Recurring Mass Mortalities of Caribbean Herrings: Implications for the Study of Major Marine Ecological Disturbances

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Abstract. — Numerous major marine ecological disturbances (MMEDs) occurred in the greater Caribbean region in the 1980s. There have been sporadic mass mortalities of herrings Harengula spp. throughout this period. Although information is too limited to suggest a cause, these events seem to represent a recurring MMED, which may not be limited to the Atlantic. More data concerning past herring mortalities and specimens from new bouts are solicited through this alert. Approaches used to understand simple epizootics are not adequate for examining MMEDs. Experimental work is too limited, and reference specimens are often not available. A correlation of the observations of many observers is suggested for following these events. These disturbances seem to be increasing in size and number, may be interrelated,
and may be indicators of global or climatic change or deterioration of the marine environment. Establishment of an alert and communications center to follow MMEDs is suggested.

In 1980, millions of individuals of numerous Caribbean fish species perished (Atwood 1981; Williams et al. 1982; Williams and Williams 1987); in 1983, 1987–1988, and 1989, corals, sponges, anemones, and other coral reef animals bleached and some died (Glynn 1984; Williams and Bunkley-Williams 1990a, 1990c); in 1983–1984, 95–98% of the ecologically important black, long-spined sea urchin *Diadema antillarum* died (Lesios et al. 1984; Williams and Williams 1987; Williams and Bunkley-Williams 1990a); and a white band disease epizootic beginning in the late 1970s drastically reduced the populations of two of the most rapidly growing Caribbean reef-building corals (Williams and Bunkley-Williams 1990a). All of these still-unexplained mass mortalities (time-related deaths of 1,000 or more organisms) affected the entire greater Caribbean region. Williams and Bunkley-Williams (1990a) defined these and other large-scale (involving more than a few square kilometers of area) disruptions as major marine ecological disturbances (MMEDs)—events which can occur over a short (3–27-d), intermediate (more than 1 month, but less than 1 year), or long (longer than 1 year) term (the complete interval from outbreak through recovery or death). Many lesser disturbances also occurred during the 1980s (Williams and Bunkley-Williams 1990a).

Mass mortalities of herrings *Harengula* spp. occurred in the Caribbean throughout the 1980s. We have attempted to find the pathogen responsible for this disturbance; however, these events may be more complicated than simple outbreaks of a disease and may be related to the recent series of MMEDs (Williams and Bunkley-Williams 1990a).

Understanding how recent herring mortalities in the Caribbean may be related to other MMEDs is important. More information is needed about present and past mass kills of these fishes. Fresh specimens are needed for disease examination and for determination of patterns, significance, and causes. The Caribbean Aquatic Animal Health Project (telephone: 809-899-2048, extension 211; fax, 809-899-5500) is attempting to follow these regional disturbances as well as the worldwide coral reef bleaching (Williams and Bunkley-Williams 1990a), the recent die-off (death of 3 of 999 organisms in an event) of brown pelicans *Pelecanus occidentalis* in the northern and southern Caribbean, and a die-off of Atlantic spotted dolphins *Stenella frontalis* in Puerto Rico and Colombia. Examination of the herring MMED may be used to illustrate how these disturbances can be investigated and how their possible connection to global changes may be explored.

**Methods**

**Alert and communications.** —Our tentative method of following MMEDs (Williams and Bunkley-Williams 1990a) is to publish a letter (Williams et al. 1987; Williams and Bunkley-Williams 1990b, 1990c) or commentary (present paper) in a national or international journal, based on the early reports of field biologists. This initial publication serves to define the problem and elicit sufficient interest to stimulate further response to a questionnaire soliciting details of the event. In addition, samples from and details about additional bouts (smallest identifiable unit, part of an event) of the MMED may be provided by field biologists after they are alerted to the significance of the event. Only through the observations of many field scientists can sufficient data be obtained to understand MMEDs. Laboratory diagnostic services, often geographically distant from the event, and limited experimental work cannot be expected to determine the causes of these complex and highly variable events.

**Herring samples.** —The Fisheries Division of the Department of Agriculture, St. Kitts, West Indies, sent frozen samples and preserved samples (10% formalin) of moribund false pilchard *Harengula clupeola* to our laboratory on 18 April 1988, and the Bellairs Research Institute, Barbados, West Indies, sent samples frozen on dry ice to L.B.-W. at the Department of Fisheries and Allied Aquacultures, Auburn University, Auburn, Alabama, on 15 June 1989. Fresh, moribund samples on ice or alive would have been preferable for disease diagnosis.

**Postmortem examinations.** —Five fish from each of the 1988 and 1989 samples were examined for parasites. Specimens of a species of Digenea recovered from both samples are being examined (W. G. Dyer, Southern Illinois University, Personal communication). Three preserved fish from the 1988 sample were embedded in paraffin, sectioned, and stained with hematoxylin and eosin. Transverse sections through the head and trunk were examined under a light microscope. To determine the presence of bacteria, samples of kidney and brain were taken aseptically and placed on tryptic soy agar (1988 samples) and brain–heart infusion agar with 5% NaCl (1989 samples). To
determine the involvement of viruses in the 1989 sample, kidneys, livers, and spleens of three fish were pooled, homogenized, and diluted 1:100 in Hanks’ balanced salt solution. The homogenate was centrifuged at 2,100 × gravity, and the supernatant passed through a 0.45-μm-pore filter. The filtrate was inoculated into 24-well plates (0.1 mL per well and four wells per pooled sample) containing cell monolayers of either chinook salmon embryo (CHSE-214) or fathead minnow (FHM). The CHSE-214 cells were incubated at 20°C and the FHM cells at 30°C for 7-10 d. During this incubaion period, the inoculated cultures were periodically examined for cytopathic effect (CPE).

Herring Mass Mortalities

Based on reports received from local fisheries officers (Table 1), millions of herrings perished in mass mortalities at different Caribbean locations during the 1980s (Figure 1). These recurring mass kills apparently affected only clupeids in one genus (false pilchard, redear sardine Harengula humeralis, and scaled sardine, H. jaguana). These fishes are commercially fished in Cuba and the Dominican Republic (Whitehead 1978) and are used as bait and food throughout the West Indies. Affected herrings swim erratically near the surface and were lethargic enough to be easily collected. The mass mortalities for which we have information may have been caused or aggravated by increased seawater temperatures because they occurred during either the warmer periods of the year or when seawater temperatures were elevated in 1987 (Williams and Bunkley-Williams 1990a). However, hyperthermia would affect other species and would not occur in such a complex pattern (Figure 1; Table 1). Bleaching of coral reefs was associated with elevated seawater temperatures in 1987, but bleaching was not reported from the areas where herring mass mortalities occurred in 1987 (Williams and Bunkley-Williams 1990a). Episodes of herring mortality were disjunct over time and geographic location (Figure 1) and sometimes affected millions of fish around entire islands; other times they were restricted to a single bay. To date, herring die-offs have not occurred over the entire region at the same time. Losses are apparently limited to herrings, suggesting a host-specific pathogen. Our examination of samples from the 1988 and 1989 kills revealed no bacterial infection, no lesions were found histologically, and only one to two digenetic flukes were found per host (an insufficient number to cause mortalities). Attempts were made to isolate viruses from frozen samples, but CPE was not observed in either the CHSE-214 or FHM cells. Fresh samples or clupeid cell lines, or both, may be necessary for a more thorough search for a virus.

We suspect that many other herring mortalities have occurred, but are unreported. The cases known to us (Figure 1) are probably more indicative of the locations of active fishery biology programs and marine laboratories than the actual number and locations of kills. We are distributing a questionnaire on herring mass mortalities to try to determine the extent and seriousness of these events.

Relations among Major Marine Ecological Disturbances

Relationships among MMEDs would be of particular interest. In 1985, mortalities of herrings occurred in Alaska in June (Meyers et al. 1986) and in Puerto Rico in August (Figure 1). In May and June of 1989, mortalities of herrings occurred

<table>
<thead>
<tr>
<th>Location (source)</th>
<th>Time</th>
<th>Size</th>
<th>Duration</th>
<th>Species</th>
<th>Abnormal behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Venezuela (1)</td>
<td>Early 1980</td>
<td>Large-scale?</td>
<td>Unknown</td>
<td>Harengula sp.</td>
<td>NO</td>
</tr>
<tr>
<td>Curacao (1)</td>
<td>Early 1980</td>
<td>Large-scale?</td>
<td>Unknown</td>
<td>Harengula sp.</td>
<td>NO</td>
</tr>
<tr>
<td>Puerto Rico (2)</td>
<td>Aug 1985</td>
<td>Undetermined</td>
<td>Few days?</td>
<td>H. jaguana</td>
<td>+</td>
</tr>
<tr>
<td>St. Eustatius, St. Kitts, and Nevis (3)</td>
<td>Nov-Dec 1987</td>
<td>Large-scale</td>
<td>3 weeks</td>
<td>H. clupeola</td>
<td>+</td>
</tr>
<tr>
<td>St. Kitts (3)</td>
<td>Apr 1988</td>
<td>Small-scale</td>
<td>Several days</td>
<td>H. clupeola &amp;</td>
<td>+</td>
</tr>
<tr>
<td>St. Vincent (3)</td>
<td>May 1989</td>
<td>Large-scale?</td>
<td>Unknown</td>
<td>Harengula sp.</td>
<td>+</td>
</tr>
<tr>
<td>Barbados (4)</td>
<td>Jun 1989</td>
<td>Large-scale</td>
<td>10-15 d</td>
<td>H. clupeola &amp;</td>
<td>+</td>
</tr>
</tbody>
</table>

a Source: 1 = Atwood, 2 = Sadovy, 3 = Wilkins, 4 = Sealy. See captions for Figure 1 for full names and affiliations of sources.

b + = fish observed swimming near surface and lethargic. NO = not observed.

c Around the islands and 5-10 mi offshore.

d Basseterre Bay.

e Examined by the authors.
in two locations in Alaska (Ingledue 1989; Meyers 1989a, 1989b, 1989c) and in St. Vincent and Barbados in the Caribbean (Figure 1). The similar timing of these MMEDs may only be a coincidence, but worldwide coral reef bleaching (Williams and Bunkley-Williams 1990a) and epizootic ulcerative syndromes (Sindermann 1988) were at first characterized by such disjunct and widely separated events that they were not recognized as large-scale disturbances. An MMED of Hawaiian diademidid sea urchins occurred in 1981 (Birkeland 1989), prior to the *Diadema antillarum* MMED in the greater Caribbean region in 1982–1984, a die-off of *Astropyga magnifica* (another diademidid) in Puerto Rico in 1985 (Williams et al. 1986), and more recent *D. antillarum* die-offs in St. Croix and Panama in 1985 (Lessios 1988). Each of these occurrences shared similar signs among the dying urchins (Lessios et al. 1984; Williams et al. 1986; Birkeland 1989), but no cause has been established for these events, and no relationship has been demonstrated.

Additional bouts of coral reef bleaching (Williams and Bunkley-Williams 1990a) and a die-off of brown pelicans occurred in the Caribbean in spring 1989. During the 1987–1988 coral reef bleaching events, numerous other MMEDs occurred, such as mass mortality of seals in Lake Baikal; mass mortality of bottlenose dolphins *Tursiops truncatus* and commercial oysters along the east coast of the USA; fish and shellfish kills along the northeastern USA; sponge mortalities and sea grass blight in south Florida; an epizootic of black band disease in the Florida Keys; mass mortality of fishes off Norway; die-offs of humpback whales *Megaptera novaeangliae* and minke whales *Balaenoptera acutorostrata* off New England; mass mortality of abalone *Haliotis* spp. along the west coast of the USA; amnesic shellfish poisoning in Canada and possibly worldwide; massive red tides off North Carolina, Hong Kong, Kuwait, and Norway; a distemper epizootic among harbor seals *Phoca vitulina* in the North Sea; eelgrass wasting disease in North America and Europe (Williams and Bunkley-Williams 1990a); and some of the herring kills (Figure 1). We must not only begin to recognize regional and worldwide disturbances, but even hierarchies and classifications of these different large-scale MMEDs.

**New Research Directions**

Aquatic animal health has traditionally focused on discovering and characterizing diseases. This direct approach does not seem to be adequate for understanding MMEDs, which may represent general conditions or environmental changes rath-
er than single diseases. Diseases occurring during these events are signs of the condition, and more than one disease can predominate at different times during the same MMED. In the 1987–1988 mass mortality of bottlenose dolphins, a variety of diseases was isolated. Geraci (1989) finally designated red tide toxins as the cause, although others disagreed (Hersh 1989a, 1989b). A pathogen, Labryrinthula sp. (Labyrinthulomycota), was isolated in the recent eelgrass wasting disease epizootic, but the cause of this large-scale event seems to be more complicated (L. K. Muehlstein, University of the Virgin Islands, personal communication). Several pathogens were isolated from bleached corals (Williams and Bunkley-Williams 1990a; R. Heard, Gulf Coast Research Laboratory, personal communication), but none appear to cause large-scale bleaching events.

Many MMEDs have been underexamined. These events spring up quickly, without warning, and often proceed and end just as quickly (Atwood 1981; Williams et al. 1986; Williams et al. 1987; Williams and Williams 1987). The tendency to seek simple, quick explanations for MMEDs may cause us to overlook the complexity of these events. Some of the diseases being blamed for MMEDs are common ailments, known for years in the affected organisms, and are not likely to cause such widespread phenomena under normal circumstances (e.g., bacteria in Diadema antillarum [Bauer and Agerter 1987] and virus in seals [Hersh 1989a]). Such MMEDs as coral reef bleaching, mass fish mortalities in the Atlantic in 1980 (Atwood 1981; Williams and Williams 1987), and D. antillarum mass mortality (Lessios et al. 1984; Williams and Williams 1987), which lack readily identifiable causes, have forced us to realize the complexity of these problems. Recurring MMEDs (separate events of the same kind that occur on two or more occasions), such as coral reef bleaching and herring mortalities, are providing more opportunities to examine these events. As we develop the ability to predict MMEDs from the patterns of their occurrence (Williams and Bunkley-Williams 1990a, 1990c), from preceding events (Williams and Bunkley-Williams 1990a, 1990c), or from the first indicators of a potential MMED (such as mortalities of Atlantic spotted dolphins, Williams and Bunkley-Williams, unpublished data), we will be able to obtain even more information about these phenomena.

The physical sciences have made great strides in advancing the study of global changes with remote sensing (U.S. Global Change Research Pro-

gram 1990), but biology has lagged behind. If global changes or other large-scale forces are already causing biological problems in the form of MMEDs, a method is needed to document this relationship. Changes in sensitive ecosystems such as coral reefs provide opportunities to examine possible correlations between biological disturbances and physical factors. We must design rating systems for spatial and temporal patterns in each MMED so that existing measurements of physical effects can be more accurately compared with the extent and severity of MMEDs. Glyn and D’Croz (1990) began such a system for the 1983 coral reef bleaching event in the eastern Pacific. They correlated exact extent and seriousness of bleaching in certain locations directly with temperature increases; however, their attempt was too small in scale to explain the 1982–1983 worldwide coral reef bleaching event, and their technique was too laborious and complicated to be applied across large-scale events. Simple, quick, but accurate, ranking systems are needed to evaluate MMEDs. They must not be too time-consuming to use and must not be size-limited. Once local or regional portions of events can be compared, possible correlation with physical effects can be accurately tested.

Lessios (1988) suggested that the coincidence of coral reef bleaching and Diadema antillarum mass mortality in 1983 was by chance. We have received reports in May 1990 of a new outbreak of D. antillarum mortality in one Caribbean location and new coral reef bleaching in five Caribbean and one eastern Pacific locations. Additional coincidences will be necessary before any relationship between these two MMEDs can be suggested. The 1987–1988 and 1989–1990 MMEDs of bottlenose dolphins on the U.S. Atlantic (Geraci 1989) and Gulf coasts, respectively, should also be closely compared.

Williams and Bunkley-Williams (1990a) found that limited preceding coral reef bleaching events occurred one year before major bleaching events in the three complexes (time-related series of events in the same MMED) of coral reef bleaching that they recognized. They used this pattern or cycle (recurring MMED that follows the same or a similar pattern of timing of events during each complex) to predict major bleaching in 1990 from a preceding event in 1989 (Williams and Bunkley-Williams 1990c). The mass mortalities of fishes in Florida in 1979 seem to similarly represent a preceding event for the major mass mortalities of fishes throughout the greater Caribbean region in
1980 (Atwood 1981; Williams et al. 1982; Williams and Bunkley-Williams 1990a). One of the complexes of coral reef bleaching recognized by Williams and Bunkley-Williams (1990a) was also composed of a preceding event in 1979 and a major event in 1980.

A host of other MMEDs were coincident with the worldwide bleaching complex of 1986–1988 (Williams and Bunkley-Williams 1990a). One cannot propose that these represent colossal, interrelated MMEDs on the scanty evidence available, but these coincidences underscore the need to study MMEDs as a discipline.

**Alert and Communications Center**

We are attempting to establish an "Alert and Communications Center" to monitor major marine ecological disturbances. This center should receive early reports of these problems, confirm the existence and extent of problems, predict potential disturbances, and quickly alert the appropriate investigators. These activities should encourage the study, explanation, management, and solution of these problems and aid in fitting them into what appears to be a pattern of ever-increasing number, intensity, and extent of these disturbances. This center could facilitate the search for interrelationships and shared causes among MMEDs and the standardization of reports to establish levels of severity in each MMED location.

An additional benefit resulting from the establishment of this center could be the exploration of their significance in the deterioration of the marine environment and in global changes. A center would coordinate the information from networks of field observers and the efforts of specialty disease laboratories, form a data base of MMED information, and aid in forming cooperative research proposals. Information concerning MMEDs, suggestions, and support would be welcomed.

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