Factors Contributing to the 1999 Mass Mortality of Reef-Associated Fish in Barbados

STEPHAN WILLOUGHBY[1], C. PARKER[1], W. HUNTE[2], V.S. ST. JOHN[3], C.J. ROACH[3], and H. FERGUSON[4]
[1]*Fisheries Division*
Ministry of Agriculture and Rural Development
Princess Alice Highway
Bridgetown, Barbados
[2]*School for Graduate Studies and Research*
University of the West Indies
Cave Hill, St. Michael, Barbados
[3]*Veterinary Diagnostic Laboratory*
Ministry of Agriculture and Rural Development
Pine Plantation, St. Michael, Barbados
[4]*Institute of Aquaculture*
University of Sterling, Scotland

ABSTRACT

During the period August to November 1999, mass mortalities of several species of reef-associated fish were reported at a number of islands in the southern Caribbean, including Tobago, Grenada, Barbados, St. Vincent and the Grenadines. Histopathological and bacteriological studies conducted in Barbados revealed that the fish died from severe disseminated bacteraemic disease caused by the pathogen *Streptococcus iniae* which had not previously been reported in the marine environment in the southern Caribbean. Analysis of satellite imagery indicated that a plume of water originating in the region of the Orinoco River, and characterised by high chlorophyll concentrations and low nocturnal oxygen levels, impacted on Barbados and the neighbouring islands at the time of the fish kill. It is suggested here that several atypical environmental conditions, including elevated sea water temperature, high phytoplankton concentration and reduced oxygen levels worked in concert to stress the fish and increase their susceptibility to *S. iniae*.

KEY WORDS: Pathogen, Oxygen Depletion, *Streptococcus iniae*

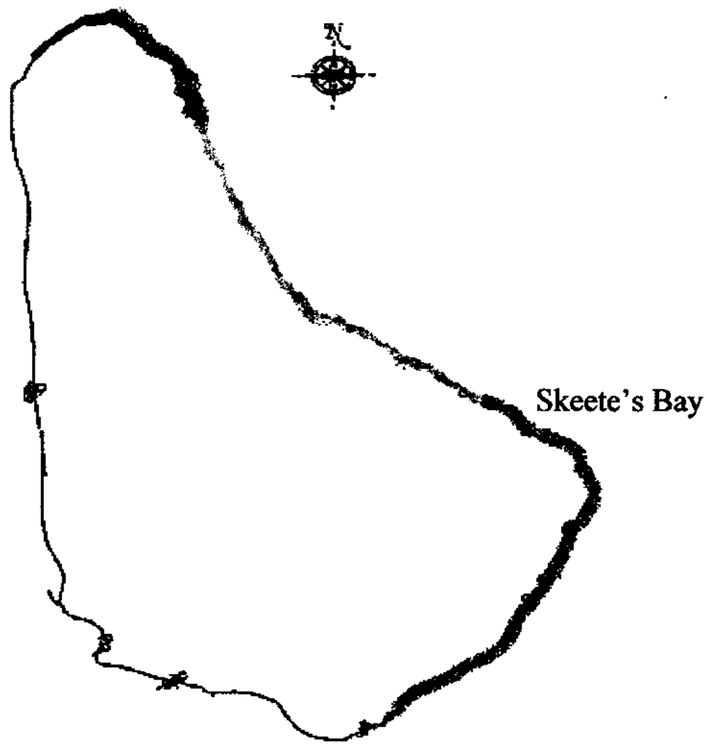
INTRODUCTION

Barbados is the most easterly of the Caribbean islands. It is located at approximately 13^{0}N and 59^{0}W (Figure 1). During the period mid-September to mid-October 1999, large numbers of dead and moribund fish were deposited on the beaches in Barbados. In the early stages of the mass mortality, fish were deposited on the eastern and southeastern coast beaches, while towards the end of the event, dead fish also washed ashore along the northeast coast (Figure 2).

Figure 1. Map of the eastern Caribbean showing the location of the islands affected by the 1999 fish kill.

Several other islands in the southeastern Caribbean also verbally reported the beaching of thousands of dead and dying fish along their eastern and southeastern Atlantic coasts, from as early as August and continuing into November 1999. The islands reportedly affected were Grenada, St. Vincent, the Grenadine islands and Tobago, (Figure 2).

Local fish kills on the individual islands are common in the southeast Caribbean. Reports of these fish kills are not usually published, but the Fisheries Officials in Grenada, St. Vincent, Tobago and Barbados have confirmed the occurrence of such events in their respective countries (pers. com. and Heileman Leo, and A. Siung-Chang 1990), while the 1994 mass mortality of reef-associated fish in Barbados was investigated and documented (Alleyne 1998).



Large deposits of fish on beaches - many *freshly dead or dying fish.*

Moderate deposits of fish on beaches – *few freshly dead or dying fish*

Few deposits of dead fish on beaches – *most fish were in an advanced state of decay*

Figure 2. Areas of Barbados where fish were beached during the 1999 fish kill.

The 1999 fish kill in the southeastern Caribbean was unusual in that it was regional affecting several islands almost simultaneously. The only previous report of a regional mass mortality of a marine organism in the Caribbean was that of the black sea urchin *Diadema antillarum* in 1983 - 1984 (Lessios et al. 1984, Hunte et al. 1986). The mortality of *D. antillarum* started in Panama and was distributed throughout the Caribbean by water currents. It is believed to be caused by a species-specific water-borne pathogen.

Based on the results of the bacteriological and histo-pathological examinations of freshly dead and moribund fish collected in Barbados during the 1999 fish kill, Ferguson et al. (in press) concluded that the fish died from severe disseminated bacteraemic disease caused by the pathogenic bacterium, *Streptococcus iniae*. *S. iniae* was isolated in pure culture from inflamed tissues of the gills, epicardium, myocardium, and liver. However, Herman (1990) emphasised that outbreaks of bacterial diseases are seldom the result of a single factor. Consequently, although the bacterium *S. iniae* was the pathogen that ultimately caused the death of the fish, predisposing factors were probably also involved in the epizootic occurrence.

This paper reports the observations made of environmental conditions existing during the 1999 fish kill in Barbados and assesses their possible roles as predisposing factors of the mass mortality.

METHODS

Information about the 1999 fish kill in the southern Caribbean was obtained from several sources, including reports of local and international governmental and non-governmental agencies, observations of personnel of the Barbados Fisheries Division and interviews with local fishermen, divers and members of the public. The Internet was used extensively to access relevant information from individuals, institutions and international agencies, and to obtain information on regional water quality characteristics during the period of the fish kill. The species of fish deposited on the beaches in the affected areas were identified, counted, and necropsies performed on sick, freshly dead and moribund fish samples. A detailed report of the post-mortem investigations of the fish is presented by Ferguson et. al. (in press).

OBSERVATIONS

Beaching of Dead Fish

Available records kept by the Ministry of Health of the Government of Barbados, indicated that an estimated 40 - 45 tons of fish were deposited on the beaches and removed by the Ministry of Health, fishermen and residents, during the clean-up exercise. The fish deposited on the beaches are believed to be less than half of the total fish killed, since divers and fishermen reported that fish deposited on the reefs, and those being carried offshore by the currents and tides, were together more than those deposited on the beaches. Many more fish were observed on the beaches in the early mornings, before the beaches were cleaned, than were deposited during the rest of the day.

Size and Species Composition

Among the affected shallow water reef species, mortality was highest among larger individuals. Forty fish species from 20 families were among the fish beached during the fish kill. The majority of dead fish were surgeon fish (46%), followed by Bermuda chubs (22%), parrot fishes (7%), sea basses (5%) and triggerfishes (4%).

All others species together accounted for only 16% of the fish beached, with individual species in this group accounting for less than 3% of the fish beached. Deep reef fish, coastal and offshore pelagics, and shellfish were not among the organisms deposited on the beaches. Divers also confirmed that these groups were not among the dead fish seen on the seabed.

Gross Anatomical Observations

Examination of the freshly dead or dying fish from the affected area revealed:

i) There were few external lesions such as haemorrhages, ulcerations and/or lesions.
ii) Gills, gut and livers were pale in colour.
iii) The gastro-intestinal tract of most species sampled, except the Bermuda chub, were empty.
iv) The stomachs of the Bermuda chubs examined were filled with unidentified green algae.
v) In some fish, the gall-blabber was enlarged or ruptured; in others, there was an excess of bile in the stomach.
vi) The spleens were enlarged and congested.

Presence of Discoloured Water

Fishermen reported the presence of murky green coloured water prior to and during early stages of the fish kill in the areas along the southeast coast of Barbados first affected by the fish kill. According to fishermen, murky green water is seen on occasions along the southeast coast during late summer, but it usually disappears within a day or two. However, in September 1999, the murky green water lingered for an extended period. Pilots flying aircraft in the southeastern Caribbean during the fish kill episode reported seeing large masses of green water around the islands. The neighbouring islands of Grenada and St. Vincent, reported discoloured coastal waters during the fish kill episode (CARICOM 1999). Satellite imagery of the southern Caribbean taken during the fish kill - specifically September 14 - 21, 1999 (Figure 3), showed that Barbados and other islands affected by the fish kill were engulfed by a mass of water with chlorophyll concentrations an order of magnitude (10 X) higher than normal (seawifs.gsfs.nasa.gov). This water mass appeared to have originated in the area of the Orinoco river, Venezuela. Similar satellite imagery for the period immediately prior to the fish kill (August 29 to September 5, 1999; Figure 4) shows the water mass heading north towards Barbados from the Orinoco area, but Barbados still surrounded by typical oceanic water of low chlorophyll concentration. Satellite imagery for the period following the fish kill (October 8 – 15, 1999; Figure 5), shows Barbados again surrounded by oceanic water, that is, no longer engulfed by the high chlorophyll water mass. In a typical September, the water mass originating from the Orinoco region tends to move south and west of Barbados and the Lesser Antilles chain, in to the Caribbean Sea (Figure 6).

Figure 3. Satellite pictures for the period 14-21 September 1999, showing Barbados engulfed by water of chlorophyll concentration (shown as white) as much as 30 times normal seawater concentration. Arrow shows location of Barbados. **Source:** seawifs.nasa. gov.

Plant Material in the Discoloured Water

During the early stages of the fish kill, when fishermen were reporting the presence of the murky green water, the beaches were being littered with organic and plant material, including large numbers of seedlings from an unidentified legume. The seedlings were not from a local legume (Carrington, S pers.com.). This suggested that the plant and organic materials were brought in from outside of Barbados. Grenada also reported floating plant materials in the discoloured water observed along their coasts during the fish kill episode (CARICOM 1999).

No harmful algae were found in water samples taken from affected coastal areas in Barbados during the latter stages of the fish kill. Water samples were not taken in Barbados during the early and peak stages of the kill. However, water samples taken off Tobago and St. Vincent during the fish kill, and analysed by agencies within those territories, showed no evidence of harmful phytoplankton known to be associated with fish kills (CARICOM 1999).

Figure 4. Satellite pictures for the period 29 August - 8 September 1999, showing a plume of water of high chlorophyll concentration (shown as green) to the southeast of Barbados. Arrow shows location of Barbados. **Source:** seawifs.nasa.gov.

Sea Surface Temperatures

Fishermen and swimmers in the near shore waters of Barbados reported that the seawater was noticeably warmer then usual. The Barbados Meteorological Office reported that unusually high sea surface temperatures (29^0 - 33^0 C) were recorded during September 1999, between longitudes 7^0 and 10^0 N and latitudes 55^0 and 60^0 W. These sea surface temperatures were reported to the Meteorological Office by ships in the area. Seawater temperatures near Barbados in August and September for 1993 – 95 varied between 28^0 and 29^0C (CARICOMP).

Oxygen Concentration

Oxygen readings taken in Grenada and to a lesser extent in Barbados, during the fish kill detected values significantly lower than normal, particularly in the early morning (Hunte, W. University of the West Indies; pers. com.)

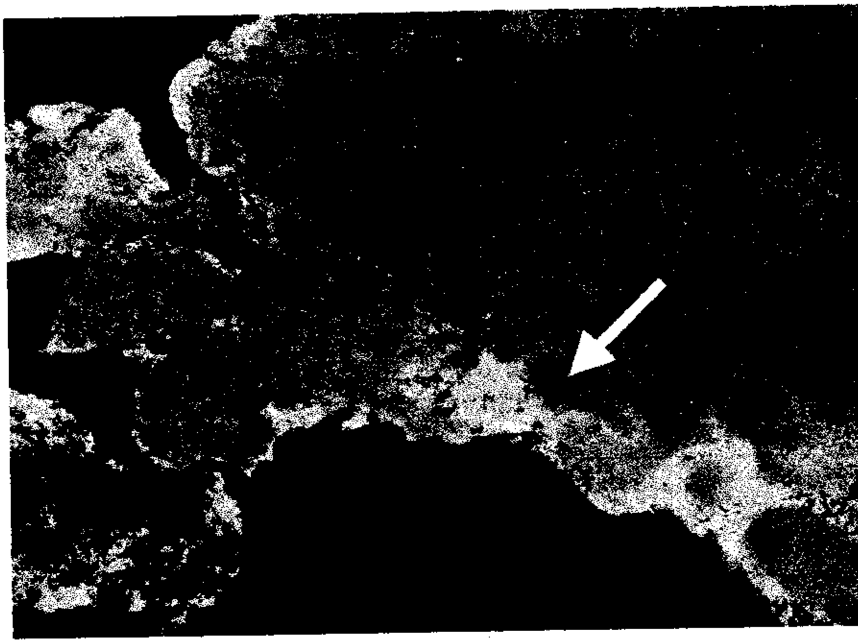


Figure 5. Satellite pictures for the period 8-15 October 1999, showing the plume of water of high chlorophyll concentration (shown as white) to the west of Barbados and extending into the Caribbean. Arrow shows location of Barbados. **Source:** seawifs.nasa.gov.

Unusual Currents

Just prior to the fish kill, tropical storm Gert passed through the southern Caribbean. In Barbados, it provided very high sea-swells and rough seas that pounded coastal areas, especially the east and southeast coasts. Prior to the first report of beaching of dead fish, divers and fishermen observed a change in current direction from the normal northwesterly pattern to a northeasterly flow. The observed change is believed to have been caused by the passage of tropical storm Gert and may have been responsible for the movement of the water mass from the Orinoco region north towards Barbados and the Lesser Antilles

.DISCUSSION

The pathogenic bacterium *Streptococcus iniae* ultimately caused the death of the fish in Barbados during the 1999 mass mortality of reef-associated fish, the fish dying from severe disseminated *Streptococcus* septicaemia, (Ferguson et al. in press). Pathogen-caused fish kills in natural systems usually involve - hosts that are susceptible to the contagion by the specific pathogen and exposure to predisposing environmental conditions that increase susceptibility of the hosts to the pathogen (Hermen 1990). The observations presented in this report indicate that the reef-associated fish affected by the 1999 fish kill were exposed to several predisposing environmental factors that may have increased the fishes' susceptibility to *S. iniae*.

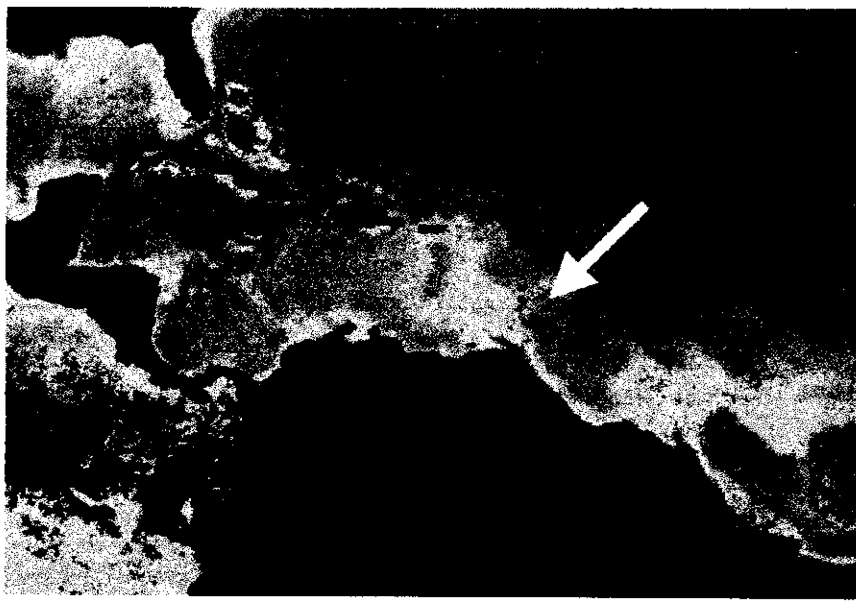


Figure 6. Satellite imagery for the period September 1998, showing the plume of water of high chlorophyll concentration (shown as green) to the south and west of Barbados and extending into the Caribbean. Arrow shows location of Barbados. Source: seawifs.nasa.gov.

In most fish kill investigations, information on the environmental conditions that contributed to the mortality are not accurately assessed, as the conditions often cease to exist before the mortality is noted and the investigation has begun. Snieszko (1964) listed temperature stress, decreased immunological response, pollution, unfavourable water chemistry, inadequate food supply and storms as some of the predisposing environmental conditions associated with fish kills. Herman and Meyer (1990) identified oxygen depletion, toxic algal blooms and sudden or excessive temperature changes as some of the agents that cause fish kills. Herman and Meyer (1990) also listed several observations that are evidence of a fish kill caused by oxygen depletion. Among these are that fish mortality occurs mainly at night and subsides during the day, that mortality rate is highest among larger individuals and that there is discoloration of water. These conditions were observed during the 1999 mortality event, indicating that low oxygen levels were a contributing factor to fish death, either directly or through increasing susceptibility to the pathogen. Oxygen depletion occurs when the total demand for oxygen by aquatic organisms exceeds the dissolved oxygen available in the surrounding water, and it is typically associated with heavy algal growth or high concentrations of organic matter or plant material (Herman and Meyer 1990).

Satellite imagery for the period of the fish kill (September 1999) shows Barbados engulfed by a plume of water that is of higher chlorophyll concentration than that of normal seawater (<seawifs.nasa.gov> 1999). The high chlorophyll content indicates the presence of large quantities of photosynthetic (phytoplankton, floating plant) material in the water. The murky green water that lingered around Barbados during the early stages of the fish kill was directly observed to be carrying plant and organic material, including seedlings that were not from local plants. The respiratory needs of the dense assemblage of phytoplankton, and the oxidative decay of the dead plant material, would have sharply reduced the supply of dissolved oxygen in the water column, making less oxygen available for other marine organisms. During the daytime, oxygen levels would have been at least partially replenished through photosynthesis. However, at night in the absence of photosynthesis, oxygen levels would not have been maintained. It is therefore expected that oxygen levels would have been lowest during the nighttime.

Excessive temperature changes are one of the environmental factors often associated with fish kills (Herman and Meyer 1990). Above normal sea surface temperatures were reported around Barbados, and throughout the southern Caribbean, during the period of the fish kill. The solubility of oxygen in water is inversely related to temperature. The above normal sea-water temperatures observed would therefore, have resulted in even lower concentrations of dissolved oxygen in the seawater, that is the creation of hypoxic conditions in the water column. Such environmental changes can stress fish to the extent that a weakening of the immune response may predispose the fish to infectious diseases (Herman and Meyer 1990). Larger fish have higher oxygen demands than smaller individuals and may therefore be expected to be more acutely affected by lowered dissolved oxygen levels. Once infected with *S. iniae*, hypoxia is especially critical in the toxaemic fish. Consequently, sick fish, especially the larger ones, would be more likely to die during the night when hypoxic conditions were most severe. This is consistent with the observation that many more fish were found on the beach in the early hours of the morning than later in the day.

The death of the fish in the 1999 fish kill was apparently not immediate, since the stomachs and guts of the freshly dead and dying fish were often empty. This suggests that the fish exposed to stressful environment conditions and to *S. iniae* were probably sick and not eating for several days before eventually succumbing to the effects of the pathogen.

The mass mortality of a wide variety of reef fish species along the east and southeast coasts, the complete absence of *S. iniae* in fish outside of the affected areas, suggests that the affected reef fish do not normally carry *S. iniae*, and were immunologically naïve. Once introduced, *S. iniae* would spread rapidly through the naïve population, already stressed by the deteriorated environmental conditions. These observations suggest that the virulent *S. iniae* may have been entrained in the same invading water mass as the predisposing environment conditions, and would therefore be available to infect fish that had not previously been exposed to the pathogen. However, it is uncertain how *S. iniae* was actually transported. It is unlikely that it was transported in the water outside the body of a host, since *S. iniae* does not survive very long in seawater. This suggests the involvement of a host, presently unknown, in carrying the pathogen in the water mass to Barbados. Once the pathogen was introduced to the area, it may have entered the fish either via the gills from the seawater or by the fish eating contaminated carriers.

In concluding, the satellite imagery and other observational data presented in this paper support the suggestion that there was a significant deterioration of water quality at the time of the 1999 Caribbean fish kill. High sea surface temperatures and the high oxygen demand resulting from the influx of large amounts of photosynthetic material into the area, depleted oxygen levels in surrounding near-shore waters. Although the oxygen levels may not have been low enough to kill healthy fish, they were low enough to critically stress fish, increase their susceptibility to S. *iniae* infection, and increase the morbidity of the disease.

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