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A historical assessment of *Karenia brevis* in the western Gulf of Mexico

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Abstract

This work examines the historical records of red tides in the western Gulf of Mexico (GOM) as they pertain to the toxic dinoflagellate *Karenia brevis* (Davis) G. Hansen and Moestrup. *K. brevis* commonly causes major fish kills, human respiratory distress, and significant economic disruption in the Gulf of Mexico. It can also lead to illness by consumption of contaminated shellfish. The nearly annual blooms that have occurred in Florida in the past several decades have focused most attention on the eastern Gulf of Mexico. There are few published chronological accounts of red tides in the western Gulf of Mexico despite a wealth of information on probable red tide blooms in Mexico during the 17th–19th century. Using these data and more modern records, we present a chronology of *K. brevis* in the western Gulf of Mexico. A 1879 report of red tide blooms in Veracruz, Mexico in the period 1853–1871 provides a clear description of concurrent fish kills and respiratory irritation, and provides the earliest verifiable account of *K. brevis* in the Gulf of Mexico. An analysis of the records suggests that Texas has experienced a notable increase in red tide frequency in the years 1996–2000. However, the record is too limited to assign any causes.

Keywords: History; Fish kills; *Karenia brevis*; Respiratory irritation

1. Introduction

Karenia brevis (Davis) G. Hansen and Moestrup is a dinoflagellate that occurs in the Gulf of Mexico (GOM) and, at times, in parts of the southeast Atlantic coast of the US. There is a report of *K. brevis* from the Caribbean Sea (Lackey, 1956); however, this report remains unconfirmed (Tester and Steidinger, 1997). This species (formerly known as *Gymnodinium breve*) produces potent chemical toxins (brevetoxins) that are harmful to both fish and mammals. These blooms are also a public health concern because of three distinct phenomena associated with the blooms: (1) massive accumulations of dead fish and public health problems arising from puncture wounds caused by fish bones exposed on beaches; (2) ingestion of neurotoxins from contaminated shellfish causing the debilitating, but non-fatal, neurotoxic shellfish poisoning (NSP); and (3) inhalation of air-borne toxins resulting in severe respiratory irritation, stinging eyes, nose, and accompanied by a dry, choking cough. There are some reports of contact irritation as well (Kusek et al., 1999; Pierce, personal communication).

Historical reports provide a record of bloom distributions and frequencies, and can possibly provide data for separating natural from anthropogenic

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effects. Since evidence suggests that some harmful algal blooms are increasing in frequency and duration (Hallegraeff, 1993; Smayda, 1990), these often-anecdotal reports are important as the only means available in many cases to examine long-term trends. Attention in the US has primarily focused on the west coast of Florida, a region with a long record of red tides and extensive coastal monitoring (reviewed by Kusek et al., 1999). There is also a wealth of information regarding red tides in Mexico that has been mentioned in the US scientific literature (Brongersma-Sanders, 1948; Halstead, 1965; Tufts, 1978). Unfortunately, the English speaking scientific community still remains largely unaware of these events. This paper presents a chronological summary of *K. brevis* red tides in the western GOM, including reports from Mexico, and provides a historical counterpart to the records available for the eastern GOM.

2. Results

2.1. *K. brevis* blooms prior to 1900

The first reports of red tide-related phenomena in the Gulf are usually attributed to Alvar Nuñez Cabeza de Vaca. Cabeza de Vaca was the chronicler, and one of a few survivors of the ill-fated expedition of Panfilo de Narvaez in 1528 that attempted to colonize the territory between Florida and the Rio Grande river. His writings (as translated and annotated by Bandelier, 1905) are the oldest history we have of native American culture. A careful examination of the record in the context of modern historical understandings suggests it is an ambiguous record of red tides at best. Cabeza de Vaca gave this account from a period when in the area now known as Texas:

> All those people had no reckoning by either sun or moon, nor do they count by months and years; they judge of the seasons by the ripening of fruits, by the time when fish die, and by the appearance of the stars, in all of which they are very clever and expert.

The reference to fish kills has led many to believe that he was describing red tides. However, Gunter (1951) discussed this passage and specifically noted that red tides are not an annual feature of the Texas coast and that Cabeza de Vaca could have been referring to either temperature or salinity-stress induced mortalities. In support of this, Nuñez Ortega (1879) noted that the local residents of Corpus Christi, Texas were aware of fish kills associated with cold fronts and would exploit them for food without any ill effects. We have found no accounts by Europeans in the 18th or 19th century that describe fish kills that could be attributed to red tide. The vagueness of de Vaca's description also precludes clear interpretation of this event as a red tide, and there is little evidence to support its use as early documentation of a red tide.

Fray Diego Lopez de Collogudo, a Franciscan monk and historian in Yucatan, Mexico, documented a massive fish kill that occurred in 1648 (Lopez Collogudo, 1688). He described the following (translated from Spanish[2]):

> A short time later, in the city of Merida, for several days, especially in the evenings when the wind blows from the sea, came a foul odor that at times could barely be tolerated, as it penetrated all parts. No one knew the cause of the odor until a ship from Spain encountered a mountain of dead fish near the coast. Dead fish were heaped on shore, and this is where the foul odor emanated.

Since that time, documented red tides have occurred east of Merida, in Chicxulub and Dzilam de Bravo, Yucatan, as recently as 1962 (Cortes-Altamirano et al., 1995). Brevetoxin contamination was found along most of the eastern coast of Mexico in 2000 (Tester, personal communication). This suggests a record of at least 350 years of red tides, although the red tides did not occur annually.

The first fish kill in the Gulf of Mexico chronicled by a government official occurred in 1792 in the city of Veracruz, Mexico. Lerdo de Tejada (1850) reported the following from 10 November 1792 (translated from Spanish):

> For several days now multitudes of dead fish have washed onto the beaches of Veracruz and some violent deaths have occurred to which were attributed to the sale of these fish. The governor decreed a ban on the sale of all types of fish from rivers and those fish from the sea could not be sold until the proper

[2] Translations are by H.A. Magaña and confirmed by Quality Spanish Translations.

authorities inspected them. This same epidemic of dead fish occurred repeatedly in this same port.

The contemporary assumption was that recent rain events and runoff had uprooted harmful plants that undoubtedly poisoned the waters (Lerdo de Tejada, 1850). *K. brevis* has never been documented to kill humans, and the "violent deaths" were likely due to bacterial contamination of spoiled fish or perhaps ciguatera poisoning as postulated by Nuñez Ortega (1879) and Tufts (1978). It was not until 1965 that McFarren et al. (1965) provided evidence of a relationship between *K. brevis* red tides and human illness in the United States.

Subsequent reports of fish kills in Veracruz, Mexico come from Nuñez Ortega (1879). Nuñez Ortega (1879) traveled to Veracruz, Mexico to investigate an outbreak of respiratory irritation and reported the following (translated from Spanish):

> In the last days of October 1875, the inhabitants of the city of Veracruz were repeatedly bothered by a dry cough caused by an irritation of the throat. This malady also affected horses, dogs, and other animals. The north wind blew with major intensity, and the authorities took notice that all along the entire coast of Barlovento an enormous quantity of dead fish had washed ashore along the beach.

During his investigation, Nuñez Ortega (1879) discovered that red tides were not uncommon in Veracruz and reported these red tide events (translated from Spanish):

> The inhabitants of Veracruz remember that the years 1853, 1861, 1865, and 1871 produced an enormous phenomenon, but the periodicals from which we obtained this information does not state if the fish kill preceded the dry cough, or if it was the dry cough alone without a fish kill, or a fish kill without the dry cough. A person performing an analysis of the air in the following days attributed the problem to sulfur gases. The inhabitants of Veracruz presumed that the cough was caused by an infection in the air caused by the dead fish, and the fish kill was caused by a submarine volcanic eruption close by and poisoned the water.

Nuñez Ortega proposed his own theories as to the cause of the fish kills and dry cough. He stated the cause of the mortality of fish was due to the abundance of hydrogen sulfide in the Veracruzan atmosphere, which emanated from the swamps that bordered the city. He also believed that the "formation of a great quantity of plants, fish, and shrimp dragged along the length of the east coast of Mexico, and deposited on the beaches decompose and emit poisonous gases, that if inhaled in its pure state produces instantaneous death." Nuñez Ortega (1879) also suggested that submarine volcanoes had poisoned the waters of the Gulf of Mexico, an idea also proposed later by Lund (1936).

The fish kill of October, 1875 in Veracruz, Mexico was the first documented report of human health problems associating respiratory irritation and dry cough to the massive fish kills[3]. The first report of human respiratory irritation associated with a Florida red tide was not made until 1917 by Taylor (1917). This accurate description of the respiratory effects of brevetoxin and the associated fish kill are compelling evidence that *K. brevis* was responsible. The only other possible explanation is a *Trichodesmium*-related respiratory syndrome known as Tamandare fever (Sato et al., 1966). This syndrome mimics *K. brevis* respiratory effects but has only been reported from Brazil. *Trichodesmium* produces multiple toxins (Endean et al., 1993) and while fish may avoid *Trichodesmium* (Nagabhushanam, 1967; McClintock et al., 1996), there are no reports of massive fish kills from open marine regions due to *Trichodesmium*; the few reports of direct mortality involve invertebrates in special circumstances (Smith, 1996). The 1875 Veracuz red tide was also the first time a scientific approach was taken to elucidate the cause of the phenomenon of massive fish kills and respiratory irritation. These early accounts of fish kills and the associated dry cough provide evidence that red tides have historically occurred in the western Gulf of Mexico and are not a new phenomenon.

The first documented *K. brevis* bloom in the US occurred in the GOM off the west coast of Florida in 1844 (Ingersoll, 1882). During Ingersoll's investiga-

[3] Tester and Steidinger (1997) cite Feinstein et al. (1955) as noting "noxious gases" along the Florida coast in 1844. This report was not examined; however, Steidinger (personal communication) indicates that this citation was in error and no noxious gases were reported.

tion, he noted that fish kills occurred in 1878–1880. He also found reports of wide spread destruction occurring as far back as 1844, and that eyewitnesses reported fish kills at intervals since those years, although to a lesser degree. He questioned the validity of some of the dates, since the person he interviewed was one of the oldest residents on Florida's coast and was recalling an event that occurred 38 years before. Ingersoll (1882) commented on the oddly colored and textured shellfish meats; however, he did not mention any illnesses from consuming the shellfish, nor did he report any respiratory effects. More red tide events occurred in Florida during 1882 and 1883, but for the next 20+ years no other red tide events were recorded in Mexico or Florida until 1908 (Taylor, 1917). The historical summary of these, and other, red tides is summarized in Table 1. *K. brevis* blooms post-1900.

Texas red tides have been less frequent than in Florida, yet can cause substantial economic losses (Evans and Jones, 2001). In general, there has been little documentation of red tides along the Texas coast until the 20th century. Lund (1936) reported a Texas red tide observed on 30 June 1935 off Padre Island, noting that an aerial reconnaissance reported dead fish to extend from Port Aransas, TX, southwards for approximately 84 miles. In addition to the multitudes of dead fish washing ashore along Padre and Mustang Islands, an irritating "gas" was reported, an appearance of irritating "gas" that was always associated with the simultaneous or previous appearances of dead fish. He estimated the fish kill to be >4,000,000 kg of fish, or two-third of the commercial fish harvest that year.

In 1946–1947, Florida experienced the largest fish kill to date (Gunter et al., 1948), and more red tides were observed in Florida during 1952–1953 (Chew, 1953). The numerous Florida red tides that have occurred since then have been described in the review of Kusek et al. (1999).

Gunter (1952) reported a mass fish mortality that occurred in fall, 1948 along the southern end of Texas coast and attributed it to red tide. This, and subsequent red tides, are identified in Fig. 1 with the location where they were first observed. A more extensive red tide bloom occurred during September 1955 near Port Isabel where Wilson and Ray (1956) collected 12 samples from a 20 square mile area of the Gulf between the mouth of the Rio Grande and 10 miles north of Port Isabel, Texas. All samples contained *K. brevis* in concentrations ranging from 50 to 500 cells/ml. Dead fish extended along the Gulf beaches from the mouth of the Rio Grande to 17 miles north of Port Isabel. At least 120 miles of coastline in the state of Tamaulipas, Mexico were also affected. Additional red tides caused fish kills along the Mexican east coast in 1956, 1961 and 1962 (Cortes-Altamirano et al., 1995).

No red tides were reported for the next 17 years, when a series of short-lived blooms affected the Texas coast in 1972, 1974, and 1976 (Buskey et al., 1996). The 1972 bloom killed an estimated 650,000 fish on the Bolivar Peninsula (Texas Parks and Wildlife Department (TPWD) data[4]). The 1974 bloom was limited to the Mexican coastline south of the Rio Grande to Tampico, Mexico (TPWD data). The bloom entered the Laguna Madre of Tamaulipas killing fish and affected the commercial oyster industry and caused several cases of NSP in people who ate the oysters (TPWD data). The only information available for the 1976 bloom is that it occurred at West Beach, Galveston adjacent to San Luis Pass (TPWD data).

The most severe red tide to affect the Texas coast to date occurred in 1986. This event was first reported to the Texas Water Commission by the US Coast Guard as a patch of brown, rusty-colored water coming ashore at San Luis Pass near Galveston, Texas on 27 August 1986. Respiratory irritation and large numbers of dead fish were reported washing ashore the next day (Trebatoski, 1988). Local investigators estimated 100,000 dead fish/ linear mile over approximately 14 miles of Mustang Island beach; these accumulations extended south into Mexico yielding an estimated mortality of 22.2 million fish (Trebatoski, 1988).

In 1990–1991, at least two blooms of *K. brevis* occurred inshore of the barrier islands (Buskey et al., 1996). The larger of the two blooms occurred in the Brownsville ship channel, Brownsville, Texas from December 1990 to April 1991. Another short-lived bloom occurred in late August to early September in Aransas and Copano Bays, South Bay and San Martin Lake (TPWD data).

Dortch et al. (1998) reported a *K. brevis* bloom in the low salinity waters of Louisiana in October

[4] All TPWD data was extracted from the Pollution Response Inventory and Species Mortality (PRISM) database, Kills and Spills Team, Resource Protection Division, Texas Parks and Wildlife Department, Austin, Texas. Contact person: Cindy Contreras.

Table 1
Chronology of *K. brevis* red tide events in the Gulf of Mexico

Year	Reference	Western GOM	Eastern GOM
1648	Lopez Collogudo, 1688	Massive fish kill; Yucatan, Mexico	
1792	Lerdo de Tejada, 1850	Massive fish kill, violent deaths; Veracruz, Mexico	
1844	Ingersoll, 1882		Massive fish kill; Florida
1853	Nuñez Ortega, 1879	Massive fish kill; Veracruz, Mexico	
1854	Ingersoll, 1882		Massive fish kill; Florida
1861	Nuñez Ortega, 1879	Massive fish kill; Veracruz, Mexico	
1865	Nuñez Ortega, 1879	Massive fish kill; Veracruz, Mexico	
1871	Nuñez Ortega, 1879	Massive fish kill; Veracruz, Mexico	
1875	Nuñez Ortega, 1879	Fish kill, dry cough, throat irritation; Veracruz, Mexico	
1878	Ingersoll, 1882		Massive fish kill; Florida
1880	Ingersoll, 1882		Massive fish kill; Florida
1882	Taylor, 1917		Massive fish kill; Florida
1883	Taylor, 1917		Massive fish kill; Florida
1908	Taylor, 1917		Massive fish kill; Florida
1935	Lund, 1936	Massive fish kill; Texas	
1946–1947	Gunter et al., 1948		Massive fish kill; Florida
1948	Gunter, 1952	Fish kill; Texas	
1946–1947 periodically to 1999	See Kusek et al., 1999 for details		Massive fish kill; Florida
1955	Wilson and Ray, 1956	Massive fish kill; Texas coast	
1956	Cortes-Altamirano et al., 1995	Massive fish kill; Tamaulipas-Veracruz, Mexico	
1961	Cortes-Altamirano et al., 1995	Massive fish kill; Yucatan, Mexico	
1962	Cortes-Altamirano et al., 1995	Massive fish kill; Chicxulub, Yucatan, and Dzilam de Bravo, Quintana Roo, Mexico	
1972	TPWD data	Fish kill; Bolivar Peninsula, Galveston, TX	
1974	TPWD data	Fish kill; Tamaulipas, Mexico	
1976	Buskey et al., 1996	Fish kill; offshore of Brownsville, TX	
	TPWD data	Fish kill; San Luis Pass, TX	
1986	Trebatoski, 1988	Massive fish kill, respiratory irritation; Texas coast	
1990–1991	Buskey et al., 1996	Brownsville ship channel; Aransas and Copano Bays	
1994	Cortes-Altamirano et al., 1995	Massive fish kill; Veracruz, Mexico	
1995	Cortes-Altamirano et al., 1995	Massive fish kill; Veracruz, Mexico	
1996	TDH, 1997	Fish kill; Texas	
1996	Dortch et al., 1998	Louisiana, low salinity	
1997 to January 1998	TPWD in Villareal et al., 2001, TPWD data	Massive fish kill; Texas	
1999	Texas Parks and Wildlife data	Massive fish kill; Texas	
2000	TPWD data	Massive fish kill, respiratory irritation; Texas	
2001–2002	UTMSI/TPWD	Fish kill; Pt. Aransas, Texas	

Western/eastern GOM refers to the geographic area of the Gulf of Mexico (GOM). Texas Parks and Wildlife Department data were extracted from the computerized database maintained by Texas Parks and Wildlife Department. Brongersma-Sanders (1948) incorrectly cites Lerdo de Tejada as 1797 instead of 1792.

to December 1996. Densities of *K. brevis* exceeded the regulatory limit for closing shellfish beds (5 cells l^{-1}) between salinities of 14 and 30 and were observed in salinities from 5 to 35 (Dortch et al., 1998). No cases of NSP occurred, but respiratory problems were reported. This was the first observation of *K. brevis* in low salinity waters of the northern Gulf of Mexico.

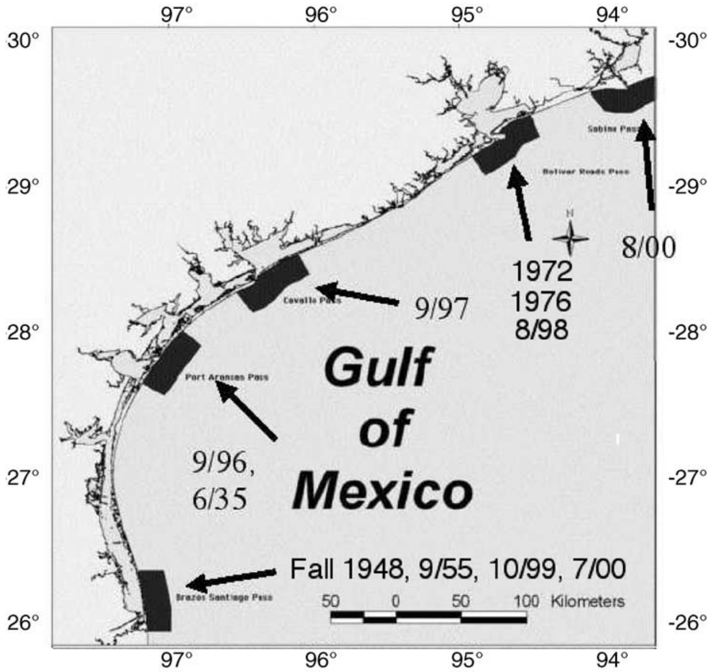

Fig. 1. General locations where red tides were first noted along the Texas coast during the various years. The dark areas note passes through barrier islands where fish kills are most easily detected. Dates are listed to month, when known; otherwise, only the years are recorded. In general, most red tides occur on the open Gulf of Mexico coast in late summer and fall.

The next Texas red tide occurred during 1996 and was first noted in mid-September when small patches were noticed near Port Aransas. On 16 September, Texas Department of Health (TDH) closed all coastal waters in the area to the taking of clams, mussels, and oysters. On 20 October, the TPWD surveyed Matagorda Island and counted 510 dead fish/100 linear feet for 10 miles. A sample of shellfish meats from Espiritu Santo Bay produced the highest results for brevetoxin in shellfish meats recorded in Texas (295 mouse units/100 g; Wiles, TDH, personal communication). In this bioassay, all test mice died within 6 min after injection of toxin.

Another red tide occurred the following year on 28 September 1997, and TDH closed shell fishing in the lower Laguna Madre and South Bay, Texas (TPWD data). On 29 September, the red tide extended along the Gulf coast from Boca Chica to the Port Mansfield jetties (TPWD data). On September 30, TPWD estimated 90,000 dead fish in the Port Mansfield-Rio Grande area, increasing to 295,000 dead fish the following day; at the Padre Island National Seashore, TPWD staff estimated 4.2 million dead fish (TPWD data). By the end of the 1997, an estimated 14.3 million fish were killed during this red tide event, mostly small fish less than 6 in. This event lingered into early January 1998 with a fish kill reported in Corpus Christi Bay, Texas (TPWD data).

Coastal Fisheries biologists (TPWD) investigated a reported red tide along the southern tip of Texas on 4 October 1999; >394,000 dead fish were found on South Padre Island. It is believed that a cold front that moved through the area may have dissipated the red tide; by 27 October no further fish kills were reported (TPWD data).

On 3 July 2000, TPWD investigated a report of dead fish washing ashore on South Padre Island; by 7 July the red tide had dissipated after moving northward along South Padre Island (TPWD data). On 15 August 2000, TPWD staff conducted an aerial reconnaissance of the northwest portion of the Gulf and reported reddish-brown water occurring south of Sabine Pass, Texas extending eastward to 12–14 miles south of the Louisiana shoreline. By 25 August, fish kills were occurring along the middle Texas coast, with more than two million fish killed (TPWD data). The red tide progressed southward from Galveston, and by September reached Port Aransas where cell counts fluctuated between 1 and 171 cells ml^{-1} from 25 September to 6 November (Magaña and Villareal, unpublished data). The bloom advected southward into Mexico in November.

During December 2001, *K. brevis* was detected in the Port Aransas ship channel (Villareal, unpublished data). This event occurred from mid-December to April 2002, and closed shellfishing beds in the area for much of the winter and spring. A fish kill reported on Padre Island near Corpus Christi during this time was likely due to *K. brevis*. Brevetoxin contamination was present along the east coast of Mexico as far south as the Yucatan in both 2000 and 2001 (Tester, personal communication). Since then, and at the time of this writing (March, 2003) no red tide has been reported along the Texas coast.

3. Conclusions

The historical records of Nuñez Ortega (1879) provide the earliest verifiable record of *K. brevis* in the Gulf of Mexico. The records of early Spanish missionaries and civil servants provide a 300+ year record of red tides in the western Gulf of Mexico. The sparse observations are not systematic and in some cases rely on memories of events rather than direct observation. However, it is clear that these blooms were widespread in both the eastern and western Gulf of Mexico long before significant industrial development.

Generalizations about bloom frequencies over time using historical accounts are limited, at best. The periods when no red tide blooms were reported are difficult to interpret since many of the records are based upon short-term investigations, rather than systematic long-term monitoring. The absence of reports may mean that there was no event, that no one recorded the event, or that it was not large enough to demand attention. However, during periods when observations were recorded (i.e. 1861–1875 in Mexico), red tides occurred at multi-year intervals, rather than annually. The Texas record is limited to post-1935, but blooms prior to the 1990s appeared to be much less frequent than in Mexico. Texas waters experienced fish-killing red tides in 1996–1997, 1999–2002. This 6-year period was the most active red tide period in Texas history since records have been kept. It is likely there has been low level *K. brevis* (or some other brevetoxin producer) present at other times. Buskey et al. (1996) noted that brevetoxin mouse bioassays conducted by the Texas Department of Health indicated some level of toxicity in oysters in Texas bays during 1987–1991 when fish kills or red tides were not observed. Villareal et al. (2001) found *K. brevis* in four samples from along the Texas coast in 1999 at times when no fish kills were reported. These suggestions of a hidden flora role for *K. brevis* further complicate interpretation of the record.

One aspect that is clear is that almost all red tide blooms along the Texas coast have advected southwards. This clearly happened during the major blooms in 1986 and 2001, and was likely a source of the shellfish contamination noted in Mexico. The most notable exception was in July 2000, when a small bloom off Brownsville, Texas (extreme southern end of Texas) advected northwards until it disappeared along Padre Island. The subsequent bloom noted off northern Texas in August, 2000 may have been related. The oceanographic evidence for this offshore transport is currently being evaluated.

Fish kills have traditionally been used as a trip-wire to initiate water sampling for *K. brevis*, and these mortalities have been recorded by TPWD for decades. However, prior to the major red tide of 1986, Gulf of Mexico red tides were largely attributed to shrimp by-catch, although there were suspicious fish kills that were probably due to red tide (Buzan, Resource Protection, TPWD, personal communication). For example, a 1983 fish kill extended from Bob Hall Pier near Pt. Aransas, Texas southwards for 46 miles. While the mortality recorded in the database was attributed to shrimp by-catch, the size of the kill could also indicate an offshore red tide that did not come ashore. This suspicious event is not unique in the state records. The massive 1986 bloom highlighted the need for state agencies to recognize and record red tide events, and resulted in increased training, linkages to academic institutions, and the formation of an intra-agency TEXHAB committee (Texas harmful algal blooms). As a consequence, there is now more accurate reporting.

Thus, while the 1996–2002 period was the most active period for red tides recorded in Texas history, it is too soon to determine if this is a long-term change due to such factors as global change (Tester, 1993), a short-term perturbation due to transient climatic conditions, or simply better documentation.

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