Northeast Fisheries Science Center Reference Document 02-09

A Compilation of Reported Fish Kills in the Hudson-Raritan Estuary during 1982 through 2001

by

Robert N. Reid, Paul S. Olsen,
and John B. Mahoney

July 2002

Recent Issues in This Series

01-12 **Northeast Fisheries Science Center Publications, Reports, and Abstracts for Calendar Year 2000.** By L. Garner and J.A. Gibson. August 2001.

01-13 **Elemental Composition of Fish Otoliths: Results of a Laboratory Intercomparison Exercise.** By V.S. Zdanowicz. September 2001.

01-14 **Identification of Seasonal Area Management Zones for North Atlantic Right Whale Conservation.** By R.L. Merrick, P.J. Clapham, T.V.N. Cole, P. Gerrior, and R.M. Pace, III. October 2001.

01-15 **Bycatch Estimates of Coastal Bottlenose Dolphin (*Tursiops truncatus*) in U.S. Mid-Atlantic Gillnet Fisheries for 1996 to 2000.** By D.L. Palka and M.C. Rossman. November 2001.

01-16 **Causes of Reproductive Failure in North Atlantic Right Whales: New Avenues for Research -- Report of a Workshop Held 26-28 April 2000, Falmouth, Massachusetts.** By R.R. Reeves, R. Roland, and P.J. Clapham, editors. November 2001.

01-17 **Collected Abstracts of the Northeast Fisheries Science Center's Seventh Science Symposium, Westbrook, Connecticut, December 11-13, 2001.** By R. Mercaldo-Allen, J. Choromanski, M.S. Dixon, J.B. Hughes, D.R. Lanyon, C.A. Kuropat, C. Martin, and J.J. Ziskowski, compilers. December 2001.

01-18 **Report of the 33rd Northeast Regional Stock Assessment Workshop (33rd SAW): Stock Assessment Review Committee (SARC) Consensus Summary of Assessments.** [By Northeast Regional Stock Assessment Workshop No. 33.] December 2001.

01-19 **Report of the 33rd Northeast Regional Stock Assessment Workshop (33rd SAW): Public Review Workshop.** [By Northeast Regional Stock Assessment Workshop No. 33.] December 2001.

01-20 **Assessment of 19 Northeast Groundfish Stocks through 2000: A Report to the New England Fishery Management Council's Multi-Species Monitoring Committee.** By Northern Demersal and Southern Demersal Working Groups, Northeast Regional Stock Assessment Workshop. December 2001.

02-01 **Workshop on the Effects of Fishing Gear on Marine Habitats off the Northeastern United States, October 23-25, 2001, Boston, Massachusetts.** By Northeast Region Essential Fish Habitat Steering Committee. February 2002.

02-02 **The 2001 Assessment of the Gulf of Maine Atlantic Cod Stock.** By R.K. Mayo, E.M. Thunberg, S.E. Wigley, and S.X. Cadrin. [A report of Northeast Regional Stock Assessment Workshop No. 33.] March 2002.

02-03 **An Age-Structured Assessment Model for Georges Bank Winter Flounder.** By J.K.T. Brodziak. [A report of Northeast Regional Stock Assessment Workshop No. 34.] March 2002.

02-04 **Re-Evaluation of Biological Reference Points for New England Groundfish.** By Working Group on Re-Evaluation of Biological Reference Points for New England Groundfish. March 2002.

02-05 **Biological Characteristics, Population Dynamics, and Current Status of Redfish, *Sebastes fasciatus* Storer, in the Gulf of Maine - Georges Bank Region.** By R.K. Mayo, J.K.T. Brodziak, M. Thompson, J.M. Burnett, and S.X. Cadrin. [A report of Northeast Regional Stock Assessment Workshop No. 33.] April 2002.

02-06 **Report of the 34th Northeast Regional Stock Assessment Workshop (34th SAW): Stock Assessment Review Committee (SARC) Consensus Summary of Assessments.** [By Northeast Regional Stock Assessment Workshop No. 34.] April 2002.

02-07 **Report of the 34th Northeast Regional Stock Assessment Workshop (34th SAW): Public Review Workshop.** [By Northeast Regional Stock Assessment Workshop No. 34.] April 2002.

02-08 **Description of the 2001 Oceanographic Conditions on the Northeast Continental Shelf.** By M.H. Taylor, C. Bascuñán, and J.P. Manning. May 2002.

Northeast Fisheries Science Center Reference Document 02-09

A Compilation of Reported Fish Kills in the Hudson-Raritan Estuary during 1982 through 2001

by

Robert N. Reid[1,3], Paul S. Olsen[2,4], and John B. Mahoney[1,5]

Postal Addresses: [1]*National Marine Fisheries Serv., James J. Howard Marine Sciences Lab., 74 Magruder Rd., Highlands, NJ 07732;* [2]*New Jersey Dept. of Environmental Protection, Bur. of Freshwater & Biological Monitoring, P.O. Box 427, Trenton, NJ 08625*
E-Mail Addresses: [3]*Robert.Reid@noaa.gov;* [4]*polsen@dep.state.nj.us;* [5]*John.Mahoney@noaa.gov*

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

July 2002

Northeast Fisheries Science Center Reference Documents

This series is a secondary scientific series designed to assure the long-term documentation and to enable the timely transmission of research results by Center and/or non-Center researchers, where such results bear upon the research mission of the Center (see the outside back cover for the mission statement). These documents receive internal scientific review but no technical or copy editing. The National Marine Fisheries Service does not endorse any proprietary material, process, or product mentioned in these documents.

All documents issued in this series since April 2001, and several documents issued prior to that date, have been copublished in both paper and electronic versions. To access the electronic version of a document in this series, go to *http://www.nefsc.nmfs.gov/nefsc/publications/series/crdlist.htm*. The electronic version will be available in PDF format to permit printing of a paper copy directly from the Internet. If you do not have Internet access, or if a desired document is one of the pre-April 2001 documents available only in the paper version, you can obtain a paper copy by contacting the senior Center author of the desired document. Refer to the title page of the desired document for the senior Center author's name and mailing address. If there is no Center author, or if there is corporate (*i.e.*, non-individualized) authorship, then contact the Center's Woods Hole Laboratory Library (166 Water St., Woods Hole, MA 02543-1026).

This document's publication history is as follows: manuscript submitted for review--February 14, 2000; manuscript accepted through technical review--June 5, 2000; manuscript accepted through policy review--June 13, 2000; and camera-ready copy submitted for publication--July 10, 2002. This document may be cited as:

Reid, R.N.; Olsen, P.S.; Mahoney, J.B. 2002. A compilation of reported fish kills in the Hudson-Raritan Estuary during 1982 through 2001. *U.S. Dep. Commer., Northeast Fish. Sci. Cent. Ref. Doc.* 02-09; 16 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026.

Table of Contents

Tables

Figures

ABSTRACT

Concern about mass fish mortalities in eastern U. S. coastal regions has increased in recent years. Major kills attributed to the toxic dinoflagellate *Pfiesteria piscicida or related species, primarily* in eutrophic estuaries in the southeast but ranging north to Chesapeake Bay and possibly to Delaware, have sparked interest in fish kill phenomena in general. We found that lack of organized information was a hindrance to the understanding of fish kills in the long-stressed Hudson-Raritan estuary. To address this we compiled kill reports for 1982 through 2001, with focus on seasonality, causes, incidence, and kill size.

All reported fish kills in the estuary during 1982-2001, a total of 15, occurred between mid-June and mid-September. Their causes were uncertain, as generally is the case with fish kills. Most were attributed to low dissolved oxygen; decomposing phytoplankton blooms; and seasonal high water temperatures. A role for toxic substances in one of the kills was suspected. Reported possible causes of some monospecific kills of Atlantic menhaden included low dissolved oxygen and spillage from fishing nets. No pattern for the kills over the 20 years was evident; incidence data were inadequate for statistical analysis. Sandy Hook Bay may be a problem locus because seven of the 15 kills were detected there. With the caveat that mortality assessments likely were consistently inadequate and low, one kill involved about one million fish and another was estimated at 3.9 million. These can be considered major incidents; the other 13 were relatively minor. The occurrence of two major kills during 20 years does not suggest the estuary to be a prime center for such phenomena. We believe, nevertheless, that the problem requires additional examination. We discuss the need for more comprehensive and unified investigation of fish kills in the estuary.

KEYWORDS: *Hudson-Raritan estuary, Raritan Bay, Sandy Hook Bay, fish kills, algal blooms, dissolved oxygen*.

INTRODUCTION

Most marine finfish kills occur in estuaries and coastal waters (Brongersma-Sanders, 1957; May, 1973; Swanson and Sindermann, 1979; Lowe et al., 1991). Fish kills have a wide variety of causes which often manifest strongly in these waters: physical conditions, e.g., storms, seaquakes, temperature and salinity changes; chemical conditions, e. g., toxic contaminants, oxygen depletion, hydrogen sulfide generation; biological phenomena, e.g., algal blooms, biotoxins, and disease; and combinations of these factors (Swanson and Sindermann, 1979). Most major kills in United States coastal waters from 1980 through 1989 were associated with high summer temperatures, low dissolved oxygen, and low water circulation (Lowe et al., 1991). Often, it has not been possible to establish with certainty what caused a given kill, or to what extent the lethal conditions were natural or anthropogenic.

The dinoflagellate *Pfiesteria piscicida,* which produces a highly potent biotoxin, or a closely related species, has been implicated as the cause of major fish kills during the last decade in southeastern and mid-Atlantic U. S. estuaries, particularly eutrophic ecosystems (Burkholder et al., 1995; U. S. Environmental Protection Agency et al., 1998). Burkholder et al. (1995) found *P. piscicida* in eastern U. S. estuarine waters and sediments as far north as Indian River, DE. The species is considered the probable cause of a fish kill in the Indian River (U. S. Environmental Protection Agency et al., 1998). In New York Bight coastal waters, Rublee (P. Rublee, University of North Carolina at Greensboro, Greensboro NC, pers. comm., 8/30/99) detected the species in the Tuckahoe River, NJ, and Long Island, NY, embayments, but not in a toxic phase or in confirmed association with fish mortality. There is no indication at present of *P. piscicida* as a threat in the New York Bight. Nevertheless, the fish kills to the south have resulted in increased concern about kills in Bight coastal waters.

The Hudson-Raritan estuary, at the apex of the Bight, has a long history of serious pollution with sewage and industrial wastes (Federal Water Pollution Control Administration, 1967). Hypoxia episodes and contamination of the estuary's sediment with toxic chemicals are two major indirect or direct consequences of the chronic pollution (Keller and Squibb, 1992). Various metals, petroleum hydrocarbons, pesticides, and halogenated hydrocarbons were detected in the estuary at levels threatening to the biota (Breteler, 1984). The estuary has been characterized as one of those most contaminated with PCBs in the U. S. (Zdanowicz et al. 1986).

Epizootics of fin rot disease that affected 23 species of fishes had their focus in the estuary (Mahoney et al., 1973); outbreaks of fin rot frequently are associated with environmental stress (Sindermann, 1979). Further indication of a long-stressed environment, intense phytoplankton blooms or "red tides" have occurred annually in the Hudson-Raritan estuary and adjacent waters for decades (Mahoney and McLaughlin, 1977; Olsen and Mahoney, 1986). It has been shown that bloom biomass can be a major contributor to hypoxia in the estuary (Olsen and Mulcahy, 1991). The estuary remains polluted although abatement measures appear to have yielded long term improvements in water quality (Brosnan and O'Shea, 1996) and sediment quality (O'Connor et al., 1998).

Organized information on fish kills can aid in understanding their causes and identifying where corrective measures are most necessary (Lowe et al., 1991). Burkholder et al. (1995) pointed out that there is widespread lack of such information for U. S. coastal waters, however. We address that need for a portion of the Hudson-Raritan estuary.

METHODS

This paper provides a synopsis of information on fish kills in the southeastern waters of the Hudson-Raritan Estuary: Sandy Hook Bay, the New Jersey portion of Raritan Bay, and the Shrewsbury and Navesink Rivers, which drain into Sandy Hook Bay ((Table 1, Figure 1). The New York or northern half of the estuary was not considered because we found no fish kill reports for that region. The reporting period is 1982 through 2001.

Information on the kills did not stem from long-term programmed fish mortality monitoring. Most was from annual reports of the New Jersey Department of Environmental Protection, Bureau of Freshwater and Biological Monitoring (NJDEP, BFBM, 1982-2001) on phytoplankton blooms and related conditions in New Jersey coastal waters. NJDEP, BFBM annually monitored phytoplankton bloom incidence, late May through early September, in cooperation with the U.S. Environmental Protection Agency (USEPA), New York Bight Water Quality Monitoring Program. Kill information was noted in the reports when available (most often provided by NJDEP Division of Fish and Wildlife). Some observations were made by NJDEP and USEPA helicopter surveillance. Information on a July 1990 incident was from a National Marine Fisheries Service, James J. Howard Marine Sciences Laboratory investigation; Howard Laboratory (HL) data augmented NJDEP information on the relatively large July 1992, July 1995 and July 1999 kills. Monmouth County (NJ) Department of Health (MCDH) provided information on the June 1990, July 1995, July and September 1999 kills, and the July 2000 kill.

The information on the July 2000 kills was provided by NJDEP, Division of Fish and Wildlife. Some of the June 1988 and July 1989 kill information, and all the September 1999 kill information, was from newspaper accounts. To our knowledge, these are the only data sources on fish kills in the estuary.

Field methods were fairly uniform among the several agencies NJDEP, MCDH, Howard Laboratory). Estimates of numbers of dead fish were obtained by multiplying the length of affected shoreline by the mean of several counts of visible carcasses per square meter along the shore. Dissolved oxygen (DO) was measured using the Winkler technique or a YSI oxygen meter. Time of day when meter measurements were made, or water samples for DO analyses were collected, was not necessarily when DO was highest or lowest for the day. Identification of dominant species in a phytoplankton bloom was made either by NJDEP, the Howard Laboratory, or MCDH. Phytoplankton counts by NJDEP, HL or MCDH were routinely done under the microscope using a Palmer-Maloney or Sedgewick-Rafter chamber; the Howard Laboratory used a Coulter counter when blooms were monospecific.

RESULTS AND DISCUSSION

Seasonality of Kills and Suspected Causes

All fish kills reported in the Hudson-Raritan estuary during 1982-2001 occurred between mid-June and early September (Table 1). Greater potential for observation due to increased human traffic may have been a factor in this apparent seasonality, but it is reasonable to assume most kills to have occurred in summer. Nationwide, 64% of all fish kills reported during 1980-1989 (accounting for 86% of the total fish reported killed) occurred from May through September (Lowe et al., 1991). In addition, the greatest number of fish species are present at this time in the Hudson-Raritan estuary, with many species in increased abundance (Wilk et al., 1998); high abundance can contribute to the magnitude of kills (Bigelow and Schroeder, 1953).

As was the majority of fish kills reported nationwide during 1980-1989 (Lowe et al., 1991), most of the kills in the Hudson-Raritan estuary were attributed to low DO, and high water temperatures (Table 1). Metabolic rates and thus oxygen needs of fish usually increase with temperature, while oxygen solubility in water decreases. Dissolved oxygen also can be dramatically reduced by high summer oxygen consumption, especially by respiration of other components of the biota and large-scale decomposition of algae.

Seven of the Hudson-Raritan fish kills were associated with decomposing phytoplankton blooms. Hypoxic DO levels were detected during four of the bloom-associated kills; DO data were not obtained or not reported for the other three kills (Table 1).

Following multiple kills in 1988, which were attributed in large part to hypoxia from bloom decomposition, NJDEP and USEPA conducted a joint field investigation of the problem (Olsen and Mulcahy, 1991). Weekly DO, phytoplankton composition and chlorophyll assessments were made during the summer of 1989 for 12 sites in the Hudson-Raritan estuary. An intense bloom dominated by the dinoflagellate *Katodinium rotundatum* occurred from about June 24 to July 2; highest phytoplankton and chlorophyll concentrations were predominantly in the southeastern portion of the estuary. Clearly showing bloom/hypoxia association, following the bloom bottom water DO levels were decreased considerably throughout the estuary for one to three weeks, with lowest levels (0.84-1.68 ml/l) in Raritan Bay and Sandy Hook Bay. Intense diatom blooms occurred from late July through early September but did not result in hypoxia. Only one minor fish kill was reported during the summer. This indicates that intense phytoplankton blooms in the estuary may or may not result in hypoxia. Also, even when considerably widespread and prolonged, hypoxia may not result in a major fish kill.

Water temperatures were not always reported for the Hudson-Raritan fish kills but all occurred (Table 1) when temperatures are seasonally at highest levels (Draxler et al., 1984). Winter flounder, *Pleuronectes americanus,* becomes inactive at temperatures above 22^{o}C, and can die at 26-32^{o}C (Buckley, 1989). During the July 1995 kill, which included an estimated 50,000 juvenile winter flounder, water temperatures as high as 29.5^{o}C were recorded. Temperature very likely had a role in this kill, at least.

High temperature and low dissolved oxygen can act in concert with other stressors, such as toxic chemicals (Keller and Squibb, 1992). They suggested that interactive effects between hypoxia/anoxia and toxic chemicals in the Hudson-Raritan estuary, could be important. In this regard, the second largest recorded kill in the estuary, in June 1988, was attributed to localized hypoxia, decomposing phytoplankton blooms etc., and possibly toxic substances (Table 1). According to Halgren (B. Halgren, NJ DEP, Nacote Creek Research Station, Port Republic, NJ, pers. comm., 11/18/99) this kill had characteristics suggesting possible involvement of anthropogenic or biological toxins; it was spatially limited, of short duration**,** and involved species which can usually avoid (e. g., bluefish, *Pomatomus saltatrix*) or tolerate (e. g., American eel, *Anguilla rostrata*) hypoxic conditions.

We have no evidence that algal biotoxins caused any of the Hudson-Raritan estuary fish kills but the possibility should not be ruled out. Phytoplankton species toxic to humans have not been identified as dominants in the area; however, the potentially icthyotoxic phytoflagellate *Heterosigma carterae* has been a dominant bloom species in the estuary for many years (Olsen and Cohn, 1979). This species is known to be toxic to fish in various parts of the world (Whyte et al., 1999). Also, a biotoxin has been reported in sea lettuce, *Ulva lactuca* (Johnson and Welch, 1985), which is the most abundant macroalga locally.

Seven kills not reported to be associated with algal blooms involved only, or predominantly, Atlantic menhaden, *Brevoortia tyrannus.* Three were in Sandy Hook Bay, one was in the Navesink River, one occurred in Waackaack and Thorns Creeks which empty into southern Raritan Bay), one was in Lanes Creek and another in Little Silver Creek, which both empty into the Shrewsbury River (Table 1, Figure 1). Of the three Sandy Hook Bay menhaden kills, the likely cause of one was reported to be spillage of dead fish from pound nets (weirs); this can be deduced from appearance of the fish, i. e., torn gill opercula, net marks on bodies. Two kills were ascribed to either low dissolved oxygen or spillage from pound nets and the cause of one was unreported. A menhaden kill in the Navesink River in July 1999 occurred at a time when juveniles were abundant, and were observed being chased into shallows by bluefish (J. Rosendale, James J. Howard Marine Sciences Laboratory, Highlands, NJ, pers. comm., 12/30/99); low dissolved oxygen and high water temperatures were recorded (Table 1). The September 1999 Waackaack and Thorns Creeks kills occurred after heavy rains, when juvenile menhaden were trapped upstream of floodgates. The July 2000 major kill of juvenile menhaden in Little Silver Creek, and a smaller kill of juvenile menhaden the same month were attributed to low DO.

The Navesink River, Waackaack Creek, Thorns Creek, Little Silver Creek and Lanes Creek kills were not necessarily associated with poor ambient water quality. Atlantic menhaden is a pelagic, schooling species which swims continuously while filter-feeding (Rogers and Van Den Avyle, 1989). Dense schools of menhaden themselves can significantly lower dissolved oxygen and raise ammonia levels (Oviatt et al., 1972). Menhaden sometimes die *en masse* when they strand themselves in shoal waters or crowd into small coves or heads of creeks, in attempts to escape predators or for other reasons (Bigelow and Schroeder, 1953; Reintjes and Pacheco, 1966).

Temporal Incidence / Water Quality Change

Kills were reported in ten of the 20 years covered, with multiple kills recorded only in 1988, 1990, 1999 and 2000 (Table 1). We note that there were seven incidents in Sandy Hook

Bay reported between 1982 and 1990, and none subsequently to 2001. Given the limitations of the data, especially irregular monitoring and imprecise estimates of numbers killed, this may or may not be significant. We did not attempt trend analysis.

Long-term trend toward smaller and/or less frequent kills (specifically those caused by low dissolved oxygen) might be expected because water quality of the Hudson-Raritan estuary improved significantly following passage of the Clean Water Act in 1972 (Brosnan and O'Shea, 1996; New York City Department of Environmental Protection, 1998). However, the only pertinent long-term uninterrupted data available for the estuary (for the northern region) (Brosnan and O'Shea, 1996; New York City Department of Environmental Protection, 1998) suggest that most of the water quality improvement, in terms of nutrient levels, was before the period we consider. That is, from 1985 through 1997, concentrations of nitrite, nitrate, total phosphorus, and orthophosphate in surface waters decreased significantly at only one of three standard monitoring stations between the mouth of the Arthur Kill and mid-Raritan Bay; there were significant reductions in ammonium in surface waters at two of the three stations (New York City Department of Environmental Protection, 1998). Data for 1989-1997 from the same three stations show there were significant increases in chlorophyll at two of the three stations and dissolved oxygen in bottom waters increased significantly at all three stations (New York City Department of Environmental Protection, 1998). This limited evidence suggests that, although phytoplankton production was not reduced, oxygen demand was lowered in the northern part of the estuary. Obviously, extrapolation of this information to the southern half of the estuary where the kills occurred is problematic.

Spatial Incidence / Cause and Effect Linkage

Given the same caveat about the data discussed under temporal incidence, location of the kills suggests Sandy Hook Bay to be a possible problem locus, because seven of the 14 kills were detected there. Kills or underlying water quality conditions may not have originated where the dead fish were observed, however. Nutrients and blooms from the Shrewsbury and Navesink Rivers discharge into Sandy Hook Bay. Net water flow in this estuary region is eastward (Jeffries, 1962), and tends to move nutrients, phytoplankton blooms, and dead or moribund fish in that direction. For example, the large June 1988 kill in Sandy Hook Bay was linked to decay of a phytoplankton bloom which first developed several km to the west of where the kill occurred (Figure 1). Much of the nutrient loading enters the estuary west of Sandy Hook Bay. Sources include the Raritan and Hudson Rivers, the Arthur Kill, and the large Middlesex County sewage outfall, which discharges a mean of 124 million gallons/day of secondary treated effluent through an outfall located 1.6 km ESE of the mouth of the Raritan River [(Figure 1) (Interstate Sanitation Commission, 1997)]. These rivers and outfall are also major sources of organic loading which contribute to reduced dissolved oxygen in the system (Mueller et al., 1982). Perhaps significant, the most recent non-menhaden kills (7/92 and 7/95) were off Cliffwood Beach (NJ) in western Raritan Bay, proximal to these pollution sources.

Size of Mortalities

Lowe et al. (1991) considered a "major" kill to be of a million or more fish. They reported 86 major kills nationwide from 1980-89; the ten largest involving mortality of ten to 50 million fish. Only the June 1988 kill in Sandy Hook Bay and the July 2000 kill in Little Silver Creek (Shrewsbury River) would be classified major by this criterion. Next in numbers, the September 1999 kill in the Waackaack and Thorns Creeks involved several hundred thousand juvenile menhaden. Assessed mortalities in all other local kills were under 60,000 (Table 1).

All counts of dead fish very likely are underestimates of actual numbers killed, however. Apparently, only shoreline observations were made, and fish mortalities usually were assessed on single observations, likely post-peak. Contributing to underestimates when this kind of observation is made is that some fish are too deep in the water to be visible, and others may be removed by predators or scavengers; these are common reasons for underestimates (American Fisheries Society, 1992). During an August 1988 fish kill investigation in Sandy Hook Bay scavenging seabirds removed almost all dead fish within two days of the estimated peak of the kill (Pacheco, Howard Laboratory internal memorandum).

Considerations in Evaluating Fish Kills

This topic is discussed thoroughly in two standard references on fish kill investigations (Meyer and Barclay, 1990; American Fisheries Society, 1992). Some considerations listed in these guides, and pertinent to our compilation are: 1) kills are more likely to be observed in warmer weather; 2) most fish species are more abundant in the warmest months, so larger kills might be expected then regardless of other factors; 3) most kill counts are underestimates; 4) causes may be complex, and often difficult or impossible to establish by observations and sampling after the fact; 5) some "kills" may be due not to habitat conditions but to other causes such as commercial fishing activity or fish behavior (e. g., spillage from nets or stranding); and

6) locations where kills are observed may not be where the kills or any underlying water quality problems originate. Another complication is that, in addition to seasonal trends in abundance, most species in the study area have cyclic long-term (years) changes in abundance. Long term population change can also influence incidence or sizes of kills (as could spatial variations in abundance).

For kills due to water quality impairments, the often ephemeral nature of the contributing conditions can increase the difficulty of detecting causes, and drawing conclusions about water quality trends. For example, bloom development which can cause precipitous change in water quality, may be short-term, often on the order of 1-2 weeks. Also, blooms can cause DO supersaturation during the day, whereas at night algal respiration can reduce oxygen drastically. Evidence for causes of kills involving some toxic chemicals may be similarly ephemeral, e. g., most pesticides are now short-lived and difficult to detect in water soon after application (Engel and Thayer, 1998).

Critique of Fish Kill Assessment in the Hudson-Raritan Estuary

Despite the Hudson-Raritan estuary's history of environmental perturbation (including high toxic contaminants burdens; chronic phytoplankton blooms and hypoxia events) fish kills during the study period with two exceptions were found to be relatively minor. However, although fish kill investigations in the area by various agencies have improved greatly in recent years, most incidents were not assessed in accordance with accepted guidelines such as developed by the American Fisheries Society (1992). Kill estimates were based on short term, shoreline sampling, not throughout the kill duration and over the water body and sub-surface. The investigations lacked a consistent, complete approach -- including analyses for toxic contaminants (metals, organics) and pathology examinations beyond gross external pathology. Sublethal effects of blooms, hypoxia and other water quality impairments on resident fish were not assessed. Poor water quality can retard growth of fishes, e. g., juvenile winter flounder (Bejda et al., 1992), or can cause avoidance of areas that may otherwise be valuable habitat (Pihl et al., 1991). Most mortality assessments focused on finfish. However, conditions that cause fish kills can also be detrimental to other components of the biota including invertebrates (Pihl, 1994). Large numbers of dead invertebrates were noted in the July 1992 kill, including blue crabs, *Callinectes sapidus,* lady crabs, *Ovalipes ocellatus*, sand shrimp, *Crangon septemspinosa*, grass shrimp, *Palaemonetes* spp., and soft clams, *Mya arenaria.* The varied sources and quality of fish kill reportage included in our compilation reflect a lack of a central, organized, fish kill data-base, such as recommended by Burkholder et al. (1995). The American Fisheries Society (1992) advised that regular monitoring using established protocols is necessary for documentation of fish kills and the conditions leading to them. Burkholder et al. (1999) advised that strong strategies in response to fish kills and epizootics must incorporate sound field data, experimental testing, and careful interpretation of data.

Fish kill studies in our study area would benefit from increased commitment and coordination among the several agencies with responsibilities for water quality and marine living resources (e. g., U.S. Environmental Protection Agency, National Marine Fisheries Service, U.S. Fish and Wildlife Service, state departments of environmental protection and county departments of health). One reason particular environmental agencies may have difficulty in responding to emergency situations is that funding and personnel are usually committed on the basis of planned rather than emergency activities. Pooling of responsibilities, expertise, and resources by several government agencies could alleviate this.

ACKNOWLEDGEMENTS

We thank A. Draxler, S. A. Fromm, L. Arlen and L. Stehlik, NMFS, James J. Howard Marine Sciences Laboratory (HL), W. Andrews, NJDEP, Division of Fish and Wildlife, E. Cosgrove, Monmouth County, NJ, Department of Health, and R. Braun and H. Grebe, USEPA, Region 2, Surveillance and Monitoring Branch, for fish kill investigations data. We also thank B. Phelan (HL)for data on winter flounder densities; C. Zetlin (HL) for the map of the Hudson-Raritan estuary showing kill locales; and L. Stehlik, F. Steimle, and J. Vitaliano (all HL), and G. Wikfors, NMFS, Milford Laboratory, for helpful comments on the manuscript.

LITERATURE CITED

AMERICAN FISHERIES SOCIETY. 1992. Investigation and valuation of fish kills. *Amer. Fish. Soc. Spec. Publ.* 24. 96 pp.

BEJDA, A. J., B. A. PHELAN, AND A. L. STUDHOLME. 1992. The effect of dissolved oxygen on the growth of young-of-the-year winter flounder, *Pseudopleuronectes americanus. Environ. Biol. of Fishes* 34:321-327.

BIGELOW, H. B., AND W. C. SCHROEDER. 1953. Fishes of the Gulf of Maine. *Fish. Bull.* 53. 577 pp.

BRETELER, R. 1984. Introduction and summary of findings. Pp. 1-4 *in* R. Breteler (ed.) 1984. *Chemical Pollution of the Hudson-Raritan Estuary*. NOAA Tech. Mem. NOS OMA 7. 72 pp.

BRONGERSMA-SANDERS, M. 1957. Mass mortalities in the sea. Pp. 941-1010 *in* Hedgepeth, J. W. (ed.). *Treatise on Marine Ecology and Paleoecology*, Vol. 1, *Geol. Soc. Amer. Mem.* 67.

BROSNAN, T. M., AND M. L. O'SHEA. 1996. Long-term improvements in water quality due to sewage abatement in the lower Hudson River. *Estuaries* 19:890-900.

BUCKLEY, J. 1989. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic). Winter flounder. *U. S. Fish and Wildlife Service, Biological Report* 82(11.87). 12 pp.

BURKHOLDER, J. M., H. B. GLASGOW, Jr., AND C. W. HOBBS. 1995. Fish kills linked to a toxic ambush-predator dinoflagellate: distribution and environmental conditions. *Mar. Ecol.* 124:43-61.

BURKHOLDER, J. M., M. A. MALLIN, AND H. B. GLASGOW, Jr. 1999. Fish kills, bottom-water hypoxia, and the toxic *Pfiesteria* complex in the Neuse River and Estuary. *Mar. Ecol*. 179:301-310.

DRAXLER, A. F. J., R. WALDHAUER, A. MATTE AND J. B. MAHONEY. 1984. Nutrients, hydrography, and their relationship to phytoflagellates in the Hudson-Raritan estuary. *Bull. N.J. Acad. Sci.* 29: 97-120.

ENGEL, D. W., AND G. W. THAYER. 1998. Effects of habitat alteration on blue crabs. *J. Shellf. Res*. 17:579-585.

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION, U.S. Dept. Of the Interior. 1967. Conference on Pollution of Raritan Bay and Adjacent Interstate Waters. Third Session. Proceedings, Vol. 1. New York. 448 pp.

INTERSTATE SANITATION COMMISSION. 1997. 1996 Report of the Interstate Sanitation Commission on the Water Pollution Control Activities and the Interstate Air Pollution Program. 91 pp.

JEFFRIES, H. P. 1962. Environmental characteristics of Raritan Bay, a polluted estuary. *Limnol. Oceanogr. 7:21-31.*

JOHNSON, D. A., AND B. L. WELCH. 1985. Detrimental effects of *Ulva lactuca* (L.) exudates and low oxygen on estuarine crab larvae. *J. Exp. Mar. Biol. Ecol.* 86:73-83.

KELLER, A. A., AND K. S. SQUIBB. 1992. Review of effects and interactions of hypoxia and toxic chemicals. *U. S. EPA Region II*, *New York-New Jersey Harbor Estuary Program Module 4.1: Nutrient and Organic Loading.* Final Report. 201 pp.

LOWE, J. A., D. R. G. FARROW, A. S. PAIT, S. J. ARENSTAM, AND E. F. LAVAN. 1991. Fish kills in coastal waters. *NOAA Strategic Environmental Assessments Division Report.* 69 pp.

MAHONEY, J.B., F. H. MIDLIGE AND D. G. DEUEL. 1973. A fin rot disease of marine and euryhaline fishes in the New York Bight. *Trans. Amer. Fish. Soc.* 102:596-605.

MAHONEY, J. B., AND J. J. A. McLAUGHLIN. 1977. The association of phytoflagellate blooms in Lower New York Bay with hypertrophication. *J. Exp. Mar. Biol. Ecol.* 28:53-65.

MAY, E. B. 1973. Extensive oxygen depletion in Mobile Bay, Alabama. *Limnol. Oceanogr.* 3:353-366.

MEYER, F. P., AND L. A. BARCLAY, eds. 1990. Field Manual for the Investigation of Fish Kills. U. S. Fish and Wildlife Service, *Resource Publication* 177. 120 pp.

MUELLER, J. A., T. A. GERRISH, AND M. C. CASEY. 1982. Contaminant inputs to the Hudson-Raritan Estuary. National Atmospheric and Atmospheric Administration (NOAA) Tech. Mem. OMPA-21. 192 pp.

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION (NJDEP). 1982 to 1999, inclusive. Annual summary of phytoplankton blooms and related conditions in New Jersey coastal waters, summers of 1982 to 1999, inclusive. NJDEP, Water Monitoring Management, Trenton, NJ.

NEW YORK CITY DEPARTMENT OF ENVIRONMENTAL PROTECTION. 1998. 1997 New York Harbor Water Quality Survey. Bureau of Wastewater Pollution Control, Marine Sciences Section, Wards Island, NY 10035-6096. 66 pp.

O'CONNOR, J. S., J. A. RANASINGHE, AND D. A. ADAMS. 1998. Temporal change in sediment quality of the New York Harbor area. *Bull. N.J. Acad. Sci.* 43:1-6.

OLSEN, P., AND, M. COHN. 1979. Phytoplankton in Lower New York Bay and adjacent New Jersey estuarine and coastal areas. *Bull. N. J. Acad. Sci.* 24:59-70.

OLSEN, P., AND, J. MAHONEY. 1986. Monitoring red tides in New Jersey. *N. J. Outdoors* 13:5-7.

OLSEN, P. S., AND R. MULCAHY. 1991. In the Hudson-Raritan estuary, recurrent red tide blooms dominated by *Katodinium rotundatum* are associated with hypoxia and consequent fauna kills. Poster Session, Abstract (pg. 90). Fifth International Conference on Toxic Marine Phytoplankton, Newport, RI, October, 1991.

OVIATT, C. A., A. L. GALL, AND S. W. NIXON. 1972. Environmental effects of Atlantic menhaden on surrounding waters. *Ches. Sci.* 13:321-323.

PIHL, L. 1994. Changes in the diet of demersal fish due to eutrophication-induced hypoxia in the Kattegat, Sweden. *Can. J. Fish. Aquat. Sci.* 51:321-336.

PIHL, L., S. P. BADEN, AND R. J. DIAZ. 1991. Effects of periodic hypoxia on distribution of demersal fish and crustaceans. *Mar. Biol.* 108:349-360.

REINTJES, J. W., AND A. L. PACHECO. 1966. The relation of menhaden to estuaries. *Amer. Fish. Soc. Spec. Publ.* 3:50-58.

ROGERS, S. G., AND M. J. VAN DEN AVYLE. 1989. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic). Atlantic menhaden. *U. S. Fish and Wildlife Service, Biological Report* 82(11.108). 23 pp.

SINDERMANN, C. J. 1979. Pollution-associated diseases and abnormalities of fish and shellfish: a review. *Fish. Bull.* 76:717-749.

SWANSON, R. L., AND C. J. SINDERMANN. 1979. Oxygen depletion and associated benthic mortalities in New York Bight, 1976. *NOAA Professional Paper* 11. 345 pp.

US ENVIRONMENTAL PROTECTION AGENCY (USEPA). 1989. New York Bight water quality, summer of 1988. Annual Report, USEPA, Region II, Surveillance and Monitoring Branch, Edison, NJ.

US ENVIRONMENTAL PROTECTION AGENCY (USEPA). 1994. New York Bight water quality, summers of 1992-1993. Annual Report, USEPA, Region II, Surveillance and Monitoring Branch, Edison, NJ.

USEPA, NOAA, USDA, USGS, USDHHS, ASIWPCA. 1998. What you should know about *Pfiesteria piscicida*. U. S. Environmental Protection Agency, U. S. Department of Commerce, National Oceanic and Atmospheric Administration, U. S. Department of Agriculture, United States Geological Survey, U. S. Department of Health and Human Services, Association of State and Interstate Water Pollution Control Administrators. EPA Document No. 842-F-98-011, 5p.

WHYTE, J. N. C., N. G. GINTHER, AND L. J. KEDDY. 1999. *Heterosigma carterae*, a major killer of pen-reared salmon in British Columbia. Proceedings of the Sixth Canadian Workshop on Harmful Marine Algae. Can. Tech. Rep. of Fish. and Aquat. Sci. No. 2261:1-9.

WILK, S. J., R. A. PIKANOWSKI, D. G. McMILLAN, AND E. M. MacHAFFIE. 1998. Seasonal distribution and abundance of 26 species of fish and megainvertebrates collected in the Hudson-Raritan Estuary, January 1992-December 1997. *Northeast Fisheries Science Center Reference Document 98-10.* 145 pp.

ZDANOWICZ, V. S., D. F. GADBOIS, AND M. N. NEWMAN. 1986. Levels of organic and inorganic contaminants in sediments and fish tissues and prevalences of pathological disorders in winter flounder from estuaries of the Northeast U.S., 1984. Pp. 578-585 *in* Oceans '86 Conference Proceedings, Vol. 2, IEEE, Marine Technology Society, Piscataway, NJ.

Table 1. Fish kills reported for Raritan and Sandy Hook Bays and the Shrewsbury and Navesink Rivers, NJ, 1982-2001. Information is from NJ Department of Environmental Protection, Bureau of Water Monitoring annual reports, except as footnoted. Atlantic menhaden = *Brevoortia tyrannus;* pipefish = *Syngnathus fuscus;* puffer = *Sphoeroides maculatus*; searobin = *Prionotus* spp.; silversides = *Menidia menidia;* summer flounder = *Paralichthys dentatus*; winter flounder = *Pseudupleuronectes americanus*; windowpane flounder = *Scophthalmus aquosus.*

Dates	**Location**	**Species and (approximate numbers)**	**Attributed to:**
"Early summer" 1982	Sandy Hook Bay	Not reported	Decomposing organic matter in water?
7/23/84	Sandy Hook Bay	Menhaden (several thousand)	Spillage from pound nets?
7/8/87	Shrewsbury River	Not reported	Low DO from decomposing phytoplankton bloom?
6/22/88-6/28/88[1,2]	Sandy Hook Bay	Primarily demersal species: sea robin, summer flounder, winter flounder, etc. (possibly 1 million fish)	Localized hypoxia created by wind and tidal concentration of phytoplankton from bloom of *Heterosigma carterae*, *Katodinium rotundatum, Eutreptia lanowii* and detrital material; toxic substances suspected.
7/22/88[3]	Sandy Hook Bay	Menhaden (hundreds to thousands)	Low dissolved oxygen or spillage from pound nets?
8/1/88-8/3/88	Sandy Hook Bay	Winter and windowpane flounder (not counted)	Bloom of *K. rotundatum, E. lanowii, Prorocentrum triestinum*, low dissolved oxygen.
7/29/89[4,5]	Sandy Hook Bay	Menhaden (1,000)	Bloom of *K. rotundatum*; low DO (0.84-1.68 ml/l).
6/18/90[6]	Branchport Creek (tributary of Shrewsbury River)	Not reported	Apparent low DO due to decomposing phytoplankton bloom.[4]
7/30/90[1]	Sandy Hook Bay	Menhaden (3,000)	Speculation: pound net spillage or low DO?

Table 1. Continued.

Dates	Location	Species and approximate numbers	Attributed to:
6/13/92-6/19/92[7]	Raritan River, Arthur Kill, Kill van Kull, Newark Bay	Menhaden (not reported)	Not reported.
7/21/92[1]	Cliffwood Beach NJ (western Raritan Bay)	Juvenile winter flounder (10,000), windowpane flounder (1000), pipefish, puffer, searobin, summer flounder (few), various invertebrates[6]	Low DO (4 samples, avg. 2.5 ml/l); moderate high temperature (24.1°C); bloom of *Heterosigma carterae.*
7/20/95-7/21/95[1,6]	Cliffwood Beach	Juvenile winter flounder (50,000), summer flounder (300), silversides (150); blue crabs	Low DO (1.4-2.8 ml/l); high temperature (to 29.5°C); decomposition of dense *Heterosigma carterae* bloom.
7/29/99[6,8]	Navesink River	Juvenile Menhaden (several hundred)	Low DO (3 samples, avg. 1.18 ml/l); high temperature (to 29.3°C); bluefish observed chasing menhaden into shallows.
9/10/99[6,8]	Waackaack and Thorns Creeks (Keansburg/Union Beach)	Juvenile Menhaden (250,000 to 500,000)	Low DO (-?,no data); fish trapped behind floodgates.
7/20/00[9]	Lanes Creek, Shrewsbury River	Juvenile menhaden (30,000)	Low DO (at~1 m, 1.71 ml/l; temperature 26°C).
7/20/00[9]	Little Silver Creek, Shrewsbury River	Juvenile Menhaden (3.9 million)	Low DO (0.98 ml/l).

[1]James J. Howard Marine Sciences Laboratory investigation.
[2]Asbury Park (NJ) Press, 6/30/88, in addition to NJ DEP annual report.
[3]U. S. Environmental Protection Agency, Region II, observations, (USEPA, 1989).
[4]Olsen and Mulcahy (1991).
[5]Asbury Park (NJ) Press, 7/31/89, in addition to NJ DEP annual report.
[6]Monmouth County (NJ) Department of Health investigation.
[7]U. S. Environmental Protection Agency, Region II, observations, (USEPA, 1994).
[8]Asbury Park Press, 9/14/99.
[9]NJDEP Division of Fish and Wildlife investigation.
[10]blue crabs, lady crabs, sand shrimp, grass shrimp, soft clams.

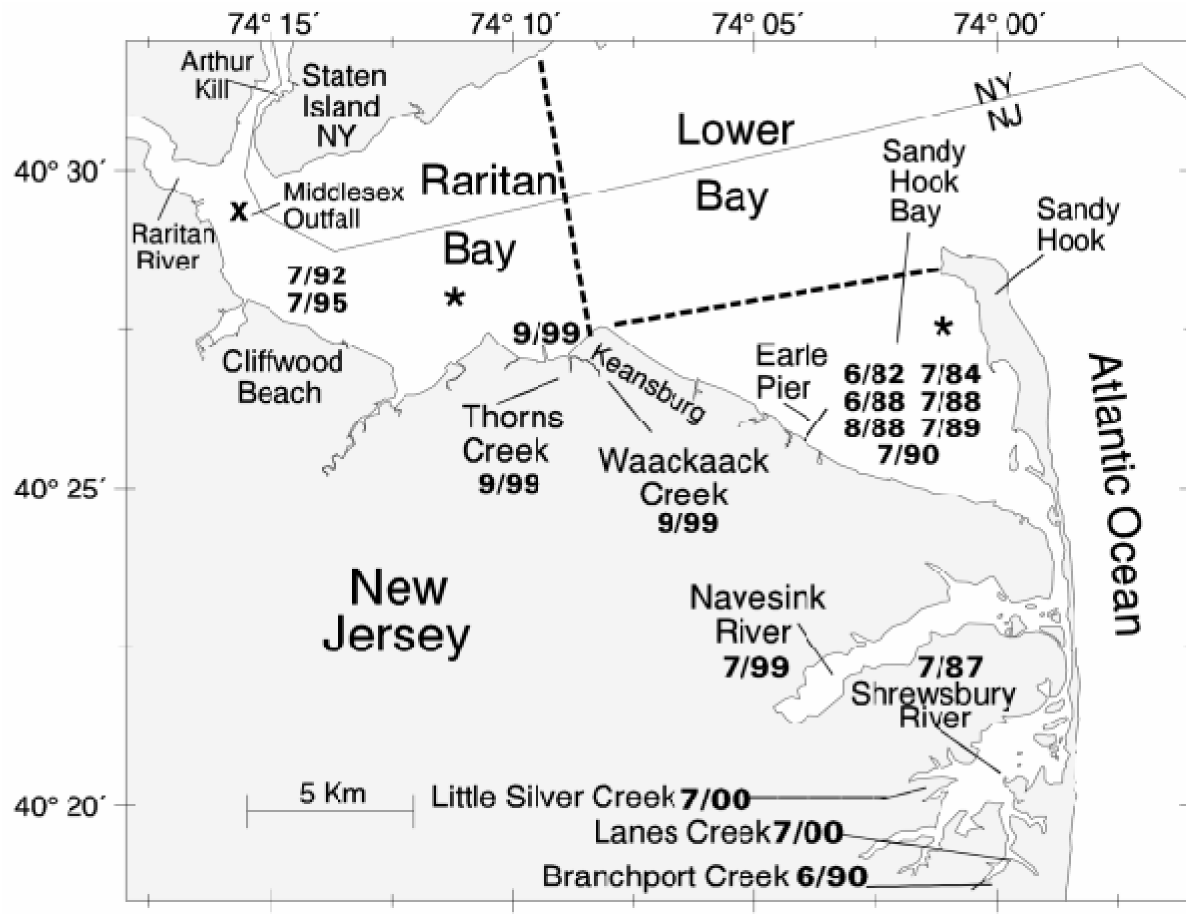

Figure 1. Logical Area of study (Sandy Hook Bay, NJ waters of Raritan Bay, and Navesink and Shrewsbury rivers), with dates and locations of kills indicated. The dashed line separates Sandy Hook Bay from the rest of the Hudson-Raritan estuary. Asterisks are U.S. EPA helicopter sampling stations.

Research Communications Unit
Northeast Fisheries Science Center
National Marine Fisheries Service, NOAA
166 Water St.
Woods Hole, MA 02543-1026

MEDIA MAIL

Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in four categories:

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series typically includes: data reports of long-term field or lab studies of important species or habitats; synthesis reports for important species or habitats; annual reports of overall assessment or monitoring programs; manuals describing program-wide surveying or experimental techniques; literature surveys of important species or habitat topics; proceedings and collected papers of scientific meetings; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing.

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series typically includes: data reports on field and lab studies; progress reports on experiments, monitoring, and assessments; background papers for, collected abstracts of, and/or summary reports of scientific meetings; and simple bibliographies. Issues receive internal scientific review, but no technical or copy editing.

Fishermen's Report -- This information report is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of this report.

The Shark Tagger -- This newsletter is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of this newsletter.

OBTAINING A COPY: To obtain a copy of a *NOAA Technical Memorandum NMFS-NE* or a *Northeast Fisheries Science Center Reference Document*, or to subscribe to the *Fishermen's Report* or the *The Shark Tagger*, either contact the NEFSC Editorial Office (166 Water St., Woods Hole, MA 02543-1026; 508-495-2228) or consult the NEFSC webpage on "Reports and Publications" (*http://www.nefsc.nmfs.gov/nefsc/publications/*).

ANY USE OF TRADE OR BRAND NAMES IN ANY NEFSC PUBLICATION OR REPORT DOES NOT IMPLY ENDORSEMENT.