Jan Culbertson

Historical Annotated Review of Winter Kills of Marine Organisms in Texas Bays

by
Joe H. Martin
and
Lawrence W. McEachron

Management Data Series
No. 118
1996

COASTAL FISHERIES DIVISION

4200 Smith School Road
Austin, Texas 78744

HISTORICAL ANNOTATED REVIEW OF WINTER KILLS OF MARINE ORGANISMS IN TEXAS BAYS

by

Joe H. Martin

And

Lawrence W. McEachron

MANAGEMENT DATA SERIES
No. 118
1996

Texas Parks and Wildlife Department
Coastal Fisheries Division
4200 Smith School Road
Austin, Texas 78744

IN MEMORIA

This publication is the last paper that Joe Martin and I were working on before his untimely death in 1993. Joe and I worked together on and published many reports in TPWD publications and peer reviewed journals throughout our years of work with the Coastal Fisheries Division. I will miss his expertise on the biology of the upper Laguna Madre, his knowledge of computer operations, and his help throughout the years I worked with him. This publication is dedicated to his memory.

Larry McEachron
Science Director

ABSTRACT

Physical features of Texas bays, combined with rapid onset of cold weather systems results in mass mortalities of marine organisms. These cold-weather systems are the result of high-altitude shifts in wind patterns causing Arctic air to rush south from Canada instead of moving east. From the chronicled records, major mortalities have occurred about every 15 years, and probably involved all bay systems at one time or another. Information about these mass mortalities has lacked accessability. Compiling information on cold induced kills through 1994 from scientific reports, newspapers, travelers' accounts, and anecdotal information should improve this condition. The earliest documented cold-weather kill was from the winter of 1527, with the most recent event occurring in 1989. Prior to 1983, the longest continuous freeze on record (19 December 1924, ending 74 hours later) had no documentation for organisms impacted. This record was eclipsed in 1983 when 77 hours of continuous below-freezing temperatures were recorded in Port Arthur. Actual estimates for total number (> 30 million) and weight (>100 million kg) of organisms impacted has an incomplete history. Changes in Texas demographics during the past 40 years has forced fishery managers to shift its passive management philosophy to a more active one.

INTRODUCTION

The Texas Gulf coast is frequented by catastrophic mass kills of marine organisms due to cold weather. Polar air masses push as far south in south Texas as at any place on earth (Gunter 1952). Texas has about 906,495 ha of relatively shallow (average depth 2-3 m) bay waters connected to the Gulf of Mexico by narrow passes. These physical features, combined with rapid onset of freezing temperatures associated with cold fronts, present a situation conducive to cold-induced kills of marine organisms. The effect of these mass mortalities on marine fish populations can be pronounced (McEachron et al. 1995). Texas winter kills since 1942 (Gunter 1945) have not been recorded or summarized in one place. The objective of this paper is to chronicle known freeze events through 1995.

METHODS

Annotated information was gleaned from available scientific literature, newspapers, magazine articles, travelers' journals, and unpublished TPWD data. Technical information and anecdotal information were graciously provided by Meteorologist Tony Derda, Archaeologist Herman Smith, and Biologist Henry Hildebrand.

RESULTS

Documented mass mortalities occurred in 1886, 1899, 1917, 1924, 1940, 1951, 1983 and 1989, for an average interval of 15 years. Less severe fish killing freezes occurred interspersed among these major freezes. Because the Texas Game, Fish and Oyster Commission (now Texas Parks and Wildlife Department, TPWD) did not hire a staff marine biologist until 1936, quantitative estimates of fishes killed by freezes before 1936 are not available. Gunter (1952) estimated that freezes alone reduced the "*fishable population*" in Texas bays by 50% in nine years out of 14 between 1940 and 1953; only in five years were coastal fish populations not adversely affected by cold weather.

Table 1 summarizes impacts of cold-induced kills on Texas coastal organisms. Actual estimates for total number and weight of organisms impacted has an incomplete history. Detailed records on freeze mortalities before 1900 are sparse. An annotated compilation of information for cold-induced kills occurring on the Texas coast from 1527 through 1995 follows:

1527

The first report of cold-induced fish kills in Texas bays was by Alvar Nunez Cabeza de Vaca, a Spanish explorer shipwrecked on the lower Texas coast in 1527. Cabeza de Vaca spent eight months with a coastal Indian tribe; he noted that although ignorant of time, they "*know and understand the differences of the seasons, when the fruits come to ripen, the fish to die*" (Gunter 1945). Although the "*season when the fish come to die*" has never been completely understood, both Gunter (1945) and Buckingham Smith (translator of the "*Narrative of Cabeza de Vaca*") believed the statement referred to numbing of fish in Texas bays during cold spells.

1820

An article in the 13 January 1886 edition of the *Galveston Daily News* (Anonymous 1886) related the story of Jane Long, wife of a U.S. Army General stationed at Fort Bolivar in 1820. When her husband was posted to Mexico, Mrs. Long overwintered on Bolivar Peninsula with her young daughter and servant. According to Mrs. Long, the winter of 1820-21 was bitterly cold, so cold that at one point Galveston Bay completely froze over. The authors believe it is possible ice could have formed out to such a great distance from

shore giving Mrs. Long that impression. However, it is unlikely Galveston Bay was completely frozen. Mrs. Long also reported the only way they survived was by breaking ice and picking up dead fish underneath.

1845-46

Zachary Taylor, bivouacked on the shore of Corpus Christi Bay during winter 1845-46, reportedly fed an army of 5,000 with freeze-killed fish (Henry Hildebrand, Marine Biologist and retired University Professor, Personal Communication).

1856

One of the earliest known written accounts of the effects of sudden cold on fishes in Texas marine waters is from the journal of J. R. Bartlett (1856):

> "Jan.3 - *A violent norther arose during the night, and we had it piercing cold today. When in the house we were seated by fires, and when outside the doors, wrapped in our overcoats. Yet in spite of all our efforts it seemed almost impossible to keep warm, so penetrating are these winds to systems which have been relaxed. When these winds blow so violently they drive the water from the shallow lagunas into the Gulf, and increase the difficulty of navigating them. Many of the bars are then nearly dry. There is one in particular, across the mouth of Nueces Bay, which deserves to be noticed. When the tide comes into this bay, as well as in all others, it is resorted to by large numbers of fish from the Gulf, to feed. The water may then be from five to ten feet deep, and is the same temperature as that of the Gulf. But after a norther has blown for twelve or twenty-four hours, its temperature is so much reduced that the fish become chilled, and not having strength enough to make their way over the bar, now more shallow than ever, they often lie there in heaps. At these times the people go to the bar in their wagons, and with a spear or fork, pick up the finest fish, weighing from ten to 100 pounds, and thus carry away many loads. Many were brought in today and they proved a great luxury.*"

1868

Gunter (1945) reported a fish killing freeze in 1868. No specific information on number of organisms killed was found by the authors.

1886

At 5:00 P.M., 9 January, air temperature in Corpus Christi was 24 C. By 5:00 A.M. the next morning, air temperature had fallen to -9 C. This is the largest drop in a 12-h period ever recorded for Corpus Christi. The *Galveston Daily News* (Anonymous 1886) reported the snowstorm of 1886 was "*the greatest that the city, state or even the lower south had ever witnessed.*" The Texas coast was sparsely populated, so no written or anecdotal information is available on organisms killed.

Storey and Gudger (1936a) ranked the 1886 freeze as the most destructive ever at Sanibel Island, Florida. So, it is reasonable to assume mortalities of Texas marine organisms also would have been catastrophic. Based on

available weather information, this could have been the worst fish kill in the past 150 years.

1899

Lowest air temperatures on record along the Texas coast occurred the morning of 12 February 1899. Lows for the day included -13 C at Galveston, and -12 C at both Corpus Christi and Brownsville. The *Corpus Christi Caller* (Anonymous 1899) reported that Nueces Bay froze completely from shore to shore; ice was so thick people rode horses across the bay. The *Corpus Christi Caller* newspaper correspondent in Tarpon (now Port Aransas) reported:

> "*The norther that started last Saturday brought the coldest weather ever known here. Our boat harbor, the cove, was frozen over and our citizens spent Sunday morning walking on the ice among the boats, which could never be done before. Thousands of frozen fish lined the shores and everybody picked out what they wanted.*"

During the five-day event, saltwater along the Corpus Christi bayfront froze, encasing boats at the wharf; local housewives had to buy their milk in chunks because it froze inside delivery boys' cans (Mies 1989).

1917

Although information is sparse on the freeze of 3 February, Gunter (1941) believed it was one of the most destructive of the Twentieth century to marine life in Texas. Little mention was found of the severe cold weather or its effects upon marine life because newspapers during early 1917 were preoccupied with the war in Europe and the German U-boat campaign off the U. S. coast.

1924

Shortly before sunrise on the morning of 19 December, air temperature in Corpus Christi was 22 C (Tony Derda, Meterologist, Channel 3 News, Corpus Christi, Texas, Personal Communication). Twelve hours later it had fallen to -6 C and would remain below freezing for the next 74 hours (Gunter 1941). This was the longest period of continuous sub-freezing air temperatures recorded along the coast up to this time. Higgins and Lord (1927) stated "*cold snaps in winter often numb great quantities of fish, and an exceptional cold spell with freezing temperatures will kill them outright, as happened in December 1924.*" Both the Corpus Christi and Galveston newspapers ran articles detailing damage inflicted on Texas' agriculture; however, no mention was made of destruction to marine life.

1930

Air temperature dropped to -10 C on 18 January in Corpus Christi (Mies 1989).

The Yearbook on Texas Conservation of Wildlife (Anonymous 1930) of the Texas Game, Fish and Oyster Commission reported the following:

> "*The severe freeze which occurred in January resulted in a great scarcity of fish along the entire coast for some time, not so much that fish were frozen as that they were driven into the deeper waters of the Gulf. In several shallow bays, however, including the Laguna and the shallow bays around Galveston, many fish were destroyed, though the*

greater loss was of fish of no commercial value. In Copano Bay which is quite shallow, the fish were so numbed that fishermen gathered them in with their hands. In this condition at many places those near the shore were washed upon the beach by tide and winds and perished."

1940

The cold spell that began 18 January was the first of the season and it came quickly (Gunter 1941). Air temperature at Rockport dropped from 18 C to -4 C in four hours. Gale force winds blew steadily for four days. Temperatures dropped below freezing for some part of each day for the next ten days. *"Mush ice"* formed on the shores of deeper bays and washed up on the beach. Shallow areas, protected from high winds, froze for up to 0.62 km offshore. Gunter (1941) reported that based on conversations with fish dealers and long-time residents, at least 453,600 kg of fish succumbed. He reported a 46% reduction in commercial finfish harvest for two years following freezes (Gunter 1952). Recovery of fish populations to pre-freeze levels did not occur until 1943 (Gunter 1952).

This was the first well-documented cold killing freeze; Gunter (1941) provided an accounting of species killed. It is the benchmark by which all following freezes are measured. The 1940 freeze was similar to those of 1886, 1899 and 1924, generally believed to be the most severe on record up to that time (Gunter 1941).

Although the 1917 weather pattern was similar to the 1940 event, Gunter (1941) speculated more fish would have been available to be killed in 1917 due to lower fishing pressure at the time. Like the 1917 freeze, Gunter (1941) believed the 1924 cold event was more destructive than the 1940 freeze because of higher availability of marine life due to lower fishing pressure.

1941

Gunter (1952) reported light mortality caused by a cold wave. No other information was found by the authors.

1942

On 1 January, a light cold wave struck the coast (Gunter 1945). In the Aransas Bay area, temperatures fell below freezing (lowest, -2.2 C) on the 6th-8th. Dead fish were reported in the storm basin at Aransas Pass. Estimated numbers of fishes killed ranged from 5,400-6,200 in Aransas and Corpus Christi Bays.

1947

A sharp drop of 16.1 C in January water temperature over five days produced a tremendous mortality of fishes along the coast (Anonymous 1947). Destruction reached from Matagorda Bay to at least Eighth Pass in Mexico (Anonymous 1947, Burr 1947). One alligator was reported killed; very few small red drum (Sciaenops ocellatus) were killed (Anonymous 1947). On 6-7 January, when the first effects of the freeze became apparent, bay shores were littered with yellowtails [sic] (Bairdiella chrysoura), sand seatrout (Cynoscion arenarius), sheepshead (Archosargus probatocephlus), small black drum (Pogonias cromis) and a great many small (152-203 mm long) spotted seatrout (C. nebulosus) (Anonymous 1947, Baughman 1947). Larger fish did not appear until the water warmed (Baughman 1947). The surface of the bays was

covered with floating fish that washed in to form long windrows along the shore (Anonymous 1947). Spotted seatrout 610-762 mm long were common, as were many exceptionally large red drum and drum [sic]. In the surf, still more spotted seatrout and black drum were floating, some very large (Anonymous 1947, Baughman 1947). Red drum up to 1,219 mm long and spotted seatrout up to 914 mm long were reported from the bays and gulf (Anonymous 1947, Baughman 1947). Loss of fish was greatest where fish were caught in shallow flats and could not reach *"deep water"* (Baughman 1947). In Baffin Bay, big trout (2.72-3.63 kg) were so thick on the surface of the water that *"they appeared like pepper on the white of an egg"* (Baughman 1947). Great numbers of pike [sic] (snook, Centropomis undecimalis) were killed in the Brownsville Ship Channel (Anonymous 1947, Baughman 1947). Estimates of number of fish killed are only *"wild approximations"*, for there were almost as many fish that remained on bottom as were brought in by waves (Anonymous 1947, Baughman 1947). Probably 4.5 kg of fish per/0.3 m were killed over a distance of 482.7 km, for a total of about 7.2 million kg (Anonymous 1947, Baughman 1947).

1948

Gunter (1952) reported light mortality caused by a cold wave. No other information was found by the authors.

1949

Gunter (1952) reported light mortality caused by a cold wave. No other information was found by the authors.

1951

The cold spell that began 28 January featured colder weather than the 1940 event (Gunter 1952). However, two cold spells preceded the 28 January freeze. Gunter and Hildebrand (1951) reported slow onset of cold weather, combined with the fact it was the third freeze of the season helped keep numbers of fishes killed below those reported in 1940. Simmons (1962) estimated 28-41 million kg of fish died coastwide. Baughman (1951) reported the Laguna Madre was the hardest hit, losing an estimated 46 million fish. Simmons (1957) reported gill nets set in upper Laguna Madre in October and November 1951 yielded only four fish. Three months later the catch had risen to 100 fish/night, evidently boosted by new fish from the Gulf or other bays. By 1954, red drum and spotted seatrout populations had returned to normal (Simmons 1957).

In the Port Arthur area, air temperatures were recorded below freezing for a total of 198 hours in January (Holder 1989).

1962

Simmons (1962) reported the following:

> At the Corpus Christi weather station, winds changed from southeasterly to northerly at 7:30 A.M. 9 January. Air temperature dropped from 15.5 C to -0.5 C by 1:30 P.M. For the next 24 hours, wind remained steady at 22-26 mph from the north then slacked off to 13-18 mph. By this time air temperature had dropped to -6.6 C. Maximum temperature on 10 January was -3.9 C and on 11 January was -1.1 C. These low temperatures remained stable until 7:00 A.M. on 12 January when the low of -8.9 C was recorded. Temperatures rose above freezing at 10:00 A.M. on 12 January. Water temperature in Aransas Bay was 13.3 C at the

> onset of cold weather. By 11 January, surface water had dropped to 3.9 C and bottom water to 0.0 C. Upper Laguna Madre reported heavy ice and a water temperature of -2.0 C. On 25 January, large spotted seatrout were found floating in Baffin Bay; number killed ranged from 540-8,520 fish/304.8 m. In Baffin Bay, about 510,291 kg of spotted seatrout (N=535,000), 18,143 kg of black drum, 7,257 kg of sheepshead, and a few red drum were killed. Loss for the entire coast did not exceed 907,185 kg of food and game fish. Except for Baffin Bay and lower Laguna Madre, the loss was negligible, particularly when compared to the 1951 kill.

TPWD trawl samples on 14 January in upper Laguna Madre found bottom water temperatures of 7-9 C (TPWD unpublished data Rockport, Texas).

1973

On the night of 11-12 January, a cold front moved through Texas and dropped air and water temperatures to below freezing (Moore 1976). Water temperatures in the shallow flats of Redfish Bay (Aransas-Corpus Christi Bay systems) were near 0.5 C, with temperatures of 4.5 C in deeper channels and boat basins. Of particular note was 54 snook found dead in local marinas. Only about 3,200 dead fish were found in the area.

The Coastal Fisheries Branch (TPWD) reported the following:

> A minor fish kill was reported in Galveston Bay following the 11-12 January freeze (TPWD unpublished data, Rockport, Texas). The kill was reported in a 64.75 square km area between Redfish Reef to just north of Texas City Dike. Water temperatures between 3.7 C and 6.1 C were recorded. Reports on scattered mortality in West Bay and in the Galveston Yacht Basin were received. Several thousand sand seatrout were killed. On 12 January, people were picking up dead and dying fish by boat, and along the shore of the Texas City Dike. On 13 January, reports of mullet (Mugilidae sp.) dying in West Bay and spotted seatrout in the Galveston Yacht Basin were received by TPWD biologists.

1982

On 10 January air temperatures overnight dropped to -5.5 C and to near 0 C the next day at Port Aransas (Holt and Holt 1983). Night temperatures from 11-13 January ranged from 0 C to -2.0 C. On 12 January temperatures warmed to 7.5 C prior to another cold front passage. Temperatures on 13 January were near 0 C with freezing rain. Fish were noticed floating in the Aransas Pass Inlet on 14 January; all dipnetted fish were moribund. About 2,000-4,000 pigfish (Orthopristis chrysoptera), and an equal number of sand seatrout were estimated to have been affected by the cold. No other reports of fish kills were reported.

1983

On 25 December, an air temperature of -10 C set a new monthly record for Corpus Christi (Mies 1989). *"Hard"* and *"mush"* ice stretched along the bays from Galveston to Brownsville (TPWD unpublished data, Rockport, Texas). Ice was 102 mm thick as far as 274.3 m off the beach in Trinity Bay (Anonymous 1983a). Temperatures remained below freezing for 77 continuous hours in the Port Arthur area (Holder 1989). Prior to the 1983 freeze, water temperatures were 15.6-18.3 C and dropped to 1.7 C in a matter of hours following the

front (TPWD unpublished data, Rockport, Texas). A water temperature of 3.3 C was recorded along the Gulf beach at Port Aransas (Harrill 1989).

Anonymous (1983b) reported the following:

> Arctic air froze oranges on the trees; utilities struggled to keep customers warm. Cold temperatures broke records in at least 45 cities around the nation. December was one of the coldest recorded since record keeping began in the 1870's. In Abilene and Fort Worth, temperatures remained below freezing for more than eight days, the longest period on record. Record low temperatures were shattered in 20 cities on Christmas Day. On 26 December, Brownsville broke a 99 year-old mark of -1.1 C with a reading of -2.2 C. The low overnight in Wichita Falls was -10.6 C, breaking the record of -8.3 C in 1935. Bursting pipes caused widespread damage to private homes and businesses throughout Houston and southeast Texas.

Goodwin (1983) reported the following:

> The National Weather Service (Corpus Christi) at 3 P. M. on 26 December reported a low of -3.3 C, breaking the previous record of -2.8 C in 1892; the high for the day was -2.2 C. Nueces Bay, behind Gunderland Marine, between Corpus Christi and Portland was frozen solid.

Anonymous (1984) reported the following:

> December 1983 may go down in meteorological history as one of the coldest on record for many parts of the U. S. This winter, Texas experienced its coldest December on record.

McEachron et al. (1995) reported the following:

> Identification of organisms killed and estimation of number of estuarine fishes and invertebrates killed was accomplished through a systematic standardized approach utilizing airplane, ground qualitative observations and quantitative counts, and trawling. About 14 million fishes and one million invertebrates were estimated killed. A detailed accounting of species killed, numbers estimated killed, length frequencies of select killed organisms, and water temperature profiles are provided in this 1995 publication.

1989

3-6 February

Air temperature in Corpus Christi dropped from 21.1 C at 3:00 A. M. on 3 February to 7.2 C by 6:00 A. M. to 3.3 C by 10:00 A. M. (National Weather Service, Personal Communication). Freezing temperatures occurred for 35 continuous hours on 4 and 5 February, followed by 10 hours of temperatures above freezing Sunday and Monday; record lows of -2.2 C and -3.3 C were set on 5 and 6 February, respectively (George 1989).

Overcast skies, relatively light winds and high tides allowed water temperatures to drop relatively slowly. No ice was seen along the bays. Water temperatures declined from about 15.6 C to 3.3 C during 72 hours; this was a slower decline than in 1983. Generally, fish in shallow bays were most

affected. Kills were localized except for in upper and lower Laguna Madre. Following the freeze, 26 live and dead green turtles were found washed up along the coastline (Bruce 1989).

The Texas Water Commission maintained datasondes at eight *in situ* locations between Matagorda bay and Corpus Christi Bay at the time of the freeze event (Hoten 1990). Mesquite Bay registered the lowest water temperature of 0.46 C on 6 February. Hoten (1990) concluded:

> *"The differences in temperatures range from bay to bay appear to be primarily influenced by bay water depth and station proximity to the Gulf of Mexico. For instance, the shallower bays like Nueces, Mesquite and San Antonio, with average depths of less than 3 ft, demonstrated the largest and most responsive temperature changes. While Aransas, Corpus Christi and Matagorda Bays, with average depths of 13 ft or less, exhibited a less dramatic change in range and reaction time. Stations located in further inland from the Gulf of Mexico like Lavaca, San Antonio, and Nueces Bays showed greater temperature changes than stations located closer to the Gulf of Mexico such as Copano, Aransas, and Matagorda Bays."*

McEachron et al. (1995) reported the following:

> Identification of organisms killed and estimation of number of estuarine fishes and invertebrates killed was accomplished using the same metholodogy as reported in the 1983 freeze. About 11.3 million fishes and 13,000 invertebrates were estimated killed. A detailed accounting of species killed, numbers estimated killed, length frequencies of select killed organisms, and water temperature profiles are provided in this 1995 publication.

22-24 December

Air temperatures dropped lower than in 1983 but did not stay below freezing for as long. Water temperatures were different than recorded in 1983. Prior to the 1983 freeze, water temperatures were 15.6-18.3 C and dropped to 1.7 C in a matter of hours following the Arctic front. Prior to the 1989 December freeze, water temperatures ranged from near 10 C along the lower coast and near 4.4 C along the upper coast.

TPWD Field Reports (TPWD unpublished data, Rockport, Texas)documented the following:

> Palacios: 22 December; air temperature -3.9 C; sleeting and snowing; wind from the northwest at 48-56 km/h; wind chill at -28.9 C 23 December; air temperature -12.8 C; bays frozen over except for isolated pockets; shoreline along Magnolia Beach frozen out into bay up to 366 m offshore.
>
> Lower Laguna Madre: 23 December; ice reported out to 183 m from shore on South Padre Island; water temperature of -1.5 C. Ice out to 46 m offshore in Port Mansfield; water temperature of -1.7 C. In Brownsville, air temperature dropped to -2.2 C on 22 December, -8.9 C on 23 December, -7.8 C on 24 December, and -1.1 C on 21 December. The -8.9 C reading was the lowest ever recorded in Brownsville for December and the lowest of the century.

Anonymous (1989) reported:

> Galveston Bay: extremely low tides; slush ice in the bays out to 403 m offshore.
>
> Matagorda: quite a bit of ice along the south shoreline.
>
> Palacios: patches of ice in the bays.
>
> Port Aransas: some ice and slush on the edges of all bays; sheet ice in the marshes.
>
> Corpus Christi: Portland shoreline frozen.

Holder (1989) reported the following from the Port Arthur area:

> Cold weather broke various monthly and all-time records held since 1916 in the Port Arthur area. The Nederland Weather Bureau Office recorded 60.5 hours of below freezing temperatures beginning 11:00 P. M. 21 December through 11:30 A. M. 24 December. Lows of -7.2 C and 0.6 C were recorded on 24 and 25 December, respectively. Lowest temperature of -11.1 C was recorded the night of 23 December; this was the lowest temperature ever logged in December since record keeping began. The daily high of 0 C on 22 December tied an all-time record; the high of -1.7 C on 23 December was also a record. The first measurable snowfall ever recorded in December was documented. The highest barometric pressure of 30.94 inches of mercury broke the previous record of 30.38 inches of mercury set on January 1924.

McEachron et al. (1995) reported the following:

> Identification of organisms killed and estimation of number of estuarine fishes and invertebrates killed was accomplished using the same methodology as reported in the 1983 freeze. About six million fishes and 155,000 invertebrates were estimated killed. A detailed accounting of species killed, numbers estimated killed, length frequencies of select killed organisms, and water temperature profiles are provided in this publication.

Following the freeze, 26 dolphins (Tursiops truncatus) were found stranded and subsequently died in the East Matagorda Bay area. Cause of death was attributed to effects of cold on the dolphins and on their main food source of striped mullet (Miller 1992).

Harrill (1989) reported Tony Amos (Research Scientist, University of Texas Marine Science Institute, Port Aransas, Texas) found 211 dead octopi along a 7-mile stretch of Mustang Island beach. Tony recorded a Gulf beach water temperature of 1.2 C.

1995

No freeze events causing mortality of organisms have occurred since December 1989.

DISCUSSION

Climatological data provide clues on severity of freezes, since most were characterized by rapidly falling air temperatures with cold of considerable duration (Tony Derda, Meteorologist, Channel 3 News, Corpus Christi, Texas, Personal Communication). During December 1983, high-altitude wind patterns shifted; Arctic air rushed due south instead of the normal eastward shift over the U. S. where the air could gradually warm (Anderson 1984). This shift in weather pattern caused unseasonably record-breaking cold weather throughout the southern U. S. Most likely, this shift in weather pattern is the cause for many of the cold weather events causing massive kills along the Texas coast.

The freeze in 1983 and two freezes in 1989 were the first ones where coastwide kill estimates were made with known levels of precision (McEachron et al. 1995). Among the 159 species identified were 103 fishes, 45 invertebrates, and 11 vertebrates other than fishes. It is difficult to compare these three freezes with earlier freezes because 1983 and 1989 kill estimates were based on numbers of organisms, rather than weight; estimates were also made for the entire Texas coast. Paucity of readily quantifiable information on pre-1983 freezes makes it impossible to quantitatively rank cold events as to severity. However, if as Gunter (1941) assumed, lower fishing pressure (i.e. low human population) is indicative of higher fish population levels, then the freezes of 1886 and 1899 were probably the most destructive in terms of numbers of organisms killed.

Assessment of short- and long-term effects of freeze events is possible through the Coastal Fisheries Division routine monitoring programs. A readily apparent short-term effect of cold-induced mass mortality of marine organisms is the immediate and often dramatic reduction in commercial and sport anglers landings. Magnitude of the short-term effect of the 1983 freeze on spotted seatrout was apparent from gill net data collected in routine gill net sampling. Catch rate (No./h) of spotted seatrout in gill nets set in upper Laguna Madre in spring (15 April-15 June) 1983 before the freeze was 0.7/h (Dailey et al. 1991). The spring 1984 catch rate dropped to 0.1/h following the freeze. Spotted seatrout catch rates recovered to near pre-freeze levels in spring 1987 (Dailey et al. 1991). Though there was no commercial fishery for spotted seatrout in 1983, the recreational fishery was severely affected by the December 1983 freeze. Sport angler catches did not reach pre-freeze levels until 1987 (Maddux et al. 1989).

Management response to freezes has changed through time in Texas. Fishery biologists historically ignored implications of naturally occurring mortalities. In the 1940's and 1950's, Gunter (1952) advocated a "*hands off*" approach, reasoning any restrictive measures would only conserve fish to be killed in the next freeze. Demographics of Texas have changed greatly during the past 40 years, resulting in changes in management strategies. Faced with increasing fishing pressure, fishery managers must address calamitous losses. During periodic catastrophic mortality, freeze events are geographically widespread and significant in terms of numbers of fishes killed. Populations must have ways to recover, otherwise successive catastrophic events would push populations closer to extinction (Hoenig and Gruber 1990). Reduction of mortality by fishing following catastrophic events should enhance recovery. Texas managers implemented more restrictive regulations for spotted seatrout following the 1983 and 1989 freezes: in January 1984 minimum size was increased from 305 mm to 356 mm and the bag limit was reduced from 20 to 10; in June 1990 minimum size was increased to 381 mm. These restrictions helped populations recover quicker than would naturally occur under unabated intense

fishing pressure (McEachron et al. 1995). The goal was to reduce fishing mortality on spawning adult fish to allow more of them to spawn. The subsequent uncrowded environment with few resource restrictions would allow for an S-shaped recovery curve for the population; *"in a salubrious and uncrowded environment, where there are no resource limitations, the population growth trajectory may approach an exponential curve, but as the population increases resources again become limiting and the population growth approaches zero"* (Hoenig and Gruber 1990). Survival rates probably increase following catastrophic loss because more resources are available for growth and reproduction of individuals (Hoenig and Gruber 1990).

One factor often implicated in the prevalence of cold related fish kills in Texas bays is the presence of organisms with tropical affinities. Primary causes of death for fish exposed to water with temperatures colder than that to which they are accustomed are asphyxia and osmoregulatory disfunction (Doudoroff 1945). Norman (1936) reported a 8.3 C range of temperature variation tolerated by most fishes; drops in water temperature greater than this range are common following passage of severe cold fronts in Texas. Storey (1937) found mortality of fish due to cold in Florida was greatest among those species with tropical distributions. In Texas, the northern limit to the range of common snook occurs in the southern portion of Texas; high numbers of snook have been killed in periodic freezes (Matlock and Osburn 1987). Snook are especially vulnerable to low temperatures (Howells et al. 1990). Many species most heavily affected by freeze events have distributions that extend into the North Atlantic. Doudoroff (1945) examined wide ranging species and concluded that individuals living at lower latitudes become acclimated to the semi-tropics and thus, become sensitive to unusual drops in temperature. Brett (1960) stated *"All species to date, endemic to the United States and Canada, given adequate acclimation, have shown the ability to tolerate temperatures in the region of the freezing point of fresh water. Rapidly onsetting low temperature, however, can constitute one of the greatest threats to survival when fish are accustomed to relatively warm water because of the inherent slow rate of acclimation to low temperature."* Bejarano (1984) reported red drum from Massachusetts and spotted seatrout from New York can tolerate lower water temperatures than individuals of the same species from Louisiana. He offered two explanations: either different physiological races have evolved or the specimens in northern waters have extended their lower incipient lethal levels via acclimatization. The former is unlikely since no biochemically distinct subspecies of red drum or spotted seatrout have been documented (Ramsey and Wakeman 1987). Additionally, no differences were found in temperature tolerances of red drum from northern (North and South Carolina) and southern (Texas) areas of its' range (Procarione and King 1993, Ward et al. 1993).

There is some evidence that young (i.e., small) marine organisms survive sudden cold better than larger animals (Gunter 1942). However, this has not been verified other than through qualitative observations.

Destruction of fishes during unusually cold weather has been reported from other Gulf states. Bejarano (1984) reported cold induced fish kills repeatedly occur in Texas and Florida (Wilcox 1887; Finch 1917; Storey and Gudger 1936a, 1936b; Miller 1940; Galloway 1941; Tabb et al. 1962; Roberts et al. 1982), seldom occur in Louisiana (Adkins et al. 1979) and Mississippi (Christmas 1973, Overstreet 1974), and are rare in Alabama (Swingle 1984). Henry Hildebrand (Marine Biologist and retired University Professor, Personal Communication) reported seeing cold related fish kills along the Mexican coast as far south as Tampico. Highest mortalities were in the Laguna Tamaulipas in extreme northeastern Mexico. On the Atlantic coast, mortalities of estuarine animals due to cold rarely occur in Georgia (Dahlberg and Smith 1970) and

North Carolina (Wells et al. 1961). Overstreet (1974) theorized mass moralities occur more frequently in Texas and Florida because water temperatures are generally warmer than in the other Gulf states. Fish in Texas and Florida would not be acclimated to lower temperatures and a sudden drop to near-freezing temperatures would affect these fishes more.

Table 1. Summary of effects of historical freezes on Texas coastal organisms. Brackets indicate approximate dates; exact extent of freeze unknown.

Description	1527	1820	1845-46	1856	1868	1886	1899
Dates	No data	No data	No data	[3 Jan-?]	[25 Dec-?]	[9 Jan-?]	12-17 Feb
Initial air temp. decreases	No data	No data	No data	No data	No data	33 C in 12 hours	No data
Continuous time of ≤0 C air temp.	No data	No data	No data	No data	No data	No data	No data
Minimum air temp.	No data	No data	No data	No data	No data	-9 C (Corpus Christi)	-13 C (Galveston) -12 C (Corpus Christi, Brownsville)
Minimum water temp.	No data	No data	No data	No data	No data	No data	No data
Area affected	Lower Texas Coast	Galveston Bay	Corpus Christi Bay	Corpus Christi Bay	No data	Entire Texas Coast	Entire Texas Coast
Ice on water	No data	Extensive (Galveston Bay)	No data	No data	No data	No data	Hard ice common (Nueces Bay; Port Aransas)
Species killed in greatest numbere	No data	No data	Edible fish	Edible fish	No data	No data	No data
Comments:	1st report of cold induced kills. Cabeza de Vaca spent 8 months with coastal Indians.	Even though Galveston Bay was reported, other areas along the coast were probably affected aa well, given the severity of the winter.	Zachary Taylor fed army of 5,000 with freeze killed fish.	Bartlett described fish becoming numbed on the oyster bar across Nueces Bay following a violent "norther"	No data	Snowstorm was greatest the south had ever seen. Possibly one of the worst freeze-kills on record.	Ice was so thick (Nueces Bay, Port Aransas) people and horses could be supported. Possibly worst freeze-kill on record

Table 1. (Continued).

Description	1917	1924	1930	1940	1941	1942	1947
Dates	3-4 Feb	19-23 Dec	[18 Jan-?]	18-28 Jan	No data	1-8 Jan	1st week Jan
Initial air temp. decreases	No data	28 C in 12 hours	No data	22 C in 4 hours	No data	No data	No data
Continuous time of ≤0 C air temp.	No data	74 hours	No data	Maybe 74 hours	No data	No data	No data
Minimum air temp.	No data	-6 C (Corpus Christi)	-10 C (Corpus Christi)	-8.9 C (Rockport)	No data	-2.2 C (Aransas Bay)	No data
Minimum water temp.	No data	No data	No data	3.9 C (Rockport)	No data	No data	16.1 C drop in water temp. over 5 days (Only mention of temp.)
Area affected	No data	Entire Texas Coast	Entire Texas Coast	Matagorda Bay into Mexico	No data	Aransas and Copano Bays	San Antonio Bay into Mexico (at least 100 miles)
Ice on water	No data	No data	No data	Up to 1 mile (Rockport) considerable mush ice	No data	No data	No data
Estimated total mortality	No data	No data	No data	No data	No data	~6,000 fish	7,257,600 kg
Species killed in greatest numbers	No data	No data	"Mullet", sand seatrout	yellowtail (silver perch), anchovies, spotted seatrout, pinfish, black drum, seacat [sic], and sheepshead. Gamefish in order of abundance: 1) black drum; 2) spotted seatrout; 3 sheepshead; 4) red drum	No data	Striped mullet, sand seatrout	Mentions spotted seatrout, black drum, red drum, yellowtail (silver perch), sheepshead, snook and small tarpon.
Comments	No data	Longest recorded period of sub-freezing temperatures up to this time	In Copano Bay, fishermen picked up numbed fish in the water	10 days of temp. <0 C during some part of the 24 hours. Spotted seatrout 114 to 203 mm. Young black drum, red drum, spot and Atlantic croaker notably absent. Dead fish on Gulf beaches. Some birds. Gunter called 1940 freeze catastrophic and worse than 1951 kill.	Called "light kill"	Cold was light and came gradually	Mentions tarpon along King Ranch, red drum up to 1,219 mm, 6.1 m alligator, 152-203 mm spotted seatrout, no small red drum, large numbers of snook in Brownsville Ship Channel and Rockport Boat Basin. Estimated 2.3 kg of fish per 0.3 m over almost 300 miles. Also 2.3 kg per 0.3 m on bottom for total of 7,257,600 kg.

Table 1. (Continued)

Description	1948	1949	1951	1962	1973	1982
Dates	No data	No data	28 Jan-3 Feb	9 -12 Jan	11-12 Jan	10-13 Jan
Initial air temp. decreases	No data	No data	Dropped slowly	16 C in 6 hours	No data	No data
Continuous time of ≤0 C air temp.	No data	No data	95 hours (Corpus Christi)	69 hours (Corpus Christi)	No data	No data
Minimum air temp.	No data	No data	-7.8 C (Corpus Christi) - 7.2 C (Rio Grande Valley)	-8.9 C (Corpus Christi)	No data	-2.0 C
Minimum water temp.	No data	No data	3.3 C (Aransas Bay)	0 C (Copano Bay) -2 C (upper Laguna Madre)	0.5 C	No data
Area affected	No data	No data	Matagorda Bay - Port Isabel	Laguna Madre	Galveston, Aransas and Corpus Christi Bays	Port Aransas
Ice on water	No data	No data	Considerable mush ice	Heavy ice (Laguna Madre)	No data	No data
Estimated total mortality	No data	No data	27 to 41 million kg	907,200 kg	≤5,000 fish	2,000-4,000 fish
Species killed in greatest numbers	No data	No data	Gunter (1951) states that mullet may have been most numerous species killed. Most of the common species were recorded (Aransas area). Estimated numbers and species from Baughman (1951): 1) mullet - 62,203,125, 2) black drum - 4,987,500, 3) spotted seatrout - 702,500, 4) red drum - 351,250	Ranked by reported weight (kg): 1) spotted seatrout - 549,000, 2) black drum - 116,000, 3) red drum - 290,000, 4) sheepshead - 19,000	Sand seatrout	Pigfish, sand seatrout
Comments	Called "light kill"	Called "light kill"	Birds, 1 leatherback turtle, people snagging fish, snagged stress fish may have lived if not caught. Large fish came to shore 3 weeks after freeze. Many invertebrates including commercial shrimp and blue crabs seen. Damage less in lower Laguna Madre than upper Laguna. Gunter felt many fish had left bays before 1951 freeze because of gradual dropping temperatures and earlier cold fronts. He felt destruction in 1940 was worse than 1951.	Only food and gamefish estimated. Pictures of dead blue crab. Within hours of freeze contract black drum netters averaged 1,100-1,360 kg/day per contractor.	54 snook dead (Aransas/Corpus Christi area). A few mullet and spotted seatrout reported killed.	Fish observed in the vicinity were moribund, not dead

Table 1. (Continued).

Description	1983	Feb 1989	Dec 1989
Dates	20 Dec-1 Jan 1984	4-6 Feb	22-24 Dec
Initial air temp. decreases	No data	17.8 C in 7 hours (Corpus Christi)	No data
Continuous time of ≤0 C air temp.	~77 hours (Port Arthur)	35 hours (Corpus Christi)	~60.5 hours (Port Arthur)
Minimum air temp.	-10 C (Corpus Christi)	-3.3 C (Corpus Christi)	-12.8 C (Palacios)
Minimum water temp.	0 C	0.46 C (Mesquite Bay)	-1.7 C (Port Mansfield)
Area affected	Entire U.S. Gulf of Mexico into Mexico	East Matagorda Bay to lower Laguna Madre	All Texas Bays
Ice on water	Extensive areas of hard ice and mush ice along shorelines and out into bays	None seen	Extensive slush ice; bays frozen over in isolated areas
Estimated total mortality	Over 11 million fishes	Over 6 million fishes	14 million fishes
Species killed in greatest numbers	Striped mullet, pinfish, spotted seatrout, Gulf menhaden	Bay anchovy, Gulf menhaden, spotted seatrout, pinfish	Striped mullet, black drum, spotted seatrout, pinfish
Comments	First coastwide quantitative assessment. Extensive fish kills in all bays. One of coldest freezes on record. Some smaller bays completely froze over. Many invertebrates killed. Hardest hit bay was the Laguna Madre. 102 mm thick ice in Trinity Bay. Gulf beach winter temperatures were 3.3 C at Port Aransas.	26 Green turtles were found along the coast. Kills were localized except in upper and lower Laguna Madre; fish in shallow bays most affected	26 dolphins died in the East Matagorda Bay area. 211 dead octpi were found along the Gulf beach at Port Aransas. Brownsville recorded the lowest air temperature (-8.9 C) this century on 22 December. Port Arthur recorded lowest air temperature (-11.1 C) on 23 December since record keeping began.

LITERATURE CITED

Adkins, G., J. Tarver, P. Bowman, and B. Savoie. 1979. A study of the commercial finfish in coastal Louisiana. Technical Bulletin Number 29. Louisiana Department of Wildlife and Fisheries, Seafood Division. New Orleans, Louisiana.

Anderson, K. 1984. Unseasonably, unreasonably cold. Time. CXXIII:(2).

Anonymous. 1886. *Galveston Daily News*. 13 January.

_____. 1899. *Corpus Christi Caller*. 17 February.

_____. 1930. Yearbook on Texas conservation of wildlife, 1929-1930. Texas Game, Fish and Oyster Commission. Austin Texas.

_____. 1947. January freeze. Pages 16-21. In. Texas Game and Fish Commission Marine Lab Annual Report, 1946-47. Texas Game and Fish Commission. Austin, Texas.

_____. 1983a. Finfish freeze kill on Gulf coast may be worst. *Houston Chronicle*. 28 December.

_____. 1983b. Brutal freeze keeps death toll climbing. *Corpus Christi Caller*. 27 December.

_____. 1984. The big freeze. In. G. C. Radonski, editor. Sport Fisheries Institute Bulletin. No. 353:April 1984.

_____. 1989. State fishing report. *Corpus Christi Caller Times*. 28 December.

Bartlett, J. R. 1856. Personal narrative of exploration and incidents in Texas, New Mexico, California, Sonora and Chihuahua, connected with the U. S. and Mexican Boundary Commission during the years 1850, 1851, 1852 and 1853. 2:530-531. Appleton, New York.

Baughman, J. L. 1947. Loss of fish due to freeze. Pages 12-13. In. Texas Game and Fish, March 1947. Austin, Texas.

_____, J. L. 1951. The fish freeze of January 1951. Pages 2-4. In. Texas Game and Fish, May 1951. Austin, Texas.

Bejarano, R. 1984. Low temperature effects on fish and cold weather fish kills in coastal Louisiana during late December 1983 and early January 1984. Louisiana Department of Wildlife and Fisheries. Unpublished Mimeo. New Orleans, Louisiana.

Brett, J. R. 1960. Thermal requirements of fish-three decades of study, 1940-1970. Pages 110-117. In. C. M. Tarzwell, editor. Biological problems in water pollution, transactions of the 1959 seminar. Public Health Service, Robert A. Taft Sanitary Engineering Center Technical Report W60-3.

Bruce, J. 1989. Green sea turtles suffer shock from recent freeze. *Corpus Christi Caller Times*. 11 February.

Burr, J. G. 1947. Undiscovered factors in the January fish freeze. Pages 6-19. In. Texas Game and Fish, May 1947. Austin, Texas.

Christmas, J. Y. 1973. Cooperative Gulf of Mexico estuarine inventory and study, Mississippi. Pages 1-71. In. Phase I. Area description. Gulf Coast Research Laboratory. Ocean Springs, Mississippi.

Dahlberg, M. D., and F. G. Smith. 1970. Mortality of estuarine animals due to cold on the Georgia coast. Ecology. 51(5):931-933.

Dailey, J. A., J. C. Kana, and L. W. McEachron. 1991. Trends in relative abundance and size of selected finfishes and shellfishes along the Texas coast: November 1975-December 1989. Management Data Series Number 53. Texas Parks and Wildlife Department, Fisheries Division. Austin, Texas.

Doudoroff, P. 1945. The resistance and acclimatization of marine fishes to temperature changes. II. Experiments with Fundulus and Atheerinops. Biological Bulletin. 88:194-206.

Finch, R. H. 1917. Fish killed by the cold wave of February 2-4, 1917, in Florida. Monthly Weather Review. April, 1917:171-173.

Galloway, J. C. 1941. Lethal effect of the cold winter of 1939-40 on marine fishes at Key West, Florida. 2:118-119.

George, R. 1989. Approaching cold front promises to be gentler. *Corpus Christi Caller Times*. 9 February.

Goodwin, B. 1983. Icy waters cause giant fish kill in area. *Corpus Christi Caller*. 27 December.

Gunter, G. 1941. Death of fishes due to cold on the Texas Coast, January 1940. Ecology. 22(3):203-208.

_____. 1942. Differential rate of death for large and small fishes caused by hard cold waves. Science. 106:472.

_____. 1945. Studies on marine fishes from Texas. Publications of the Institute of Marine Science. 1(1):1-190.

_____. 1952. The import of catastrophic mortalities for marine fisheries along the Texas coast. Journal of Wildlife Management. 16(1):63-69.

_____, and H. H. Hildebrand. 1951. Destruction of fishes and other organisms on the south Texas coast by the cold wave of January 28-February 3, 1951. Ecology. 32(4):731-736.

Harrill, R. 1989. Marine life victims of cold spell. *Corpus Christi Caller Times*. 27 December.

Higgins, E., and R. Lord. 1927. Preliminary report on the marine fisheries of Texas. Report of the United States Commissioner of Fisheries for the Fiscal Year 1926. United States Department of Commerce, Bureau of Fisheries. Washington, District of Columbia. 168-199.

Hoenig, J. M., and S. H. Gruber. 1990. Life-history patterns in the elasmobranchs: implications for fisheries management. Pages 1-16. In. H. L. Pratt Jr., S. H. Gruber, and T. Taniuchi, editors. Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries. NOAA Technical Report NMFS90. United States Department of Commerce, NOAA, NMFS.

Holder, E. 1989. Freeze makes fish kill one of worst. *The Port Arthur News*. 28 December.

Holt, S. A., and G. J. Holt. 1983. Cold death of fishes at Port Aransas, Texas: January 1982. The Southwestern Naturalist. 28(4):464-466.

Hoten, M. J. 1990. Extreme cold weather effects on eight Texas bays. Texas Water Commission. LP 90-1. Austin, Texas.

Howells, R. G., A. J. Sonski, P. L. Shaffland, and B. D. Hilton. 1990. Lower temperature tolerance of snook, Centropomis undecimalis. Northeast Gulf Science. 11(2):155-158.

Maddux, H. R., H. R. Osburn, D. L. Trimm, and K. S. Spiller. 1989. Trends in finfish landings by sport-boat fishermen in Texas marine waters, May 1974-May 1988. Management Data Series Number 8. Texas Parks and Wildlife Department, Fisheries Division. Austin, Texas.

Matlock, G. C., and H. R. Osburn. 1987. Demise of the snook fishery in Texas. Northeast Gulf Science. 9(1):53-58.

McEachron, L. W., G. C. Matlock, C. E. Bryan, P. Unger, T. J. Cody, and J. H. Martin. 1995. Winter mass mortality of animals in Texas bays. Northeast Gulf Science. 13(2):121-138.

Mies, J. 1989. The deep freeze of '89. *Corpus Christi Caller Times*. 22 December.

Miller, E. M. 1940. Mortality of fishes due to cold on the southwest Florida coast. Ecology. 21(3):420-421.

Miller, G. W. 1992. An investigation of bottlenose dolphin *Tursiops truncatus* deaths in East Matagorda Bay, Texas, January 1990. Fisheries Bulletin. 90(4):791-797.

Moore, R. H. 1976. Observations on fishes killed by cold at Port Aransas, Texas, 11-12 January 1973. The Southwestern Naturalist. 20(4):461-466.

Norman, J. R. 1936. A history of fishes. London.

Overstreet, R. M. 1974. An estuarine low-temperature fish-kill in Mississippi, with remarks and restricted necropsies. Gulf Research Reports. 4(3):328-350.

Procarione, L. S., and T. L. King. 1993. Upper and lower temperature tolerance limits for juvenile red drum from Texas and South Carolina. Journal of Aquatic Animal Health. 5:208-212.

Ramsey, P. R., and J. M. Wakeman. 1987. Population structure of Sciaenops ocellatus and Cynoscion nebulosus (Pisces: Sciaenidae): biochemical variation, genetic subdivision and dispersal. Copeia. 1987(3):682-695.

Roberts, H., L. Rouse, N. Walker, and J. Hudson. 1982. Cold water stress in Florida Bay and northern Bahamas. A product of winter cold outbreaks. Journal of Sedimentary Petrology. 52(1):145-155.

Simmons, E. G. 1957. An ecological survey of the upper Laguna Madre of Texas. Publications of the Institute of Marine Science. 4(2):156-200.

_____. 1962. The effects of a hard freeze on marine life. Pages 10-11. In. Texas Game and Fish, April 1962. Austin, Texas.

Storey, M. 1937. The relation between normal range and mortality of fishes due to cold at Sanibel Island, Florida. Ecology. 18(1):10-26.

_____, and E. W. Gudger. 1936a. Mortality of fishes due to cold at Sanibel Island, Florida. 1888-1936. Ecology 17(4):640-648.

_____, and _____. 1936b. Mortality of fishes due to cold on the southeast Florida coast, 1940. Ecology 21(3):420-421.

Swingle, H. A. 1984. Observations of a winter kill of fishes in coastal Alabama. Department of Conservation and Natural Resources, Marine Resources Division. Unpublished Mimeo.

Tabb, D., D. Dubrow, and R. Manning. 1962. The ecology of northern Florida Bay and adjacent estuaries. Florida Board of Conservation. Technical Series 39:1-81.

Ward, R., I. Blandon, T. King, and T. L. Beitinger. 1993. Comparisons of critical thermal maxima and minima of juvenile red drum (Sciaenops ocellatus) from Texas and North Carolina. Northeast Gulf Science. 13(1):23-28.

Wells, H. W., M. J. Wells, and I. E. Gray. 1961. Winter mortality in Pamlico Sound, North Carolina. Ecology. 42(1):217-219.

Wilcox, J. 1887. Fish killed by cold along the Gulf of Mexico and coast of Florida. Bulletin of the United States Fish Commission. 6:123.

PWD RP V3400-431 (02/96)