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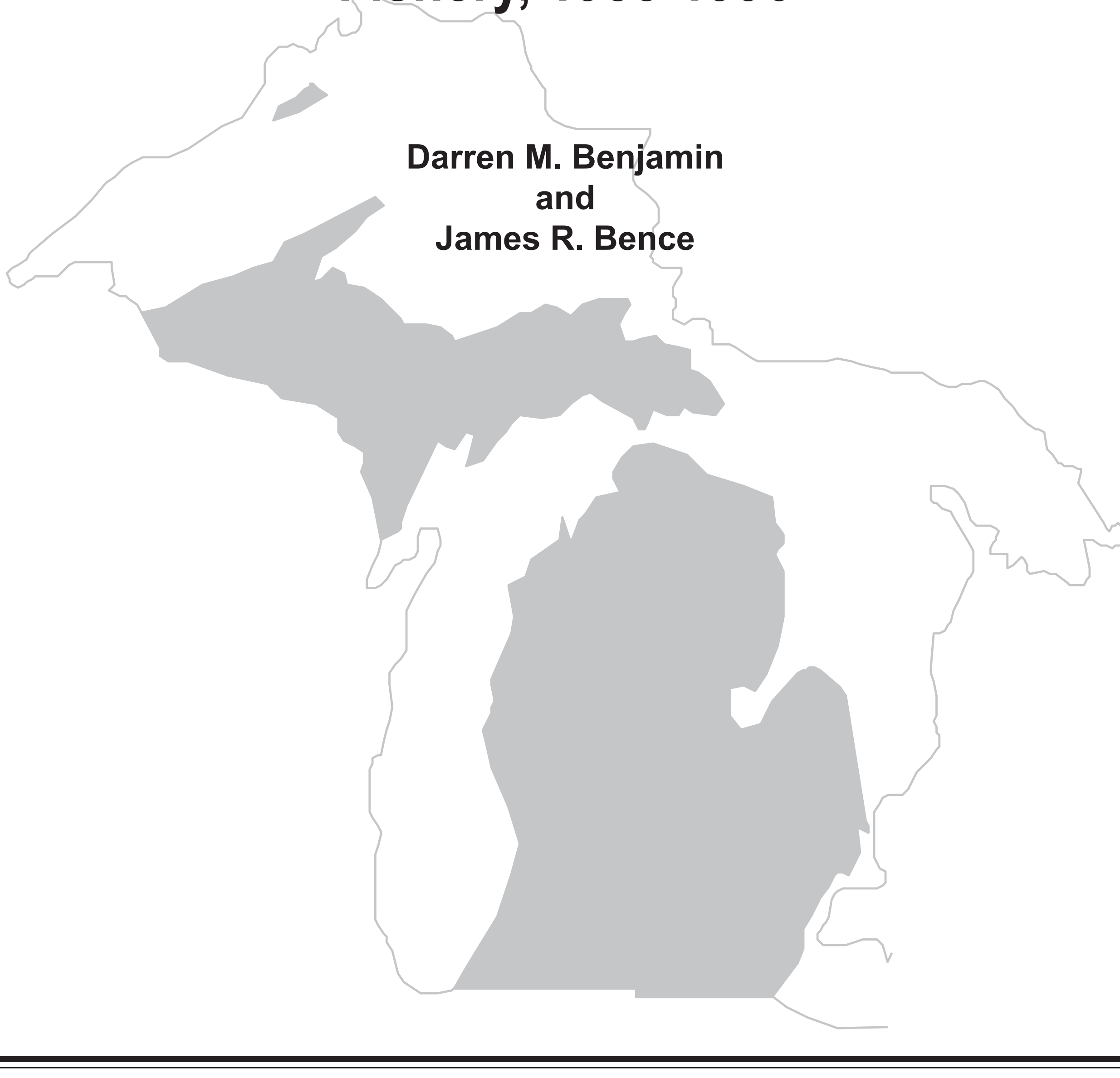

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Spatial and Temporal Changes in the Lake Michigan Chinook Salmon Fishery, 1985-1996

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Abstract.–The chinook salmon population in Lake Michigan underwent dramatic changes between 1986 and 1996. These changes were most directly felt by the sport fishery, as harvest and harvest rates for chinook salmon began declining in 1987, triggering a decline in sport fishery effort, which led to a cycle of further declines in harvest. Greatest declines in the fishery were seen in the Michigan waters of the lake along the eastern shoreline, where chinook salmon harvest declined by 95%. Complete collapse of the entire salmonine sport fishery, however, was avoided. The fishery that was once dominated by chinook salmon harvest was able to diversify and maintain high harvest rates by targeting other salmonine species. Part of the reason for spatial differences in trends in the chinook salmon fishery was due to changes in the spatial distribution of chinook salmon, as evidenced by spatial differences in harvest rate trends. It is likely that chinook salmon concentrated in the western regions of the lake in response to spatial changes in the distribution of alewives, their primary forage.

Introduction

The present Lake Michigan fish community is complex and dynamic. The 1940s and 1950s were periods of dramatic change, as native lake trout (*Salvelinus namaycush*) and cisco (*Coregonus sp.*) populations either declined or became extinct due to invasions by exotic species, commercial overfishing, and degraded spawning habitat (Wells and McLain 1973). By the late 1950s, the fish community was of little economic or recreational value. Successful management efforts to control exotic sea lamprey (*Petromyzon marinus*), as well as the need to control overabundant alewives (*Alosa pseudoharengus*), prompted the introduction of trout and Pacific salmon in the 1960s. The introduction of salmonines served several purposes: to restore lake trout, to control nuisance alewives, and to support a sport fishery (Tody and Tanner 1966).

Lake Michigan's modern salmonine stocking program began with the successful introductions of rainbow trout (steelhead) (*Oncorhynchus mykiss*) in 1963. Lake trout were re-introduced in 1965. Coho salmon (*O. kisutch*), brown trout (*Salmo trutta*), and brook trout (*S. fontinalis*) were introduced in 1966, followed by chinook salmon (*O. tshawytscha*) in 1967. Stocking of all salmonines increased from the 1960s to the 1980s. Stocking rates by some states increased more slowly or even declined in the mid-1980s due to limits in hatchery production capacity and increased concerns about lake carrying capacity (Stewart et al. 1981; Kitchell and Crowder 1986; Keller et al. 1990). Lake-wide stocking of all salmonines has been relatively constant since the late 1980s (Keller et al. 1990; Holey 1996).

The salmonine sport fishery grew rapidly through the 1970s and 1980s; angler effort increased by an order of magnitude, harvest rate doubled, and harvest increased 20-fold in the Wisconsin waters of Lake Michigan (Hansen et al. 1990). Much of the fishery growth was driven by increases in annual stocking of salmonines. Of these salmonines, chinook salmon was the most heavily stocked and was the most prized sportfish because of its size and fighting ability. By the mid-1980s, Lake Michigan supported the most spectacular sport fishery in its history and contributed to an estimated $2 billion Great Lakes fishery (Keller et al. 1990).

As stocking levels continued to grow through the 1970s, biologists became concerned that high levels of stocking would produce a predator-prey system in which predator abundance would not be governed by prey dynamics, and leading to instability (Stewart et al. 1981). Stewart et al. (1981) challenged Lake Michigan fishery managers to consider temporal fluctuations in forage biomass and species composition when determining stocking levels. Michigan created a plan to reduce forage consumption by 10% by reducing its overall stocking by 8.5% relative to the 1980-84 average, beginning in 1985 and extending through 1990 (Keller et al. 1990). Wisconsin, in turn, planned to reduce chinook salmon stocking rates by 10% in response to declines in the species' condition and in alewife abundance (Hansen 1986; Keller et al. 1990).

In 1986 and 1987, dead chinook salmon were littering beaches along the southeastern shoreline. By 1988, the number of visible dead chinook salmon was estimated at 10,000 fish (Nelson and Hnath 1990; Johnson and Hnath 1991), and increased to an estimated minimum of 20,000 in 1989. Clinical tests indicated that these fish ultimately died from an infestation of *Renibacterium salmoninarum*, a bacterium that causes bacterial kidney disease (BKD) (Nelson and Hnath 1990). Because *R. salmoninarum* is common even in healthy salmon, it is believed that some other environmental stress weakened these fish to the point where BKD became lethal (Nelson and Hnath 1990). It has been suggested that the additional stress is nutritional stress from a reduced alewife population (Nelson and Hnath 1990; Stewart and Ibarra 1991; Jones et al. 1993; Rybicki and Clapp 1996; Wesley 1996). Chinook salmon continued to die from BKD through 1996 (Clark 1996), although the presence of dead chinook on the beaches had declined (Marcquenski 1997). Increases in natural mortality of chinook salmon were reflected in the sport fishery, as harvest rates, harvest, and fishery effort declined beginning in 1987. By 1993, Lake Michigan chinook salmon harvest had severely declined despite the maintenance of high stocking levels.

The purpose of this study was to describe more fully the spatial and temporal trends in the Lake Michigan chinook salmon fishery from 1986 to 1996, within the context of the entire salmonine fishery. A better understanding of the extent and location of harvest declines, as well as a spatial understanding of fishing mortality and chinook salmon movements will aid in stocking decisions and in population modeling.

Methods

Stocking Data

Information on salmonine stocking was provided by Lake Michigan fishery management agencies. Illinois stocking data were provided by Rich Hess (Illinois Department of Natural Resources). Indiana stocking data were compiled from Indiana DNR stocking reports provided by Jim Francis (Indiana Department of Natural Resources). Michigan stocking information from 1963 to 1978 was compiled from summarized data provided by Bill McClay (Michigan Department of Natural Resources). Stocking information from 1979 to 1996 was provided by Christine Larson through the Fish Stocking Information System (Michigan Department of Natural Resources). Wisconsin stocking information was compiled from Wisconsin DNR summary reports (Hansen 1988; Coshun 1991; Hansen et al. 1991; Burzynski and Multhauf 1995; Burzynski 1996).

Compiled lake-wide data were entered into a database and checked for accuracy. The database was compared to an existing Lake Michigan stocking database developed for the Great Lakes Fishery Commission (M. Holey, USFWS, personal communication). The existing GLFC database was missing data for rainbow trout from 1963 to 1974, for brook trout from 1966 to 1975, and for brown trout from 1966 to 1974. The GLFC database covered stocking of chinook salmon from 1967, and coho salmon from 1966. For stocking years included in both databases, differences in stocking numbers across databases were generally minor. For example, chinook salmon stocking data differed in only 5 years between 1967 and 1988, and differences in those years were less than 7%. Coho salmon stocking differed in 9 of the years between 1966 and 1988, and most of those differences were less than 7% except for 1966 (60%) and 1985 (20%). Discrepancies were most commonly due to double entry errors in the GLFC database, while in other minor cases the GLFC database contained records of additional plants that could not be accounted for. This second situation is not surprising since most of our stocking numbers originated from summary reports and not raw data. Still, any errors in our database would have originated within the summary reports themselves. The GLFC database contained stocking records up through 1988 for all species except lake trout, which contained records through 1992. Our database contained records from 1963 to 1996 for all salmonines except lake trout. Results of this comparison and copies of the updated database were presented to the Lake Michigan Technical Committee in 1996.

Monitoring of the Sport Fishery

Data and estimates on sport fishery harvest, effort, and catch rates were carefully reviewed. There were two primary sources for these data. The first was from creel surveys run by each of the states and the second source was from mandatory reports obtained from charter operators. In Michigan, Illinois, and Wisconsin, these creel surveys explicitly exclude the charter component (before 1990, Michigan's charter fishery was covered as part of the creel survey). The charter trips are included as part of the Indiana creel survey and these data were used to evaluate that component of the fishery. For the other states, information on the charter component of the fishery comes from mandatory charter reports.

Creel Survey Data and Estimates

Annual creel surveys are conducted by each of the states surrounding Lake Michigan in order to monitor the sport fishery. Consistent estimates of total effort and harvest were available from 1986 through 1996. Wisconsin conducted a creel survey of the salmonid fishery in the Wisconsin waters of Lake Michigan from 1969 to 1985 (Hansen et al. 1990), and began sampling the entire fishery in 1986. Illinois began consistently sampling its fishery in 1986, though additional surveys were done in 1969, 1979, and 1985. Indiana has sampled its portion of Lake Michigan annually beginning in 1974, though sampling methods have been consistent since 1986. Michigan began consistently monitoring its Lake Michigan fishery in 1985.

Austen et al. (1995) compared and contrasted the creel survey methods from each of the states. Creel surveys on Lake Michigan are generally conducted from April through October, and ice fisheries on Green Bay and Grand Traverse Bay are occasionally sampled as well. Each survey approximates a two-stage sampling design, with sampled days treated as the first stage, and counts or interviews within days treated as the second stage. Sampling is stratified by period (month or similar interval), day type (weekday or weekend/holiday), area (port, site, or management area), and fishing mode (boat, pier, shore, stream, etc.). The boat fishery was grouped here to include estimates from surveys of launched boats, moored boats, and charter boats (see *Charter report data*). The shore fishery included surveys of shore, pier, and ice fishery anglers. The stream fishery was not included in this study due to a lack of information for Michigan's stream fishery.

Fishing effort is estimated from interval counts at access sites or from instantaneous counts of boats, pedestrian anglers, ice shanties, cars, or trailers. Average daily counts are converted to a measure of fishing effort (angler-hours), and fishing effort is estimated for a stratum by multiplying the average daily effort by the number of days in the stratum. Harvest rates (harvest per angler-hour) are calculated from the angler interviews within each stratum, and are multiplied by fishing effort to estimate harvest for a stratum. Summary harvest rates reported here were calculated by dividing the sum of the annual harvest by the sum of the annual effort. Variances were available for Michigan and Wisconsin surveys only. For Wisconsin, variances were provided by the WDNR for total harvest by species and total fishery effort. For Michigan, variances were calculated for total harvest and targeted harvest by species, total effort, and salmonine effort. Standard errors were reported here for Michigan and Wisconsin waters only.

Changes in harvest rates, or catch-per-unit-effort (CPUE), can be used to assess trends in relative abundance. In spite of drawbacks in using CPUE as an index of abundance (Malvestuto 1983), this was necessary in Lake Michigan since there had been no lake-wide fishery-independent survey for salmonines. In Lake Michigan, the sport fishery effort is primarily directed towards salmonines and yellow perch. Targeted harvest rates were used in this study to avoid bias due to changes in contribution of effort for yellow perch or other species. Targeted effort was defined as effort directed at the harvest of salmonines. Targeted harvest was estimated from targeted effort, and targeted harvest rates were calculated as the quotient of targeted harvest and targeted effort.

Summary information on the sport fishery was provided by biologists from Wisconsin, Illinois, and Indiana. Wisconsin data were provided by Brad Eggold (Wisconsin Department of Natural Resources). Illinois creel data were obtained from annual summary reports (e.g. Brofka and Marsden 1997), and additional data were provided by Wayne Brofka (Illinois Natural History Survey). Illinois charter fishery data were provided by Rich Hess (Illinois Department of Natural Resources). Indiana data were obtained from annual summary reports (Braun 1987; Palla 1997), and for recent years were provided by Jim Francis (Indiana Department of Natural Resources).

Michigan's creel survey estimates were recalculated from the raw data for this study. Pre-existing methods utilized a mean-of-ratios catch rate estimator that is inappropriate for Michigan access point angler surveys (Lockwood 1997). Estimates for Michigan's waters of Lake Michigan were recalculated for this study using a ratio-of-means catch rate estimator and new variance estimators, as outlined in Lockwood et al. (1999).

Charter Report Data

Charter fishery information was generally obtained from harvest reports filed by licensed charter captains to their respective state. Wisconsin initiated a mandatory reporting system in 1974, although because of early underreporting these reports were not considered to be reliable until 1976 (Hansen et al. 1990). Illinois charter boat reporting began in 1976. In Indiana, charter fishery information is sampled in the creel. Charter boat reporting for the Michigan waters began in 1990. Prior to 1990, the Michigan charter fishery information was sampled in the creel.

Harvest Ratio

One way to gauge the success of a stocking program is to know the percentage of stocked fish that are harvested by the fishery. This harvest ratio is defined as the ratio of total number of fish harvested to the total number of fish stocked (Hansen et al. 1990). Naturally reproduced fish were not specifically identified in the calculation of harvest ratio, although they very likely contributed to the estimate of total fish harvested. Estimates of naturally reproduced age-0 fish were not added to the estimate of total fish stocked. To estimate a harvest ratio, an annual harvest age composition was calculated for chinook salmon aged by the Michigan creel survey. These age compositions were applied to the lake-wide harvest to estimate year-class harvest for the 1985 to 1992 year classes. The Michigan age compositions were assumed to apply to the lake-wide population, which seemed reasonable, based on similar length-frequency data from the Wisconsin and Michigan creel surveys. In addition, coded wire tag studies suggest that the chinook salmon population is highly mixed throughout the lake (Bence et al. 1996). The analysis included only the 1985 to 1992 year classes because the 1993 year class had not been completely harvested by the fishery in 1996.

Lake Regions

For this spatial analysis of the Chinook salmon fishery, the lake was divided into seven distinct regions (Figure 1). These regions followed statistical district boundaries (Smith et al. 1961), where aggregates of two or more statistical districts constituted a lake region. The Green Bay region includes statistical districts WM-1 and WM-2 from the Wisconsin waters of Green Bay, and MM-1 from the Michigan waters of Green Bay. The Northern region included Michigan statistical districts MM-2, MM-3, and MM-4 (Grand Traverse Bay). The Northwestern region included Wisconsin statistical districts WM-3 and WM-4 along the eastern shore of the Door Peninsula. The Northeastern region included Michigan statistical districts MM-5 and MM-6. The Southwestern region included Wisconsin statistical districts WM-5 and WM-6. The Southeastern region included Michigan statistical districts MM-7 and MM-8. The Illinois-Indiana region included all waters within Illinois and Indiana state boundaries.

Results

Stocking History

Lake-wide stocking of salmonines in Lake Michigan has been presented elsewhere (Keller et al. 1990; Holey 1996). The lakewide stocking history of salmonines in Lake Michigan is reviewed here because past work has not always given information on all life stages and all years stocked, and because there are inconsistencies in stocking summaries derived from various sources. The procedure used to ensure that the stocking summary presented here is as accurate as possible is described in the Methods. While the trends presented are quite similar to other presentations, details do differ, and these differences become more important when stocking is considered for sub-regions of the lake.

Chinook salmon have historically dominated the stocking program. They are stocked almost entirely as spring fingerlings. Stocking levels increased annually from 900,000 in 1967 to 6 million in 1980 (Figure 2). From 1980 to 1996, stocking fluctuated around 6 million fingerlings with peak years in 1984 (7.7 million) and 1989 (7.9 million).

Significant numbers of lake trout were stocked into Lake Michigan beginning with 1.3 million yearlings in 1965, although 292,000 yearlings were stocked from 1959 to 1962 (Figure 2). Annual stocking of yearlings increased annually to 2.5 million in 1980. Stocking of yearlings ranged from 1.1 million to 2.8 million from 1981 to 1996. Relatively few fingerlings were stocked in comparison to yearlings in the 1960s and 1970s. Fingerling and fry stocking contributed from 10% to 63% of the total number stocked in the 1980s, and fry were not stocked after 1987. Total stocking peaked at 5.4 million fish in 1989.

Coho salmon stocking began in 1966 and exceeded 3 million by 1969 (Figure 2). From 1969 to 1996, coho stocking declined from 3.5 million to 2.5 million with a peak year in 1979 (4.4 million). Coho were usually stocked as yearlings, although the proportion of fingerlings stocked has increased from 1987 to 1996.

Annual rainbow trout (steelhead) stocking levels increased annually from 1963 to 1973, reaching a peak in 1973 at 3 million fish (Figure 2). Stocking fluctuated between 1.2 million and 3.2 million fish from 1974 to 1984. From 1985 to 1996, stocking was relatively consistent, ranging from 1.5 to 2 million fish. The stocking ratio of yearlings to fingerlings was roughly 1:1 from 1970 to 1984. Since 1985, stocking was composed of roughly 75% yearlings.

Brown trout stocking began in 1966 and increased to 2 million fish by 1973 (Figure 2). Stocking fluctuated between 500,000 and 1.5 million fish from 1974 to 1981. From 1982 to 1996, annual stocking levels fluctuated between 1.5 and 2 million fish. Brown trout were stocked both as fingerlings and as yearlings.

Brook trout were stocked primarily in Wisconsin waters as both fingerlings and as yearlings, although they were occasionally stocked in Michigan waters until 1990, and in Illinois until 1980. Fewer than 100,000 brook trout were stocked annually from 1966 to 1976 (Figure 2). In 1977, an additional 500,000 fingerlings were stocked in Wisconsin for a total of 623,000 – the most of any year. Stocking levels fluctuated between 200,000 and 300,000 from 1978 to 1986, and between 100,000 and

500,000 from 1987 to 1989. Stocking levels declined from 1990 to 1996.

Salmonine Fishery Lake-wide Trends

Sport fishery effort in Lake Michigan declined from 1986 to 1996. Total effort declined by 54%, from 14.1 million angler-hours in 1986 to 6.5 million angler-hours in 1996 (Figure 3). Salmonine effort comprised 61% of the total fishery effort in 1986, but fell to 41% in 1992 before returning to 49% in 1996. Salmonine effort declined by 63% from 8.6 million angler-hours in 1986 to 3.2 million angler-hours in 1992. Salmonine effort was stable at 3.2 million angler-hours from 1992 to 1996.

Harvest of salmonines declined by 53% from 1.8 million salmonines in 1986 to 855,000 in 1990 (Figure 4). From 1990 to 1996, salmonine harvest was relatively consistent at 800,000, with a low harvest occurring in 1992 at 746,000 salmonines. Targeted salmonine harvest rate (targeted salmonine harvest per salmonine angler-hour) fluctuated between 0.12 and 0.16 from 1986 to 1990 (Figure 4). Harvest rate increased from 1990 to a period high of 0.19 in 1996.

Lake-wide harvest of coho salmon peaked in 1989 at 407,000 and declined to 155,000 in 1991. Harvest levels from 1992 to 1996 ranged from 181,000 to 295,000 with an average of 237,000. Contribution of coho salmon harvest to the total salmonine harvest increased from 18% in 1986 to 35% in 1993.

Lake trout are generally not preferred by anglers, but are relied upon when fishing for other salmonines is poor (Lange et al. 1995). Lake trout harvest comprised 13% to 27% of the salmonine harvest between 1986 and 1996. Peak harvest was in 1989 at 347,000 while 1996 was the lowest harvest year at 115,000.

Rainbow trout harvest was limited to a stream fishery in the mid- to late-1980s. In 1986, the lake harvest of rainbow trout was 68,000, less than 5% of the salmonine harvest. An offshore fishery developed for rainbow trout as anglers learned to target rainbow trout along surface temperature breaks, and harvest increased to a peak of 172,000 in 1993, comprising 20% of the salmonine harvest. Harvest declined to 142,000 in 1996.

Brown trout harvest has accounted for 6% to 13% of salmonine harvest from 1986 to 1996. Harvest declined from 171,000 in 1986 to 73,000 in 1988. Harvest fluctuated between 63,000 and 110,000 from 1987 to 1996. Most brown trout were harvested in Wisconsin and Michigan.

Brook trout harvest historically accounted for less than 1% of lake-wide salmonine harvest. Most brook trout harvest was concentrated in Wisconsin, although a small fraction was harvested in Michigan. Harvest ranged from 500 to 6,000 from 1986 to 1996.

Chinook Salmon Fishery Lake-wide and Regional Trends

In the subsections that follow, detailed information is presented on temporal trends in harvest, effort, and catch rate for chinook salmon for each region of Lake Michigan. These detailed results show the following general patterns. First, there were substantial differences in how the overall collapse of the chinook salmon fishery unfolded. Most notably, the decline was greater on the eastern (Michigan) shore in comparison with the western (Wisconsin) shore, with the greatest decline in the southeast. This generalization applied to harvest (Figure 7), harvest rate (Figure 8), and harvest ratio (percent of a stocked year class harvested (Figure 10), but less so to the amount of fishing effort on salmonines (Figure 6). These results suggest some spatial changes over time in either the distribution or survival of chinook salmon (see also Discussion). In addition, comparisons of stocking, harvest, and harvest ratio provided no evidence that regional in-lake harvest was closely tied to regional stocking numbers.

Regional Trends in Salmonine Effort for the Sport Fishery

Trends in salmonine effort for each region of Lake Michigan generally followed a lake-wide trend of declining effort in the late 1980s, followed by a consistently low level of effort in the early to mid-1990s. The major differences between regions were the years in which the declines actually began and ended, and the overall extent of the declines (Figure 6).

Salmonine effort in Green Bay increased from 1986 to 1988 before declining by 69% from 384,000 angler-hours in 1988 to 119,000 angler-hours in 1996. Effort was relatively consistent from 1992 to 1996. In comparison to the lake-wide salmonine effort, effort in Green Bay contributed 3-7% of the lake-wide total from 1986 to 1996.

Salmonine effort in the Northern region was at a period-low level in 1986 in contrast to a period-high level lake-wide. Effort peaked in 1987 at 245,000 (±20,000) angler-hours and fluctuated between 157,000 (±16,000) and 194,000 (±17,000) angler-hours from 1988 to 1993. Effort declined from 194,000 (±17,000) in 1991 to 119,000 (±6,900) in 1996. Similar to Green Bay, effort in the northern region contributed between 3% and 6% of the lake-wide effort from 1987 to 1996.

Salmonine effort in the Northwest region declined by 55% from 984,000 angler-hours in 1986 to 439,000 angler-hours in 1990, similar to the lake-wide rate of decline of 53% over the same years. Effort from 1990 to 1996 was relatively stable at 400,000 to 450,000 angler-hours. Effort in the northwest comprised 9-14% of the lake-wide total from 1986 to 1996.

The high rate of decline of salmonine effort in the Northeast region was second only to the Southeast, declining by 69% from 1.6 million (±172,000) angler-hours in 1986 to 510,000 (±33,000) angler-hours in 1992. Period-low salmonine effort occurred in 1995 at 424,000 (±34,000) angler-hours. Effort in the northeast comprised 13-23% of the lake-wide total from 1986 to 1996.

Salmonine effort in the Southwest did not begin to decline until 1988, and declined by 62% from 1.4 million angler-hours in 1987 to 542,000 angler-hours in 1990 (Figure 6). Effort remained low from 1990 to 1993, and increased slightly to 620,000 angler-hours from 1994 to 1996. Effort in the southwest comprised 13-20% of the lake-wide total from 1986 to 1996.

The greatest declines in Lake Michigan salmonine effort occurred in the southeast region. Salmonine effort declined by 77% from a peak of 2.75 million (±241,000) angler-hours in 1986 to a period low level of 621,000 (±38,000) angler-hours in 1992. Effort remained below 715,000 angler-hours from 1992 to 1996 (Figure 6). Effort in the southeast once comprised 32% of the lake-wide total in 1986, but declined to 19% by 1993. Salmonine effort in the Illinois-Indiana region was large relative to its lake area, due primarily to the high human population density along almost it's entire shoreline. In 1992, 1994, and 1996, this region reported more salmonine effort than any other region in the lake (Figure 6). Salmonine effort declined by 55% from 1.6 million angler-hours in 1986 to 706,000 angler-hours in 1990. Effort was relatively stable from 1990 to 1996 at 682,000 to 782,000 angler-hours. The relative contribution of effort in the Illinois-Indiana region to the lake-wide total increased from 15-18% from 1986 to 1991, to 21-24% from 1992 to 1996.

Chinook Salmon Harvest

The decline in salmonine harvest from 1986 to 1988 was driven by declines in chinook salmon harvest (Figure 5). In 1986, chinook salmon harvest comprised more than 50% of the total salmonine harvest. By 1993, chinook salmon comprised only 16% of the salmonine harvest. Lake-wide chinook salmon harvest declined by 86% from 950,000 in 1986 to 132,000 in 1993 (Figure 7). Harvest increased from 226,000 in 1994 to 304,000 in 1996, but remained less than one-third of the peak harvest in 1986. Trends in chinook salmon harvest differ across regions and do not follow a general lake-wide trend. In general, harvest declines were greater in the eastern regions of the lake than in the western regions.

Chinook salmon harvest in Green Bay increased from 27,000 in 1986 to 42,000 in 1989, while the lake-wide harvest declined over the same period. Harvest declined by 46% from 1989 to 1990, and period-low harvest of 6,000 occurred in 1993 for an overall decline of 86% from 1989 to 1993. Harvest in Green Bay was 3% of the lake-wide total in 1986, increased to 12% in 1989, and fluctuated between 3 and 10% from 1990 to 1996.

Only a small fraction of the lake-wide salmonine fishery was contained in the Northern region of the lake, probably because the region is less densely populated, fewer salmonines were stocked there, and because tribal fisheries and lake trout refuges limited sport fishing effort. Relatively few chinook salmon were harvested in the northern waters of Lake Michigan. From 1986 to 1996, harvest in the northern waters contributed 1-6% of the lake-wide harvest. Still, declines in harvest generally followed the lake-wide trend, with a peak in harvest of 23,000 (±3,700) in 1987 and a low harvest of 2,400 (±300) in 1994 for an overall decline of 90% (Figure 7).

Chinook salmon harvest in the northwest region contributed 11% to 32% of the lake-wide harvest from 1986-1996 (Figure 7). Peak harvests were 102,000 in 1986 and 113,000 in 1987. Harvest from 1988 to 1996 was lower than previous years, with additional peak years in 1989 and 1996. Period-low harvest occurred at 42,000 in 1992 for an overall decline of 63% from 1987 to 1992. Harvest increased annually from 1993 to 1996.

Second only to the southeast, chinook salmon harvest in the northeast region declined more than any other region. Harvest in the northeast region peaked in 1986 at 304,000 (±46,000) and declined by 95% from 1986 to 15,000 (±1,100) in 1994 (Figure 7). Harvest increased to 70,000 in 1996, the highest level of harvest since 1988.

Chinook salmon harvest in the southwest region increased from 115,000 in 1986 to 128,000 in 1987 before declining by 53% in 1988 (Figure 7). Harvest continued to decline to a period low of 24,000 in 1993 – an overall decline of 81% between 1987 and 1993. Harvest increased to 75,000 in 1995 and 1996.

Chinook salmon harvest in the southeast region declined by 63% from a peak of 348,000 (±41,000) in 1986 to 129,000 (±19,000) in 1987. Harvest continued to decline to a low of 14,000 (±1,400) in 1992 – an overall decline of 96% from 1986 to 1992. Harvest increased from 16,000 (±1,600) in 1993 to 40,000 (±3,100) in 1996 (Figure 7). Along with declines in salmonine effort, chinook salmon harvest declined more in the southeast than any other region of the lake.

Chinook salmon harvest from the Illinois and Indiana waters followed a decline similar to the lake-wide trend from 1986 to 1994 (Figure 7). Peak harvest occurred in 1986 at 49,000 and declined by 85% to 7,000 in 1994. Harvest increased from 1994 to 1996. From 1986 to 1991, contribution of harvest from the Illinois and Indiana waters to the lake-wide harvest increased from 5% to 10% before declining to 5% again in 1996.

Chinook Salmon Targeted Harvest Rates as an Index of Abundance

Lake-wide targeted harvest rates (targeted chinook salmon harvest per salmonine angler-hour) of chinook salmon suggested that relative abundance declined from 1986 to 1993, and increased from 1994 to 1996 (Figure 8). Harvest rate declined concurrently with declines in harvest, from 0.087 in 1986 to 0.027 in 1993, and increased to 0.064 by 1996. There were regional differences in harvest rate trends, namely, declines occurred in the north and eastern regions of the lake, while declines in the western regions were not as severe and in some cases harvest rate actually increased. Because much of the fishery was concentrated in the eastern regions, these regions had the most influence on the lake-wide harvest rate trend. Regional differences in harvest rate trends suggest a change in the spatial distribution of chinook salmon rather than simply a decline in lake-wide abundance.

Targeted harvest rates in Green Bay ranged from 0.030 to 0.083 from 1986 to 1996, but did not show a declining trend, as peak rates occurred in 1989, 1991, and 1995 (Figure 8). Harvest rates in the northern region declined by 82% from 0.086 (±0.017) in 1987 to 0.016 (±0.002) in 1994. Harvest rates in the northwest showed the largest decline from 1987 to 1988 but fluctuated between 0.046 and 0.075 from 1989 to 1995. Harvest rates increased from 1992 to 1996, with a period-high harvest rate of 0.11 in 1996. Harvest rates in the northeast similarly declined from 0.13 (±0.024) in 1986 to 0.024 (±0.003) in 1994. Harvest rates increased in 1995 and 1996, surpassing the 1987 level. In the southwest region, harvest rates peaked at 0.061 in 1987 before declining to a low of 0.020 in 1994—a 70% decline. However, by 1995, harvest rates returned to 1986-1987 levels. Harvest rate in the southeast declined by 82% from 0.12 (±0.018) in 1986 to 0.021 (±0.003) in

1992. By 1996, harvest rate had returned to the 1987 level of 0.063 (±0.006). In the Illinois-Indiana region, harvest rates declined from 0.031 in 1986 to 0.010 in 1994 before increasing to 0.024 in 1996.

Regional Year Class Stocking, Harvest, and Harvest Ratio (% Return)

From 1985 to 1988, lake-wide stocking levels fluctuated by 10% from 5.4 million to 5.9 million. Harvest of those year classes, however, declined by 55% from 464,000 for the 1985 year class to 209,000 for the 1988 year class (Figure 9). Stocking increased to an all-time high of 7.85 million in 1989 while the harvest of that year class was 185,000 and the harvest ratio (percent of stocked fish harvested by the fishery) fell below 3%. Harvest ratio remained below 3% for the 1990 to 1992 year classes (Figure 10). All regions of Lake Michigan experienced declining year class harvest from the 1985 year class to the 1992 year class. Additionally, changes in regional year class harvest did not appear to have been affected by local (within region) changes in stocking. If year class harvest was affected by stocking levels, it was masked by the influence of changes in stocking outside the local region, which further suggested that chinook salmon spatial distribution was changing, and that this change had an effect on the fishery.

Year-class harvest in Green Bay declined from the 1985 to the 1988 year classes concurrent with declines in stocking (Figure 9). Stocking was highest in 1989 before declining again through 1992. Increased stocking levels in 1989 and 1990 did not improve year class harvest. Harvest ratio for the 1985 to 1988 year classes was relatively constant at 5.1-5.7%, and dropped below 3% for the 1989 to 1992 year classes (Figure 10). The low harvest ratios for these four year classes were comparable to the lake-wide values.

Harvest in the northern region was highest for the 1985 year class, and declined for the 1986 and 1987 year classes (Figure 9). Year class harvest was relatively consistent for the 1987 to 1991 year classes before declining again for the 1992 year class. Stocking increased from 1985 to 1989 before declining slightly from 1990 to 1992. Harvest ratio showed a similar trend to year class harvest. Harvest ratios in the North peaked at 2.75% for the 1985 year class and declined to 0.5% for the 1992 year class (Figure 10).

Year class harvest in the northwest region declined by 31% from 72,000 for the 1985 year class to 50,000 for the 1987 year class, despite consistent stocking levels of 1.1 million (Figure 9). Harvest was relatively consistent for the 1987 to 1992 year classes at 42,000 to 53,000. Stocking levels were reduced in 1988 to 728,000 but peaked in 1989 at 1.2 million fingerlings before declining again from 1990 to 1992. Harvest ratio ranged from 4.96 to 6.42 from the 1985 year class to the 1988 year class, but declined to 3.63 for the 1989 year class. The harvest ratio increased for the 1990 to 1992 year classes, reaching a peak of 10.6 for the 1992 year class (Figure 10).

Approximately 800,000 chinook salmon were stocked annually in the northeast from 1985 to 1987, while harvest of those three year classes declined by 65% from 130,000 to 45,000 (Figure 9). Stocking increased each year from 1988 to 1990, while year class harvest remained consistently below 50,000. Harvest ratio for the 1985 year class exceeded 15%, and declined for each subsequent year-class to a low of 1.8% for the 1992 year class (Figure 10).

Year class harvest in the southwest declined by 61% from 78,000 for the 1985 year class to 31,000 for the 1991 year class (Figure 9). Stocking declined by 59% from 1.1 million in 1985 to 455,000 in 1988, concurrent with the decline in year-class harvest. Increases in annual stocking of 1.1 million in 1989 and 1990 did not cause an increase in year-class harvest. Harvest ratio fluctuated from 3.2% for the 1990 year class to 8.6% for the 1988 year class (Figure 10).

Harvest in the southeast declined by 85% from 115,000 for the 1985 year class to 17,000 for the 1991 year class (Figure 9). Harvest ratio followed the same trend as year class harvest, declining by 89% from 9.3% to 1.0% from the 1985 year class to the 1991 year class (Figure 10). Stocking from 1985 to 1988 was relatively constant at 1.3 million. Stocking increased to 1.8 million in 1989 and declined to 1.5 million in 1992. Changes in stocking did not increase year class harvest.

Harvest in the Illinois-Indiana region declined by 42% from 26,000 to 15,000 from the 1985 year class to the 1987 year class, despite increases in stocking by 54% from 1985 to 1987 (Figure 9). Harvest ratio similarly declined by 63% from 4.7% to 1.8% over the same period (Figure 10). Harvest ratio was consistently low at 1 to 2% from the 1987 to the 1992 year class.

Discussion

The Lake Michigan salmonine fishery changed dramatically from 1986 to 1996. Lakewide effort declined from 1989 to 1992 and was consistently low from 1992 to 1996. Salmonine harvest declined from 1986 to 1990, and remained relatively stable from 1990 to 1996. An increase in the targeted salmonine harvest rate from 1990 to 1996 indicated that the salmonine fishery was not completely dependent upon the success of the chinook salmon harvest. Those remaining anglers shifted their efforts towards other salmonines and maintained high harvest rates. The harvest rate of 0.14 in 1996 was higher than the peak harvest years of 1986 and 1987. Hansen et al. (1990) reported a salmonine harvest rate exceeding 0.15 from 1982 to 1985 for the Wisconsin waters, suggesting that the lake-wide fishery may have peaked prior to 1986.

The question remains as to why the chinook salmon fishery collapsed in the late 1980s. Keller et al. (1990) suggest that the collapse was driven by changes in the geographical distribution of chinook salmon, poor year class survival, and increased mortality due to disease. This study provides information on the extent and location of the declines in the fishery as well as some additional insight into the causes of the fishery collapse. The evidence indicates that declines in the Lake Michigan chinook salmon fishery were the result of changes in fishing effort, natural mortality, and the spatial distribution of the salmon.

Declines in salmonine effort from 1986 to 1996 were a lake-wide phenomenon with relatively little difference in the rate of decline across lake regions. There is little doubt that at least some of this decline was an angler response to perceived declines in chinook salmon abundance. Salmonine harvest likely declined as a result of declining effort, although rates of harvest decline were not consistent across species. Chinook salmon harvest declined far more than harvest of any other salmonine, indicating that changes in chinook salmon harvest was driven by more than simply changes in effort.

While following trends in salmonine effort eliminates bias associated with effort for yellow perch or other species, changes in salmonine effort may not accurately track changes in effort targeted at chinook salmon. Anglers contend that they use different fishing methods to target lake trout, rainbow trout, and salmon by fishing different depths, fishing with different lures or colors, or by fishing along temperature breaks (Bence and Smith 1999; personal observation). Anglers increasingly targeted chinook salmon in the early 1980s, but shifted their effort towards other salmonines when chinook salmon fishing was poor (Bence and Smith 1999).

Further analysis suggests that salmonine effort shifted away from chinook salmon and towards other species during the late 1980s. In 1986, 10% of angling parties interviewed in Michigan's boat fishery indicated that they were specifically targeting chinook salmon (Jerry Rakoczy, Michigan DNR, unpublished data). By 1993, only 1% of anglers were targeting chinook salmon. Similarly, the percentage of boat anglers that were specifically targeting salmon was 26% in 1987, and declined to 8% by 1992. In contrast, the percentage of boat anglers targeting trout in general increased from 1% in 1986 to 8% in 1994. Boat anglers may have also become less specific as the fishery changed in the 1980s and 1990s. The percentage of boat anglers targeting salmon *and* trout increased from 24% in 1986 to 34% in 1991. Finally, the percentage of anglers that indicated they were not targeting anything at all increased from 3% in 1986 to 12% in 1992.

Because of the popularity of chinook salmon in Lake Michigan, and because they are the most important salmonine in terms of numbers stocked and harvested, declines in harvest rates for chinook salmon probably contributed to the initial cause of the decline in salmonine effort from 1986 to 1988 (Bence and Smith 1999). Successful anglers were able to redirect their effort towards other salmonines, while unsuccessful anglers reduced their fishing effort or left the fishery altogether. The result was an increasing salmonine harvest rate from 1988 to 1996 (Figure 4).

Increasing public knowledge of contaminants in Great Lakes fish and fish consumption advisory publications may have played a role in declines in effort. In 1989, the National Wildlife Federation (NWF) published a controversial Lake Michigan fish consumption report that had an immediate impact on the fishery and caused a cascade of media coverage (Associated Press 1989; Campbell 1989; NWF 1989). Reports of dead chinook salmon on Lake Michigan beaches from 1987 to 1989 could have also served as a message to the angling public that the fish in Lake Michigan were not healthy to eat and therefore not worth the effort and money required to catch them. Consumption issues are unlikely to be the cause of the continued low levels of fishery effort. A 1996 survey of Great Lakes anglers revealed that concerns about fish contamination was the least likely reason for low fishery effort. A lack of free time was cited as the most likely reason, followed by low catch rates (Michigan Sea Grant 1998).

Another explanation for declines in fishing effort is that the pattern on Lake Michigan reflects a trend that goes beyond what is happening on either Lake Michigan or the Great Lakes in general. It could reflect part of a national trend for the public to spend less time in activities such as fishing and hunting (Bence and Smith 1999).

Poor year class survival has been implicated as one of the causes of the poor chinook salmon fishery in the late 1980s (Keller et al. 1990). Poor returns to the sport fishery and to the weirs are evidence of poor year class survival beginning with the 1984 year class, although the causes are unknown. Most likely, though, the poor survival was a result of in-lake processes and was not caused by changes in the condition of the hatchery product (Keller et al. 1990). Since no marked changes in growth rates were observed for chinook salmon prior to 1985 and the onset of BKD (Wesley 1996), it is likely that poor survival prior to 1985 was due to early life mortality. Higher mortality rates probably affected the older age classes after 1985 because most chinook that washed up on beaches in the late 1980s were age 2 or older (Nelson and Hnath 1990; Johnson and Hnath 1991). Further, growth rates of older chinook salmon significantly increased after the BKD outbreak than before the outbreak, suggesting that density-related stress immediately prior to the BKD outbreak may have slowed growth rates and triggered increased mortality (Wesley 1996). Finally, the age structure of the harvest in Michigan's waters shifted towards younger age classes in the late 1980s (Benjamin and Bence 2003).

Quantifying these increased mortality rates has been difficult. Because BKD was implicated as the ultimate cause of death for chinook salmon on beaches in the late 1980s, managers have monitored the incidence of BKD in an attempt to monitor natural mortality rates. Incidence of BKD is monitored in chinook salmon returning to the weirs and in fishery-independent surveys. Fish are examined for clinical signs of disease, and blood samples are tested specifically for BKD (Clark 1996). While this monitoring is intended to provide an index of in-lake BKD mortality, the statistic "percent positive with BKD" is difficult to interpret because it could mean one of two things. First, a decrease in BKD incidence could reflect in-lake decreases in BKD mortality, which assumes that the sampled fish are representative of the population. Second, a decrease in BKD incidence could instead reflect in-lake increases in BKD mortality, which assumes that a greater proportion of infected fish die than survive to be tested (Clark 1996). Because of this dichotomy, "percent infection rates" should not be used as the only index of BKD mortality rates (Clark 1996).

Tests for the presence of *Renibacterium salmoninarum*, the causative agent of BKD, at the Strawberry Creek weir in Sturgeon Bay, Wisconsin, have shown a decline in the percentage of positive chinook salmon from a peak of 67% in 1988 to a low of 2% in 1994 (Marcquenski 1996). Incidence of clinical signs of BKD in chinook salmon returning to Michigan weirs was about 85% in the late 1980s and declined to less than 10% by 1992 (Clark 1996). Clinical signs of BKD returning to the Manistee weir in 1992, however, were greater than 20% and declined to less than 10% in 1995. Visual signs of BKD in chinook salmon collected from a fishery-independent survey from 1990 to 1996 showed a peak level of about 37% and declined to less than 5% in 1996 (Clapp 1997). Laboratory tests for BKD of survey-caught fish in 1996, however, showed greater than 10% incidence. Visual estimates of BKD incidence from surveys were consistently higher than visual estimates from Michigan weirs (Clapp 1997) and could be an indication that fewer BKD-infected fish survived to maturity.

Keller et al. (1990) noted that catch of chinook salmon in 1987 occurred in the northern regions of the lake one month earlier in the season than normal. They suggested that chinook salmon were more evenly distributed throughout the lake than normal due to milder winter temperatures, and that this change in distribution contributed to the poor 1987 chinook salmon fishery. An even distribution of chinook salmon throughout the lake should be reflected by similar trends in regional catch rates. Poor survival would decrease abundance lake-wide, and similar declines in regional catch rates would reflect this. However, catch rates did not decline similarly across all regions, which suggests that chinook salmon were not evenly dispersed but were in fact spatially congregated.

Temperature and food seem to be the two driving factors that influence chinook salmon distribution (Keller et al. 1990; Elliott 1993). Chinook salmon prey primarily upon alewife, bloater, and smelt, but there is debate about whether chinook salmon prefer alewife (Jude et al. 1987), or whether they are opportunistic (Elliott 1993; Rybicki and Clapp 1996). Forage abundance in Lake Michigan varies seasonally and spatially (Brandt et al. 1991). In particular, alewife and rainbow smelt have been more abundant and constitute a larger proportion of the forage abundance in the northern and western waters of the lake. Bloaters are abundant throughout the lake but are dominant in the eastern waters. Regional diets of sport-caught chinook salmon reflect regional forage abundance (Hagar 1984; Toneys 1992; Elliott 1993; Peeters 1993; Rybicki and Clapp 1996).

Alewife spatial distribution in Lake Michigan shifted between 1985 and 1995 (Ann Krause, Michigan State University, unpublished results). Alewives were abundant across western and eastern regions of the lake in the mid-1980s, as indicated in trawl surveys conducted by the Great Lakes Science Center. Abundance then declined in the eastern regions of the lake in the early 1990s as abundance in the western regions increased (Figure 11). Trends in alewife distribution and abundance appear to match trends in chinook salmon harvest and targeted harvest rates (Figure 7 and Figure 8), and suggest that the spatial distribution of chinook salmon changed as the spatial distribution of alewife changed. This is further supported by preliminary survey data which showed a correlation between high chinook catch rates and a high proportion of alewives in their stomachs (Dave Clapp, Michigan DNR, personal communication). Earlier studies showed seasonal and spatial differences in chinook diets that corresponded with forage abundance and species composition (Elliott 1993), suggesting that chinook salmon demonstrated a seasonal migration in the spring away from eastern waters and back again in the fall. If chinook salmon prefer alewife as their primary prey, then changes in prey distribution would cause changes in predator distribution and would be reflected in the fishery. Chinook salmon that successfully migrated in order to continue to prey on alewives survived, while those that did not follow alewives were forced to prey on other species—namely bloater and rainbow smelt. Chinook salmon that preyed primarily upon species other than alewife may have been more susceptible to nutritional stress and subsequent mortality.

While localized increases in mortality may have been possible, especially in the southeast region of the lake, it is not accurate to think of the lake as consisting of several distinct populations suffering different mortality rates. Chinook salmon that tend to stay in a given area may suffer different mortality rates than fish in other areas, but the fish in each area is a mix of fish that originated from different stocking and spawning locations, and the mix is itself likely to be dynamic as forage abundance changes spatially over time. This highly migratory nature of chinook salmon suggests that changes in spatial distribution are likely to have caused most of the regional differences in how the fishery changed.

Attempts to increase local yields in Lake Michigan by increasing local stocking are likely to lead to frustration. Regional increases in stocking levels did not improve regional year class harvest. This was particularly true for the Northeast and Southeast regions, where year class harvest continued to decline for the 1985 to 1993 year classes despite increases in stocking levels from 1985 to 1992 (Figure 9). During the study period, lake-wide increases in numbers stocked for a year class also did not lead to lake-wide increases in harvest. If anything, lake-wide increases in stocking led to declines in harvest, CPUE, and other measures of fishery success. This is probably due to density dependent processes, which although not proven, is consistent with the data. For example, BKD infection rates were positively related to stocking levels (Clark 1996). Of special importance, the harvest ratio observed for the 1989 through 1992 year classes (about 2.5%) represented a substantial decline over that seen for the 1985 (about 8%). Harvest ratios probably had already declined for the 1985 year class in comparison with earlier cohorts. This year class was impacted by BKD mortality, and the harvest ratios for the 1985 year class calculated for Wisconsin's waters were already substantially below those reported for Wisconsin for the 1969-1982 year classes (Hansen et al. 1990).

Conclusion

The collapse of a fishery is often caused by overfishing, but this was not the case with the Lake Michigan chinook salmon fishery from 1987 to 1992. The chinook salmon population is driven by annual stocking, and returns to the fishery declined despite the maintenance of high stocking levels. Chinook salmon suffered high mortality rates due in part to bacterial kidney disease, while the underlying cause of the disease is probably related to nutritional stress due to a decline in the abundance of alewives. Additional stress may be temperature-related, as most visual accounts of mortality occur in early spring, when water temperatures are coldest.

The decline of the fishery differed across regions. A complete collapse of the fishery was seen in the eastern regions of the lake, although declines in effort and harvest were observed in all regions. The greatest declines occurred in the Northeast and Southeast regions that traditionally had the highest levels of stocking, effort, harvest, and harvest rates. With a decline in the fishery came a change in the distribution of the harvest. For example, 21% of the lake-wide chinook salmon stocking in 1985 occurred in the Southeast region, and accounted for 25% of the lake-wide harvest of the 1985 year class. By 1992, stocking in that region increased to 27% of the lake-wide total, while year class harvest fell to 13% of the lake-wide total. In contrast, stocking in the Northwest region of the 1985 year class was 19% of the lakewide total, and year class harvest was 16%. By 1992, stocking in the Northwest region decreased to 9% of the lake-wide total, and year class harvest increased to 34% of the lake-wide total. The relative contributions of the Green Bay, North, and Illinois-Indiana regions to the lake-wide harvest remained relatively constant for the 1985 to 1992 year classes.

Trends in the sport fishery data suggest that a change in the spatial distribution of chinook salmon was the driving force behind regional differences in the decline of the fishery. Increases in lake-wide mortality probably contributed to these declines, but spatial differences in mortality are unlikely to be the primary cause of these differences. Tagging studies and similar harvest size distributions show that chinook salmon do not form distinct subpopulations, but rather mix widely. Most likely chinook salmon migrated in response to local stresses, and concentrated in the western regions of the lake when alewife abundance in the eastern regions declined.

Acknowledgments

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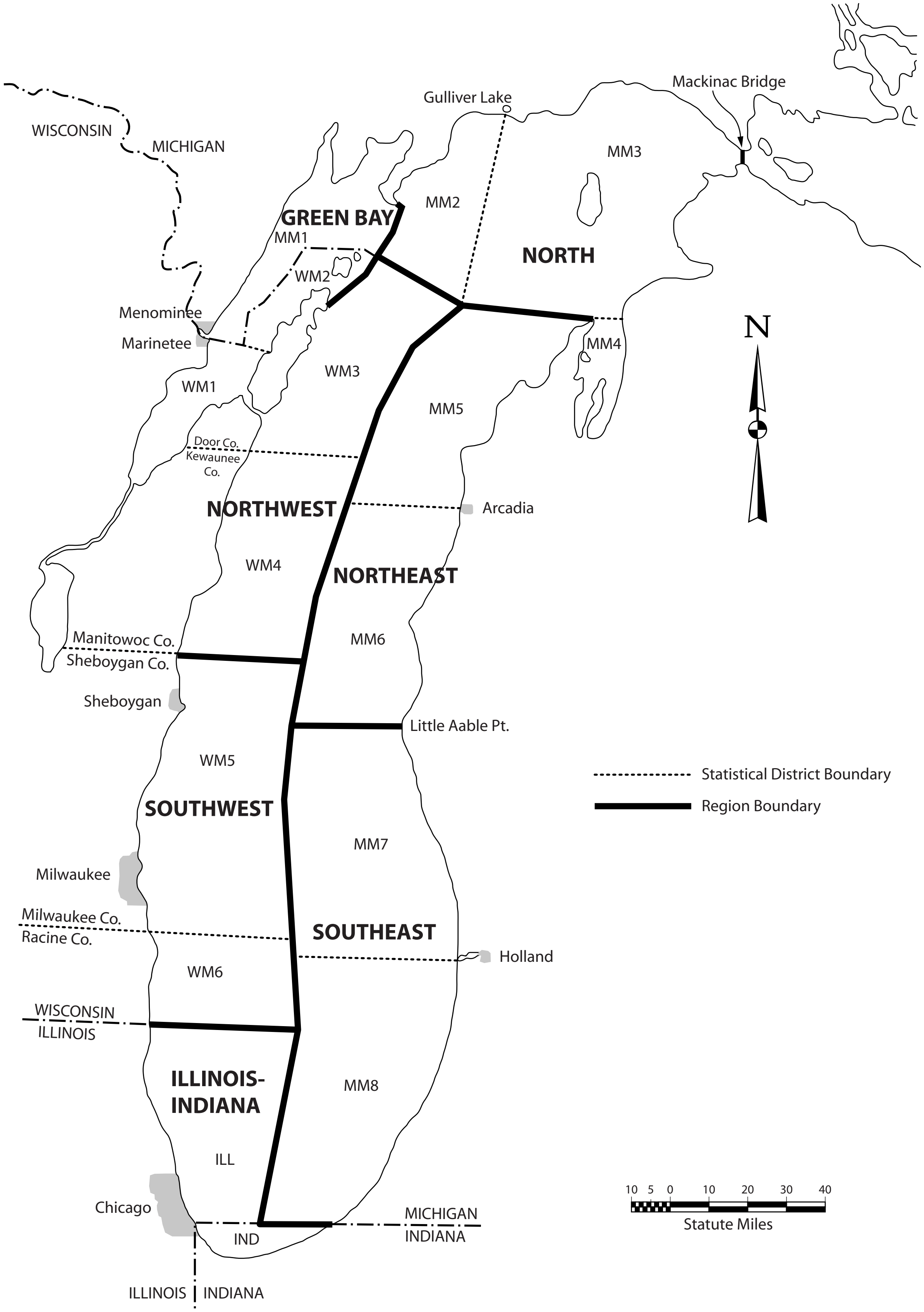

Figure 1.–Map of Lake Michigan divided into 7 regions: Green Bay, North, Northwest, Northeast, Southwest, Southeast, and Illinois-Indiana.

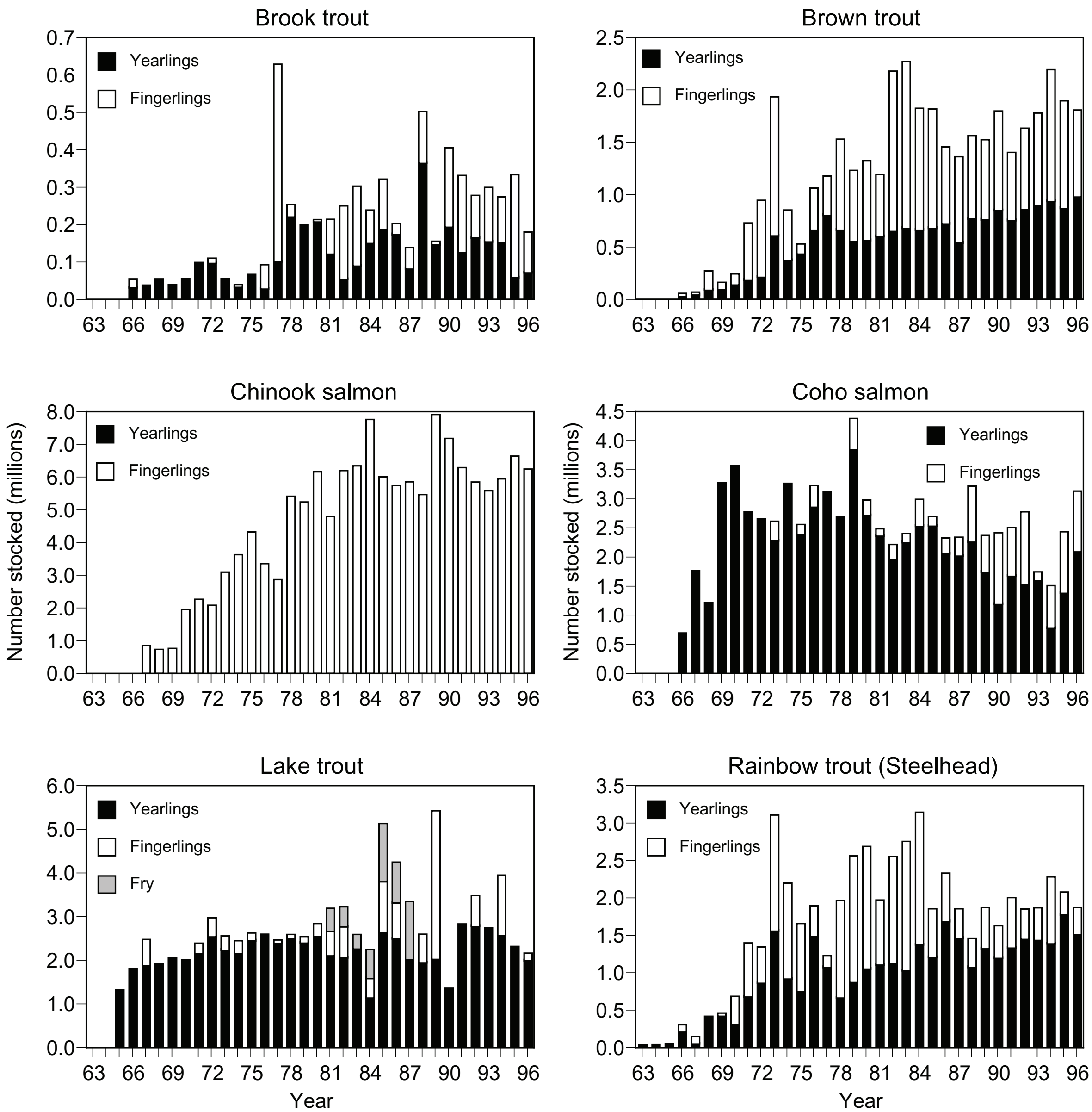

Figure 2.–Lake Michigan stocking levels for six species of salmonines from 1963 to 1996.

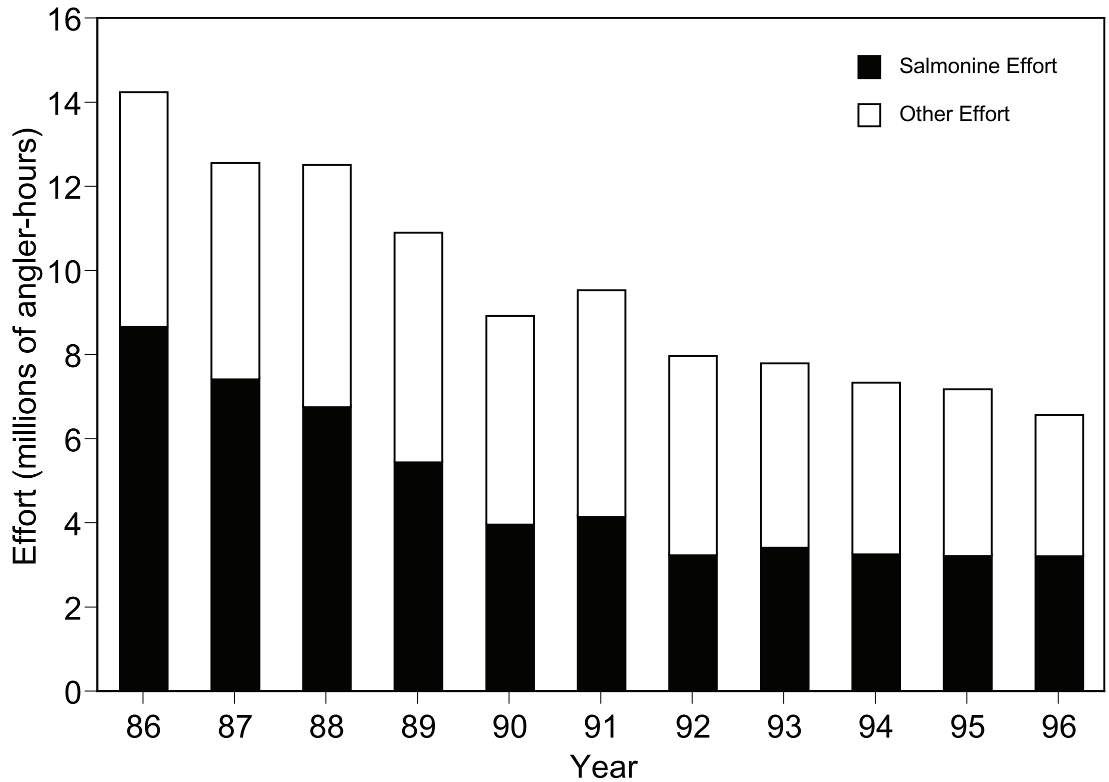

Figure 3.–Total effort and salmonine effort (in millions of angler-hours), from the Lake Michigan sport fishery, 1986 to 1996. Other effort included effort not directed at salmonines, as well as effort reported by the charter fishery.

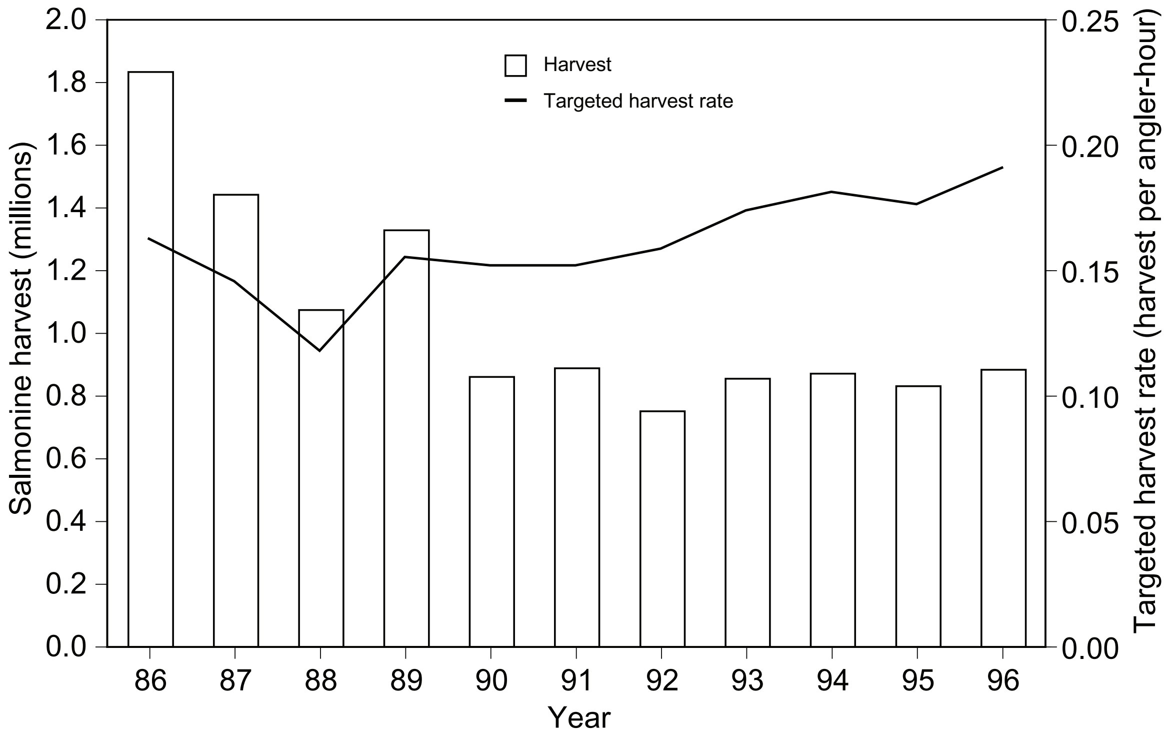

Figure 4.–Salmonine total harvest (in millions of fish) and targeted harvest rate of salmonines from the Lake Michigan sport fishery, 1986-1996. See Methods for a description of targeted harvest rate.

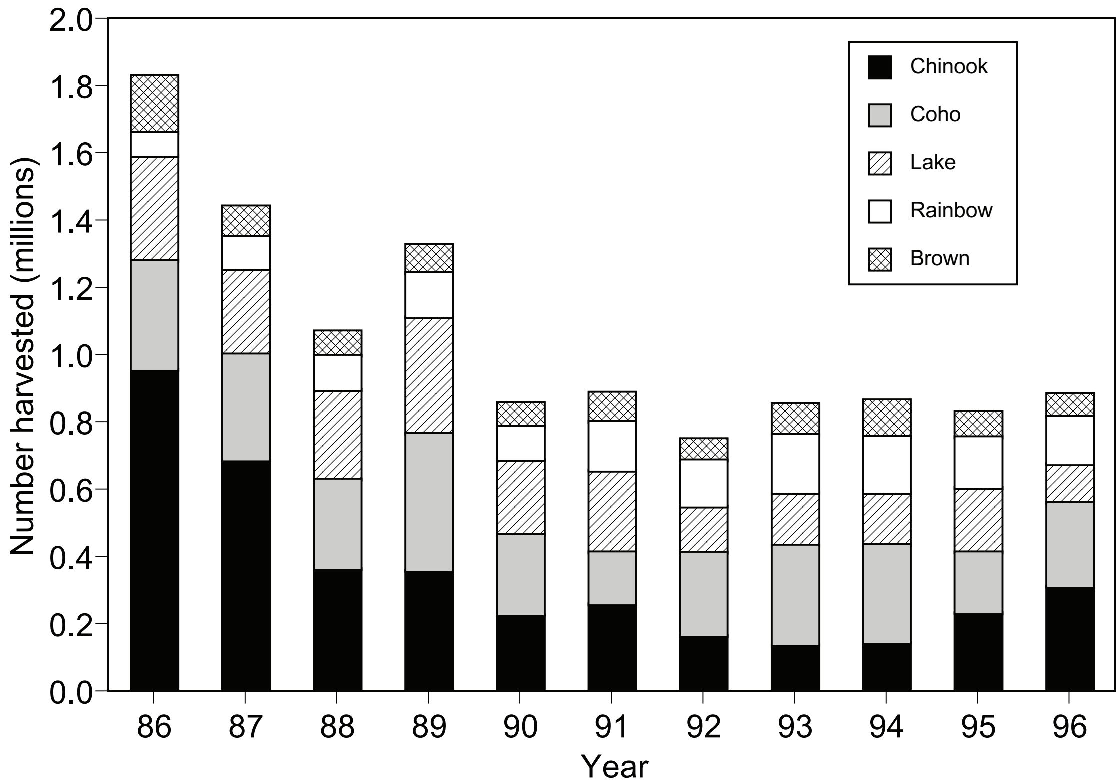

Figure 5.–Lake-wide salmonine harvest (in millions of fish) by species for the Lake Michigan sport fishery, 1986-1996. (Chinook = chinook salmon, Coho = coho salmon, Lake = lake trout, Rainbow = rainbow trout and steelhead, Brown = brown trout)

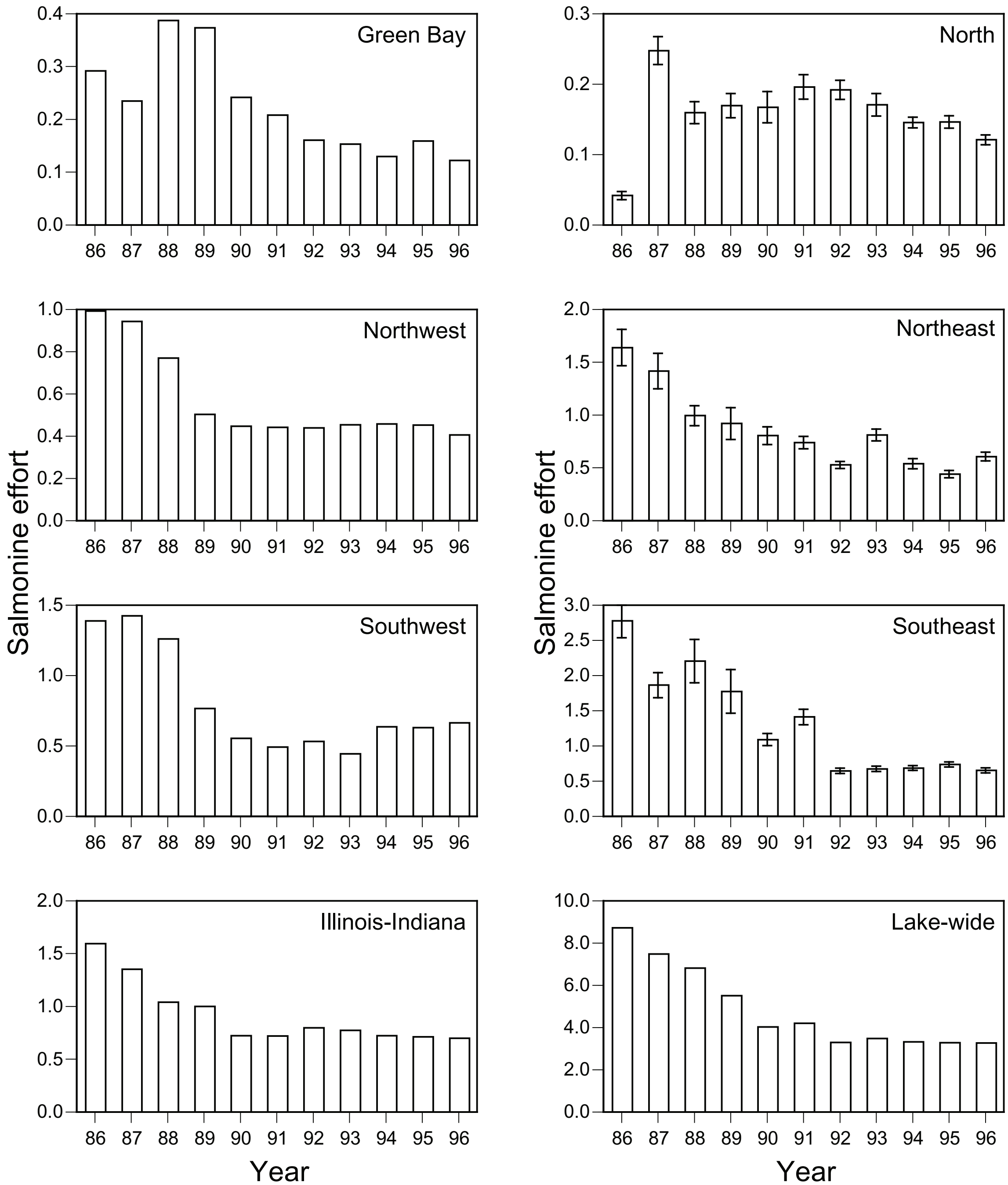

Figure 6.–Salmonine effort (in millions of angler-hours) from the Lake Michigan sport fishery, 1986 to 1996. Standard error bars are shown for regions within Michigan's waters only. See Figure 1 for a definition of lake regions.

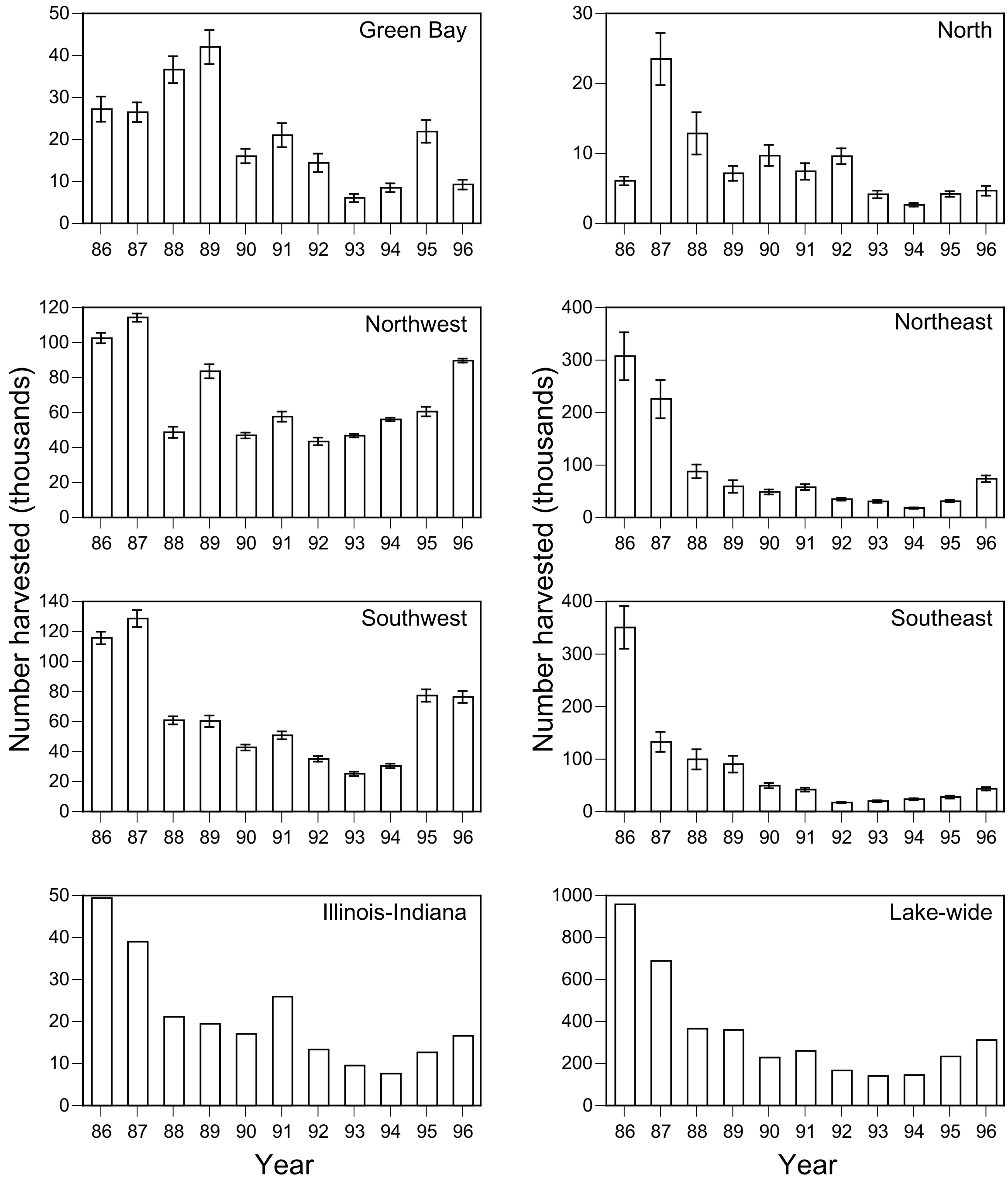

Figure 7.–Chinook salmon harvest from the Lake Michigan sport fishery, by lake region, 1986 to 1996. Standard error bars are shown for Michigan and Wisconsin harvest only. See Figure 1 for a definition of the lake regions.

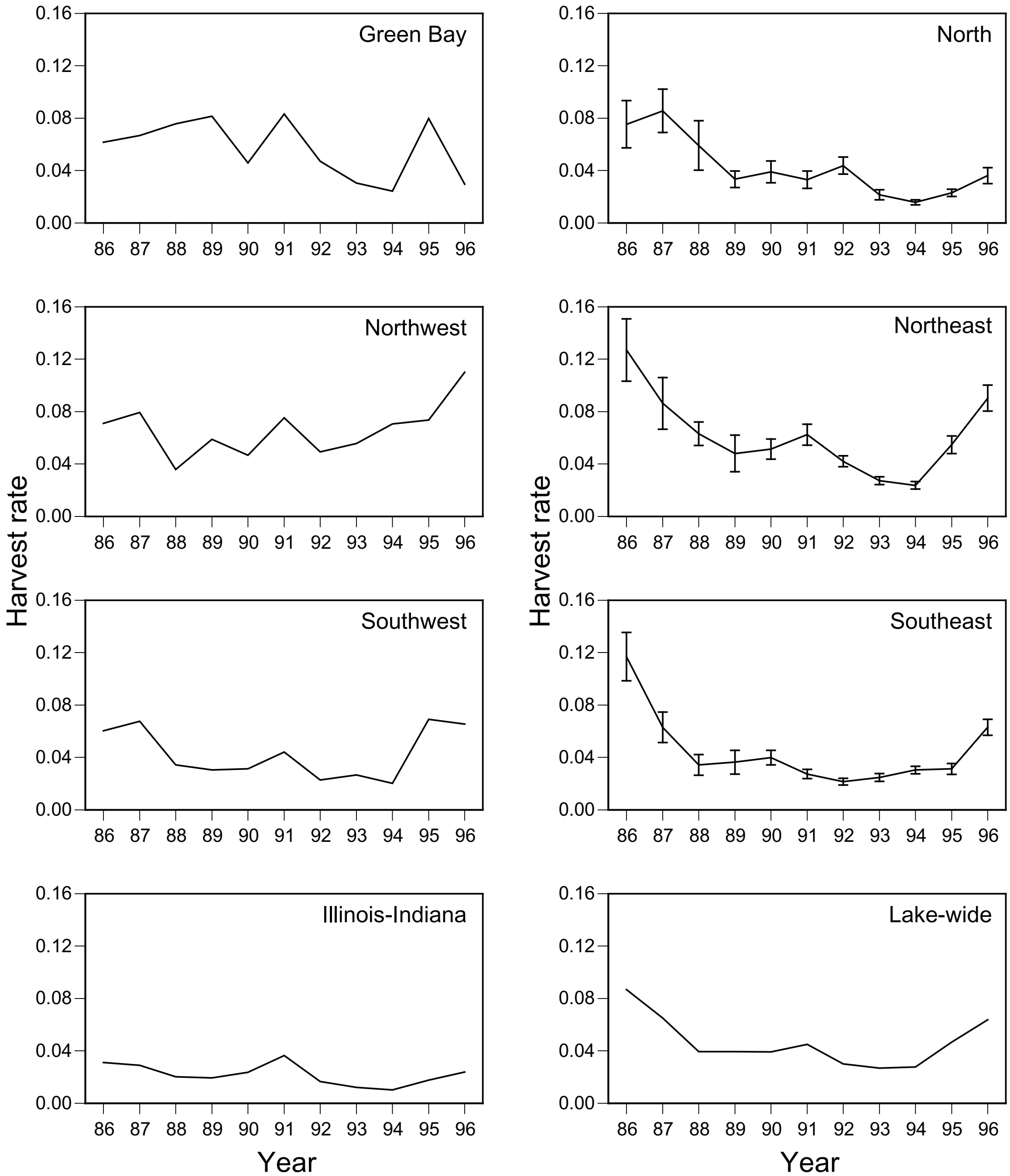

Figure 8.–Chinook salmon targeted harvest rates (targeted harvest per salmonine angler-hour), by lake region, for the Lake Michigan sport fishery, 1986-1996. Standard error bars are shown only for Michigan (see Methods). See Figure 1 for a definition of lake regions.

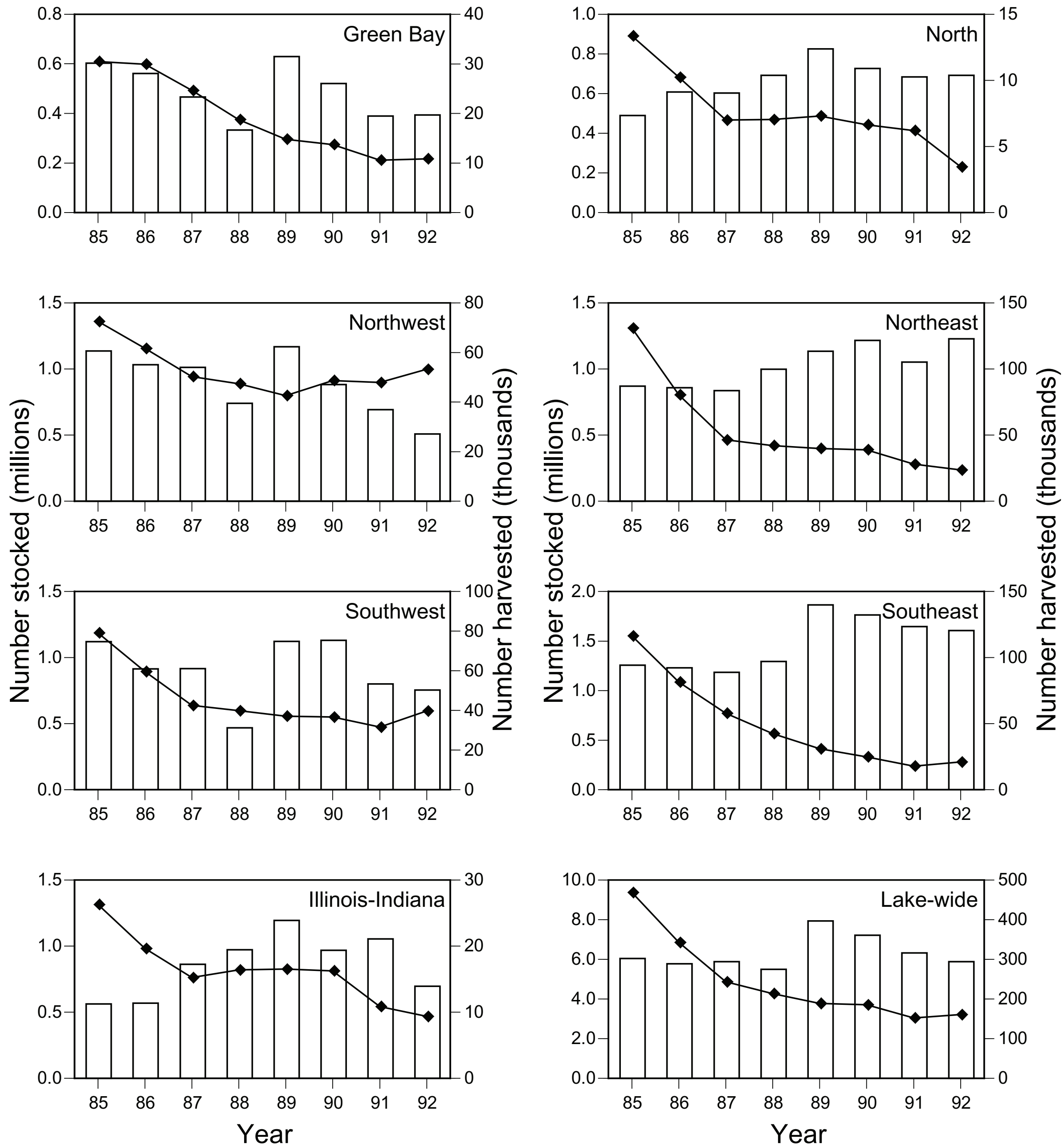

Figure 9.–Chinook salmon stocking and harvest, by year-class and region, for the Lake Michigan sport fishery. See Figure 1 for a definition of lake regions.

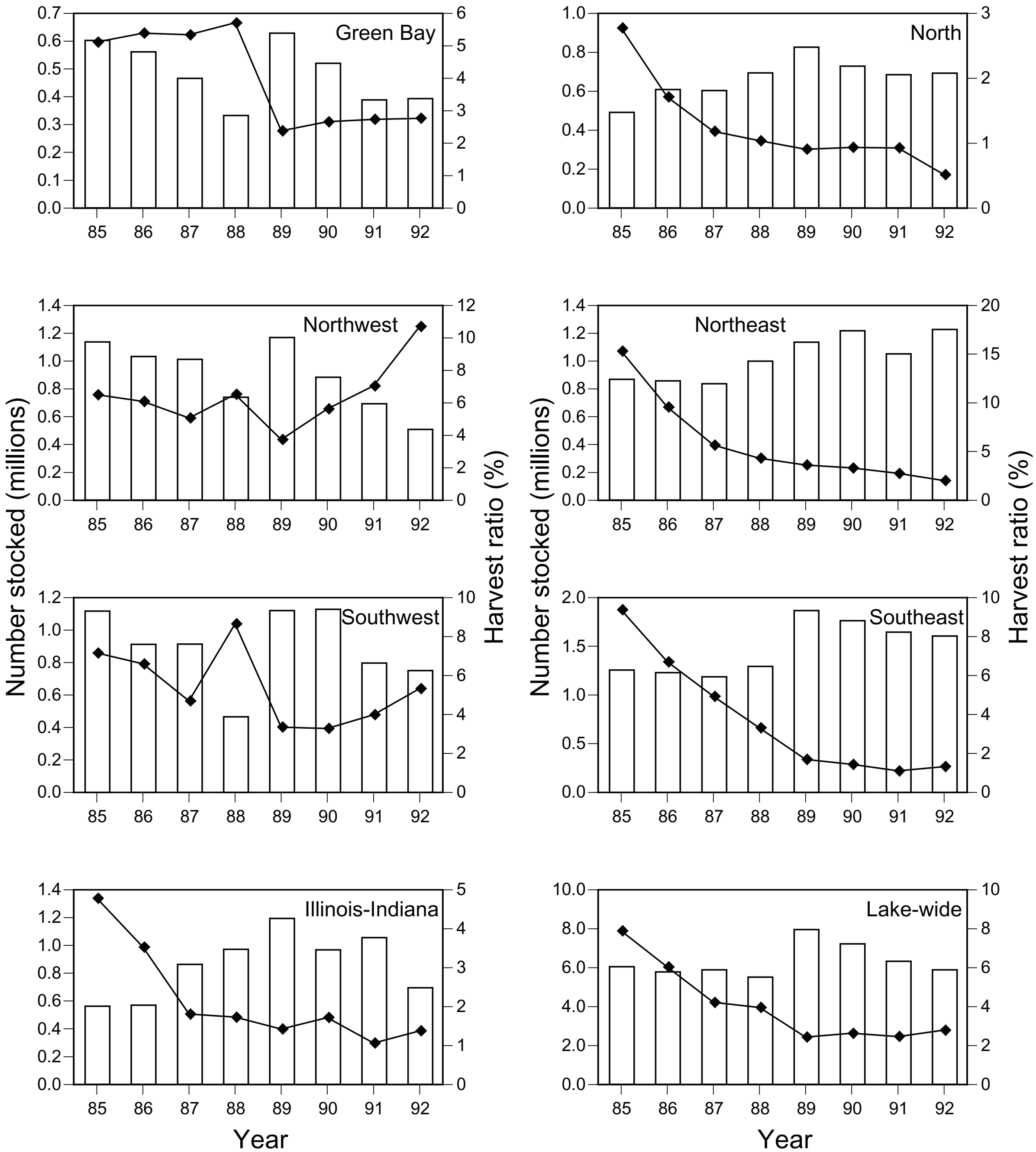

Figure 10.–Chinook salmon stocking and harvest ratio, by year-class and region, for the Lake Michigan sport fishery. See Figure 1 for a definition of lake regions.

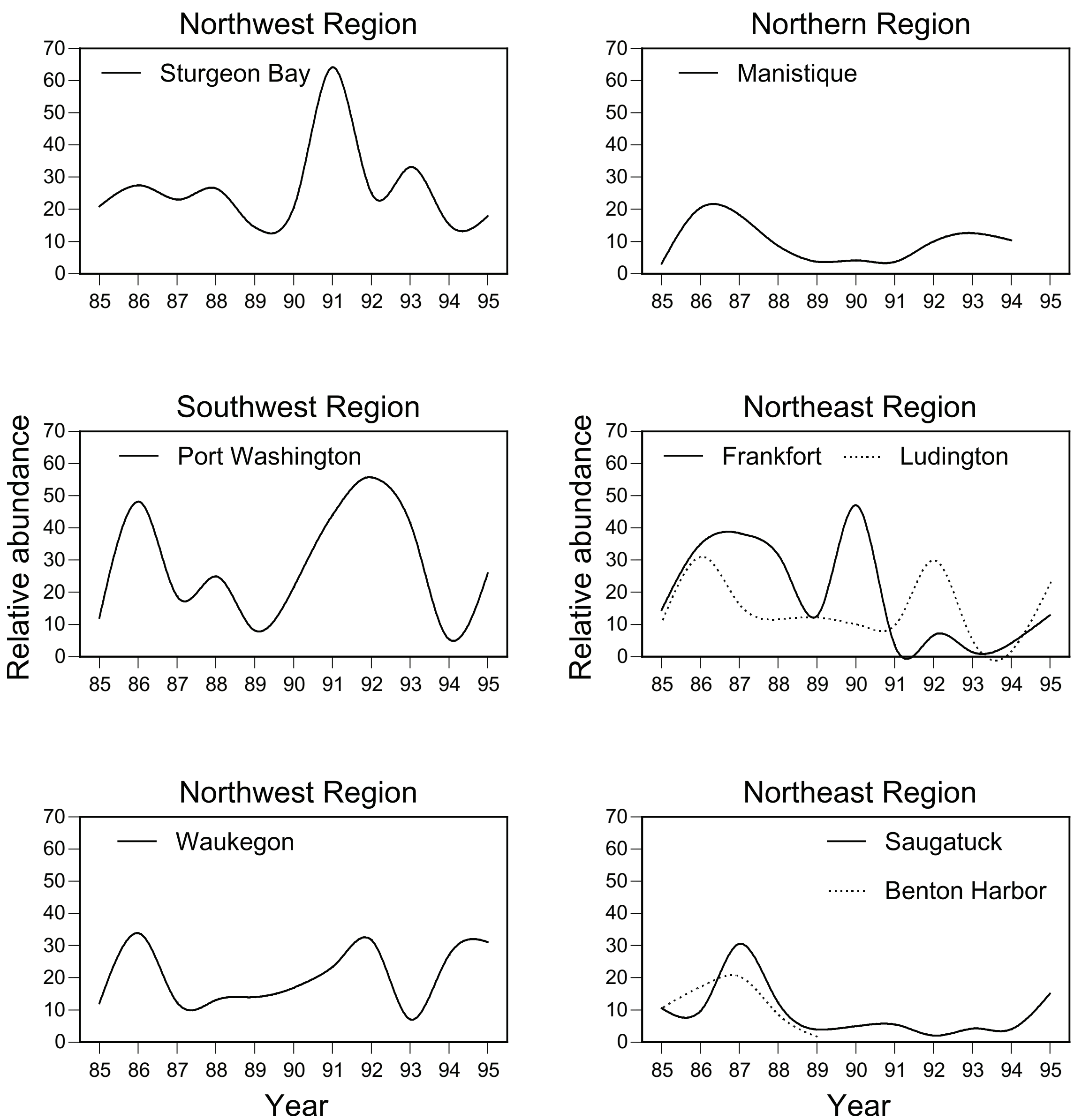

Figure 11.–Relative alewife abundance from various regions of Lake Michigan, 1985-1995. Data were from Great Lakes Science Center annual fall bottom trawl surveys. Estimates were based on fitting a general linear mixed model to these data, including year and depth effects as well as port and year-port interactions (Ann Krause, Michigan State University, unpublished results).

Table 1.–Number of salmonine fingerlings stocked in Lake Michigan, by species, 1963 to 1996.

	Species						
Year	Brook trout	Brown trout	Chinook salmon	Coho salmon	Lake trout	Rainbow trout	Total
1963	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0
1966	20,000	16,300	0	0	0	81,299	117,599
1967	0	12,540	802,390	0	569,600	74,695	1,459,225
1968	0	172,400	686,692	0	0	0	859,092
1969	0	57,200	717,585	0	0	22,200	796,985
1970	0	94,540	1,903,492	0	0	362,088	2,360,120
1971	0	531,804	2,215,198	0	208,000	702,579	3,657,581
1972	9,980	722,740	2,032,128	0	405,400	465,832	3,636,080
1973	0	1,313,842	3,045,767	313,700	300,000	1,532,270	6,505,579
1974	4,000	469,300	3,578,053	0	260,250	1,261,815	5,573,418
1975	0	82,647	4,275,782	156,200	149,000	894,061	5,557,690
1976	61,290	387,922	3,302,057	352,728	0	392,669	4,496,666
1977	524,772	362,200	2,818,561	0	47,500	143,661	3,896,694
1978	30,000	854,247	5,365,263	0	65,000	1,284,753	7,599,263
1979	0	663,947	5,184,271	511,506	120,271	1,667,085	8,147,080
1980	2,560	753,074	6,105,924	244,486	268,700	1,620,094	8,994,838
1981	89,070	578,440	4,747,799	101,953	560,500	847,700	6,925,462
1982	193,477	1,516,793	6,146,427	245,581	707,347	1,410,712	10,220,337
1983	210,035	1,578,114	6,291,913	127,555	31,480	1,709,163	9,948,260
1984	85,481	1,149,178	7,709,792	439,704	445,920	1,755,442	11,585,517
1985	130,739	1,127,110	5,955,523	139,018	1,158,423	631,128	9,141,941
1986	25,460	719,318	5,692,678	246,352	822,600	629,729	8,136,137
1987	53,277	811,485	5,800,757	299,429	24,984	378,371	7,368,303
1988	135,050	783,652	5,416,870	939,153	623,600	371,960	8,270,285
1989	6,000	753,140	7,859,479	608,324	3,371,122	536,978	13,135,043
1990	208,700	936,747	7,128,723	1,206,152	0	418,722	9,899,044
1991	203,000	639,296	6,237,562	815,515	0	654,428	8,549,801
1992	109,700	765,382	5,795,465	1,225,339	673,621	385,399	8,954,906
1993	142,300	869,905	5,529,950	130,105	0	417,558	7,089,818
1994	119,400	1,244,853	5,892,950	710,082	1,357,821	874,559	10,199,665
1995	271,932	1,014,458	6,590,976	1,030,639	0	287,990	9,195,995
1996	105,330	816,765	6,193,377	1,021,630	143,629	345,336	8,626,067

Table 2.–Number of salmonine yearlings stocked in Lake Michigan, by species, 1963 to 1996.

	Species					
Year	Brook trout	Brown trout	Coho salmon	Lake trout	Rainbow trout	Total
1963	0	0	0	0	9,200	9,200
1964	0	0	0	0	15,000	15,000
1965	0	0	0	1,273,878	24,830	1,298,708
1966	29,240	21,700	659,356	1,766,190	194,290	2,670,776
1967	32,809	35,935	1,732,298	1,854,820	40,230	3,696,092
1968	49,481	79,190	1,183,872	1,875,900	389,349	3,577,792
1969	33,518	84,377	3,237,856	1,999,805	409,454	5,765,010
1970	49,500	129,820	3,535,930	1,960,000	294,189	5,969,439
1971	93,048	177,311	2,743,046	2,135,545	665,849	5,814,799
1972	94,782	203,469	2,619,908	2,520,120	850,220	6,288,499
1973	50,150	598,953	2,265,257	2,209,150	1,546,452	6,669,962
1974	30,250	363,358	3,230,972	2,137,100	905,888	6,667,568
1975	61,300	425,345	2,368,691	2,428,424	734,928	6,018,688
1976	25,820	653,188	2,843,671	2,547,800	1,473,445	7,543,924
1977	98,480	793,525	3,088,218	2,370,100	1,058,108	7,408,431
1978	218,225	655,202	2,658,941	2,474,400	651,767	6,658,535
1979	192,970	548,202	3,832,337	2,376,601	865,394	7,815,504
1980	205,000	554,564	2,698,884	2,522,600	1,040,119	7,021,167
1981	119,397	591,242	2,349,478	2,081,530	1,094,020	6,235,667
1982	51,226	642,821	1,934,960	2,038,790	1,116,517	5,784,314
1983	87,403	670,682	2,236,817	2,209,590	1,016,864	6,221,356
1984	147,561	653,768	2,514,343	1,119,140	1,360,818	5,795,630
1985	185,226	670,437	2,519,665	2,623,399	1,193,695	7,192,422
1986	171,436	714,735	2,045,045	2,474,406	1,671,942	7,077,564
1987	79,000	529,684	2,005,142	1,973,350	1,447,628	6,034,804
1988	361,936	761,627	2,243,742	1,922,628	1,058,959	6,348,892
1989	144,100	750,835	1,725,601	2,005,600	1,308,187	5,934,323
1990	191,448	841,024	1,173,901	1,317,115	1,181,337	4,704,825
1991	123,100	743,983	1,655,396	2,779,482	1,320,495	6,622,456
1992	162,720	849,225	1,516,871	2,761,244	1,437,414	6,727,474
1993	151,794	888,817	1,578,646	2,697,835	1,422,809	6,739,901
1994	149,185	927,527	761,291	2,545,512	1,376,435	5,759,950
1995	56,025	861,602	1,367,189	2,264,428	1,762,601	6,311,845
1996	69,464	969,981	2,075,803	1,971,448	1,499,149	6,585,845

Table 3.–Total number of salmonines stocked in Lake Michigan, by species, from 1986-1996. Includes fingerlings, yearlings, and lake trout fry.

	Species						
Year	Brook trout	Brown trout	Chinook salmon	Coho salmon	Lake trout	Rainbow trout	Total
1963	0	0	0	0	0	9,200	9,200
1964	0	0	0	0	0	15,000	15,000
1965	0	0	0	0	1,273,878	24,830	1,298,708
1966	49,240	38,000	0	659,356	1,766,190	275,589	2,788,375
1967	32,809	48,475	802,390	1,732,298	2,424,420	114,925	5,155,317
1968	49,481	251,590	686,692	1,183,872	1,875,900	389,349	4,436,884
1969	33,518	141,577	717,585	3,237,856	1,999,805	431,654	6,561,995
1970	49,500	224,360	1,903,492	3,535,930	1,960,000	656,277	8,329,559
1971	93,048	709,115	2,215,198	2,743,046	2,343,545	1,368,428	9,472,380
1972	104,762	926,209	2,032,128	2,619,908	2,925,520	1,316,052	9,924,579
1973	50,150	1,912,795	3,045,767	2,578,957	2,509,150	3,078,722	13,175,541
1974	34,250	832,658	3,578,053	3,230,972	2,397,350	2,167,703	12,240,986
1975	61,300	507,992	4,275,782	2,524,891	2,577,424	1,628,989	11,576,378
1976	87,110	1,041,110	3,302,057	3,196,399	2,547,800	1,866,114	12,040,590
1977	623,252	1,155,725	2,818,561	3,088,218	2,417,600	1,201,769	11,305,125
1978	248,225	1,509,449	5,365,263	2,658,941	2,539,400	1,936,520	14,257,798
1979	192,970	1,212,149	5,184,271	4,343,843	2,496,872	2,532,479	15,962,584
1980	207,560	1,307,638	6,105,924	2,943,370	2,791,300	2,660,213	16,016,005
1981	208,467	1,169,682	4,747,799	2,451,431	3,142,030	1,941,720	13,661,129
1982	244,703	2,159,614	6,146,427	2,180,541	3,176,137	2,527,229	16,434,651
1983	297,438	2,248,796	6,291,913	2,364,372	2,541,070	2,726,027	16,469,616
1984	233,042	1,802,946	7,709,792	2,954,047	2,195,060	3,116,260	18,011,147
1985	315,965	1,797,547	5,955,523	2,658,683	5,081,822	1,824,823	17,634,363
1986	196,896	1,434,053	5,692,678	2,291,397	4,197,006	2,301,671	16,113,701
1987	132,277	1,341,169	5,800,757	2,304,571	3,298,334	1,825,999	14,703,107
1988	496,986	1,545,279	5,416,870	3,182,895	2,546,228	1,430,919	14,619,177
1989	150,100	1,503,975	7,859,479	2,333,925	5,376,722	1,845,165	19,069,366
1990	400,148	1,777,771	7,128,723	2,380,053	1,317,115	1,600,059	14,603,869
1991	326,100	1,383,279	6,237,562	2,470,911	2,779,482	1,974,923	15,172,257
1992	272,420	1,614,607	5,795,465	2,742,210	3,434,865	1,822,813	15,682,380
1993	294,094	1,758,722	5,529,950	1,708,751	2,697,835	1,840,367	13,829,719
1994	268,585	2,172,380	5,892,950	1,471,373	3,903,333	2,250,994	15,959,615
1995	327,957	1,876,060	6,590,976	2,397,828	2,264,428	2,050,591	15,507,840
1996	174,794	1,786,746	6,193,377	3,097,433	2,115,077	1,844,485	15,211,912

Table 4.–Number of chinook salmon fingerlings stocked in Lake Michigan, by region, from 1967 to 1996.

Year	Region							Total
	Green Bay	North	Northeast	Northwest	Southeast	Southwest	Ill. - Ind.	
1967	0	0	591,830	0	210,560	0	0	802,390
1968	0	0	321,912	0	364,780	0	0	686,692
1969	0	0	300,000	66,000	351,585	0	0	717,585
1970	100,000	200,034	408,900	119,000	965,558	0	110,000	1,903,492
1971	100,934	0	557,248	254,000	1,105,412	10,000	187,604	2,215,198
1972	124,528	0	597,290	180,000	993,634	113,000	23,676	2,032,128
1973	442,750	102,700	608,406	340,000	1,181,390	197,000	173,521	3,045,767
1974	140,496	201,578	854,282	356,400	889,596	220,000	915,701	3,578,053
1975	519,321	353,947	911,215	400,600	1,187,284	366,275	537,140	4,275,782
1976	454,340	202,880	588,229	692,000	903,109	281,500	179,999	3,302,057
1977	397,340	25,095	525,528	245,000	804,921	332,608	488,069	2,818,561
1978	554,000	100,000	1,018,362	862,000	1,305,192	701,149	824,560	5,365,263
1979	395,000	50,000	1,053,098	863,200	1,203,602	905,611	713,760	5,184,271
1980	684,200	150,156	1,250,846	797,300	1,451,890	998,000	773,532	6,105,924
1981	618,800	50,000	979,231	557,100	1,125,516	723,160	693,992	4,747,799
1982	434,479	100,094	1,101,573	970,300	1,423,940	1,009,700	1,106,341	6,146,427
1983	554,900	365,495	1,187,250	1,283,200	1,318,085	811,000	771,983	6,291,913
1984	587,850	550,108	1,231,109	1,255,000	1,973,063	1,169,000	943,662	7,709,792
1985	595,756	481,912	857,095	1,125,000	1,239,020	1,107,000	549,740	5,955,523
1986	555,000	600,080	845,164	1,020,000	1,213,141	902,567	556,726	5,692,678
1987	460,000	594,700	823,787	1,000,000	1,168,939	903,484	849,847	5,800,757
1988	326,000	684,390	986,543	728,150	1,277,528	455,143	959,116	5,416,870
1989	622,624	816,697	1,122,792	1,156,711	1,849,089	1,110,580	1,180,986	7,859,479
1990	514,000	719,059	1,204,768	870,722	1,745,519	1,118,609	956,046	7,128,723
1991	382,600	675,956	1,039,962	680,613	1,628,604	787,405	1,042,422	6,237,562
1992	387,176	683,534	1,215,067	495,859	1,589,615	741,092	683,122	5,795,465
1993	349,740	614,030	1,061,780	539,951	1,506,709	801,079	656,661	5,529,950
1994	348,780	697,833	1,128,613	577,907	1,767,838	718,370	653,609	5,892,950
1995	365,874	749,606	1,202,145	625,532	1,935,320	794,780	917,719	6,590,976
1996	394,260	680,346	1,158,390	623,768	1,580,688	818,929	936,996	6,193,377

Table 5.–Lake Michigan total sport fishery effort and targeted salmonine effort, total salmonine harvest, and salmonine targeted harvest rate from 1986 to 1996. Does not include stream fishery.

Year	Total effort	Salmonines Targeted effort	Salmonines Total harvest	Salmonines Targeted harvest rate
1986	14,171,232	8,639,616	1,827,816	0.163
1987	12,486,847	7,394,333	1,436,853	0.146
1988	12,446,497	6,728,453	1,068,753	0.118
1989	10,839,150	5,417,639	1,323,159	0.155
1990	8,857,896	3,941,503	855,166	0.152
1991	9,461,886	4,121,606	883,339	0.152
1992	7,902,011	3,209,131	746,374	0.159
1993	7,727,446	3,393,389	849,328	0.174
1994	7,267,320	3,230,568	865,479	0.181
1995	7,108,768	3,191,348	826,370	0.176
1996	6,501,426	3,185,371	878,181	0.191

Table 6.–Salmonine harvest by the Lake Michigan sport fishery, 1986 to 1996. Does not include the stream fishery.

Year	Species: Brook trout	Brown trout	Chinook salmon	Coho salmon	Lake trout	Rainbow trout	Total
1986	3,565	170,959	948,915	324,622	311,774	67,980	1,827,816
1987	1,168	90,418	680,126	315,592	253,050	96,498	1,436,853
1988	4,452	72,702	357,325	265,374	266,668	102,232	1,068,753
1989	1,966	83,906	351,937	407,115	346,983	131,252	1,323,159
1990	4,444	70,928	220,399	239,215	221,268	98,912	855,166
1991	1,286	87,928	252,589	154,635	242,551	144,349	883,339
1992	3,104	62,844	158,097	247,887	136,723	137,719	746,374
1993	1,463	91,921	131,928	295,170	157,340	171,506	849,328
1994	6,303	109,366	136,921	292,072	154,050	166,767	865,479
1995	1,450	76,055	225,564	181,216	191,808	150,278	826,370
1996	364	67,898	303,893	249,569	114,911	141,546	878,181

Table 7.–Salmonine effort from the Lake Michigan sport fishery, by region, from 1986 to 1996. Does not include stream fishery.

Year	Region							Total
	Green Bay	North	Northeast	Northwest	Southeast	Southwest	Illinois-Indiana	
1986	288,361	39,430	1,621,667	983,812	2,751,815	1,375,337	1,579,193	8,639,616
1987	231,145	245,187	1,398,749	933,803	1,837,411	1,412,317	1,335,721	7,394,333
1988	383,624	156,981	977,026	761,419	2,180,123	1,247,220	1,022,061	6,728,453
1989	369,962	166,959	902,139	494,276	1,748,471	753,816	982,017	5,417,639
1990	238,439	164,864	787,409	438,681	1,063,919	542,383	705,807	3,941,503
1991	204,915	193,587	722,407	432,870	1,385,944	479,729	702,155	4,121,606
1992	156,995	189,506	509,971	429,978	620,827	520,291	781,563	3,209,131
1993	149,826	168,422	793,741	444,376	648,165	431,771	757,089	3,393,389
1994	126,093	143,162	521,597	449,624	660,329	623,817	705,947	3,230,568
1995	155,511	144,039	423,690	444,093	711,150	617,728	695,138	3,191,348
1996	118,643	118,597	589,836	397,307	626,805	651,765	682,419	3,185,371

Table 8.–Chinook salmon harvest by the Lake Michigan sport fishery, 1986 to 1996. Does not include stream fishery.

Year	Region							Total
	Green Bay	North	Northeast	Northwest	Southeast	Southwest	Illinois-Indiana	
1986	26,805	5,821	303,755	101,518	347,456	114,569	48,991	948,915
1987	26,053	23,246	222,315	113,248	129,168	127,509	38,588	680,126
1988	36,209	12,604	84,471	47,660	95,994	59,651	20,736	357,325
1989	41,577	6,905	55,819	82,574	86,927	59,095	19,040	351,937
1990	15,624	9,456	45,294	45,848	45,938	41,598	16,641	220,399
1991	20,581	7,183	54,623	56,622	38,403	49,654	25,523	252,589
1992	13,995	9,360	31,353	42,446	14,095	33,934	12,915	158,097
1993	5,633	3,904	27,189	45,699	16,323	24,021	9,159	131,928
1994	8,099	2,414	14,675	55,044	20,213	29,299	7,177	136,921
1995	21,498	3,976	27,894	59,516	24,288	76,104	12,288	225,564
1996	8,853	4,422	70,397	88,682	40,067	75,248	16,224	303,893

Table 9.–Chinook salmon annual targeted harvest rates for the Lake Michigan sport fishery, 1986 to 1996. Does not include stream fishery.

	Region							
Year	Green Bay	North	Northeast	Northwest	Southeast	Southwest	Illinois-Indiana	Lake-wide
1986	0.062	0.075	0.127	0.071	0.117	0.060	0.031	0.087
1987	0.067	0.086	0.086	0.079	0.063	0.068	0.029	0.065
1988	0.076	0.059	0.063	0.036	0.034	0.034	0.020	0.039
1989	0.082	0.033	0.048	0.059	0.036	0.030	0.019	0.039
1990	0.046	0.039	0.051	0.047	0.040	0.031	0.024	0.039
1991	0.083	0.033	0.062	0.075	0.027	0.044	0.036	0.045
1992	0.047	0.044	0.042	0.049	0.021	0.023	0.017	0.030
1993	0.030	0.021	0.027	0.056	0.025	0.027	0.012	0.027
1994	0.024	0.016	0.024	0.071	0.030	0.020	0.010	0.028
1995	0.080	0.023	0.055	0.073	0.031	0.069	0.018	0.047
1996	0.030	0.036	0.090	0.110	0.063	0.066	0.024	0.064

Table 10.–Estimated year-class harvest of chinook salmon for the Lake Michigan sport fishery. Does not include stream fishery.

Year	Region							
class	Green Bay	North	Northeast	Northwest	Southeast	Southwest	Illinois-Indiana	Total
1985	30,145	13,239	129,702	71,869	115,144	78,293	26,037	464,431
1986	29,603	10,110	79,255	60,981	80,270	58,786	19,385	338,389
1987	24,297	6,871	45,121	49,610	56,635	41,685	14,988	239,206
1988	18,423	6,912	40,839	46,739	41,255	39,025	16,145	209,339
1989	14,476	7,189	38,602	41,963	29,738	36,301	16,270	184,539
1990	13,385	6,521	37,694	48,016	23,598	35,807	16,010	181,031
1991	10,256	6,087	26,743	47,200	16,577	30,740	10,613	148,216
1992	10,507	3,334	22,304	52,550	19,754	38,867	9,101	156,417

Table 11.–Estimated year-class harvest ratio (harvest per number stocked) of chinook salmon for the Lake Michigan sport fishery. Does not include stream fishery.

Year class	Region							Lake-wide
	Green Bay	North	Northeast	Northwest	Southeast	Southwest	Illinois-Indiana	
1985	5.1	2.7	15.1	6.4	9.3	7.1	4.7	7.8
1986	5.3	1.7	9.4	6.0	6.6	6.5	3.5	5.9
1987	5.3	1.2	5.5	5.0	4.8	4.6	1.8	4.1
1988	5.7	1.0	4.1	6.4	3.2	8.6	1.7	3.9
1989	2.3	0.9	3.4	3.6	1.6	3.3	1.4	2.3
1990	2.6	0.9	3.1	5.5	1.4	3.2	1.7	2.5
1991	2.7	0.9	2.6	6.9	1.0	3.9	1.0	2.4
1992	2.7	0.5	1.8	10.6	1.2	5.2	1.3	2.7

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