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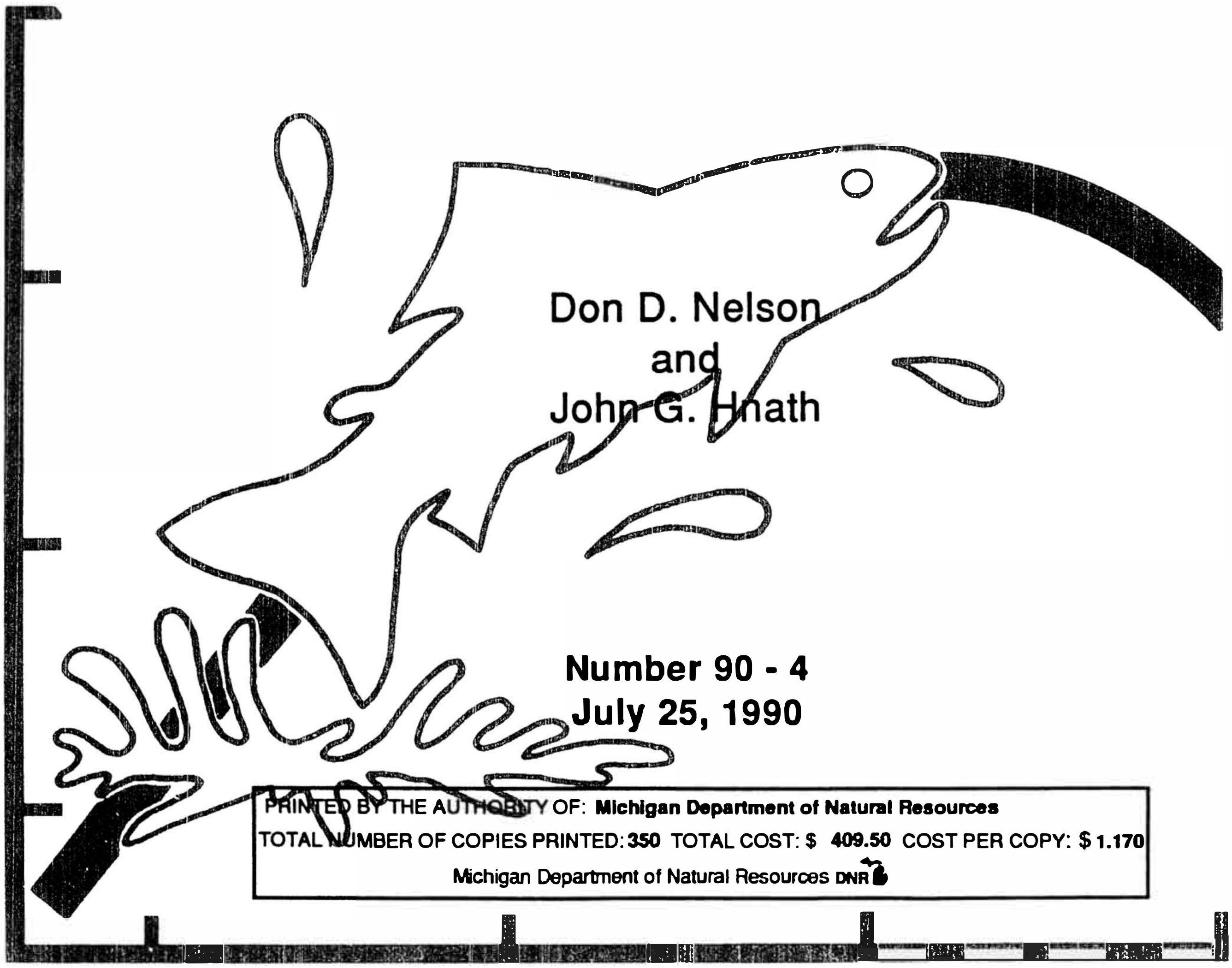
FISHERIES DIVISION

TECHNICAL REPORT

Lake Michigan Chinook Salmon Mortality - 1989



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Abstract.—In the spring of 1988, dead chinook salmon began appearing along the shores of southern Lake Michigan. Early spring searches found most dead fish in the southern part of Lake Michigan between Portage, Indiana, and St. Joseph, Michigan. As the season progressed, reports of dead fish moved further north. By June, the mortality appeared to have ended. In March of 1989 a renewal of significant mortality appeared. Similar to 1988, dead salmon first appeared near Michigan City, Indiana, and then sightings moved progressively north until the month of June. The most northern observations came from the vicinity of Frankfort, Michigan. In both years, tissue samples were collected from fish found dead and dying. These samples were examined for known disease and toxic agents by pathologists and histopathologists at ten laboratories throughout the United States. Based on aerial surveys and counts made at several sites along the shore, we estimate that a minimum of 20,000 chinook salmon died in the spring of 1989. To date, no cause for these deaths has been determined. Bacterial kidney disease (BKD) has been present in all of the samples and appears to be the final cause of death. However, BKD has not been shown to cause significant mortalities in wild salmon populations. Therefore, we conclude that an unknown stress or disease agent might have caused a normally nonlethal infection of BKD to result in death.

During the spring and summer of 1988, many adult salmon died in southern Lake Michigan. This was the first known instance of a large mortality in salmon populations in the Great Lakes since the beginning of the salmon program in 1966. Chinook salmon (*Oncorhynchus tshawytscha*) was the primary species affected, although some coho salmon (*O. kisutch*), brown trout (*Salmo trutta*), and steelhead trout (*O. mykiss*) were involved.

Mortalities appeared to be restricted to southern Lake Michigan, with most carcasses appearing along Michigan's shoreline. No reports of dead salmon were received from the northern portion of Lake Michigan or any of the other Great Lakes.

In response to this mortality, Michigan, Indiana, Illinois, Wisconsin, and Minnesota committed a variety of resources to research both the cause and extent of the problem. Michigan's efforts and findings are detailed by Johnson and Hnath (1991).

In 1988, findings indicated that approximately 7,000 to 10,000 chinook salmon may have died in Michigan waters from April through June. No specific cause for the mortality could be identified although all of the affected fish had bacterial kidney disease (BKD). However, under normal conditions BKD does not produce mortalities in wild salmon populations (Warren 1983); therefore, the investigators believed that some unknown stress or pathogen had weakened the fish, and that this allowed normally non-lethal infections of BKD to cause death.

In anticipation that salmon mortalities might occur again in 1989, the states of Michigan, Indiana, Illinois, Wisconsin, and Minnesota developed strategies to increase the quantity and quality of information to be collected. Under the direction of the Lake Michigan Committee of the Great Lakes Fish Disease Control Committee, guidelines were established for data and specimen collection. Fisheries administrators of the various natural resource agencies became increasingly involved in the problem. Several states increased the number of people assigned to work on the project. In Michigan, a field biologist was assigned to assist the State Fish Pathologist to coordinate the overall investigative activities. This report details the results of those activities for 1989 and the recommendations for 1990.

Study Area

The area of observed mortalities has been the southern portion of Lake Michigan. In Michigan waters the northern limit of the mortality was at Manistee, with only a few reports coming from as far north as Charlevoix (Figure 1). The Two Rivers area of Wisconsin appeared to be the most northern point of mortality on the west shore of Lake Michigan. In total, there was nearly 450 miles of shoreline involved.

Methods

Magnitude and Location

In order to assess the magnitude and the spatial and temporal trends of the mortality, several direct counting methods were employed.

As in 1988, an airplane was used to observe the entire eastern shoreline of Lake Michigan from Manistee to the Indiana border. Three flights were spaced evenly over the mortality period. Two of the flight dates were selected to correspond to 1988 flight dates.

The airplane flew at an altitude of approximately 400 feet with an average speed-over-ground of approximately 90 miles per hour. All of the observations in both 1988 and 1989 were made by David Johnson, Michigan Department of Natural Resources (MDNR), District Fisheries Supervisor at Plainwell.

Because of the nature of fixed wing flights, only the most easily observed fish were counted. Such fish included sick salmon that were swimming aimlessly near shore and dead fish that were near the shore/water interface. No attempt was made to count old carcasses that had washed on the beach. As much as possible, recently dead fish were distinguished from other carcasses by a subjective evaluation of silver skin color.

In addition to the shore run, the pilot was directed to fly over open-water areas of Lake Michigan so the observer could look for sick or dead salmon in areas away from shore.

Other sampling included beach counts at a series of locations. The MDNR fisheries personnel at Plainwell established 15 observation sites between New Buffalo and Saugatuck. These sites were located at easily accessible points where long sections of beach could be observed. At most sites no attempt was made to walk the beach; counts were made using binoculars. At four sites where the beach could be accessed, observations regarding the size and species composition of the dead fish were made by walking the beach.

Also, a complete beach count was made at Van Buren State Park, which is located between St. Joseph and South Haven. Throughout the observation period, park personnel counted and removed all dead salmon from a 3/4-mile section of beach. Generally, this was done a minimum of twice a week and more frequently when there were many dead fish.

Several other less quantitative measures were also used to gain additional insight into the magnitude and extent of the mortality. Over 3,000 observation record forms were distributed to MDNR field personnel, law enforcement officers, charter fishing captains and Great Lakes fishing associations. This one-page form included a short description of the problem and asked individuals to report sightings of sick fish. Spaces were provided for information on species, number, size, location, date, and symptoms.

Other agencies that conduct research on Lake Michigan were asked for assistance. In particular the research vessels of the U. S. Fish and Wildlife Service, National Fisheries Center—Great Lakes and the MDNR Lake Michigan Research Station were making a joint evaluation of Lake Michigan forage stocks during the period of April 15-25, 1989. Although most of this effort was spent in the northern portion of Lake Michigan, the first 4 days were spent in the study area south of Ludington. Not only were the vessel crews able to make visual surface observations in offshore areas, but they also made bottom trawls as part of the forage study.

Finally, all other state and provincial agencies that had Great Lakes projects were contacted. They were provided with general information about the southern Lake Michigan salmon mortality and asked to report any unusual fish mortalities.

Total mortality

Because of the nature of the problem, it is difficult to make a precise estimate of the total mortality. The aerial surveys only provided instantaneous counts of sick and dead salmon near the shore/water interface, and detailed beach counts were lacking along most portions of the Lake Michigan shoreline. Still, a rough estimate of the minimum total mortality is possible.

Both beach counts and aerial surveys were made in the three shore stations between Michigan City, Indiana, and Saugatuck, Michigan. Assuming the beach counts were more representative of total mortality, an adjustment factor was calculated to estimate beach counts for the rest of the shoreline. The adjustment factor was simply the average beach count divided by the average shore count from the three stations at which both were made. The aerial flight survey counts for the other stations were then multiplied by this adjustment factor to estimate beach counts in those areas. Beach counts could only be considered minimum estimates of total mortality, because they would include only dead fish washed up on shore.

Pathology

Because of the geographical distribution of the mortality, pathological procedures and investigations were closely coordinated between fish health units in Michigan, Illinois, and Wisconsin. Samples and information were shared by the three agencies.

In 1989 the first samples of sick fish were collected between April 2 and April 6. A total of 14 chinook salmon and 1 steelhead were taken at St. Joseph, Michigan, and Michigan City, Indiana, for examination by the Michigan Fish Health Laboratory. On April 5 and April 6, Illinois pathologists collected 10 sick chinook salmon from the waters of Indiana for examination at their laboratory. During the second week of April, Wisconsin personnel collected eight chinook salmon from the Racine area. Although these fish had been dead for several days, they were analyzed for BKD.

With the exception of the fish taken from Wisconsin, all were collected alive and kept on ice until they were necropsied within a few hours of death. Tissues from the gills, anterior kidney, posterior kidney, liver, spleen, and hindgut were collected from each fish. Tissues were also taken from areas of the fish that appeared clinically abnormal. All tissues were preserved in 10% neutral buffered formalin. Skin-on fillets were taken from several of the fish collected by the Michigan and Illinois pathology labs and frozen for pesticide analysis. Both labs prepared and examined cultures made from tissues of the fish for bacterial pathogens other than BKD. In addition, the number of acanthocephalans (spiny-headed worms) in the lower gut of each fish was estimated.

In addition to the salmon, two species of forage fish were collected for BKD analysis. During the 1989 Lake Michigan forage assessment study, the crew of the MDNR Lake Michigan research vessel, S/V *Steelhead*, collected samples of chubs and alewife. A sample of 50 chubs was taken on April 15 at Saugatuck, Michigan, and a sample of 84 alewives was taken on April 18 at Two Rivers, Wisconsin. These fish were frozen for later examination at the Michigan Fish Health Laboratory.

In May of 1989 a second effort was made to collect samples of sick fish. Because the lake-wide mortality had decreased, fish were very difficult to find. After an intensive effort, which included the use of spotting aircraft, Michigan was able to collect only one chinook salmon. This fish was collected near Muskegon. Several days later the Wisconsin Department of Natural Resources (WDNR) collected two distressed salmon from their waters. In addition to the three fish collected from southern Lake Michigan, control samples of three apparently healthy chinook salmon were taken from both Lake Huron (MDNR) and northern Lake Michigan (WDNR). Standard tissue samples and blood samples for plasma contaminant analysis were taken from these nine fish.

As an adjunct to the investigations conducted at the Fish Health Labs in Michigan, Illinois, and Wisconsin, a wide variety of material was sent to other labs throughout the United States. These facilities are listed in Table 1. Also included in the table is a designation of the primary field of investigation.

Finally, in order to assess the incidence of BKD in apparently healthy chinook salmon, fish health personnel from both Michigan and Wisconsin examined fish which were caught at several salmon fishing tournaments on the Great Lakes. These fish were examined for gross clinical signs of BKD; however, tissue samples from fish that exhibited clinical signs were later examined for the presence of BKD organisms.

Results

Magnitude and Location

In 1989 almost all of the reports of dead and dying salmon came from Michigan waters. During March through June, Wisconsin reported only a few dead and dying salmon in the Racine/Kenosha area. An early April report of many sick salmon in the Two Rivers area of Wisconsin could never be confirmed and only a few dead salmon were observed in this area. In Illinois only a few dead salmon were seen; primarily during early spring. Indiana reported more dead and distressed salmon than Wisconsin and Illinois; however, the total number of fish involved was less than in 1988. Beginning on April 5, there were many distressed salmon near the pier at Michigan City, Indiana. Schools of 15 to 25 sick fish were reported. By the following week most of the fish had disappeared and only a few sick and dead fish were seen during the remainder of the period.

In Michigan the first report of sick salmon came from St. Joseph on March 27, and by April 8, dead fish were being reported along the beach in this vicinity. By April 10, sick fish were being seen in the vicinity of Muskegon and by May 2 several sick fish were observed as far north as Frankfort. In general reports of dead salmon followed observations of sick fish by approximately 1 week. The most northerly observations came from north of Frankfort in Platte Bay except for one observation of a dead chinook salmon that was received in June from the vicinity of Charlevoix. The last reported observation of a sick salmon was made June 15 in the vicinity of Manistee; however, unverified reports of a few dead salmon persisted through the end of June.

The results of the three aerial flights are shown in Table 2. Overall, the greatest number of dead and distressed fish per mile occurred along the shoreline between St. Joseph and Whitehall. No sick or dead fish were ever observed in off-shore areas.

It is presumed that most of the dead and dying fish seen from the air were salmonids. Due to their behavior and distinctly dark dorsal pigmentation, sick salmon were relatively easy to identify. And, based on concurrent shore observations of dead fish, other large fish, such as carp (*Cyprinus carpio*) and suckers (*Catostomus* spp.) were rarely encountered. For example, at Van Buren State Park only one carp was found dead during the entire mortality period, and suckers were never encountered.

On the first sampling date of April 25 the greatest concentration of dead and distressed fish was between South Haven and Whitehall. Unfortunately, the flight had to be terminated north of Whitehall because of dense fog. It is likely that dead and distressed fish would have extended north of Whitehall, based on the number of fish per mile observed directly south of Whitehall on this date.

The results of the second flight on May 15 were somewhat surprising. More dead fish were observed in the four southern shore segments than had been counted during the first flight. It is unclear whether this represented a second peak of mortality, or whether dead fish had been transported into the area as a result of strong southwesterly winds on May 5 and May 9.

Information gained during the third flight on June 6 indicated that the mortality had decreased but was moving north, as shore observers had reported. Most of the June 6 count was comprised of fish that had been dead for some time. It included only 5 sick fish and 13 recently dead fish out of a total count of 209 fish.

Table 3 shows a comparison of the average number of dead and distressed salmon per mile observed during the 1988 and 1989 aerial survey flights on two comparable sampling dates. In 1988, flights were made on April 9, April 26, and June 7. In 1989, flights were made on April 25, May 15, and June 6. Only the flights during the last week of April and the first week of June are compared. However, it is important to realize that the differences in the number of fish between years could easily be caused by different wind and current patterns.

By mid-to-late April cooperating agencies were reporting that fewer fish were involved in 1989. Table 3 confirms these reports. Along the shoreline between Michigan City, Indiana, and Muskegon, Michigan, there were only 42% as many dead and distressed fish in 1989 as in 1988. However, the 1989 mortality was more extensive in the more northern waters of southern Lake Michigan. In 1989, the number of dead and distressed fish between Muskegon and Manistee was 38% greater than in 1988. For the total shoreline between Michigan City, Indiana, and Manistee, Michigan, 23% fewer dead and distressed salmon were observed in 1989 compared to 1988.

Table 2 shows the percentage of sick and recently dead salmon to the total number of dead and dying fish on each of the three 1989 aerial flights. The total number of fish per mile at each station is also included. In general the percentage of sick and recently dead salmon at each station decreased over time. And, on the May 15 and June 6 sampling dates there was a trend for the percentage of sick and recently dead salmon to be higher at the northern stations.

On-site beach counts for the shore between New Buffalo and Saugatuck are presented in Table 4. These counts, standardized to number of fish per mile, are relatively high and variable through the May 8 sampling date and then decrease to low levels by the end of May. It is unclear whether the variability is caused by an unequal distribution of sick salmon, an unequal distribution of death among salmon, or by environmental events such as windstorms which cause an unequal accumulation of carcasses on shore.

The relationship between high winds and waves is apparently represented in the counts made at Van Buren State Park (Table 5). Since these salmon carcasses were counted and removed, there was no opportunity for them to be counted more than once. Strong westerly winds and high surf conditions were reported in this area on May 5, 9, 10, and 19. Of the total counted, nearly 60% were collected during the May 6 to May 11 period.

Total mortality

On the average, beach counts were 82 times higher than aerial counts made during the same period at the three stations between Michigan City, Indiana and Saugatuck, Michigan. Adjusting the aerial counts by the factor of 82 gave minimal estimates of the number of dead salmon at the other stations (Table 6).

Although this procedure has only limited application, it was interesting to compare the actual beach counts at Van Buren State Park to the estimate for the shore segment that includes the park. In this case, the estimate of total mortality for the St. Joseph—South Haven Station was 180 fish per mile (Table 6). The actual number of fish collected at Van Buren State Park was 192 fish per mile (Table 5). Even though the numbers were derived by two different sampling methods, they are very similar. On this basis the total 1989 salmon mortality in the shoreline area between Michigan City, Indiana, and Onekama, Michigan, was estimated to be about 20,000 fish (Table 6).

Since most fish were counted from the air or from shore with binoculars, it was not possible to give a detailed analysis of species composition and size. However, more detailed observations made while walking beaches and collecting fish allowed us to estimate that chinook salmon comprised over 99% of the total mortality, by number. A few steelhead and coho salmon were also reported. The largest reported chinook salmon was 16.5 pounds and the smallest was 0.75 pounds

Except for southern Lake Michigan, state, federal, tribal, and provincial agencies did not report any unusual salmon mortalities in waters of the Great Lakes. During the 1989 Lake Michigan forage study conducted jointly by the U. S. Fish and Wildlife Service and the MDNR, no dead salmon were seen or collected with bottom trawls either inside or outside of the study area.

Pathology

Even though more fish and tissue samples were collected and examined in 1989 than in 1988, there is no clear consensus on the exact cause of death. Bacterial kidney disease (BKD) organisms (*Renibacterium salmoninarum*) were detected in all samples, although the pathology was not entirely consistent with the disease. In some cases, healthy looking fish had extensive BKD infections, while some of the apparently sick fish had only minor infections. In fact, for some of the fish with only low levels of infection, blood loss was listed as a possible cause of death.

Results received to date from viral screening and histopathology examinations indicate that no known viral agent was detected using standard virological diagnostic procedures and cell lines for known salmonid viral agents. However, these results do not necessarily exclude the possibility that an unknown infectious agent, such as a virus, may be present.

In addition to the BKD organisms, other disease agents were sometimes observed in the samples. Histological examinations revealed an unidentified algae-like organism in the gills of most fish and in the heart of one fish. Other fish had high concentrations of filamentous bacteria on the gills. Bacterial gill disease organisms and protozoan parasites were observed in some of the gill tissue samples. *Pseudomonas* infections were common in many sick fish and *Aeromonas hydrophila* organisms were found in several of the affected fish. Also, fungus (water mold) was seen on the gills and body surface of some of the fish and acanthocephalans (spiny-headed worms) were universal in the lower intestines of both healthy and sick fish.

The clinical and pathological signs of the affected fish were extensive (Tables 7 and 8). Membranes with a cheesy appearance were present in varying degrees on the liver, spleen, and heart. The kidney was swollen and sometimes covered with pustules. Bleeding from the anus was nearly universal in the sick fish and was caused by hemorrhages in the lower gut. Hemorrhages in the stomach mucosa, liver, flesh, and ventral body wall were also common. As a result of blood loss, the gills were pale and hematocrit levels ranged from 3% to 24% (normal level is 40%, or greater). The body cavity contained bloody fluids, and cloudy fluids were sometimes present in the stomach and pericardial cavities. Feeding activity had apparently stopped in sick fish as the gut was void of food, there was little or no visceral fat and the liver glycogen stores were low. Scales were extremely loose and separated from the skin with only slight pressure. When observed in the water, the dorsal surface of sick fish was darkly pigmented.

At this time, not all of the sample analyses have been completed. Results are pending on the blood plasma contaminant analyses, flesh contaminant analyses, and electron microscope evaluations. Fluorescent antibody analysis of the chub and alewife samples is complete and was negative for BKD.

During the months of July, August, and September, Michigan fish health personnel attended a total of five salmon fishing tournaments. These tournaments were located at Berrien Springs (St. Joseph), South Haven, Ludington, Manistee, and St. Ignace (see map). During the tournament weigh-in phase, sport-caught fish were examined for clinical signs of disease. The results are shown in Table 9. Overall, a total of 65 chinook salmon and 38 steelhead were examined. Eleven chinook salmon (17%) and seven steelhead (18%) exhibited signs of disease. Of these, five chinook salmon (8%) were judged to have positive clinical signs of BKD.

Wisconsin also examined tournament-caught fish in the Racine/Kenosha area and the Manitowoc/Two Rivers area (Sue Marcquenski, Wisconsin DNR, personal communication). Early in the summer nearly 40% of sport-caught fish at Racine exhibited clinical signs of BKD. However, by early July less than 5% of fish caught near Racine had clinical signs of BKD. Likewise, less than 5% of salmonids examined in the Manitowoc area showed clinical signs of BKD.

Discussion

Even though almost 2 years of data have been collected and analyzed on the chinook salmon mortality, the underlying cause is still unknown. The majority of sick fish examined had severe clinical cases of BKD, which was presumed to be the final cause of death. It is also possible that the acanthocephalans (spiny-headed worms) in the lower gut may exert a deleterious effect on the fish, although the number of worms in sick versus healthy fish was not significantly different (*t* test, $P > 0.05$).

Since BKD is not believed to cause mortalities in wild salmon populations, most researchers think that some unknown stress was operating to make southern Lake Michigan salmon more vulnerable to the disease. This view is primarily supported by the fact that most chinook salmon stocked by the State of Michigan in Lake Michigan and Lake Huron came from the same egg source and, to some degree, harbored BKD organisms. The incidence of detectable levels of BKD in returning spawners, based on concentrated ovarian fluid procedures, now approaches 100%. Wisconsin reported similar findings (Sue Marcquenski, Wisconsin DNR, personal communication). Yet, only in southern Lake Michigan do salmon apparently die from the disease.

Theories about possible sources of stress have varied widely and include environmental problems (such as water quality), ecological problems (such as changing food webs and foraging behavior), or unidentified disease problems.

The total impact of this mortality is difficult to judge. While 20,000 fish is a very large number, it is relatively small when compared to the nearly 6 million chinook salmon fingerlings that were stocked in Lake Michigan by the states of Michigan, Indiana, Illinois, and Wisconsin. In addition, there was an unknown contribution to the stocks from natural reproduction.

Most of the affected fish were age 2 and age 3 and had survived the high mortality period of early life. Natural mortality rates for fish of these ages is normally low and most would be expected to survive to be caught or to spawn. In addition, the estimate of 20,000 fish should be viewed as a conservative number. Because sick fish appear to seek warm protected waters near shore, the probability they will eventually be observed is good. Unfortunately, no research has been conducted to examine the percentage of fish that die and wash ashore. If many fish died and were never moved to shore where they could be counted, the actual number of dead fish could be much larger.

Because we have no data on fishing exploitation rates for chinook salmon of this age in Lake Michigan, it was impossible to predict what percentage of these fish would have been caught by anglers if the fish had not died. For comparison purposes, the total 1985 Lake Michigan open-water chinook salmon harvest was 922,000 fish. This was the most recent year for which the total lake-wide harvest was available. The estimated 1989 Lake Michigan chinook salmon sport harvest, from Michigan waters only, was 162,000 fish.

In summary, the loss of 20,000 salmon cannot solely account for the poor salmon fishing in Lake Michigan during 1988 and 1989. BKD does, however, represent an additional component of mortality which, when combined with other sources of mortality, can degrade Lake Michigan's salmon fishery. Every reasonable procedure should be followed to reduce or eliminate the cause of this mortality.

Recommendations

Hatchery Management

Although the cause or causes of the stress have not been identified, action must be taken to mitigate the mortality. Since both stress and BKD organisms are apparently required to produce mortalities, the elimination of either factor should produce positive results. At this point, a logical next step is hatchery management of BKD. Michigan has already initiated several steps which were directed at reducing the incidence and magnitude of BKD infections.

1. Beginning with the 1989 chinook salmon egg-taking operations, the body cavity of all fish to be spawned will be examined for clinical signs of BKD. All fish with signs of the disease will be rejected. All equipment, work surfaces and employee hands and gloves will be disinfected after handling clinically ill fish.

2. All ovarian fluids will be drained and the eggs will be "dry" spawned.

3. One entire day's production will be water hardened in Argentyne (an iodine disinfectant) and the resulting lot of eggs will be separately maintained and monitored for hatchery performance through the eye-up stage. If this procedure successfully eliminates BKD organisms, all future eggs will be water hardened in Argentyne.

4. Prior to release, all chinook salmon smolts will be treated with an antibiotic.

5. Finally, Michigan is attempting to locate a source of BKD-free eggs. The State of New York has indicated that BKD has not been detected in Lake Ontario chinook salmon in recent years. If an egg surplus exists, Michigan will attempt to obtain chinook salmon eggs from New York in order to establish a stock of BKD-free fish.

Magnitude and Location

1. Aerial flights should continue in 1990. A fourth flight should be added to cover the early April period. The entire shoreline between Portage, Indiana, and Manistee, Michigan, should be covered on each flight.

2. The quantity and quality of beach counts should be increased throughout the entire study area. Shore counts similar to those made in 1989 at Van Buren State Park, with removal or marking, should be made throughout the study area.

3. In 1990, mid-winter, late winter, and early spring observations should be made in the southern part of the lake to insure there is no overwinter mortality. It is unclear whether the mortality actually starts in late March or whether this date coincides with the time of year people begin using the lake and are, therefore, available to make observations.

4. Underwater video cameras should be used in 1990 to inspect a portion of the lake bottom for carcasses. "Sick" fish appear to seek warm, protected waters near shore. If true, this behavior increases the probability that most carcasses will eventually be washed ashore where they can be observed. There was some concern, however, that many fish may die and sink to the lake bottom and cannot be counted.

Pathology

1. A long-term goal should be established to mark a larger portion of the salmon stocked in Lake Michigan. Presently, there is no method to determine the source of the affected fish. For example, there is no way to judge whether these fish came from a single hatchery or state agency, whether wild or production fish are involved, or whether the mortality is equally distributed between all Lake Michigan chinook salmon stocks. A tetracycline marking program scheduled for 1990 will provide answers regarding wild versus hatchery fish.

2. Samples of sick fish should continue to be collected for the analysis of contaminants, pathology, histopathology, and virology. In addition gill, blood, liver, spleen, and gut tissues should be examined for the presence of *Chlamydia*.

3. Live fish from Lake Michigan should be examined in February/March and October for the presence of intestinal sporozoa.

4. Examinations for viral erythrocytic necrosis and erythrocytic inclusion body syndrome should be conducted on affected fish.

5. Infectivity trials on live fish should be performed using tissues or cultures from moribund fish.

6. The strain of BKD organisms found in southern Lake Michigan salmon should be cultured, typed, and evaluated for toxin production.

7. Age-0 and age-1 chinook salmon should be collected from Lake Michigan and examined for the presence of disease.

8. Field personnel should be trained in sampling methodologies and, in 1990, more Great Lakes tournament fish should be examined for the presence of disease.

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Figure 1.—Map of Lake Michigan showing the major ports.

Table 1.—Laboratories that examined tissue samples collected during the 1989 study of southern Lake Michigan salmon mortality, with the primary area of investigation indicated.

Facility	Area of investigation
Michigan Fish Health Laboratory Mattawan, Michigan	General pathology/BKD
Illinois Fish Health Laboratory Manito, Illinois	General pathology/BKD
Wisconsin Fish Health Laboratory Madison, Wisconsin	General pathology/BKD
New York State Fish Health Laboratory Rome, New York	Viral screening
Minnesota Fish Health Laboratory St. Paul, Minnesota	Viral screening
National Fisheries Research Laboratory Leetown, West Virginia	Pathology/histopathology
Veterinary Science Laboratory University of Rhode Island Kingston, Rhode Island	Histopathology
Washington Fish Health Laboratory Longview, Washington	Histopathology/ electron microscopy
Veterinary Medical College University of Wisconsin Madison, Wisconsin	Histopathology
Wisconsin Department of Natural Resources Environmental Laboratory Madison, Wisconsin	Pesticide analysis/ blood plasma analysis

Table 2.—Percent of sick and recently dead (silver colored) salmon in the total number of dead and dying salmon. Average number of dead and dying salmon counted in aerial flights per mile is given in parentheses. Asterisk indicates that no observation was made.

		Flight dates		
Station	Number	April 25, 1989	May 15, 1989	June 6, 1989
Michigan City to New Buffalo	1	17 (0.6)	6 (1.6)	50 (0.2)
New Buffalo to St. Joseph	2	75 (0.8)	10 (2.9)	0 (0.5)
St. Joseph to South Haven	3	35 (1.7)	18 (4.9)	0 (0.2)
South Haven to Saugatuck	4	43 (2.8)	15 (2.7)	0 (0.4)
Saugatuck to Holland	5	100 (3.2)	0 (0.5)	0 (0.3)
Holland to Port Sheldon	6	89 (4.6)	14 (0.7)	0 (1.5)
Port Sheldon to Grand Haven	7	91 (3.4)	25 (1.2)	8 (1.3)
Grand Haven to Muskegon	8	100 (3.4)	28 (1.8)	18 (1.1)
Muskegon to Whitehall	9	94 (6.8)	100 (1.3)	0 (1.9)
Whitehall to Little Pt. Sable	10	* *	92 (1.2)	4 (2.4)
Little Pt. Sable to Pentwater	11	* *	* *	6 (1.8)
Pentwater to Ludington	12	* *	* *	10 (2.0)
Ludington to Manistee	13	* *	* *	20 (1.0)
Manistee to Onekama	14	* *	* *	17 (0.6)

Table 3.—Comparison of the average number of dead and dying salmon per mile and the total number observed during the 1988 and 1989 aerial survey flights along Lake Michigan beaches on two comparable sampling dates (April 26, 1988, and April 25, 1989; and June 7, 1988, and June 6, 1989).

Station	Station number	Shore length (miles)	Number per mile		Number	
			1988	1989	1988	1989
Michigan City to New Buffalo	1	9.9	0.6	0.4	6	4
New Buffalo to St. Joseph	2	25.8	2.2	0.4	57	10
St. Joseph to South Haven	3	22.7	3.8	0.9	86	20
South Haven to Saugatuck	4	19.5	4.6	1.6	90	31
Saugatuck to Holland	5	6.6	2.3	1.2	15	8
Holland to Port Sheldon	6	8.5	2.5	2.4	21	20
Port Sheldon to Grand Haven	7	11.4	1.8	1.9	21	22
Grand Haven to Muskegon	8	12.3	2.0	1.6	25	20
Muskegon to Whitehall	9	10.4	0.6	2.6	6	27
Whitehall to Little Pt. Sable	10	20.5	0.7	2.4	14	49
Little Pt. Sable to Pentwater	11	10.0	0.6	1.7	6	17
Pentwater to Ludington	12	12.3	0.4	2.0	5	25
Ludington to Manistee	13	23.5	0.2	0.9	5	21
Manistee to Onekama[1]	14	—	—	—	—	—
Total		193.4			357	274

[1]Aerial observations were made only on June 6, 1989.

Table 4.—Number of dead salmon per mile counted along selected southern Lake Michigan beaches south of Saugatuck, Michigan, in 1989. Values based on beach counts.

Station (segment number)	Date					
	Apr 14	Apr 21	May 3[1]	May 8	May 22	May 30[2]
2: New Buffalo-St. Joseph						
Segment 1	—	5	23[1]	41	0	—
Segment 2	—	9	18[1]	26	0	0
Average	—	7	20[1]	34	0	0
3: St. Joseph-South Haven						
Segment 3	--	35	0	18	0	0
Segment 4	188	23	211	12	0	0
Segment 5	26	20	13	15	10	2
Segment 6	29	18	18	44	11	2
Segment 7	0	23	0	12	6	0
Segment 8	—	—	—	4	0	4
Segment 8A	18	18	—	35	—	—
Average	65	23	81	20	5	1
4: South Haven-Saugatuck						
Segment 9	9	2	20[1]	37	9	0
Segment 10	9	18	25[1]	32	9	3
Segment 11	12	53	58[1]	62	18	9
Segment 12	10	7	16[1]	25	14	4
Segment 13	153	59	53[1]	47	12	29
Segment 14	0	12	12[1]	12	29	0
Segment 15	88	53	97[1]	141	35	35
Average	40	29	40[1]	51	18	11

[1]Counts were not made on May 3, 1989 at the New Buffalo-St. Joseph stations (1-2) or the South Haven-Saugatuck stations (9-15). These values were calculated by taking the average of the counts made on April 21, 1989 and May 8, 1989.

[2]Most of the dead fish counted on May 30, 1989 were extremely decomposed.

Table 5.—Number of dead salmon per mile counted and removed from the Van Buren State Park beach during the 1989 southern Lake Michigan salmon mortality. The beach is 3/4 mile long.

Date	Number (per mile)
April 22	11
April 25	7
May 2	9
May 4	9
May 6	36
May 9	9
May 10	27
May 11	40
May 13	8
May 16	4
May 20	3
May 27	7
May 31	11
June 4	11
Total	192

Note: Strong westerly winds and high surf conditions were reported on May 5, May 9-10, and May 19.

Table 6.—Estimate of the total number of dead salmon observed along Lake Michigan beaches from Michigan City, Indiana, to Onekama, Michigan, during the spring and summer of 1989.

Station	Shore miles	Average[1] aerial count per mile	Estimated[2] beach count per mile	Estimated[3] number dead salmon
Michigan City to New Buffalo	9.9	0.8	65.6	649
New Buffalo to St. Joseph	25.8	1.3	106.6	2,750
St. Joseph to South Haven	22.7	2.2	180.4	4,095
South Haven to Saugatuck	19.5	1.9	155.8	3,038
Saugatuck to Holland	6.6	1.0	82.0	541
Holland to Port Sheldon	8.5	1.8	147.6	1,255
Port Sheldon to Grand Haven	11.4	1.6	131.2	1,496
Grand Haven to Muskegon	12.3	1.6	131.2	1,614
Muskegon to Whitehall	10.4	1.8	147.6	1,535
Whitehall to Little Pt. Sable	20.5	0.8	65.6	1,345
Little Pt. Sable to Pentwater	10.0	0.6	49.2	492
Pentwater to Ludington	12.3	0.7	57.4	706
Ludington to Manistee	23.5	0.3	24.6	578
Manistee to Onekama	11.5	0.2	16.4	189
Total	204.9			20,283

[1]Mean number of dead salmon observed per mile in each shore station during the three 1989 aerial flights.

[2]Values calculated by multiplying the mean number of dead salmon observed during the 1989 aerial flights (column 3) by a factor of 82.

[3]Values calculated by multiplying the estimated beach count per mile of dead salmon (column 4) by the number of miles in each shore segment (column 2).

Table 7.—Summary of Bacterial kidney disease (BKD) incidence in dead and moribund salmonids examined by the State of Michigan Fisheries Pathologist. All fish were collected between April 2 and September 15, 1989.

ID number	Species	Location	Clinical signs	BKD results
1	Chinook salmon	St. Joseph	+	+
2	Steelhead	St. Joseph	+	+
3	Chinook salmon	Michigan City	+	+
4	Chinook salmon	Michigan City	+	+
5	Chinook salmon	Michigan City	+	+
6	Chinook salmon	Michigan City	+	+
7	Chinook salmon	Michigan City	+	+
8	Chinook salmon	Michigan City	+	+
9	Chinook salmon	Michigan City	+	+
10	Chinook salmon	St. Joseph	+	+
13	Chinook salmon	St. Joseph	+	+
14	Chinook salmon	St. Joseph	+	+
15	Chinook salmon	St. Joseph	+	+
46	Coho salmon	New Buffalo	+	+
47	Chinook salmon	Muskegon	+	+
50	Steelhead	St. Joseph	+	-
51	Steelhead	Ludington	+	-

Table 8.—Clinical signs and pathology of dead and moribund fish collected between April 2, 1989, and September 15, 1989.

ID number	Description
Fish #1	Heavy scale loss; bleeding from vent; slight ascites; one pustule on spleen; liver pale with pustules and hemorrhages; multiple pustules in posterior kidney.
Fish #2	Extensive hemorrhage from gills; fluid in pericardial cavity; nodules on heart; a few spots of hemorrhage on the liver; slight ascites; fluid in swim bladder. Kidney and spleen appeared normal.
Fish #3	Most scales missing; bloody vent; gills pale with hemorrhage; bloody ascites; very pale liver; petechiae in swim bladder; bloody hindgut; kidney slightly convex; "blebs" in kidney; hemorrhage in liver; stomach void of food with some hemorrhagic areas.
Fish #4	Many missing scales; gills pale; bleeding from vent; slight bloody ascites; liver pale with hyperemic area; kidney slightly swollen; stomach devoid of food and filled with clear fluid; stomach lining inflamed.
Fish #5	Many missing scales; petechiae on gills; bloody vent; bloody ascites; multiple tiny hemorrhages in swim bladder, visceral fat, mesenteries, internal body wall, and along the intestinal tract; liver pale with hemorrhages; fluid-filled pericardial cavity; kidney slightly convex; small amount of clear fluid in stomach.
Fish #6	Bleeding from vent; hemorrhage on ventral body surface and around eyes; gills dark red and clubbed; slight bloody ascites; pericardial cavity filled with gelatinous fluid; extreme extra-vascularization over internal organs and body wall; no visceral fat; heart covered with white gelatinous material; stomach contained clear yellowish fluid tinged with blood; some hemorrhage in stomach lining.
Fish #7	Many missing scales; bleeding from vent and gills; slight bloody ascites; liver mottled and hyperemic; spleen grossly enlarged and hyperemic, with pustules and a false membrane; kidney grossly swollen and convoluted, with multiple white lesions; no visceral fat; stomach empty.
Fish #8	Many missing scales; bleeding from vent; gills dark red; some hemorrhage in mouth; slight bloody ascites; no visceral fat; liver with white pustules and partial false membrane; white false membrane on spleen (cheesy material); a few gray lesions in kidney; hemorrhages in heart.
Fish #9	Most scales missing; bloody vent; some bleeding from gills; considerable bloody ascites; no visceral fat; liver pale; white cheesy material on spleen; kidney swollen with pustules; hindgut flaccid and blood-filled; thin fluid in stomach; some hemorrhage in stomach lining.

Table 8.—Continued:

ID number	Description
Fish #10	Many loose and missing scales; bloody vent; bleeding in the eyes; slight hemorrhage in isthmus; slight cloudy ascites; multiple tiny hemorrhages in body wall, swim bladder, and viscera; spleen covered with cheesy material; cheesy material covered portions of swim bladder; bloody hindgut; stomach full of milky fluid; extensive hemorrhage of stomach lining; multiple tiny hemorrhages throughout the musculature.
Fish #11	Loose scales; bleeding from vent; apparent bloody ascites. Organs were too necrotic for further examination.
Fish #12	Loose scales; bleeding around eyes; hemorrhages along ventral body surface and around vent; bloody ascites; hemorrhagic areas in spleen and lower gut; kidney swollen with pustules; pustules in liver.
Fish #13	Many loose and missing scales; bloody vent; hemorrhages in eyes and along ventral body surface; much clear watery fluid in body cavity; considerable hemorrhage in pyloric caecae; liver and heart pale; stomach lining highly inflamed.
Fish #14	Loose and missing scales; hemorrhages along ventral surface; some necrotic areas in gills; bloody ascites; hemorrhage throughout visceral fat and along hindgut; liver covered with cheesy material; spleen surrounded by gelatinous fluid and covered with cheesy material; stomach empty; stomach lining highly inflamed; hard yellow material attached to stomach lining in two places; hindgut inflamed.
Fish #15	Loose scales; one eye full of blood; hemorrhage along ventral body surface; liver covered with cheesy material; many hemorrhages over body wall and swim bladder; stomach lining highly inflamed; hindgut inflamed; many acanthocephala; multiple petechiae through the musculature.
Fish #46	"Boil" on caudal peduncle filled with reddish gelatinous material; sore on ventral body surface; blood in body cavity (ascites?); kidney slightly swollen.
Fish #47	Many loose and missing scales; cloudy ascites; areas of cheesy material on spleen and liver; body wall and swim bladder hemorrhagic; no visceral fat; liver pale.
Fish #50	Hemorrhage under scales on ventral surface between anal and caudal fins; slightly cloudy fluid in abdominal cavity; fluid-filled cavity in the caudal peduncle; many adhesions among the viscera; extra vascularization in the fat and hindgut; thin, tough (not cheesy) membrane covered spleen; kidney and liver appeared normal.
Fish #51	Lesion on internal body wall.

Table 9.—Summary of 1989 Great Lakes salmon tournament inspections for the incidence of symptomatic disease and clinical signs of bacterial kidney disease (BKD).

Location (date)	Species	Number of fish	Number with symptomatic disease	Number with clinical BKD
South Haven (Jul 8, 1989)	Chinook	5	0	0
	Steelhead	4	0	0
Ludington (Jul 14, 1989)	Chinook	1	0	0
	Steelhead	6	0	0
St. Joseph (Jul 24, 1989)	Steelhead	28	7 (25%)	0
St. Ignace (Aug 26, 1989)	Chinook	29	3 (10%)	3 (10%)
	Pink salmon	1	0	0
Manistee (Sep 1, 1989)	Chinook	30	8 (27%)	2 (7%)

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