse effect on fishery resource abundance and composition (Carlise, 1969; Dart and Jenkins, 1981; Mearns, 1981; Russo, 1982; Cross et al., 1985; Spies, 1984; Farrington et al., 1982; Capuzzo and Kester, 1987, a and b; O'Connor et al., 1985, 1987, a and b; Werme[6,7]; SCCWRP[8]; Zdanowicz et al.[9]; NMFS[10,11]; Studholme et al.[12]). A contaminant distribution model presented by O'Connor et al. (1985) (see also Reed et al., 1985) indicated that New York and New Jersey sewage sludge has the immediate effect of increasing concentrations of polychlorinated biphenyls (PCB's), Zn, Pb, Cr and Cu. In addition, the potential area of influence (**PAI**) of waste disposal at the 106-MDS extends over a wide region (Fig. 1) off the Middle Atlantic outer continental shelf and upper slope (Bisagni, 1983; O'Connor et al., 1985; Gentile et al., 1989; Warsh[13], Bisagni[14], Ingham[15]).

A change in fish species population abundance and composition is known to have occurred near shallow-water sewage sludge disposal outfalls in southern California (Mearns 1981; Sherwood[16]). For example, a bothid flounder (Pacific sanddab, *Cithaichthys sordidus*) was replaced by a pleuronetcid (Dover sole, *Microstomus pacificus*). Increased growth rates and high prevalence of fin erosion of Dover sole, however, appear to have resulted from exposure to sediments contaminated with chemical wastes from the outfalls. Liver anomalies were noted as well and seem to have been associated with exposure to sludge-related contaminants (Mearns, 1981). Spies (1984) reported that distribution of bottom-feeding fishes (e.g., Dover sole) is probably affected by degraded benthic habitats and abundance of benthic (e.g., polychaete, *Capitella capitata*) and pelagic prey around these outfalls in the southern California Bight. Some chemical contaminants associated with the sewage accumulated at higher trophic levels in predatory fishes, e.g., Pacific sanddab and boccaccio, *Sebastes paucispinis*. Benthic-pelagic coupling was evident in the accumulation of chlorinated hydrocarbons in Dover sole and Pacific sanddab.

Cessation of sewage sludge dumping on the biomass of the most frequently occurring fish species around the coastal waters near 12-MDS from 1986 to 1989 was examined by Studholme et al.[12]. There were no significant changes, although American lobster (*Homarus americanus*) biomass increased (Pikanowski, 1992; Wilk et al.,[17]). Possibly this 39-month-long study period was insufficient to detect a recovery of any finfish species alterations resulting from decades of sewage dumping at the old 12-MDS. Interestingly, the high prevalence of fin-rot disease of winter flounder (*Pleuronectes americanus*) around the 12-MDS reported earlier (Ziskowski and Murchelano, 1975; Murchelano and Ziskowski, 1976) declined significantly after cessation of the dumping (O'Connor et al.[18]; Pacheco and Rugg[19]). It was also shown earlier that Atlantic mack-

[6]Werme, C., R. Shokes, W. Steinhauer, S. McDowell, P. Debrule, P. Hamilton, and P. Boehm. 1988a. Evaluation and recommendations for bioaccumulation studies for the 106-mile deepwater municipal sludge site monitoring program. Battelle Memorial Institute, Duxbury, MA, 36 p.

[7]Werme, C., K. M. Jop, S. Y. Freitas and P. Boehm. 1988b. Implementation plan for the 106-mile deepwater municipal sludge site monitoring. Battelle Memorial Institute, Duxbury, MA, 51 p.

[8]SCCWRP (Southern California Coastal Water Research Project). 1989. Recovery of Santa Monica Bay after termination of sludge discharge. Southern California Coastal Water Research Project. Annual Report 1988–1989, 46–53 p.

[9]Zdanowicz, V. S., M. C. Ingham, and S. Leftwich. 1990. Monitoring the effects of sewage sludge disposal at the 106-mile dumpsite using mid-water fish as sentinels of contaminant metal uptake: a feasibility study. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Northeast Fish. Sci. Cent., Woods Hole, MA. Ref. Doc. 90-02, 6 p.

[10]NMFS. 1992a. Interim report on monitoring the biological effects of sludge dumping at the 106-mile dumpsite. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Northeast Fish. Sci. Cent., Woods Hole, MA 02543, 128 p

[11]NMFS. 1992b. Second annual report on monitoring the biological effects of sludge dumping at the 106-mile dumpsite. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Northeast Fish. Sci. Cent., Woods Hole, MA 02543, 157 p

[12]Studholme, A. L., J. O'Reilly, and M. C. Ingham (eds.). 1993. Effects of the cessation of dumping at the 12-mile site. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Northeast Fish. Sci. Cent., Sandy Hook Lab., Highlands, NJ 07732. (In review.)

[13]Warsh, C. E. 1975. Physical oceanography hist. rical data for Deepwater Dumpsite 106. NOAA Dumpsite Evaluation Report 75-1. U.S. Dep. Commer., NOAA, Natl. Ocean Survey, Rockville, MD, 105–140 p.

[14]Bisagni, J. J. 1976. Passage of anticyclonic Gulf Stream eddies through Deepwater Dumpsite 106 during 1974 and 1975. NOAA Dumpsite Evaluation Report 76-1. U.S. Dep. Commer., NOAA, Natl. Ocean Survey, Rockville, MD, 39 p.

[15]Ingham, M. C. 1977. The general physical oceanography of deepwater dumpsite 106. NOAA Dumpsite Evaluation Report, 77-1. U.S. Dep. Commer., NOAA, Natl. Ocean Survey, Rockville, MD, 29–54 p.

[16]Sherwood, M. J. 1978. The fin erosion syndrome. Southern California Coastal Water Research Project. Annual Report 1978, 203–221 p.

[17]Wilk, S. J., R. A. Pikanowski, A. L. Pacheco, D. G. McMillan, and L. L. Stehlik. 1993. Response of fish and megainvertebrates of the New York Bight apex to the abatement of sewage sludge dumping: an overview. *In* A. L. Studholme, J. O'Reilly and M. C. Ingham (eds.), Effects of the cessation of dumping at the 12-mile site. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Northeast Fish. Sci. Cent., Woods Hole, MA, 14 p. (In review.)

[18]O'Connor, J. S., J. J. Ziskowski, and R. A. Murchelano. 1987. Index of pollutant-induced fish and shellfish disease. NOAA Spec. Rep. Ocean Assessment Div. U.S. Dep. Commer., NOAA, Natl. Ocean Survey, Rockville, MD, 29 p.

[19]Pacheco, A. L., and J. Rugg. 1993. Disease incidence of inner New York Bight winter flounder collected during the 12-mile dumpsite study, 1986–1989. *In* A. L. Studholme, J. O'Reilly, and M. C. Ingham (eds.), Effects of the cessation of dumping at the 12-mile site. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Northeast Fish. Sci. Cent., Sandy Hook Lab., Highlands, NJ, 14 p. (In review.)

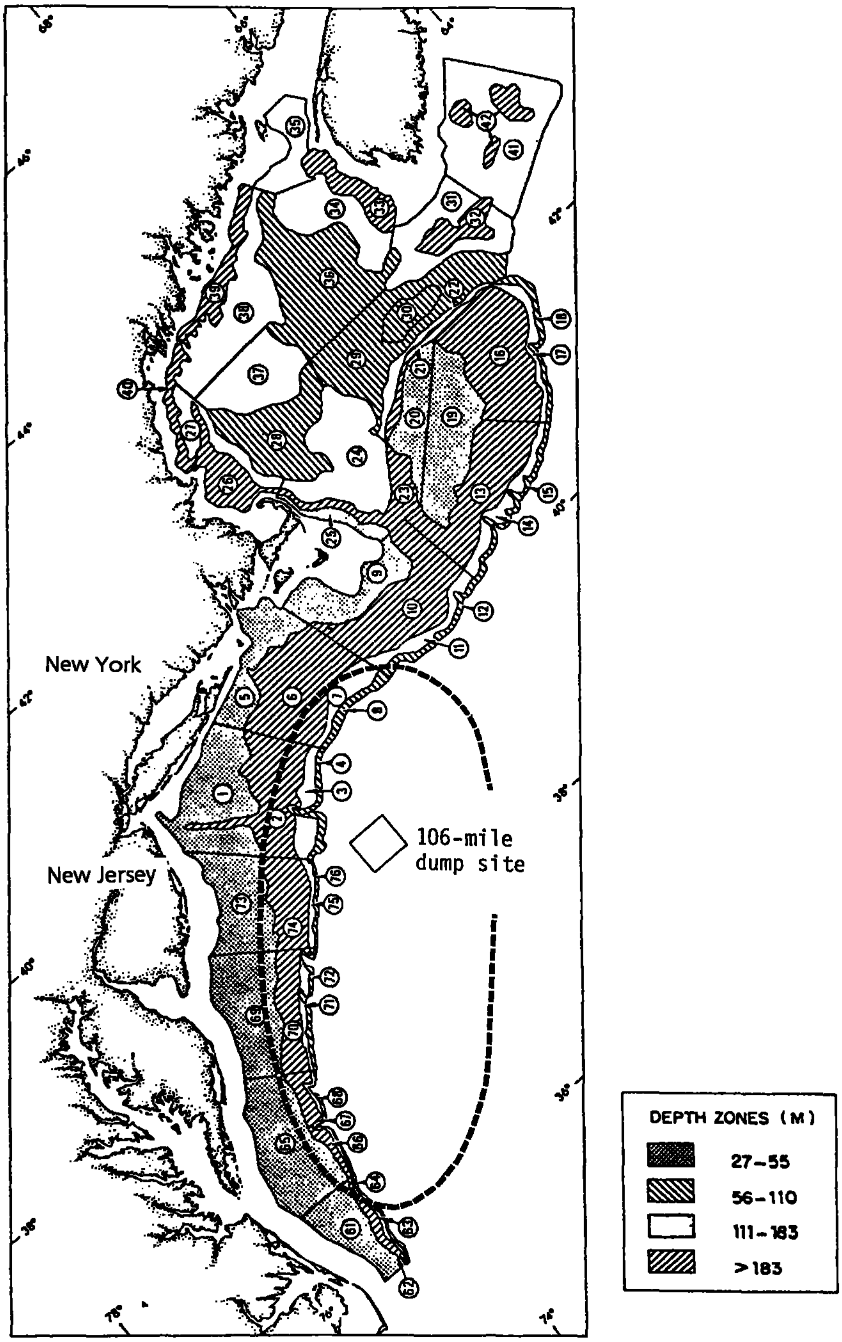

Figure 1
Location of the 106-mile dumpsite and strata used in Northeast Fisheries Science Center bottom trawl surveys (1963 to present). The potential area of influence (PAI) by sewage sludge dumping is within the dashed line, which is adapted from Biasagni (1983).

erel (*Scomber scombrus*) embryos developing in surface waters about the 12-MDS (1974–1978) had greater mortality and gross malformation, more mitotic abnormality and mitotic inhibition than those in less contaminated bight areas, and this was linked to site contamination (Chang and Longwell, 1984; Longwell,1988; Longwell et al., 1992).

Unlike the 12-MDS in the New York Bight apex and the sewage outfalls in southern California, the 106-MDS is situated in a physically dynamic zone characterized by periodic shifts and overturns in water masses. The toxic water is rapidly diluted and dispersed. This may diminish the impact of dumped waste and associated chemical contaminants, but it also makes determination of any adverse effects on the resource more difficult to study than those associated with sewage sludge dumping in shallow-waters. Still, the economic value of the nearby fisheries warrants some effort at directly measuring potential adverse impacts of the 1986–92 sludge dumping on the fishery resource in the vicinity of the 106-MDS.

The study reported here is an attempt to determine if any change in fishery resource abundance on the adjacent continental shelf and slope could be detected after sewage sludge disposal commenced at the 106-MDS in March 1986. Although ocean dumping is now banned, this period of sludge dumping in the deep ocean provides an interesting case study for consideration of effects of ocean pollution in general on economically important fishery resources. This analysis is of potential interest in respect to any future reconsideration of ocean dumping. There are no prior population level studies on abundance changes in marine fishes associated with the sewage sludge dumping in deep ocean waters.

The general null hypothesis that was tested is that no change in resource species abundance and composition was coincident with sewage dumping at the deepwater 106-MDS during the period 1986–90. Assessments were made of temporal, spatial, and seasonal differences in 11 individual finfish species, and of all these species combined. The general hypothesis was subdivided into three more specific hypotheses, each of which was likewise tested: 1) there are no *temporal* differences in species abundance between the period prior to sewage sludge dumping at the 106-MDS and the period after dumping resumed; 2) there are no *spatial* differences in species abundance between the area north of the 106-MDS and the area south of the dump site, the latter more likely to be influenced by the sewage sludge that supposedly moved through the dump site toward the west-southwest shallow outer shelf (PAI; Fig. 1); and 3) there are no *seasonal* differences for individual and all species for the north and south areas within the pre- and post-dumping periods.

Methods

Data from NOAA's Northeast Fisheries Science Center (NEFSC) bottom trawl surveys were used for analysis. From 1963 to the present, NEFSC has conducted bottom trawl surveys on the Northwest Atlantic Shelf and upper slope, from the Scotian Shoals to Cape Hatteras including the areas adjacent to the 106-MDS (Fig. 1). The entire survey area has been stratified by depth down to 365 m, and surveys have been based on a stratified random design that provides statistically valid samples for estimating indices of species population abundance. All fishes and invertebrates are sorted, counted, and weighed by species to the nearest 0.1 kg. Large catches are subsampled by weight and volume and expanded to estimate the entire catch. Detailed information pertinent to the rationale, descriptions of trawl gears and sampling schemes, as well as history of the NEFSC bottom trawl survey are provided by Grosslein (1974) and more recently Azarovitz (1981). Grosslein et al. (1979) summarized research, assessment, and management of the northwest Atlantic ecosystem using data from NEFSC bottom trawl surveys.

Data from the spring 1982 through spring 1986 NEFSC surveys were evaluated as the pre-dumping period, and data from autumn 1986 through spring of 1990 as the post-dumping period. Eleven economically important species were selected for analysis: silver hake (*Merluccius bilinearis*); red hake (*Urophycis chuss*); summer flounder (*Paralichthys dentatus*); goosefish (*Lophius americanus*); black sea bass (*Centropristes striatus*); scup (*Stenotomus chrysops*); butterfish (*Peprilus triacantus*); longfin squid (*Loligo pealei*); American lobster (*Homarus americanus*); sea scallop (*Placopecten magellanicus*); and spiny dogfish (*Squalus acanthias*). Species were selected on the basis of their commercial values and landings, and the known availability of data for the entire 106-MDS study area (Chang, 1990). In addition, all species, a category comprising the total catch for each cruise, was also used.

The multivariate rank sum test (Puri and Sen, 1971) was employed for temporal, spatial, and seasonal differences in the population abundance analyses by using the catch per unit of effort (CPUE) as a measure of population abundance: 1) the *average* CPUE values for each bottom trawl survey stratum for all cruises occurring in the pre-dumping period cruises (spring 1982–spring 1986), and for all cruises occurring in the post-dumping period cruises (autumn 1986–spring 1990), and 2) the average CPUE data from the area defined as south of the 106-MDS, including strata 61–76 and data from the area defined north of the site including strata 1–12 (Fig. 1). Test statistics for CPUE were calculated and compared with critical values from the chi-square table to determine the following:

1. there are no temporal differences in CPUE of pre- and post-dumping periods for spring and autumn cruises collectively in the regions north and south of the 106-MDS (cf. Table 1),
2. there are no spatial differences in CPUE north and south of the 106-MDS for pre- and post-dumping period cruises collectively in spring and autumn seasons (cf. Table 2),
3. there are no seasonal differences in CPUE of spring and autumn surveys for pre- and post-dumping period cruises collectively in the regions of north and south of the 106-MDS (cf. Table 3).

Test statistics were also computed and compared with the critical values for testing CPUE for spatial differences for individual species and for all species taken on each cruise in the area north and south of the 106-MDS. Test statistics and abundance indices of individual species in tabulated form are not included among tables given here.

The values of test statistics for temporal, spatial, and seasonal differences are readily comparable (Tables 1–3). When examining values of the test statistics for temporal differences, secondary differences for species, regions, and seasons were also assessed. Test statistics were similarly examined for spatial and seasonal differences among species, regions, and seasons.

Changes in significance or non-significance of the test statistics between pre- and post-dumping period surveys may be interpreted as indicative of temporal differences in CPUE. Significant changes of test statistics between regions north and south of the 106-MDS indicate spatial differences. Changes between spring and autumn surveys indicate seasonal differences. Significant differences in CPUE in time, space, and season may thus be interpreted as some shift in species abundance. *Negative* differences are taken here as a response of the population to some adverse

Table 1
Results of the rank sum test for **temporal** differences in species catch per unit of effort (CPUE) between pre- and post-dumping periods using spring and autumn cruises collectively in north and south regions.

	Pre-dumping period vs. post-dumping period					
	Spring Cruises			Autumn Cruises		
Species name	CPUE (weight)	CPUE (number)	No. of species	CPUE (weight)	CPUE (number)	No. of species
North						
Silver hake	0.098	4.709*		2.064	0.621	
Red hake	0.596	0.075		10.087*	3.320	
Summer flounder	8.553*	2.349		1.409	1.817	
Goosefish	2.290	0.001		15.520*	1.192	
Black sea bass	0.423	0.140		0.482	2.964	
Scup	0.127	1.035		7.656*	2.910	
Butterfish	7.288*	11.810*		1.361	0.161	
Longfin squid	0.225	0.039		4.443*	0.001	
American lobster	3.170	0.168		1.184	0.639	
Sea scallop	3.626	5.285*		1.199	1.736	
Dogfish	17.166*	10.993*		0.003	0.094	
All species[1]	10.077*	4.094*	2.503	0.671	0.051	3.278
South						
Silver hake	1.472	0.040		0.966	6.984*	
Red hake	6.391*	4.576*		0.707	0.700	
Summer flounder	6.645*	10.785*		1.219	1.440	
Goosefish	0.934	0.118		3.664	0.033	
Black sea bass	5.207*	6.474*		0.386	0.240	
Scup	1.184	0.077		0.943	0.087	
Butterfish	0.147	0.050		8.443*	12.691*	
Longfin squid	1.801	1.395		2.548	0.327	
American lobster	0.247	2.792		1.713	1.539	
Sea scallop	16.057*	12.614*		0.973	1.600	
Dogfish	0.242	0.043		0.362	1.297	
All species[1]	14.641*	21.212*	1.834	9.099*	2.377	8.473*

[1] "All species" includes the eleven listed and all other species.
* Significant difference with the critical values at 95% level in the chi-square table.

biological or environmental perturbation, to fishing pressure or to some combination of these factors. *Positive* differences are taken as increased species abundance in response to favorable conditions. Nonetheless, significant differences of this sort alone do not establish a direct causal association between change in population abundance and sewage sludge dumping, or alternately between fishing pressure, natural environmental perturbations, or any of combination of these. Any such inference must come from further interpretation of the data in respect to what is known about natural ecology of the subject species, fishing pressure on these, and any known sensitivities to sewage sludge.

Abundance indices for the 11 species individually and for all species combined for pre- and post-dumping period surveys (Tables 4–7, pgs. 601–604) were computed by using the groundfish survey analysis program (Kramer[20]). Basic assumptions and methodology for estimation of abundance indices based on NEFSC bottom trawl survey data are detailed by Pennington and Brown (1981). Trends in indices and variabilities in time and space may also be interpreted as suggesting some general shift in species abundance attributable to sludge dumping, even though there may be no direct proof of an association between population abundance change and sludge disposal.

[20]Kramer, W. P. 1985. Groundfish survey analysis program (SURVAN version 5.2), program report. Prepared for U.S. Dep. of Commer., NOAA,. Natl. Mar. Fish. Serv., Northeast Fish. Cent., Input Output Computer Service Inc., Waltham, MA. 137 p.

Results

Temporal differences

Test statistics based on species CPUE, and species abundance indices, including estimates for both spring and autumn cruises, are summarized in Tables 1 and 4–7. Combining the information from these two sources reinforces the inferences of significant change in species abundance over time.

Table 2
Results of the rank sum test for **spatial** differences in species catch per unit of effort (CPUE) between north and south regions using pre- and post-dumping period cruises collectively in spring and autumn seasons.

	North region vs. south region					
	Pre-dumping cruises			Post-dumping cruises		
Species name	CPUE (weight)	CPUE (number)	No. of species	CPUE (weight)	CPUE (number)	No. of species
Spring						
Silver hake	13.402*	28.189*		17.765*	35.719*	
Red hake	3.654	6.591*		15.014*	22.364*	
Summer flounder	5.833*	5.161*		2.356	0.624	
Goosefish	0.228	0.469		0.467	0.023	
Black sea bass	0.259	0.727		1.956	2.217	
Scup	2.483	1.295		0.511	8.128*	
Butterfish	12.030*	10.791*		0.496	0.154	
Longfin squid	1.201	4.823*		0.004	7.375*	
American lobster	0.160	1.747		2.235	6.298*	
Sea scallop	0.001	0.351		5.503*	4.505*	
Dogfish	16.084*	3.279		0.115	1.561	
All species[1]	1.078	0.943	11.532*	0.113	6.313*	8.808*
Autumn						
Silver hake	40.064*	8.555*		41.868*	24.898*	
Red hake	33.139*	17.622*		11.277*	7.116*	
Summer flounder	11.877*	1.987		12.920*	1.263	
Goosefish	46.468*	4.564*		24.837*	0.819	
Black sea bass	6.133*	2.938		14.058*	0.304	
Scup	0.532	2.283		0.018	0.729	
Butterfish	5.400*	0.062		16.728*	10.153*	
Longfin squid	10.717*	10.898*		5.531*	12.555*	
American lobster	0.178	1.747		0.140	4.371*	
Sea scallop	0.635	1.157		0.288	0.639	
Dogfish	10.896*	3.279		29.296*	18.483*	
All species[1]	24.920*	9.559*	5.992*	50.827*	21.397*	43.765*

[1] "All species" includes the eleven listed and all other species.
*Significant difference with the critical values at 95% level in the chi-square table.

Analyses of red hake data are used here as an example of a detailed interpretation of temporal differences in species CPUE. (Black sea bass could be equally well used because of its similar pattern of CPUE indices.) Species test statistics for red hake revealed significant temporal differences in CPUE indices both by weight (biomass) and number of individuals in the south, but not in the north region (Table 1). Biomass indices declined from pre-dumping spring cruises to post-dumping spring cruises (Table 4). Numerical abundance indices also declined from pre-dumping spring cruises to post-dumping spring cruises (Table 5). Red hake autumn data were also analyzed, but the species test statistics were not significant (Table 1). Biomass indices (Table 6) and number indices (Table 7) declined from the pre-dumping to the post-dumping period. These negative temporal differences for red hake are interpreted as an indication of significant reduction in abundance over time.

CPUE test statistics for several other species also suggest significant temporal differences between pre- and post-dumping periods. The number of significant differences was greater for spring cruises than for autumn cruises (Table 1). Biomass indices were relatively low for both spring and autumn cruises in both north and south regions generally, with the exception of high values for dogfish (Tables 4 and 6). Species number indices were mixed (Tables 5 and 7).

Test statistics for summer flounder and sea scallop CPUE by weight and number for the spring cruises were significantly different in the southern region. In the northern region, only summer flounder biomass and scallop number indices were significantly different. Indices for summer flounder and sea scallop for autumn cruises, however, failed to be significant in either region (Table 1). Summer flounder abundance indices of both biomass and number indicate a decline from the pre-dumping period to the post-dumping period, while both indices for the sea scallop increased (Tables 5 and 7). This suggests a decline (negative differences) over time for summer flounder, and an enhancement (positive differences) for sea scallop.

Table 3

Results of the rank sum test for testing **seasonal** differences in species catch per unit of effort (CPUE) between spring and Autumn seasons using pre- and post-dumping period cruises collectively in north and south regions.

Species name	Spring season vs. autumn season: Pre-dumping cruises CPUE (weight)	CPUE (number)	No. of species	Post-dumping cruises CPUE (weight)	CPUE (number)	No. of species
North						
Silver hake	1.444	1.473		8.382*	2.653	
Red hake	8.745*	4.845*		0.057	0.291	
Summer flounder	5.024*	0.471		8.835*	1.378	
Goosefish	0.098	4.898*		3.337	0.681	
Black sea bass	6.519*	2.850		8.597*	0.009	
Scup	0.078	2.757		2.498	6.681*	
Butterfish	1.123	0.945		6.645*	14.920*	
Longfin squid	9.991*	21.686*		0.262	14.070*	
American lobster	0.988	0.033		4.137*	0.683	
Sea scallop	4.774*	4.137*		1.490	0.806	
Dogfish	11.294*	4.527*		20.414*	16.008*	
All species[1]	15.317*	41.133*	1.944	57.442*	22.629*	0.265
South						
Silver hake	35.795*	2.322		27.903*	2.594	
Red hake	6.125*	0.291		0.707	0.108	
Summer flounder	0.035	0.150		0.002	0.045	
Goosefish	28.811*	0.509		16.162*	0.131	
Black sea bass	3.476	0.506		10.751*	4.645*	
Scup	6.210*	3.409		0.019	0.085	
Butterfish	4.236*	16.741*		0.292	0.742	
Longfin squid	3.229	0.342		0.762	3.974*	
American lobster	0.095	5.804*		0.013	0.689	
Sea scallop	6.425*	4.257*		0.289	0.206	
Dogfish	16.927*	8.076*		53.442*	37.763*	
All species[1]	51.240*	12.546*	0.919	140.185*	7.022*	24.325*

[1] "All species" includes the eleven listed and all other species.
* Significant difference with the critical values at 95% level in the chi-square table.

Biomass and number test statistics for butterfish in spring cruises were significantly different between pre- and post-dumping periods in the northern region, but not significantly different in the southern region. Conversely, those statistics from autumn cruises were not significant in the northern region, but significant in the southern region. Test statistics for spiny dogfish showed similar patterns (Table 1). Species abundance indices for butterfish and spiny dogfish fluctuated, but generated much higher values for the test statistics than did those of other species (Tables 4–7). Accordingly, interpretation of the butterfish and spiny dogfish statistics suggests a positive difference in these two species over time.

In spring cruises, test statistics in CPUE both by weight and number for goosefish, scup, longfin squid, American lobster, and silver hake were not significantly different for pre- and post-dumping periods for either the north or south region, with exception of silver hake number indices in the north region. For autumn cruises, however, there were significant differences between pre- and post-dumping periods for goosefish, scup, and longfin squid (Table 1). Abundance indices for goosefish declined from the pre- to the post-dumping period for both cruises and regions. Longfin squid indices declined from the pre to the post period in spring cruises, but increased in autumn cruises. All scup indices declined but increased in autumn cruises within the south region. American lobster indices showed little change between pre- and post-dumping periods. Silver hake indices increased in spring cruises but declined in autumn cruises from the pre to post period (Tables 4–7). The lower abundance indices of these species may signify that the populations responded negatively to adverse differences.

In spring cruises, CPUE statistics for all species, both by biomass and number, were significantly different between pre- and post-dumping periods in both regions. This occurred though test statistics for some individual species were significantly different and

Table 4

Species abundance indices (e.g., mean and SSE [standard error]) based on **weight** of stratified catch per tow and variabilities (CV in %) using pre- and post-dumping spring cruises collectively in north and south regions.

Species name	Pre-dumping spring cruises — Abundance indices			Post-dumping spring cruises — Abundance indices		
	Mean	SSE	CV (%)	Mean	SSE	CV (%)
North						
Silver hake	1.529	0.62509	41	1.217	0.31258	26
Red hake	1.549	0.78584	51	0.863	0.23815	28
Summer flounder	0.401	0.09030	23	0.211	0.05036	24
Goosefish	1.109	0.28732	26	0.656	0.14389	22
Black sea bass	0.104	0.05443	52	0.025	0.01060	42
Scup	0.510	0.23137	45	0.192	0.09896	52
Butterfish	1.820	1.03770	57	0.383	0.13748	36
Longfin squid	1.009	0.27199	27	2.038	0.55665	27
American lobster	0.440	0.19855	45	0.350	0.09429	27
Sea scallop	0.194	0.09369	48	0.877	0.38851	44
Dogfish	51.186	14.36400	28	115.671	36.00800	31
All spp.[1]	183.027	23.42700	13	259.398	38.04700	15
South						
Silver hake	0.426	0.14559	34	0.389	0.10256	26
Red hake	0.671	0.31264	47	0.147	0.06884	45
Summer flounder	0.413	0.10370	25	0.260	0.06533	25
Goosefish	0.938	0.33040	35	0.367	0.17910	49
Black sea bass	0.238	0.08226	20	0.429	0.22193	52
Scup	0.635	0.46357	73	1.293	0.61669	48
Butterfish	0.340	0.15347	45	0.682	0.36380	53
Longfin squid	0.811	0.20697	26	2.382	0.86509	36
American lobster	0.082	0.02381	29	0.151	0.07966	53
Sea scallop	0.092	0.03275	36	1.245	0.73640	59
Dogfish	92.764	36.88800	40	74.456	15.59700	21
All spp.[1]	226.566	53.61400	24	181.878	18.19100	10

[1] "All species" includes the eleven listed and all other species.

others not. In the autumn cruises, biomass statistics were statistically significant between pre- and post-dumping period cruises, but for the southern region only (Table 1). These results substantiate the negative temporal differences. They suggest a reduction over time for all species abundance and biomass in both regions of the study area.

Abundance indices for all species in spring cruises decreased from the pre- to the post-dumping periods but increased in autumn cruises. Variabilities for all species were consistently lower (9–24%) than those for individual species (18–88%) (Tables 4–7). This suggests that fluctuations in total biomass in the study area from 1982 to 1990 for all species were lower as a whole and masked fluctuations in individual species. One may infer that the impacts of fishing, ecological perturbations, or natural factors acting on all species as a whole, therefore, were relatively low in the spring. Although impact on the abundance indices for all species was less than on some individual species, there were no significant differences in the number of species between pre- and post-dumping periods in either region.

Spatial differences

To assess spatial differences for species CPUE between north and south regions, the same approach was used as for temporal differences. Test statistics for spatial differences are summarized in Table 2 and Tables 4–7. These are based on species CPUE, species abundance indices, and their variability estimates from collective cruises in pre- and post-dumping periods.

More species test statistics for autumn cruises were significantly different between the north and south

Table 5

Species abundance indices (e.g., mean and SSE [standard error]) based on **number** of stratified catch per tow and variabilities (CV in %) using pre- and post-dumping spring cruises collectively in north and south regions.

Species name	Pre-dumping spring cruises			Post-dumping spring cruises		
	Abundance indices			Abundance indices		
	Mean	SSE	CV (%)	Mean	SSE	CV (%)
North						
Silver hake	7.143	1.66440	23	9.255	2.13410	23
Red hake	6.491	2.35950	36	5.298	1.52160	29
Summer flounder	0.591	0.12461	21	0.350	0.07453	21
Goosefish	0.410	0.08432	21	0.285	0.05213	18
Black sea bass	0.410	0.23043	56	0.101	0.05330	58
Scup	3.027	1.76110	58	0.574	0.31650	55
Butterfish	28.105	13.54800	48	9.375	4.93800	53
Longfin squid	17.936	5.27820	29	37.478	15.55800	42
American lobster	0.995	0.46534	47	0.897	0.27397	31
Sea scallop	3.214	1.77760	55	35.384	23.24100	66
Dogfish	49.555	16.10700	33	79.592	22.47900	28
All spp.[1]	511.574	48.78400	10	554.673	51.95500	9
South						
Silver hake	2.431	0.57454	24	4.874	1.80180	37
Red hake	2.311	0.79196	34	0.641	0.21119	33
Summer flounder	1.016	0.31625	31	0.760	0.18100	24
Goosefish	0.314	0.07206	23	0.147	0.04088	28
Black sea bass	0.816	0.26722	33	2.007	0.71847	37
Scup	21.419	18.81900	88	17.119	8.51020	50
Butterfish	11.695	6.16760	53	51.810	44.22500	85
Longfin squid	50.430	21.27200	42	119.842	57.41000	48
American lobster	0.133	0.03483	26	0.137	0.04451	32
Sea scallop	1.845	0.62564	34	25.703	17.49900	68
Dogfish	45.598	16.41000	36	39.621	7.73790	20
All spp.[1]	450.046	47.42500	11	675.431	70.50500	10

[1] "All species" includes the eleven listed and all other species.

regions than those for spring cruises (Table 2). Several patterns are evident in significant test statistics for the autumn cruises. Biomass CPUE for eight species showed highly significant differences for both pre- and post-dumping periods. These species were silver hake, red hake, summer flounder, goosefish, black sea bass, butterfish, longfin squid, spiny dogfish, and all species. Fewer significant differences were observed in the number of CPUE. No distinct pattern was obvious for spring cruises. Only silver and red hake CPUE showed significant test statistics for both periods. Scup, American lobster, and sea scallop CPUE showed generally lower values that were not significantly different. There was a significant difference between north and south in number of species for autumn cruises in both the pre-dumping and post-dumping periods (Table 2).

Interpretation of these significant spatial differences requires special caution. In 1982, the first year for which data were used in this study, populations were not of comparable size in the north and south regions. One must consider how populations of unequal size could have accommodated differing environmental perturbations and fishing pressure in the north and south regions. Silver hake, red hake, butterfish, and spiny dogfish indices were highest. Goosefish and American lobster indices were lower overall, but higher in the north than in the south, while scup were higher only in the south. Longfin squid indices were consistent with its migratory pattern (concentrated in the south in spring and in the north in autumn) (Tables 4–7). Test statistics of all eight species were significantly different between north and south (Table 2).

Test statistics were tabulated for species CPUE between north and south, and for species abundance indices, including all species in the north and south regions for individual cruises, but are not presented here. This information supplemented the findings from collective cruises (Tables 2, 4–7). Indices from individual cruises

Table 6

Species abundance indices (e.g., mean and SSE [standard error]) based on **weight** of stratified catch per tow and variabilities (CV in %) using pre- and post-dumping autumn cruises collectively in north and south regions.

Species name	Pre-dumping spring cruises			Post-dumping spring cruises		
	Abundance indices			Abundance indices		
	Mean	SSE	CV (%)	Mean	SSE	CV (%)
North						
Silver hake	1.573	0.31258	23	0.997	0.30246	31
Red hake	2.707	0.69497	26	0.380	0.09313	25
Summer flounder	0.328	0.08221	25	0.135	0.06060	45
Goosefish	1.539	0.34043	22	0.350	0.10007	29
Black sea bass	0.010	0.00598	60	0.005	0.00363	73
Scup	0.905	0.40331	45	0.203	0.07233	36
Butterfish	9.356	3.27910	35	7.924	2.74850	35
Longfin squid	7.771	2.77170	36	4.266	0.94622	22
American lobster	0.539	0.10552	20	0.630	0.11589	18
Sea scallop	0.284	0.10900	38	1.810	1.07450	59
Dogfish	53.835	32.34200	60	19.980	13.61500	68
All spp.[1]	129.958	21.28800	16	76.576	7.16770	9
South						
Silver hake	0.178	0.05236	30	0.060	0.01787	30
Red hake	0.225	0.11908	53	0.052	0.02049	39
Summer flounder	0.439	0.16250	37	0.072	0.02495	34
Goosefish	0.111	0.03029	27	0.032	0.01329	42
Black sea bass	0.082	0.04975	61	0.060	0.02440	41
Scup	1.779	1.05160	59	4.660	3.96680	85
Butterfish	2.605	1.04430	40	2.803	1.43660	51
Longfin squid	2.716	0.64098	24	1.433	0.35703	25
American lobster	0.125	0.02937	24	0.069	0.02283	33
Sea scallop	0.278	0.14392	52	1.126	0.50005	44
Dogfish	0.006	0.00351	59	0.022	0.00672	31
All spp.[1]	65.832	11.32200	17	44.661	9.18910	21

[1] "All species" includes the eleven listed and all other species.

provided insights into how individual fish and shellfish populations responded in time and space. The variabilities were relatively consistent in both regions, despite confounding biotic and abiotic factors. Fluctuations of total biomass for eleven individual species, and for all species as a whole, were relatively stable in both north and south regions during the period 1982–90.

Seasonal differences

Seasonal differences between spring and autumn were determined by the same method used to evaluate temporal and spatial differences. Test statistics for seasonal differences based on species CPUE and species abundance indices with their variability estimates were drawn from collective cruises of the pre- and post-dumping periods. They are summarized in Tables 3 and 4–7.

Species test statistics for the pre-dumping cruises showed more significant differences between spring and autumn seasons than did post-dumping cruises. Weight test statistics provided more significant differences than those based on number. Spiny dogfish CPUE revealed significant test statistics for all categories. Test statistics for black sea bass, based on both biomass and number, showed significant differences between seasons for the post-dumping cruises in the southern region, but not for the pre-dumping cruises in the same region. Similarly, silver hake, butterfish, and American lobster indices in the northern region were significantly different for the post-dumping cruises, but not significantly different for pre-dumping cruises (Table 3). Some species weight abundance indices declined from the pre-dumping to post-dumping periods for both spring and autumn seasons (Tables 4 and 7). These included silver and red hakes, summer flounder, goosefish, and black sea bass. Number of species for the post-dumping cruises in the southern region was also significantly different (Table 3).

Table 7

Species abundance indices (e.g., mean and SSE [standard error]) based on **number** of stratified catch per tow and variabilities (CV in %) using pre- and post-dumping autumn cruises collectively in north and south regions.

Species name	Pre-dumping spring cruises Abundance indices Mean	SSE	CV (%)	Post-dumping spring cruises Abundance indices Mean	SSE	CV (%)
North						
Silver hake	32.869	9.57110	29	16.073	4.51730	28
Red hake	13.974	3.72120	27	2.968	0.72162	24
Summer flounder	0.268	0.07093	26	0.135	0.05503	41
Goosefish	0.658	0.13661	21	0.334	0.07429	22
Black sea bass	0.530	0.24114	46	0.137	0.05997	44
Scup	9.652	3.80610	39	7.770	5.12530	66
Butterfish	191.717	60.39400	32	241.977	87.52200	36
Longfin squid	307.679	141.09000	46	297.160	92.28000	31
American lobster	1.245	0.24816	20	1.573	0.30140	19
Sea scallop	4.165	1.58340	30	39.042	25.79400	66
Dogfish	32.848	18.35200	56	13.260	8.71090	66
All spp.[1]	1481.352	162.12000	11	1365.058	154.03000	11
South						
Silver hake	8.632	2.41370	28	3.340	1.03060	31
Red hake	1.436	0.65891	46	0.482	0.19790	41
Summer flounder	1.136	0.40306	22	0.200	0.06627	33
Goosefish	0.252	0.05769	23	0.128	0.03517	27
Black sea bass	1.003	0.62278	62	0.823	0.36718	45
Scup	40.626	24.08400	59	149.944	132.31000	88
Butterfish	85.958	32.22600	37	84.561	47.39100	56
Longfin squid	107.343	33.92100	32	74.365	38.98300	52
American lobster	0.152	0.03600	24	0.142	0.04323	30
Sea scallop	5.443	3.00540	55	22.849	9.84010	43
Dogfish	0.039	0.02346	60	0.131	0.03651	28
All spp.[1]	842.080	117.52000	14	815.743	133.00000	16

[1] "All species" includes the eleven listed and all other species.

Discussion

Analyses of fisheries abundance data, based on catch per unit of effort (CPUE) of NOAA's Northeast Fisheries Science Center (NEFSC) bottom trawl surveys, indicate that abundances of silver hake, red hake, summer flounder, goosefish, and black sea bass declined about the 106-mile dumpsite (106-MDS) from spring of 1982 through spring of 1990. These declines are concurrent with the temporary dumping there of sewage sludge from the New York and New Jersey metropolitan area. Changes in total abundance and biomass for all species combined occurred to a lesser degree because of increased abundance of spiny dogfish, skates (*Raja* spp.) and some pelagic species (e.g., Atlantic mackerel) (NMFS 1991, 1992). There were statistically significant, temporal differences in average abundance values for some individual species and for all species based on spring and autumn bottom trawl surveys within the north and south dumpsite areas. It is particularly worth noting that much of the abundance decline occurred in the south area of the dumpsite. The south region is most likely to be influenced by sewage sludge introduced in waters passing toward the west-southwest shallow outer shelf through the dumpsite in the potential area of influence (**PAI**) of the sewage sludge (Fig. 1; Bisagni, 1983; O'Connor et al., 1985; Gentile et al., 1989; Ingham[15]; Warsh[13]; Bisagni[4]). There were also statistically significant spatial differences in average abundance of many individual species and all species sampled on the spring and autumn surveys within the pre- and post-dumping period at the 106-mile dumpsite. There were seasonal differences, as well, in average values for several individual species and all species for north and south areas at the site, and within the pre and post sludge dumping periods.

The hypothesis that fishery resource abundance in the vicinity of the 106-MDS and adjacent outer continental shelf waters was not affected by sewage sludge dumping there from 1986 to 1990 is thereby rejected. Also rejected are the three secondary hypotheses related to the primary one. The likelihood remains that waste disposal, even in deep-ocean waters, has measurable adverse impacts on the resource abundance, at least in the area of direct influence of the toxic waste.

Analysis of survey data alone, however, does not establish cause and effect. It is necessary to consider the likelihood that events neither directly nor indirectly related to sewage sludge dumping at the 106-MDS could have led to the measured decline in abundance and shift in species composition within the study period. Also, it is necessary to consider how an abundance shift could have occurred through sludge dumping within this period of time.

Fishing is foremost among factors affecting fishery resource abundance and species composition unrelated to any effect of ocean disposal of toxic waste. Impacts of fishing pressure on the species sampled at the offshore dumpsite and analyzed in this study are poorly known. There are also other poorly understood natural factors affecting species population abundance around the 106-MDS in the PAI and elsewhere that could have influenced abundance and species composition at this site over the period of the study reported here. These include shifts in spawning time and area, size of predator stocks, decline in size of the spawning biomass, and increase in early life mortality (Gross, 1976; Hempel, 1978; Mayer, 1982; Cross et al., 1985; Tiews, 1985). The dramatic reductions in stock size affected by powerful modern fishing techniques, however, through sheer reduction in stock size, may influence all these factors so that their fluctuation is no longer entirely natural. These same natural factors are likewise potentially affected by ocean dumping of toxic waste as evidenced in the environmental literature (Carlise, 1969; Gross, 1976; Mearns, 1981; Mayer, 1982; Spies, 1984; Wolf and O'Connor, 1988; Champ and Park, 1989; Hood et al., 1989; Baumgartner and Duedall, 1990; Longwell et al. 1992; Longwell[21]; Young and Mearns[22]; NMFS[10,11]; Studholme et al.[12]). Changes in water mass patterns and global warming are possibly the only phenomena not potentially influenced by ocean dumping. Given the complexity of natural and anthropogenic forces acting on populations, existing data sets from fishery ecology are simply not sufficiently synoptic or complete enough to be useful in sorting out direct sludge dumping effects from natural or pseudo-natural processes driving population fluctuation.

Oceanographic dynamics around the 106-MDS make it unlikely that any change in harvestable fishery resources or catch composition could be the result of direct mortality attributable to the sewage since relocated sludge dumping began there in 1986. There is some evidence from embryo studies of planktonic eggs collected in the wake of sludge and acid waste disposal at 106-MDS that direct kills of floating fish eggs can occur, but this dumpsite is not a significant spawning grounds for resource species (Longwell[21]).

Changes in fishery resource abundance at 106-MDS could, however, have been affected by a change in fish behavior in response to dumped material as well as to natural environmental perturbations (Olla et al., 1980). Migration to other areas to escape sludge disposal and its aftermath or to search for other feeding grounds is likely to alter the time and place of spawning and subsequent early-life survival.

Reduced reproductive success and recruitment resulting from increased baseline contaminant body burdens of spawners is another mechanism whereby the population changes measured in the study presented here could have resulted from sludge dumping (Cross and Hose, 1988; Longwell et al., 1992). Offshore contamination of fish has the same potential of affecting subsequent spawning and recruitment as does contamination in nearshore waters and on the spawning grounds. Shifts in species composition could have come about if predator or competitor, or both, species were more tolerant of the sludge than were the resource species. In addition, poor quality eggs could have resulted from inadequate maternal nutrition if there was much direct prey mortality or pollution-impaired reproduction of prey organisms in the wake of the sludge. Contaminant burdens of the reproductive tissues or ripe eggs of the species analyzed in this study are unknown. Extrapolation and formal treatment of existing data on muscle and liver tissues of these or on the reproductive tissues of other species are probably not worthwhile. Contaminant burdens of mature winter flounder eggs alone (Calabrese et al.[23]) suggest that

[21] Longwell, A. C. 1981. Cytological examination of fish eggs collected at and near 106-Mile Site. *In* NOAA Special Report. Assessment Report on the Effects of Waste Dumping in 106-Mile Ocean Waste Disposal Site. Dumpsite Evaluation Report 81-1. U.S. Dep. Commer., NOAA, Office of Mar. Pollution Assessment. Rockville, MD, 257–276 p.

[22] Young, D. R., and A. J. Mearns. 1978. Pollutant flow through food web. Southern California Coastal Water Research Project. Annual Report 1978, 185–202 p.

[23] Calabrese A., A. C. Longwell, and F. P. Thurberg. 1989. Final report on early reproductive success of winter flounder from Boston Harbor with comparisons made to Long Island Sound. Prepared for U.S. Environmental Protection Agency. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Northeast Fish. Sci. Cent., Milford Lab., Milford, CT, 61 p.

safety margins for adverse reproductive effects of several contaminants (Susani, 1986; Sorenson, 1991) on fish species at the 106-MDS could easily have been exceeded. Only moderate concentrations of chlorinated hydrocarbons have been shown to be associated with detrimental reproductive effects (Susani, 1986; Westernhagen et al., 1989).

An interdisciplinary effort was made to determine changes in contaminant burdens of fish at the 106-MDS once sludge dumping began (NMFS[10,11]). In 1991, concentrations of metals were relatively low in the epibenthic megafauna species of deepwater fishes, such as blue hake (*Antimora rostrata*), rattails (*Coryphaenoides carapinus* and *C. armatus*), halosaur (*Halosauropsis macrochir*) and commercially valuable slope-dwelling tilefish (*Lopholatilus chamaeleonticeps*), shrimp (*Nematocarcinus ensifer* and *Glyphocrangon sculpta*), and American lobster (*Homarus americanus*). This was generally true for American lobster, with the exception of elevated liver Cd, which could reflect its trans-shelf migration and possible exposure to coastal pollution. Finfishes, however, generally contained relatively high concentrations of chlorinated pesticides and total PCB's in their livers (NMFS[10,11]). Significantly elevated levels of several metals (Ag, Cu,and Cr) were found in midwater myctophids (e.g., *Benthosema glaciale, Lobianchia dofleini, Ceratoscopelus maderensis,* and *Hygophum hygomii*) at stations southwest of the 106-MDS in the principal area of influence of the sludge.

Plankton (primarily copepods) provide a pathway for entry of potentially toxic chemical contaminants from the sludge into the ocean food-web, because it constitutes the main prey of smaller midwater fishes. Concentrations of metals in plankton samples taken in 1991 were comparable to, or higher than, those observed in fishes collected in 1989. The geographic distributions of metal concentrations in 1991 fishes and plankton suggest that the elevated levels of metals found in certain samples are probably attributable to dumping activity at the 106-MDS. Boehm (1983), however, postulated that offshore, southerly transport of organic contaminants along the New Jersey shore and down-valley transport from the New York Bight apex caused increased metal contaminants. Organic contaminants (PCB's, polynuclear aromatic hydrocarbons (PAH's) and pesticides) were present in lower concentrations in zooplankton than in midwater fishes (NMFS[10,11]).

The highest concentration patterns of PAH's, PCB's, and Ag in the sediment surface layer (0–0.5 cm) tended to follow the distribution patterns of spores of *Clostridium perfringens* (a bacterial indicator of sewage) in sediments collected from depths of 100 to 2800 m in the vicinity of the 106-MDS. *Clostridium perfringens* counts declined gradually to the southwest. Surface sediments were not detectably contaminated with other trace metals. Organic contaminant concentrations in sub-surface strata (0.5–3.5 cm) were higher than in the sediment or deeper layers. Artifacts in sediment cores in the 106-MDS tend to confirm that chemical concentration is related to dumping. All data imply that material dumped at the 106-MDS reached the seabed in the area southwest of the site in the PAI. Data imply that the chemicals associated with the sludge entered the food-web around the dumpsite in the area believed to have been under principal influence of the sludge (NMFS[10,11]). This is the area accounting for the most of the decline in fish species measured in this study.

Unless absorbed by particles or precipitated by other constituents in the water column, slowly sinking wastes must take a long time to reach the bottom because of the great water depth. This increases the likelihood of significant ingestion of waste and associated contaminants by mid-water column prey species of resource fish. Deepwater food-web dynamics have been explored in the 106-MDS by Van Dover et al. (1992) by using the natural stable isotopes of organic carbon nitrogen and sulphur in sewage sludge to trace sewage-oriented organic matter. Organic matter from the sludge was found to reach the deep-sea floor and enter the benthic food-web through consumption by surface-deposit feeders, including a sea urchin (*Echinus affinus*) and a sea cucumber (*Benthodytes sanquinolenta*). Other surface-deposit feeders, including infaunal benthic species such as polychaetes and molluscs, probably also ingest this organic matter contributing to sludge impacts in the open ocean via food-chain dynamics.

There are strong associations of benthic macrofauna with habitat types and sediment contaminants in the continental shelf of the New York Bight (Chang et al., 1992). Species most common in the contaminated area around 12-MDS were mainly polychaetes (e.g., *Tharyx acutus, Nephtys incisa, Pherusa affinis,* and *Capitella* spp.), as well as a nemertean (*Cerebratulus lacteus*), an anemone (*Ceriantheopsis americanus*), a phoronid (*Phoronis architecta*) and the nut clam *Nucula proxima*. Another group of species was consistently associated with minimally contaminated sediments and appeared to represent a basic natural benthic macrofaunal assemblage for the typical sandy habitat of the Bight shelf. This group included the sand dollar (*Echinarachnius parma*) and several species of amphipods (e.g., *Byblis serrata, Corophium crassicorne,* and *Ampelisca agassizi*), as well as polychaetes (e.g., *Goniadella gracilis* and *Exogone hebes*). The roles of these contaminant-sensitive and insensitive species within certain food-web dynamics for commercially important fisheries resources in the New York Bight are becoming known (Steimle, 1985; Steimle and Terranova, 1991). Chemical analyses of sediment cores tend to confirm that sediment chemical concentration around the 12-MDS is related to some types of dumping, and that sediment concentrations decrease appreciably in some areas 20 months after cessation of sewage sludge dumping (Zdanowicz et al., 1993[24]). Distribution of the contaminant-sensitive and insensitive benthic invertebrate species assemblages in the New York Bight (Chang et al., 1992) then imply that material dumped at the 12-MDS reached the bottom in the area where it was dumped, entered the food-web at the lower trophic levels of benthic organisms, and ascended to the higher trophic levels of predatory fish species (Steimle et al.[25,26]). Similar food-web dynamics could have influenced the temporal and spatial differences in abundance of commercially important species measured in the principal area of sludge influence at the 106-MDS.

Conclusions

Effects of sewage sludge dumping even in the deep ocean at the 106-MDS, like sludge dumping at the 12-MDS in the New York Bight and release of sewage from outfalls in southern California outfalls, cannot be excluded as a factor measurably affecting fishery resource abundance and composition. Natural factors may have caused the population fluctuation assessed around the 106-MDS, but there are no adequate data sets for testing the likelihood that such phenomena, and not deepwater dumping, are responsible. Data sets are even more inadequate for measuring interactive effects of dumping, fishing, and natural phenomena, which must certainly occur. On the other hand, there are identifiable mechanisms by which changes in abundance and composition of fishery resources could have come about in relatively few years as a result of sludge dumping after prior years of industrial and chemical waste disposal at this deepwater site. Increased contamination of the food-web and environment could well have directly and indirectly, possibly differentially, affected both behavior and reproduction of ecologically linked species leading to the unfavorable temporal, spatial, and seasonal differences of the fishery resources around the 106-MDS.

Analyses of bottom trawl surveys and fishery landings data in relation to environmental pollution are of increasing importance as efforts are made to measure any impact of toxic contaminants on fishery resource. The influence of natural and man-induced environmental factors, such as waste dumping, on fishery resources can be treated as concomitant variables (Thomas et al., 1976; Butler and Schutzman, 1979; Marking and Kimerle, 1979; Geyer, 1981, a and b; Reed et al., 1985; Miller et al., 1988; Wallace et al., 1988; Stoddard and Walsh, 1988; Connor, 1989; Gift et al., 1989; Stanford and Young, 1988, Furness and Rainbow, 1990; Word et al., 1990; Manning, 1991). Interpretation of fishery assessment data in relation to the sewage sludge dumping at the 106-MDS, as developed in the discussion above, makes clear that future efforts in all these regards would benefit from better and updated baseline data on the fishery resources. If there were food-web dynamics data as well as more behavioral and reproductive data on responses of marine fish to contaminant levels known to occur in the ecosystems of concern, we would then be better able to understand and determine causal factors influencing species abundance and fishery resources in the vicinity of the 106-MDS and adjacent continental shelf waters. Much is still to be learned about both the natural fluctuation of environmental factors that influence species abundance and population dynamics and about anthropogenic effects on the natural environment. A better understanding of natural and man-induced effects on fishery resources is necessary to minimize adverse controllable impacts on fisheries resources and requires further synthesis of environmental and fishery assessments.

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