POPULATION DYNAMICS AND INTERAGENCY MANAGEMENT OF THE BLOATER (*COREGONUS HOYI*) IN LAKE MICHIGAN, 1967–1982

Great Lakes Fishery Commission

TECHNICAL REPORT No. 44

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries between Canada and the United States, which was ratified on October 11, 1955. It was organized in April 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: first, develop coordinated programs of research in the Great Lakes and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; second, formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes.

The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties. In fulfillment of this requirement the Commission publishes the Technical Report Series, intended for peer-reviewed scientific literature, and Special Publications, designed primarily for dissemination of reports produced by working committees of the Commission. Technical Reports are most suitable for either interdisciplinary review and synthesis papers of general interest to Great Lakes fisheries researchers, managers, and administrators or more narrowly focused material with special relevance to a single but important aspect of the Commission's program. Special Publications, being working documents, may evolve with the findings of and charges to a particular committee. Sponsorship of Technical Reports or Special Publications does not necessarily imply that the findings or conclusions contained therein are endorsed by the Commission.

POPULATION DYNAMICS AND INTERAGENCY MANAGEMENT OF THE BLOATER *(COREGONUS HOYI)* IN LAKE MICHIGAN, 1967-1982[1]

by

EDWARD H. BROWN, JR.
Great Lakes Fishery Laboratory
U.S. Fish and Wildlife Service
Ann Arbor, Michigan 48105

RONALD W. RYBICKI
Great Lakes Fishery Station
Michigan Department of Natural Resources
Charlevoix, Michigan 49720

and

RONALD J. POFF
Bureau of Fish Management
Wisconsin Department of Natural Resources
Madison, Wisconsin 53707

TECHNICAL REPORT NO. 44

Great Lakes Fishery Commission
1451 Green Road
Ann Arbor, Michigan 48105

March 1985

1 Contribution 635 of the Great Lakes Fishery Laboratory, Ann Arbor, Michigan

CONTENTS

ABSTRACT

This paper examines the population dynamics of the bloater *(Coregonus* hoyi) in Lake Michigan during a progressive decline in abundance from about the mid-1960s through the mid-1970s, and during a subsequent recovery that is still underway. The study focused on developing a data base and methodology for projecting fishable surpluses, in cooperation with a chub technical committee sponsored by the Great Lakes Fishery Commission. The Technical Committee was formed in 1974 because of depletion of bloaters and other deepwater ciscoes or "chubs," as they are known by Great Lakes fishermen. Subsequently the Technical Committee recommended a lakewide ban on chub fishing that was fully enacted by the states of Illinois, Michigan, and Wisconsin in 1976.

With the Committee's help, commercial fishery statistics and stock assessment data were obtained from state and federal research files and used with various indirect analytical techniques to estimate relevant population parameters. The lakewide fishable stock in fall 1973, before the fishery was affected by several incomplete closures and then by the lakewide ban, was estimated as 48 to 73 million bloaters weighing 20 to 29 million pounds. Exploitation of the estimated stock varied considerably among 11 statistical districts in the several jurisdictions. Yield to the fishery exceeded production by the stock in some districts.

Theoretical yields of bloaters totaling 3.59 to 3.72 million pounds were projected for 1979 from all waters combined. These projected yields were intended as guidelines for experimental quotas that the states might establish, because the population had stabilized and the potential for recruitment had improved in most areas.

INTRODUCTION

For more than two decades, the population complex of deepwater ciscoes *(Coregonus* spp.) in Lake Michigan has been composed predominantly of bloaters *(Coregonus* hoyi), historically the smallest of several species marketed collectively as "chubs" since late in the last century (Smith 1964). Bloaters constituted more than 90% of the ciscoes caught in experimental gillnets fished throughout the lake in 1960-61 (Smith 1964) and more than 99% of those taken in trawls fished in the southeastern sector in 1964 (Wells 1966). Because of their small size at sexual maturity, bloaters survived in Lake Michigan while most of the other ciscoes disappeared, first from selective fishing for the preferred larger species and later from predation by sea lampreys *(Petromyzon marinus)* in the 1940s and 1950s (Smith 1968 and 1972). Sea lampreys preyed heavily on the larger cisco species, after nearly eliminating lake trout *(Salvelinus namaycush)* and burbot (Lota lota), the principal predators of ciscoes (Smith 1968). Ciscoes were also simultaneously exploited more intensively as fishermen diverted their effort (mainly with gillnets) from the disappearing lake trout. Relieved of predation from lake trout and burbot and of competition for food and space with larger species of ciscoes, bloaters had increased greatly in abundance by the mid- 1950s when they averaged 76% of the lakewide cisco catch in experimental gillnets as compared with only 31% of that in 1930-32 (Smith 1964).

Two unrelated factors probably helped to drive the bloater population into a severe decline that extended from about the mid-1960s through the mid-1970s. The most important of these was an explosive increase in abundance of the alewife *(Alosa pseudoharengus),* which like the rainbow smelt *(Osmerus* mordax)-another non-endemic species present since the 1920s - competes with ciscoes for space and possibly food (Smith 1970 and 1972) and may prey on their young. The second factor that may have adversely affected bloaters was an otter-trawl fishery created in 1959 to take small ciscoes for animal food (Smith 1968). That fishery and the conventional gillnet fishery combined landed a record 12 million pounds of chubs in 1960 (Fig. 1).

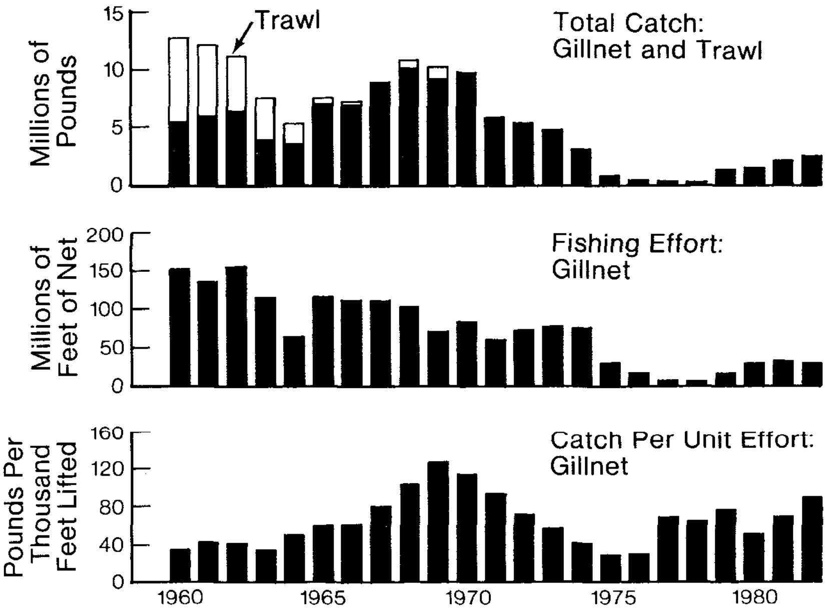

Fig. 1. Catch and effort statistics of the Lake Michigan chub fishery, 1960-1982: the gillnet catch and an undetermined part of the otter trawl catch are dressed weights, as reported by fishermen.

Statistical and Biological Indicators of the Population Decline

The prolonged decline in bloater abundance was amply indicated by experimental trawl (Table 1) and graded-mesh gillnet catches at index stations throughout the lake (Fig. 2). But the seriousness of the situation was masked for several years by high commercial catch rates of the late 1960s and early 1970s (Fig. 1). This paradox resulted from density-dependent growth increases (Fig. 3), which made proportionately more large (and heavier) adult bloaters available to the gillnets of a fishery that had diminished substantially in size because of depressed markets since the early 1960s (Brown 1970; Fig. 1). On the basis of their representation in the experimental trawl catches in southeastern Lake Michigan, five comparatively good year-classes (1960-64) contributed to the commercial catch during the short period of improved fishing success (Wells and Brown 1974). Landings dropped steadily after 1970, however, and in 1974 were the lowest in 30 years (Fig. 1).

A marked reduction in population density of larval bloaters, sampled systematically with tow nets in southeastern Lake Michigan, roughly paralleled that of the adult stock during 1964-77 (Fig. 4). We suspect that fewer larvae were produced in the late 1960s because of a highly unbalanced adult sex ratio (97% females), in addition to possible competition and predation from alewives and smelt. Although conclusive evidence of a functional relation between sex ratio and the abundance of progeny produced by bloaters is lacking, the extremely small proportions of males in the 1960s (Brown 1970) may have been far below that required for optimum reproductive efficiency. The subsequent shift to a more balanced sex ratio in the early 1970s (unpublished data, Great Lakes Fishery Laboratory), following a mass lakewide die-off of alewives in 1967, was more than coincidental if, as some have proposed, the extreme predominance of females was a physiological response by bloaters to population pressure from alewives (Brown 1970; George 1977).

Interagency Efforts to Protect Bloaters and Regulate their Harvest

Concern about the depleted bloater population brought state and federal agencies together in an effort to protect and manage the stocks on a unified, lakewide basis, and led in 1974 to the formation of a Lake Michigan Chub Technical Committee, as recommended by the Lake Michigan Committee of the Great Lakes Fishery Commission. Operating under auspices of the Commission, this ad hoc committee reviewed available scientific information and as a result recommended that the fishery be closed until the resource recovered sufficiently to provide a harvestable surplus (Poff 1974). The committee concluded that the fishery had in effect been subsisting on the basic brood stock during a period of falling recruitment, when record market prices for chubs offset high operating expenses.

Efforts by the states to implement a lakewide ban on chub fishing were challenged by the fishing industry in the courts of Illinois (the state was upheld by its Supreme Court), Michigan, and Wisconsin. Late in 1976 an enforceable

TABLE 1, Number of adult [a] bloaters caught per bottom trawl transect[b] at eight index stations in Lake Michigan, October-November and May-June 1967-82: Either one or two (asterisk) transects covering the depth range shown (fathoms) were fished at each station.

Year	Benton Harbor (3-40)	Saugatuck (3-40)	Ludington (5-40)	Frankfort' (10-50)	Manistique[c] (5-50)	Sturgeon Bay[c] (10-50)	Port Washington[c] (10-40)	Waukegan (3-40)	**Mean[d]** -
	Number of fish per transect by station and (in parentheses) depth								
1967	411*	213*	319	635		58	-	594	372
1968	180*	303*	699*	427	-	30		631*	378
1969	151*	120*	542*	553	86	16	136	567*	325
1970	204*	139*	436*	215	25	6	28	484*	247
1971	226	129*	403	210	141	17	33	134*	187
1972	89	100*	220	139	-	5	-	35*	98
1973	46	22	264	566	51	9	16	33	1.57
1974	39	33	78	75	18	16	47	48	48
1975	73	43	93	84	20	3	24	63	60
1976	62	14	35	22	41	10	-	17	27
1977	34	39	19	15	42	11	14	14	22
1978	25	483	233	267	33	18	43	178	201
1979	196	1047	1324	1250	108	63	347	438	597
1980	730	1015	2476	422	407	60	1132	1914	1103
1981	827	3550	3498	3600	1521	631	1725	2753	2476
1982	-	3671	4307	4481	987	328	1143	1154	2788

a Arbitrarily include fish ≥ 140 mm, 1967-79 and ≥ 120, 1980-82.
b Transects varied from 7 to 12 IO-minute tows along the contour; catches at several depths not sampled in some years were estimated from those adjacent to simulate equal sampling effort in all years at a given station.
c Spring sampling during 1967-72, fall sampling in later years; fall sampling entirely at stations if not specified.
d Manistique and Port Washington excluded.

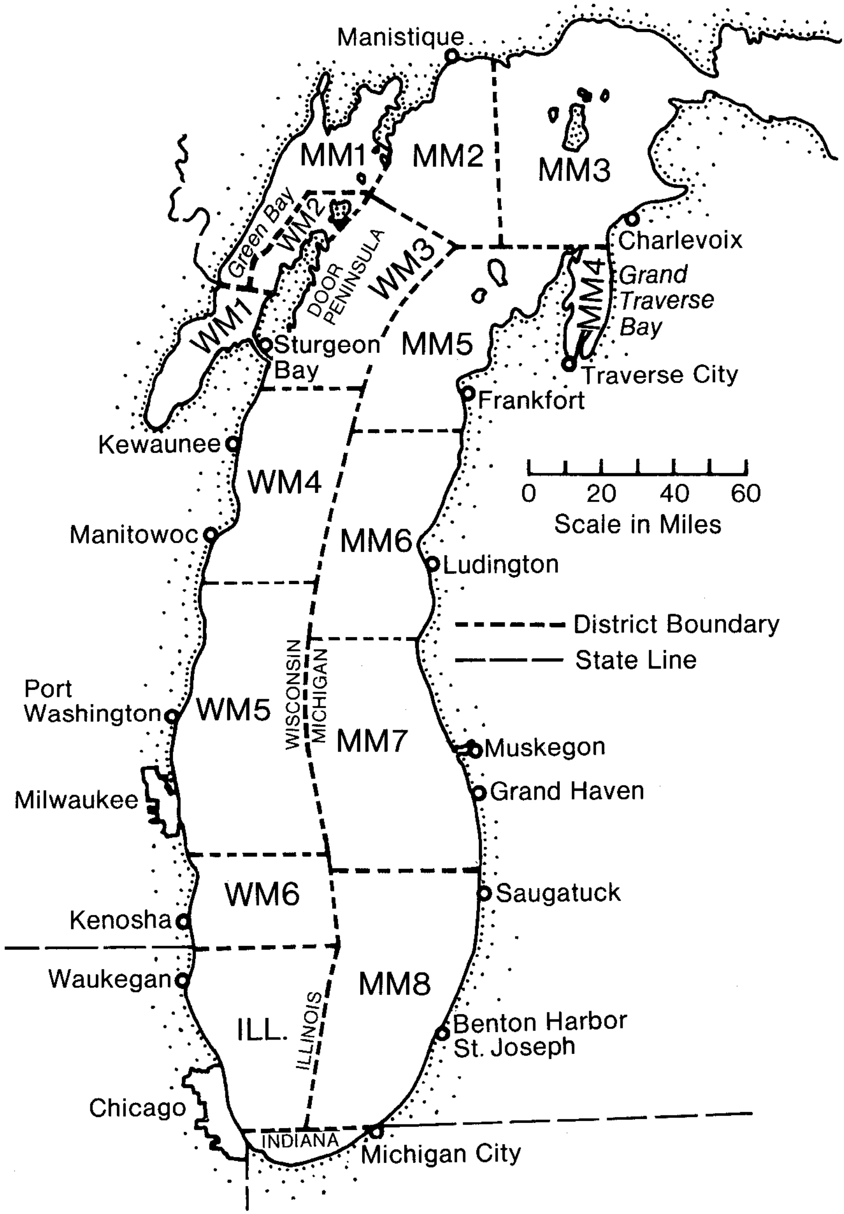

Fig. 2. Lake Michigan, showing fishery statistical districts (Hile 1962) and localities mentioned in the text.

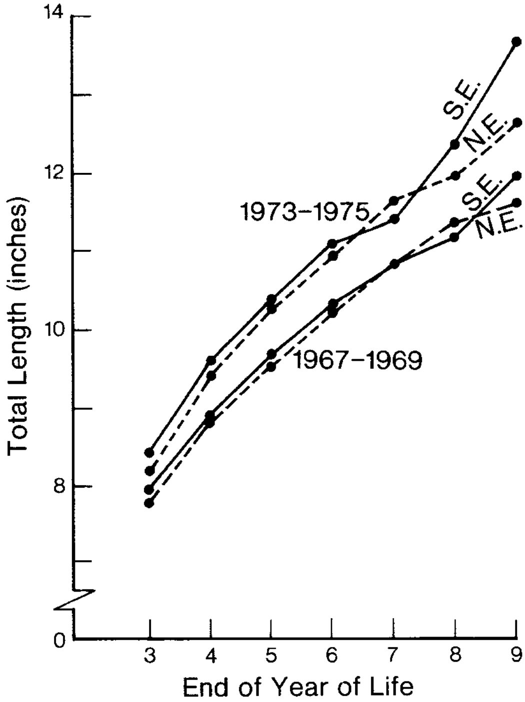

Fig. 3. Changes in growth of bloaters taken in southeastern (S.E.) and northeastern (N.E.) regions of Lake Michigan in fall trawl surveys of 1967-69 and 1973-75.

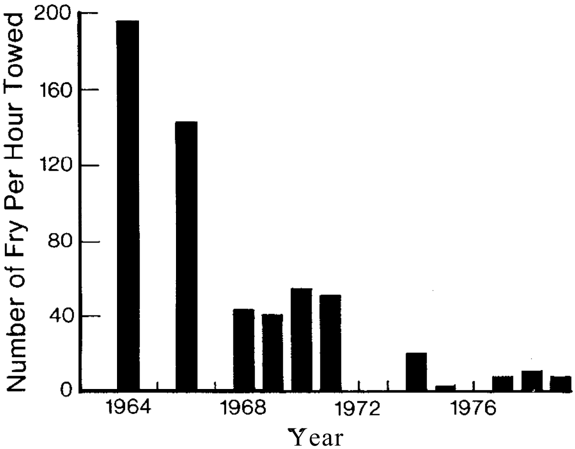

Fig. 4. Relative abundance of bloater fry taken in one-meter tow nets fished systematically off Saugatuck, Michigan, June 1964-1979; fry surveys were not conducted in 1965, 1967, 1972, 1973 and 1976.

lakewide ban was finally obtained with full closure in Wisconsin waters on 1 October, following earlier closures in Michigan on 7 August, and in Illinois on 20 January (Poff 1976). Indiana did not have a chub fishery because of little or no chub habitat. Following the technical committee's 1974 recommendation to ban chub fishing in Lake Michigan, the states jointly established and divided a nominal quota (310,000 pounds) to monitor the performance of the stocks during the impending closure. Use of this quota through contracts with commercial fishermen was impeded, however, by the ensuing legal confrontations, questioning the authority of the state agencies to regulate fishing. The chub stocks have now been monitored by commercial fishermen under state contract in Wisconsin since 1975; similar monitoring began in Michigan waters early in 1976 but was terminated late in 1977 because high dieldrin levels precluded marketing the catch. Limited monitoring was resumed in Michigan waters north of Muskegon in 1979-82 (Fig. 2). The contract fishermen used commercial-type gillnets with minimum mesh size of 2⅜ inches (stretched measure), supplemented in Wisconsin waters in the fall by gangs of graded-mesh gillnets. In addition Illinois, Michigan and the U.S. Fish and Wildlife Service continued to conduct annual assessment surveys with trawls and/or graded-mesh gillnets at widespread locations.

Study Objectives and Background

The primary objective of the present study was to develop, in cooperation with the Technical Committee, a data base and methodology for assessing the bloater stocks and determining when and to what extent fishable surpluses exist in the several state jurisdictions. An earlier draft of this paper was submitted by Edward H. Brown, Jr. as a research completion report in May 1979 to document work conducted at Great Lakes Fishery Laboratory (GLFL). The Chub Technical Committee, which provided counsel as well as data input from state and federal files, also used that draft as an appendix to their final report to the Lake Michigan Committee of the Great Lakes Fishery Commission (Lake Michigan Chub Technical Committee 1979).

GENERAL ANALYTICAL APPROACH

We first used commercial fishery and survey statistics from the various agency files to estimate the size of the standing stock of bloaters (by age group) in each statistical district of Lake Michigan proper in fall 1973, the beginning of what we refer to as the 1973-74 baseline period. Fairly extensive commercial catch statistics were available for that period because it just preceded the various bans on chub fishing. It was also chosen as a baseline because it encompassed the first comprehensive sampling of bloaters in the commercial catch for age and size by the state of Wisconsin. The standing stock estimates and related vital statistics were then used directly to compute biological production for comparisons with landings in the baseline period and in Ricker-type yield models (Ricker 1975) to project theoretical yields for 1979. The rationale in making these projections was that the annual yield should not exceed biological production if the bloater stocks were to maintain the *status quo* or continue their recent recovery (Patriarche 1968 and 1977).

All of the standing stock, production, and yield estimates for bloaters were made in "replicate" from two partly independent sets of models. The first set was developed from vital statistics derived from lakewide experimental trawling in fall 1967-75 by GLFL vessels. The second set was developed after adjusting age-distributions from the trawl catches to represent those that theoretically would have been obtained with standard gangs of gillnets containing graded meshes of 1½, 2, 2½, 3, 3½, and 4 inches (stretched measure).

Trawls and graded-mesh gillnets sample the bloater population more representatively in regard to *size* and age than do the highly selective gillnets (2½- to 2¾-inch mesh) used by commercial fishermen. But even samples of fish taken with trawls or graded-mesh gillnets are not necessarily free of size- and age-selection bias. The ability of bloaters to elude trawls probably increases as their size and age increase. On the other hand, graded-mesh gillnets may take disproportionately more older fish because, for some species, larger meshes capture fish of optimal retention sizes more efficiently than do smaller meshes (Hamley and Regier 1973). Mortality rates of Lake Michigan bloaters are therefore likely to have fallen between the rates estimated with the two different kinds of experimental gear.

PARAMETER ESTIMATION

The framework of parameter estimates developed for this study contains many indirectly generated components because of the need to adapt and use data from diverse survey sources, and because of the long term instability of the population. The resulting first-order approximations can be refined and updated, however, as the bloater population continues to change and as more systematic data are acquired by contract fishing in waters of the participating states.

FISHING INTENSITY

A good measure of fishing intensity, or effective fishing effort, was an important prerequisite for estimating mortality rates and exploitation rates of bloaters. We defined fishing intensity as fishing effort per unit area (square mile) of Lake Michigan, weighted according to the fractions of the stock that occupy the various 10-fathom depth intervals during the fishing year. Regression of instantaneous total mortality rates on fishing intensity subsequently provided estimates of natural mortality as well as catchability coefficients used for estimating fishing mortality rates in each statistical district during the 1973-74 reference period. Our derivation of fishing intensity (f) is summarized by the following notation:

$$\hat{f} = \sum_{i=1}^{n} \frac{f_i}{A_i} \; k \; C_i \, A_i \Bigg/ \sum_{i=1}^{n} \; k \; C_i \, A_i$$

$$\hat{f} = k \sum_{i=1}^{n} f_i \, C_i \Bigg/ k \sum_{i=1}^{n} A_i \, C_i$$

$$\hat{f} = \sum_{i=1}^{n} f_i \, C_i \Bigg/ \sum_{i=1}^{n} A_i \, C_i$$

where f_i = fishing effort in the ith depth zone; A_i = area of the ith depth zone in square miles; C_i = catch per effort in the ith depth zone; and k = a theoretical constant of proportionality between C_i and absolute stock density.

As a basis for computing fishing intensity, we used 1,000 feet of gillnet lifted without regard for the time between lifts (i.e., nights out) as the standard unit of fishing effort. (Mesh size of the gillnets fished for chubs ranges from a legal minimum of 2½ inches to about 2¾ inches.) The procedure of ignoring the length of time that each net fished was considered adequate in the past for computations involving large quantities of catch-effort statistics, because the pattern of fishing tended to be fairly constant from year to year (Hile 1962). The quantity of fish taken in gillnets increases with time fished, however, until the gear becomes saturated (Van Oosten 1935; unpublished data, Great Lakes Fishery Laboratory). The fishing interval for all statistical districts of Lake Michigan combined averaged 5.2 nights during 1971-76, when depth of fishing was recorded. This fishing interval decreased seasonally and increased somewhat during recent contract fishing, and increased to a greater extent with increases in depth and distance from shore. For the 6 years combined the duration of sets differed by 35% or less among the lo-fathom intervals from 20 to 59 fathoms, where most fishing for bloaters occurred and where most of the stock was concentrated. We conclude that this variation did not disqualify the unit of effort for the use intended.

Computation of fishing intensity also required that the final statistic be weighted to account for seasonal changes in depth distribution of the stock during the fishing season, which historically included all 12 months. Since 1975, however, Wisconsin has prohibited chub fishing during January-March, the principal spawning season of the bloater (Emery and Brown 1978). The modal "center" of the bloater population in Lake Michigan is at slightly more than 35 fathoms in fall, winter, and spring, but shifts closer to shore and shallower water by mid-summer (Wells 1968). The importance of adjusting for these changes was increased by depth restrictions imposed on chub fishermen by Michigan in

1967-68 to protect young salmonines. Chub fishing was prohibited inside of 35 fathoms in Michigan waters in 1967. Since 1968 this depth had been modified to 30 fathoms south of Grand Haven (Fig. 2) and 40 fathoms north of that port (Ned Fogel, personal communication). The depth limitations provided a sanctuary for part of the bloater stock during the period of the year that it occupies inshore waters.

To adjust fishing intensity for effects of the depth restrictions and seasonal changes in depth distribution of the stock, we computed weighting factors from 880 30-min trawl tows during lakewide fishing in all months except February in 1963-65 (Reigle 1969a and 1969c). These factors, which follow, represent average yearly (relative) densities of the stock for all seasons and regions of the Lake combined and are denoted by C_i above.

Depth interval (fathoms)	Pounds per 30-min tow
From 0 to 10	8.2
" 10 " 20	72.2
" 20 " 30	148.5
" 30 " 40	199.4
" 40 " 50	155.5
" 50 " 60	89.6
" 60 " 70	41.5
" 70 " 80	22.5
" 80 " 90	9.6

MORTALITY RATES

Before computing total mortality rates of year-classes represented in the 1967-75 lakewide trawl samples, we regressed trawl catch per unit of effort (CPE) for all ages combined on time (years) in each of four major sampling areas (i.e., Saugatuck and Benton Harbor combined, Ludington, Frankfort, and Waukegan - Fig. 2), and obtained predicted CPEs for use in the rate calculations. We assumed in adopting this procedure that daily variations in catchability caused by storms, upwellings, and unknown phenomena contributed substantially more to deviations from the above regressions than did yearly variations in absolute abundance. An extremely large CPE off Frankfort in 1973 (Table 2) was the most aberrant deviation from the long-term downward trend in relative abundance. The annual CPEs predicted by the regression equations were then subdivided into age groups by the scale method for computing instantaneous total mortality Z in successive years of life. Because of a severe drop in sample size from the declining recruitment, however, we obtained pooled estimates of Z by area for each age interval in each of two periods (1967-7 1 and 197 l-75) from the CPEs of the respective four year classes represented in each interval (Table 3). (Here and in subsequent sections, cohort age during the 12-month interval from one fall survey period to the next is indicated by the corresponding age interval, in accordance with annual age incrementation on January 1).

Corresponding estimates of Z were made in the same way for use in the hypothetical graded-mesh gillnet segment of the analysis, after first adjusting the

TABLE 2. Observed and predicted" catches of adult bloaters per trawl transect (CPE) off Saugatuck-Benton Harbor, Ludington and Frankfort, Michigan, and Waukegan, Illinois: October-November surveys except for April-May surveys off Frankfort in 1967-72.

Year (Code)[b]	Saugatuck/ Benton H. CPE	Predicted	Ludington CPE	Predicted	Frankfort CPE	Predicted	Waukegan CPE	Predicted
1967 (1)	312	300	567'	662	635	682	594	830
1968 (2)	242	234	699	589	427	503	631	543
1969 (3)	136	182	542	516	553	371	567	356
1970 (4)	172	142	436	443	215	273	484	233
1971 (5)	178	111	402	370	210	202	134	153
1972 (6)	94	86	220	297	139	149	35	100
1973 (7)	34	67	264	224	566	92	33	65
1974 (8)	36	52	78	151	75	68	48	43
1975 (9)	58	41	93	78	84	50	63	28
1976 (10)	38	32	35	5	22	37	17	18

a Prediction equations for the respective survey areas were:
Saugatuck-B. Harbor, Log CPE = 2.585-0.1082 Year code;
Ludington, CPE = 735.2-73.02 Year code;
Frankfort, Log CPE = 2.999-0.1322 Year code; and
Waukegan, Log CPE = 3.103-0.1839 Year code.

b Adjusted year codes at Frankfort were:
1967-72, given code + 0.33 to represent spring; and
1973-76, given code + 0.83 to represent fall.

c May 1968 value substituted for fall 1967 value of 319, because the latter was affected by adverse sampling conditions caused by high winds.

above trawl CPEs for bloaters at each age interval with efficiency factors for those caught in graded-mesh gillnets relative to those caught in trawls off Grand Haven in spring 1974 (Table 4).

Instantaneous natural mortality (M) of the bloater was estimated to be 0.54 from fall of the 5th to fall of the 6th year of life (age IV to V). This estimate was obtained by regressing the instantaneous total mortality rates of 1967-71 and 1971-75 from the four trawling areas on average annual fishing intensities of the commercial fishery in surrounding statistical districts (Fig. 5). The equivalent annual natural mortality rate (N) of 0.42 is almost identical to the 0.43 computed by biologists of the Michigan Department of Natural Resources (MDNR) for an unfished local population in Grand Traverse Bay (Fig. 2), using data from experimental trawl catches of age-VI to age-XI bloaters in 1973-76 (unpublished data, MDNR). An update of MDNR's analysis incorporating 1977 catch data slightly shifted the natural mortality estimate to 0.39. We used a constant natural mortality rate (or rates) for all ages of bloaters after full recruitment to the fishable stock in Lake Michigan because there was no statistically significant departure from a straight line in the catch curves of fish age-VI and older in the unfished Traverse Bay population.

The regression estimate of instantaneous natural mortality from age IV to V for hypothetical catches of bloaters in graded-mesh gillnets, computed after adjusting the trawl data with the relative catch efficiencies of the gillnets (i.e.,

TABLE 3. Average annual fishing intensity[a] for Lake Michigan chubs by the smallmesh gillnet fishery, and pooled estimates of total mortality in age intervals IV-V through VIII-IX for year classes represented in trawl-survey periods 1967-71 and 1971-75 at five sampling areas: (Hypothetical rates based on graded-mesh gillnets in parentheses.[b])

Location	Years	Season trawled	Fishing intensity	Total instantaneous mortality Z IV-V	V-VI	VI-VII	VII-VIII	VIII-IX
Benton Harbor Saugatuck combined (MM 8)	1967-71	Fall	5.33	0.71 (0.39)	0.99 (0.66)	1.03 (0.70)	1.73 (1.40)	1.32 (1.00)
	1971-75	Fall	4.99	0.74 (0.41)	1.34 (1.00)	3.02 (2.69)	2.49 (2.14)	-
Ludington (MM 6)	1967-71	Fall	5.39	0.81 (0.47)	0.73 (0.39)	1.06 (0.49)	1.29 (0.96)	- -
	1971-75	Fall	5.20	0.81 (0.47)	1.06 (0.72)	1.16 (0.83)	1.70 (1.37)	- -
Frankfort (MM 5/MM6)	1967-71	Spring	8.23	0.71 (0.38)	1.26 (0.92)	1.34 (1.00)	1.31 (0.98)	- -
	1973-75	Fall	6.54	0.90 (0.57)	2.17 (1.83)	0.88 (0.54)	1.53 (1.19)	- -
Waukegan (Ill.)	1967-71	Fall	13.32	1.01 (0.68)	1.10 (0.77)	1.43 (1.09)	1.47 (1.14)	2.81 (2.48)
	1971-75	Fall	8.63	0.99 (0.65)	-		-	- -
Mean	-	-	-	0.82 (0.48)	1.24 (0.90)	1.42 (1.05)	1.65 (1.31)	-
Equivalent annual mortality	-	-	-	0.56 (0.38)	0.71 (0.59)	0.75 (0.65)	0.81 (0.73)	- -

[a] Thousands of feet of gillnet lifted per square mile per year, adjusted for average availability by depth.
[b] Computed after adjusting numbers in age groups with factors for the relative efficiency of the gillnets to trawls in comparative sampling with each gear at Grand Haven, Michigan, spring 1974.

relative to trawls), was 0.21-equivalent to an annual rate of 0.19. This value, which is roughly half as large as the trawl estimate, may be unrealistically low, because it would indicate a survival of about 35% from age IV to IX in an unfished stock.

We next estimated instantaneous fishing mortality for bloaters in each statistical district of Lake Michigan proper during 1973-74 as the product of the appropriate coefficient of catchability and fishing intensity in the respective district. Catchability coefficients for fish in age interval IV-V were taken as the slopes of the previously mentioned total mortality-fishing intensity regressions-0.041 for both the trawl and graded-mesh gillnet models. Because of small sample sizes and high variability at greater ages, slopes of the regressions of total

TABLE 4. Efficiency of capturing Lake Michigan bloaters of various ages in graded-mesh gillnets relative to bottom trawls, Grand Haven, Michigan, spring 1974.

Age	Relative efficiency	
	Observed	Predicted”
II	0.78	
III	0.80	-
IV	0.90	0.88
V	1.24	1.23
VI	1.55	1.71
VII	2.55	2.40
VIII	3.35	3.35
IX	-	4.68
X		6.55
XI	-	9.16

“From Log Efficiency = -0.650 + 0.146 Age, derived from age IV-VIII observations.

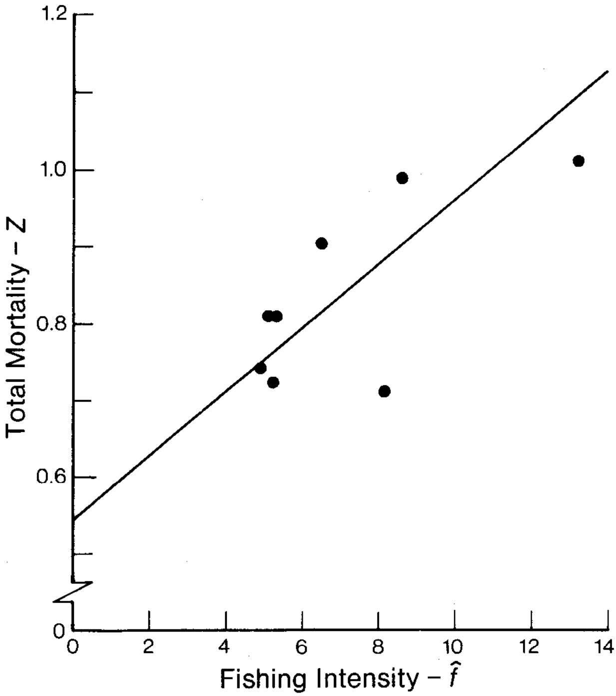

Fig. 5. Relation between instantaneous total mortality (Z) of bloaters in age interval IV-V and fishing intensity (f) with small-mesh gillnets, using mean trawl-based estimates of mortality for Saugatuck and Benton Harbor (combined), Ludington, Frankfort, and Waukegan areas, 1967-71 and 1971-75.

mortality Z in higher age intervals on fishing intensity did not differ significantly from zero. We nevertheless fit regressions to the clusters of Z andf coordinates in each successive age interval from V-VI through VII-VIII, but forced each regression to intercept the Z axis at the estimated natural mortality rates (M) in IV-V. The slopes of the following regression lines so obtained were used as catchability coefficients to estimate fishing mortality rates of the older fish:

$Z_{6-7} = 0.54 + 0.086\,\hat{f}$; trawl models
$Z_{6-7} = 0.21 + 0.085\,\hat{f}$; gillnet models
$Z_{7-8} = 0.54 + 0.105\,\hat{f}$; trawl models
$Z_{7-8} = 0.21 + 0.101\,\hat{f}$; gillnet models
$Z_{8-9} = 0.54 + 0.129\,\hat{f}$; trawl models
$Z_{8-9} = 0.21 + 0.128\,\hat{f}$; gillnet models

where the Z subscripts are years of life or ages in fall + 1.

The age of bloaters at full recruitment to the fishable stock has an important bearing on the accuracy of the preceeding mortality estimates. On the basis of the trawl catch, this parameter has appeared to change considerably over the last two decades, although the extent of the change has probably been masked by changes in year-class strength. The survival curves for bloaters (Fig. 6) peaked at age III in spring during the early 1960s and at age V in the years following the mass lakewide die-off of alewives in 1967 (Brown 1968). This die-off may have reduced population pressure in pelagic waters, allowing bloaters to remain there longer before recruitment to the demersal stock sampled by trawls. Because bloaters of age IV in fall and age V in the following spring have consistantly outnumbered those of the next greater ages, fish of those ages were considered to be fully recruited. The accuracy of this assumption is uncertain, however, because considerable curvature in the survivorship graph may be caused by incomplete recruitment as well as by differential catchability with age in gillnets of the commercial fishery (Fig. 6). On the basis of its straight catch curve, the unexploited population of bloaters in Grand Traverse Bay was not fully vulnerable to survey trawls until age VI in the 1970s (unpublished data, MDNR).

Instantaneous fishing mortality rates and annual exploitation rates of the recruited fractions of partially recruited age groups were estimated for use in the above analysis on the basis of their differing efficiencies of capture in the size- and age-selective commercial fishing gear. Normal selection curves were first fitted to the age-specific efficiency ratios of commercial-mesh (approximated by 2⅜-, 2½-, and 2¾-inch) gillnets relative to trawls and to graded-mesh gillnets (Fig. 7), respectively, by using the comparative fishing data from spring 1974 off Grand Haven. The iterative procedure involved (1) choosing an approximate modal age, (2) computing the sum of squares for ages represented by the various efficiencies minus the mode on the left side of the curve, (3) doubling the sum of squares to represent unknown variation on the right side, and (4) taking the standard deviation as the normal-curve parameter. A chi-square value computed from the actual and predicted efficiency ratios indicated goodness of fit. The curve-fitting procedure was then repeated with successively smaller or larger

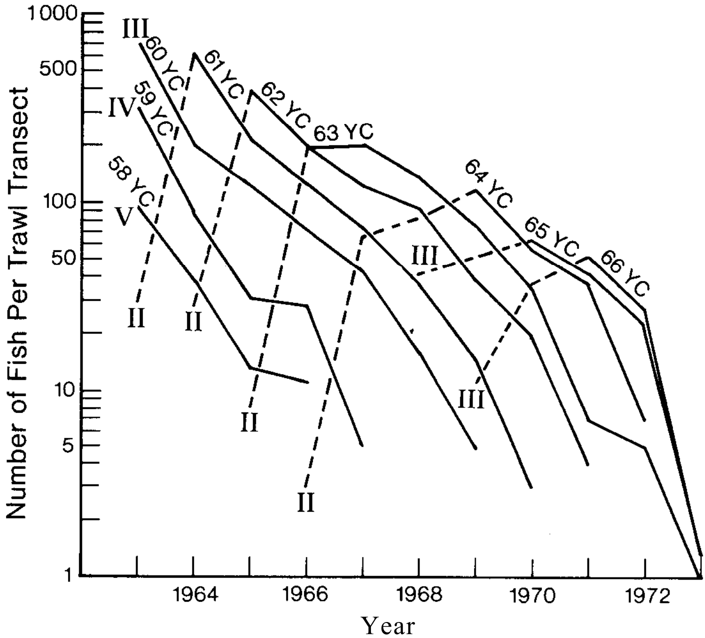

Fig. 6. Survival curves for year classes (YC) of bloaters represented in trawl catches off Saugatuck, Michigan, spring 1963-1973: the first age group sampled in a year class is identified by Roman numeral.

modal ages until a chi-square of 1.0 or less was attained. Fishing morality rates of the partially recruited fractions of fish in age intervals II-III and III-IV were then estimated with the predicted relative efficiencies (Table 5), by the following relation:

$$\frac{F_1}{F_2} = \frac{E_1}{E_2}$$

where F_1 = estimated instantaneous fishing mortality for bloaters in age interval IV-V; F_2 = unknown fishing mortality of lower partly recruited age groups (e.g., in III-IV); E_1 = relative efficiency of commercial-mesh nets for bloaters in age interval IV-V; and E_2 = relative efficiency of commercial-mesh nets for partly recruited age groups (e.g., in III-IV).
A similar procedure was used for fully recruited bloaters in age intervals IX-X and X-XI, which were poorly represented in the samples.

Growth Rate and Maturity

The growth rate of the bloater has been strongly density dependent in Lake Michigan for several decades. It increased to a plateau in the mid-1970s at or

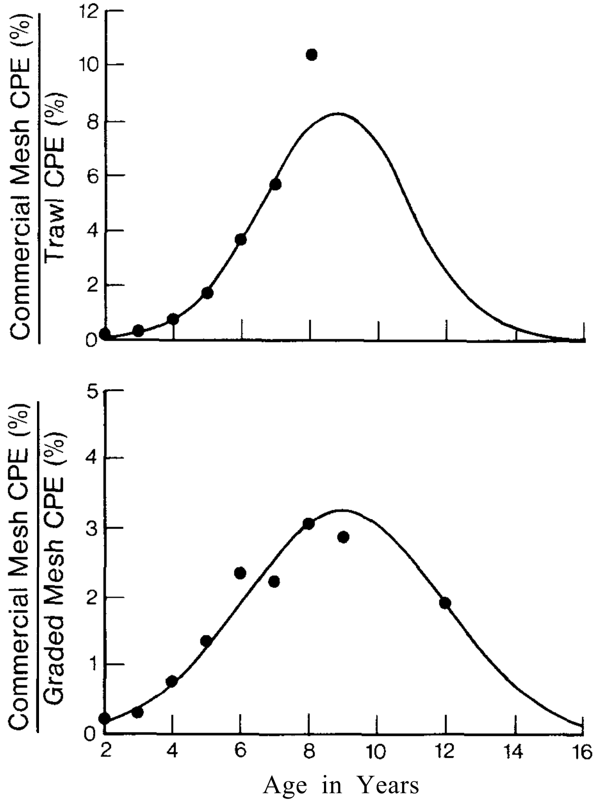

Fig. 7. Efficiency of capture of bloaters in commercial-mesh gillnets relative to bottom trawls (upper panel) and to graded-mesh gillnets (lower), Grand Haven, Michigan, spring 1974; the normal selection curves were fitted to the data by a special iterative method.

near the end of the long-term population decline that began in the 1960s. This comparatively high rate contrasted markedly with that in the mid-1950s, for example, when numerical abundance of bloaters was near the highest yet recorded (Smith 1964; Brown 1970).

We estimated the instantaneous growth rates of successive ages of bloaters in the 1973-74 reference period from predicted weights corresponding to mean lengths of fish taken in trawls and gillnets fished throughout the lake in 1973-75 (Table 6). Lengths and weights from certain ages in certain gears were excluded from the computations because of size selections bias. In general, average lengths at a given age tended to vary more randomly among the various gears as age increased.

As growth rates increased in recent decades, mean ages at which males and females matured decreased. In fall 19.54, 42% of the age-1 males and 44% of the age-1 females taken in bottom trawls were sexually mature, as compared with 68

TABLE 5. Efficiency of capturing Lake Michigan bloaters in commercial-mesh gillnets relative to bottom trawls and graded-mesh gillnets, Grand Haven, Michigan, spring 1974.

	Relative efficiency			
	to trawls		to graded mesh	
Age	Observed	Predicted[a]	Observed	Predicted[b]
II	0.16	0.07	0.21	0.18
III	0.24	0.25	0.30	0.38
IV	0.70	0.76	0.78	0.74
V	1.71	1.88	1.37	1.26
VI	3.70	3.74	2.39	1.91
VII	5.72	6.01	2.25	2.58
VIII	10.42	7.83	3.11	3.08
IX	-	8.26	2.91	3.27
X		7.05		3.08
XI		4.87		2.58
XII	–	2.72	1.95[c]	1.91

a From fitted normal curve of mean age 8.75 years and standard deviation 2.17 years.
[b]From fitted normal curve of mean age 9.00 years and standard deviation 2.89 years.
c Not used to fit curve.

and 49% of the respective sexes in 1973-74 (Table 7). Most of the age-11 fish of each sex were mature in both periods, but proportionally more mature females were sampled in 1954 (95%) than in 1973-74 (88%).

EXPLOITATION RATES

The exploitation rates referred to here and in later sections were estimated for the age groups in each statistical district of Lake Michigan proper (Fig. 2) from the following relation:

$$u_i = \frac{F_i A_i}{Z_i}$$

where u_i = exploitation rate for bloaters in the ith year of life, A_i = total annual mortality rate, and F and Z are previously defined instantaneous rates. The same procedure was used for both the trawl and graded-mesh gillnet segments of the study.

Rate of exploitation varied considerably for bloaters among the various statistical districts during the 1973-74 reference period (Table 8). Fishing intensity estimated at almost 25,000 feet of gillnet per square mile in Wisconsin's WM-6, the smallest district in the main body of the lake, was more than double that in any other district. As a consequence, exploitation by the size-

TABLE 6. Average total length (in) and predicted weight[a] (oz) of Lake Michigan bloaters taken in trawls and gillnets combined, 1973-75: lengths at capture in 2 to 8 of the lowest age groups were excluded from various collections to reduce size selection bias attributed to the gear.

Age[b]	Number of fish	Length	Weight
I	168[c]	3.9[f]	0.2
II	168[c]	6.7[f]	1.3
III	156[c]	8.4	3.0
IV	240[c]	9.7	4.8
V	408[d]	10.4	6.1
VI	192’	10.9	7.3
VII	80’	11.5	8.6
VIII	31’	12.0	10.2
IX	17’	12.7	12.0
X	3’	13.3	14.1

a Log weight = -2.65 + 3.39 Log length; trawl samples, fall 1973-75.
[b]Age that would be attained (fall samples) or was attained (spring samples) on 1 January, following the completed year of growth.
c Trawl samples, fall 1973-75.
d Above samples plus samples from trawls and graded-mesh gillnets, spring 1974.
e Above samples plus samples from commercial-mesh gillnets, fall 1973 - spring 1974.
f Backcalculated by scale method; all others length at capture.

TABLE 7. Maturity schedule of male and female bloaters taken in bottom trawls off Grand Haven, Michigan, October 1954, and off Waukegan, Illinois, and Saugatuck, Ludington, and Frankfort, Michigan, October and November 1973-74.

	1973-74				1954			
	Males		Females		Males		Females	
Age group[a]	% Mature	Number of fish	% Mature	Number of fish	% Mature	Number of fish	% Mature	Number of fish
0	14	7	0	5	-	-	0	9
I	68	127	49	83	42	12	44	32
II	98	91	88	82	97	61	95	105
III	100	128	99	152	100	25	100	67
IV	98	97	99	127	100	11	100	17
V	100	37	100	81	100	6	100	10
VI	100	7	100	28	100	1	100	8
VII	-		100	17	-	-	-	-
VIII	-	-	100	6	-			

a Fish would have advanced one year in age on 1 January near the start of the next spawning season.

selective commercial gillnets in the most vulnerable years (8th and 9th) of life ranged from 0.84 to 0.91 in that district, according to the respective trawl and gillnet modelling procedures. Heaviest fishing pressure during the reference period occurred in central and southern Wisconsin and in Illinois, followed by that in northcentral Michigan (MM-5 and MM-6).

The intensive fishing in WM-6 contrasted with that in WM-3, where the fishery had declined markedly since the early 1950s. In 1953, for example, 38 million feet of gillnet were fished for chubs in WM-3 as compared with 12 million feet in WM-6 (Hile and Buettner 1955). By 1973, however, only 2 million feet were fished in WM-3 (an 83% decrease), whereas fishing effort was almost unchanged at 11 million feet in WM-6 (unpublished data, Great Lakes Fishery Laboratory). The intensive fishing for chubs in waters off the Door Peninsula and other areas of northeastern Wisconsin and the concurrent early buildup there of a large alewife population, much of which spawns in Green Bay, greatly reduced the chub population before it was as severely affected in other regions of Lake Michigan (Fig. 2). By 1969, most full-time chub fishermen from Door and Kewaunee counties had moved south to the Milwaukee area, which traditionally has produced more chubs (unpublished reports, Wisconsin Department of Natural Resources [WDNR]).

THE FISHABLE STOCK, 1973-74

Age-specific exploitation rates were finally used with the various year-class components of the commercial catch in each district to obtain lakewide estimates of the fishable stock of bloaters present in fall 1973 at the beginning of the baseline period. Computations leading to the estimated number (N) and biomass (B) of fish are summarized as follows:

$$N = \sum_{i=1}^{11} \sum_{j=3}^{10} \frac{W_{ij}}{\bar{w}_j \, u_{ij}}$$

$$B = \sum_{i=1}^{11} \sum_{j=3}^{10} \frac{W_{ij}}{u_{ij}}$$

where W_{ij} = round weight (pounds) of the commercial catch of the jth age group in the ith statistical district in November 1973-June 1974; $\bar{w}_j$ = mean round weight (pounds) of individual bloaters in the jth age group in samples from the commercial catch or from experimental sets of commercial-mesh gillnets (Table 9); and u_{ij} = rate of exploitation of the jth age group in the ith statistical district

TABLE 8. Commercial fishing intensity[a] and rate of exploitation of Lake Michigan bloaters in the fishery statistical districts of Michigan (MM), Wisconsin (WM), and Illinois by age during November 1973-October 1974 (year classes in parentheses).

Statistical district	Fishing intensity	Exploitation in age interval								
		II–III[b]	III-IV[b]	IV-V	V-VI	VI-VII	VII-VIII	VIII-IX	IX-X	Mean
		(1971)	(1970)	(1969)	(1968)	(1967)	(1966)	(1965)	(1964)	(1969–64)[c]
MM2	0.75	0.004	0.01	0.02	0.05	0.06	0.07	0.07	0.05	0.05
		0.01	0.02	0.03	0.06	0.07	0.08	0.08	0.07	0.06
MM3	3.50	0.02	0.05	0.10	0.20	0.24	0.29	0.27	0.22	0.21
		0.04	0.08	0.12	0.23	0.27	0.33	0.33	0.27	0.25
MM5	8.51	0.04	0.11	0.23	0.41	0.47	0.54	0.52	0.44	0.42
		0.10	0.18	0.27	0.61	0.53	0.61	0.61	0.53	0.51
MM6	7.47	0.04	0.10	0.21	0.38	0.43	0.50	0.48	0.40	0.39
		0.09	0.16	0.24	0.43	0.48	0.57	0.57	0.48	0.44
MM7	2.97	0.02	0.04	0.09	0.18	0.21	0.25	0.24	0.19	0.18
		0.04	0.07	0.10	0.20	0.24	0.29	0.29	0.24	0.21
MM8	5.34	0.03	0.07	0.15	0.29	0.34	0.40	0.38	0.31	0.30
		0.07	0.12	0.18	0.33	0.38	0.45	0.45	0.38	0.35
WM3	3.13	0.02	0.04	0.09	0.18	0.22	0.26	0.25	0.20	0.19
		0.04	0.07	0.11	0.21	0.25	0.30	0.30	0.25	0.23
WM4	9.64	0.05	0.13	0.26	0.45	0.51	0.58	0.56	0.48	0.46
		0.12	0.20	0.30	0.51	0.57	0.65	0.65	0.57	0.53
WM5	11.55	0.06	0.15	0.30	0.51	0.57	0.64	0.62	0.54	0.52
		0.14	0.23	0.34	0.57	0.63	0.71	0.71	0.63	0.58
WM6	24.95	0.12	0.29	0.52	0.74	0.79	0.84	0.83	0.77	0.74
		0.28	0.43	0.59	0.82	0.86	0.90	0.91	0.86	0.82
Ill.	10.62	0.05	0.14	0.28	0.48	0.54	0.61	0.60	0.51	0.49
		0.13	0.22	0.32	0.55	0.60	0.69	0.69	0.60	0.56

a Thousands of feet of small-mesh gillnet lifted per square mile, adjusted for yearly depth distribution of the stock.
b Exploitation only of the fraction of the year class recruited by fall 1973.
c Geometric mean.

TABLE 9. Percentage weight composition by age of bloaters taken in experimental gillnets[a] off Grand Haven, Michigan, April-June 1974, and from the Wisconsin commercial fishery at Kenosha north to Sturgeon Bay, 24 October, 1973-17 June, 1974.

	Michigan		Wisconsin	
Age group[b]	Weight in %	Number of fish	Weight in %	Number of fish
II	0.5	3	0.2	4
III	2.8	13	4.5	50
IV	32.0	104	35.9	304
V	32.9	97	40.0	262
VI	13.4	37	12.8	68
VII	9.4	22	3.1	13
VIII	4.0	8	1.5	6
IX	3.7	6	0.8	2
X	-	-	0.7	2
XI				
XII	1.3			
XIII	-	-	0.5	1
Total	100.0	291	100.0	712

[a]Mesh sizes of 2 3/8, 2 1/2, and 2 3/4 inches (stretched measure).
[b]Age group entered on January 1, 1974 or that would have been entered on that date.

during November 1973-June 1974. Commercial catches reported as dressed weight by fishermen were converted to round weight for use in these calculations with the multiplier 1.19 (unpublished data, WDNR).

The November through October baseline period (i.e., fishing year) was chosen to coincide first with annual mortality rate and exploitation rate computation from one fall survey (trawling) period to the next, and second with commercial-catch sampling by WDNR for age-and-size-composition data, beginning in fall 1973 (Table 9). Age data were not obtained by WNDR, however, during the July-October 1974 period of growth, maturation, and recruitment. We therefore used the commercial landings of November through June in each district (Table 10) and recalculated exploitation rates on an S-month basis for estimating the standing stock. This limitation in the data base necessitated additional arithmetic but did not pose a serious technical problem. Natural mortality (M) was taken as 8112 (66.7%) of the 12-month values in the "recalculations," whereas fishing mortality (F) in each District was reduced in proportion to the amount of the annual fishing effort (f) that was expended during the 8-month period from November through June. The partial *f* values in the 11 statistical districts averaged 70.8% of the annual values.

By summing the individual standing-stock estimates for eight age groups and 11 statistical districts, we estimated that Lake Michigan had a total fishable stock of 48 million bloaters (based on exploitation rates computed after sample adjustment to represent catches from graded-mesh gillnets) to 73 million bloaters (based on exploitation rates computed from trawl data) weighing 20 to 29 million pounds in fall 1973 (Table 11).

TABLE 10. Reported commercial landings (dressed weight) of bloaters from fishery statistical districts of Lake Michigan during 2-month periods from November 1973 through October 1974.

	Thousands of pounds landed						
District	Nov-Dec	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Combined
MM2	4.3	11.6	3.5	-	0.3	-	19.7
MM3	34.5	29.2	20.5	36.3	44.5	26.1	191.1
MM5	33.8	21.0	17.0	17.7	24.5	26.3	140.3
MM6	63.4	59.8	58.4	76.5	21.0	6.9	286.0
MM7	13.3	40.7	98.1	80.6	53.4	18.8	304.9
MM 8	98.3	18.2	78.3	52.3	42.5	54.2	343.8
Subtotal	247.6	180.5	275.8	263.4	186.2	132.3	1,285.8
WM3	10.8	28.4	2.5	6.4	0.7	-	48.8
WM4	23.3	23.7	15.4	11.7	14.2	13.3	101.6
WM5	106.7	225.9	142.1	97.0	99.4	89.5	760.6
WM6	142.1	149.5	61.7	35.3	44.9	34.5	468.0
Subtotal	282.9	427.5	221.7	150.4	159.2	137.3	1,379.0
Ill.	76.5	177.3	142.4	59.9	142.6	91.6	690.3
Total	607.0	785.3	639.9	473.7	488.0	361.2	3,355.1

TABLE 11. Estimated fishable stocks of bloaters (numbers and weights [pounds] of fish in millions) in 11 statistical districts of Lake Michigan proper in fall 1973.

	Number		Weight	
District	Trawl[a]	Gillnet[b]	Trawl[a]	Gillnet[b]
MM 2[c]	3.2	2.2	1.2	0.9
MM3	10.0	5.0	3.8	2.0
MM5	2.1	1.4	0.8	0.6
MM6	6.1	4.2	2.3	1.7
MM7	14.8	10.1	5.6	4.0
MM 8	10.1	7.0	3.9	2.8
Subtotal	46.3	29.9	17.6	12.0
WM3	2.0	1.3	0.9	0.6
WM4	1.6	1.1	0.7	0.5
WM5	9.6	6.4	4.2	3.0
WM6	3.3	2.3	1.5	1.1
Subtotal	16.5	11.1	7.3	5.2
Ill.	9.8	6.6	4.3	3.0
Districts combined	72.6	47.6	29.2	20.2

a Commercial catch divided by exploitation rate, based on mortality rates estimated from trawl data.

b Commercial catch divided by exploitation rate, based on mortality rates estimated after adjusting trawl data to represent hypothetical data from graded-mesh gillnets.

c Estimates highly tentative because of low fishing effort in MM 2.

SIMULATED YIELD AND PRODUCTION IN THE BASELINE PERIOD

On a lakewide basis, almost identical yields to the fishery of 4.63 and 4.56 million pounds of bloaters were simulated for the 1973-74 baseline period by the trawl and graded-mesh gillnet models, respectively (Table 12). The mean of those yields was 15% larger, however, than the actual yield of 4.00 million pounds reported by the industry. This difference would be increased somewhat if in making the comparison, bloaters recruited to the fishable stock in July-October 1974 could be "identified" and deducted from the actual landings (Table 10), because those recruits were not included in the estimated yield values.

In contrast to yield, biological production was simulated at a substantially higher level (X1.4) by the trawl model than by that based on graded-mesh gillnets for individual districts and for the districts combined (Table 12). The lower exploitation rates implicit in the former models generated larger standing stocks of partly recruited bloaters in age intervals II-III and III-IV, contributing to the higher production.

Despite the range of possibilities covered by the models, it was apparent that bloaters in the II-III age interval and higher in several districts were being harvested faster than they were being generated. Indeed, both simulated and

TABLE 12. Comparison of estimated biological production and commercial yields of Lake Michigan bloaters during the November 1973-October 1974 reference period, preceding partial and then complete bans on fishing; all values are in millions of pounds (round weight).

District	Biological production		Estimated yield		
	Trawl[a]	Gillnet[b]	Trawl[a]	Gillnet[b]	Actual yield[c]
MM2	0.27	0.20	0.02	0.02	0.02
MM 3	0.78	0.44	0.28	0.25	0.23
MM5	0.16	0.12	0.16	0.16	0.17
MM6	0.48	0.36	0.44	0.44	0.34
MM7	1.19	0.89	0.43	0.43	0.36
MM 8	0.80	0.59	0.51	0.52	0.41
Subtotal	3.68	2.60	1.84	1.82	1.53
WM3	0.20	0.14	0.06	0.06	0.06
WM4	0.14	0.10	0.14	0.14	0.12
WM5	0.88	0.61	0.97	0.99	0.91
WM6	0.27	0.19	0.69	0.68	0.56
Subtotal	1.49	1.04	1.86	1.87	1.65
Ill.	0.90	0.61	0.93	0.87	0.82
Districts combined	6.07	4.25	4.63	4.56	4.00

a Estimates based on mortality rates derived from trawl data.
b Estimates based on mortality rates derived after adjusting trawl data to represent hypothetical data from graded-mesh gillnets.
c Dressed weight x 1.19 (Wisconsin Department of Natural Resources, unpublished data).

actual yields exceeded biological production by wide margins in statistical district WM-6, to lesser degrees in WM-5 and MM-5, and for the simulations by the gillnet models only, in district MM-6 and in Illinois. Although not shown in Table 12, the differences between yield and production were even greater for the fraction of the stock in age intervals IV-V and higher, because the growth rate declined gradually with increasing age (through VIII or IX), and fishing mortality induced by the size-selective commercial gillnets increased substantially.

PROJECTED YIELDS FOR REFERENCE IN ESTABLISHING CATCH QUOTAS

By late 1978 the long-term decline in bloater abundance had ended and the stocks appeared to be recovering in some areas. Generally higher catch rates in the limited commercial fishing under state (assessment) contracts may have exaggerated the recovery because of reduced gear competition (Table 13, and Ricker 1975). However, catch rates of young-of-the-year were higher in fall 1978 trawl surveys than in those of any previous fall (1967-77), confirming that fundamental improvement in the stocks was underway. The high production of young bloaters in 1978 was a forerunner of even higher abundance that would be monitored into the early 1980s. In contrast, lower young-of-the-year abundance indices calculated for years before 1978 had oscillated about a slightly declining trend marked by two or three moderately stronger year-classes followed by several that were weaker (Table 14).

This reversal in status of the bloater population created an urgent need for information on potential yields which managers could use when setting catch quotas. We therefore projected theoretical yields for 1979 (approximated by the period fall 1978-fall 1979) based on specified equilibrium rates of fishing (i.e.,

TABLE 13. Changes in catch per unit of effort” (CPE)[b] for bloaters in Michigan, Wisconsin, and Illinois waters of Lake Michigan, 1973-82.

	Illinois		Michigan		Wisconsin		Entire Lake	
Year	CPE	Effort	CPE	Effort	CPE	Effort	CPE	Effort
1973	61	661	65	3269	A7	3921	56	7857
1974	56	1372	49	2484	33	3720	42	7576
1975	48	225	37	1240	23	1517	31	2982
1976	64	45	31	572	35	603	34	1220
1977	74	38	47	175	80	322	69	535
1978	110	14	53	297	73	320	64	631
1979	55	143	71	232	79	1266	76	1641
1980	80	163	66	327	46	2391	50	2880
1981	78	200	90	482	65	2373	70	3054
1982	79	258	93	666	92	1950	91	2874

a Thousands of feet (x 10) of small-mesh gillnet lifted.
[b]Pounds of bloaters (dressed weight) per thousand feet of net lifted.

TABLE 14. Number of young-of-the-year and yearling" bloaters per bottom trawl transect[b] at eight index stations in Lake Michigan, October-November and May-June 1967-77: Either one or two (asterisk) transects covering the depth range shown (fathoms) were fished at each station.

	Number of fish per transect by station and depth								
Year	Benton Harbor (3-40)	Saugatuck (3-40)	Ludington (5-40)	Frankfort[c] (10–50)	Manistique[c] (5-50)	Sturgeon[c] Bay (10-50)	Port[c] Washington (10–40)	Waukegan (3-40)	Mean[d]
1967	10*	2*	5	0	-	0	-	17	4.7
1968	22*	15*	14*	0	-	2	-	60*	12.1
1969	20*	16*	22*	36	1	5	2	91*	19.1
1970	70*	30*	28*	5	2	21	58	72*	21.2
1971	11	5*	27	24		4	34	8*	9.3
1972		4*	[illegible]	5		5	-	3*	3.3
1973	14	52	44	14	3	4	2	18	12.5
1974	24	15	137	76	0	15	4	2	13.4
1975	7	7	33	6	1	2	2	6	6.1
1976	4	0	2	4	2	0		2	2.5
1977	6	8	45	390	5	5		12	13.4
1978	62	394	517	451	33	60	87	80	129.4
1979	48	414	942	116	44	201	39	33	112.0
1980	258	382	13,602	541	269	118	1,826	177	598.4
1981	36	1,011	5,350	2,398	34	838	56	48	278.0
1982		7,804	6,038	8,486	523	5,899	6,402	1,403	3,784.4

a Yearlings in spring, young-of-year in fall; both arbitrarily include fish ≤ 139 mm, 1967-79 and ≤ 119 mm, 1980-82.

[b]Transects varied from 7 to 12 lo-minute tows along the contour; catches at several depths not sampled in some years were estimated from those adjacent to simulate equal sampling effort in all years at a given station.

c Spring sampling during 1967-72, fall sampling in later years; fall sampling entirely at stations if not specified.

d Geometric mean; yearlings included only in calculating the means of the year preceding the year of capture.

yield = production) but adjusted them for the effects of expected variations in recruitment. These yields were intended for use as reference points below which catch quotas might be set while allowing sufficient production for continuing expansion of the population. The procedures leading to the yield projections involved a number of steps.

First, theoretical equilibrium yields (per 1000 pounds of age-IV fall recruits) approximating production were determined for the trawl and gillnet models by varying fishing mortality (F) within each age interval and holding natural mortality constant at 0.53 and 0.21 over all intervals in the respective models (Fig. 8). *F* in age interval IV-V was varied from 0.05 to 0.50 in

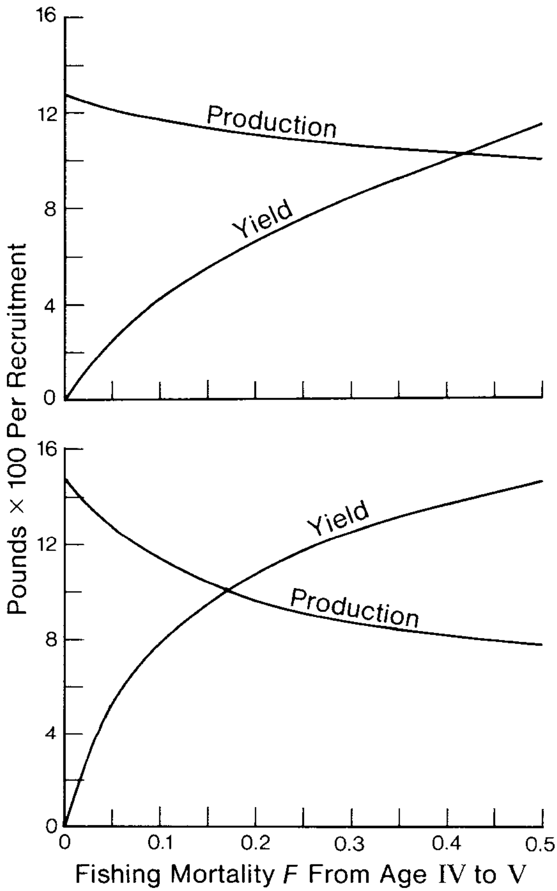

Fig. 8. Theoretical production and (equilibrium) yield per 1,000 pounds of bloaters recruited at age IV in fall combined with that from partial recruitment at ages II and III, under different fishing mortality regimes identified by the component of each in age interval IV-V: trawl models (upper panel), graded-mesh gillnet (lower).

increments of 0.05 and 0.10; corresponding, but differing, *F* values in each lower and higher age interval were then incremented proportionately. Equilibrium yields were also computed and added to the above for bloaters only partly recruited by ages II and III in fall; these computations were made from averages of the standing stocks in the 11 statistical districts in fall 1973, corrected for variations in year-class strength with ratios of young-of-the-year abundance (fall trawl surveys) relative to young-of-the-year abundance of the 1969 year class, which was fully recruited by age IV in fall 1973.

The estimated pounds of fully recruited age-IV bloaters in each statistical district at the start of the baseline period (1973-74) in fall 1973 were then used to expand from the above relative theoretical equilibrium yields to district and lakewide yields. The latter were substituted in the following formula to project yields in balance with production in fall 1978-79:

$$\frac{Y'}{Y} = \frac{T'}{\bar{T}}$$

where Y' = the reference equilibrium yield in pounds, per recruitment equal to the fishable biomass of age-IV bloaters (1969 year class) present in fall 1973, Y = projected yield from fall to fall in 1978-79 (or other annual period when specified), *T'* = relative year class strength as young-of-the-year (i.e., mean trawl CPE) of the reference year class (i.e., 1969) in lakewide fall surveys, and T = weighted average of the relative year class strengths as young-of-the-year of the year classes that would be represented (e.g., 1969-76) in the 12-month period for which the yield was being projected. To adjust the projected yield for effects of changes in strength of these contributing year-classes, we weighted values of $\bar{T}$ according to the relative contribution that each would make to the yield under specified equilibrium conditions (Table 15). (Because of large variances in the trawl catches of young-of-the-year bloaters, the geometric mean of the CPEs for the young from eight index stations throughout the lake was held to be a more accurate measure of relative year class strength than the arithmetic mean.)

By executing these steps in sequence, we projected theoretical yields from fall to fall in 1978-79 from the lakewide fishable stock of bloaters in age intervals II-III through VIII-IX of 3.59 and 3.72 million pounds in the round, according to the respective graded-mesh-gillnet and trawl models (Table 16). The average of the two estimates (3.66 million pounds) is equal to a conservative 19% of the average fall 1978 fishable biomass (19.2 million pounds), which we have since projected with biomasses of 1974-77 by sequentially multiplying each fully recruited age component of the standing stock by its survival rate, beginning with the previously estimated average standing stocks of fall 1973 (Table 17). (Before making these projections, the biomasses of age IV bloaters and those in each younger partly available age group in a given year were estimated as the ratios of their CPEs as young-of-the-year to the CPEs as young-of-the-year of fish of the same ages present in fall 1973, times the latter's estimated fall 1973 biomasses.) The slightly larger of the above yields (i.e., that

TABLE 15. Indices of mean annual abundance in fall trawl surveys of young-of-the-year bloaters of the 1969-76 year classes, weighted with yield factors based on respective trawl and gillnet models, and used to project theoretical commercial yields from those year classes during November 1978-October 1979.

Age interval 1978-79	Yield weighting Factor		Year class	YOY abundance index[a]
	Trawl	Gillnet		
II-III	0.241	0.136	1976	2.5
III-IV	0.905	0.511	1975	6.1
IV-V	1.000	0.624	1974	13.4
V-VI	0.874	1.000	1973	12.5
VI-VII	0.306	0.819	1972	3.3
VII-VIII	0.088	0.661	1971	9.3
VIII-IX	0.017	0.394	1970	21.2
IX-X	0.003	0.190	1969[b]	19.1
Mean (trawl)	-	-		9.5’
Mean (gillnet)	-	-	-	10.4d

ªGeometric mean of number per trawl transect at eight sampling stations.
b Pivotal year class in projecting the 1978–79 yield.
c Weighted with equilibrium yield factors, based on pounds, from the trawl model, where M = 0.54 and F = 0.40 at IV-V.
d Weighted with equilibrium yield factors, based on pounds, from the graded-mesh gillnet model, where M = 0.21 and F = 0.15 at IV-V.

TABLE 16. Theoretical yields of bloaters” to potential commercial fisheries with small-mesh gillnets in statistical districts of Michigan (MM), Wisconsin (WM) and Illinois waters of Lake Michigan, projected for November 1978-October 1979 on the basis of trawl and graded-mesh gillnet models.

District	Trawl model		Gillnet model	
	Round[b]	Dressed	Round[b]	Dressed
MM2	0.16	0.13	0.15	0.13
MM3	0.35	0.30	0.34	0.29
MM5	0.10	0.09	0.10	0.08
MM6	0.30	0.25	0.29	0.24
MM7	0.72	0.60	0.69	0.58
MM8	0.50	0.42	0.48	0.40
Subtotal	2.13	1.79	2.05	1.72
WM3	0.12	0.10	0.11	0.10
WM4	0.09	0.08	0.09	0.08
WM5	0.58	0.48	0.56	0.47
WM6	0.21	0.18	0.21	0.17
Subtotal	1.00	0.84	0.97	0.82
Ill.	0.59	0.49	0.57	0.48
Districts combined	3.72	3.12	3.59	3.02

a Fish that were in age groups II through X in fall 1978.
b Dressed weight x 1.19 (Wisconsin Department of Natural Resources, unpublished data).

TABLE 17. Fishable stocks of Lake Michigan' bloaters projected sequentially through fall 1978 by year class from fall 1973 estimates, using young-of-the-year trawl indices to generate recruits, and survival rates based on trawl and (hypothetical) graded-mesh gillnet samples: data are millions of fish and corresponding pounds.

	Trawl		Gillnet		Mean	
Year	Number	Weight	Number	Weight	Number	Weight
1973[b]	72.6	29.2	47.6	20.2	60.1	24.7
1974	47.5	20.8	38.7	17.8	43.1	19.3
1975	44.7	18.3	35.6	16.2	40.2	17.2
1976	56.4	22.0	41.9	20.4	49.2	21.2
1977	51.3	22.1	43.4	22.3	47.4	22.2
1978	35.8	16.9	37.0	21.4	36.4	19.2

a Lake proper waters of the states of Michigan, Wisconsin, and Illinois combined.

b Commercial catch divided by exploitation rate, after estimating round weight as reported (dressed) weight × 1.19.

of the trawl model) included, for example, 2.13 million pounds for Michigan, 1.00 for Wisconsin, and 0.59 for Illinois. (Yields projected separately for the range of fully recruited age intervals [IV-V and higher] were equal to only 60 and 32% of those given above for all intervals, according to the respective gillnet and trawl models; effects on biomass accumulation by the older fish having the higher natural mortality rate derived from trawl data are reflected in the smaller of the two partial yields.)

The projection of these yields from the 1973-74 baseline on the basis of young-of-the-year indices and the weighting technique described earlier implied a constant fishing rate from year to year when, in fact, fishing intensity dropped and was nil in some areas during part of the 1970s. Yields subsequently computed for 1978-79 by the alternative method of multiplying the sequentially projected biomasses (at each age) of fall 1978 by exploitation rates corresponding to the specified equilibrium level of fishing were less conservative (i.e., averaged 29% of the standing stock). The validity of each of these methods was highly dependent on the accuracy of the assumption of a constant ratio between relative abundance of young-of-the-year and of later recruits from the same year classes in the 1960s and 1970s, as well as on the accuracy of the abundance indices themselves. When projecting future fishable stocks and yields, allowances must be made for effects on the ratios of expected increases in prerecruit mortality as the large year classes produced since the late 1970s approach carrying capacity. (Therefore a wider range of abundance indices resulting from the recent upsurge in bloater abundance are now being assembled to determine the mathematical form of any relations among young-of-the-year, yearlings, and recruits.

For final comparison, potential yields from fall 1978 to fall 1979 were computed with the formula $Y \simeq \frac{1}{2} MB_v$, which approximates a relation observed for a number of marine stocks, and where B_v is the unfished population biomass

(Gulland 1971). Substitution in that formula of the mean lakewide fishable biomass sequentially projected to fall 1978 (Table 17), and the mean of the two natural mortality rates from the present study gave a potential mean yield of 3.4 million pounds, which is close to the mean value of 3.66 obtained above.

SUBSEQUENT STATE ACTIONS TOWARD QUOTA MANAGEMENT

In its final report to the states through the Lake Michigan Committee, the Chub Technical Committee advised that reservation of ½ of the 1978-1979 average projected yield of 3.66 million pounds for population increase, followed by periodic adjustments based on performance, constituted a reasonable management approach. However, subsequent state actions in lifting the ban on fishing in some waters and establishing total allowable catches (TAC) reflected views ranging from liberal to conservative, vis a vis how much the stocks had improved.

In 1979 Wisconsin established a then very liberal TAC of 1 million pounds (dressed weight) for its chub fishery south of Kewaunee, requiring that no more than ⅓ be harvested within each successive 3-month interval from 1 April to 31 December (Fig. 2). The TAC, which was increased each year, reached 2 million pounds in 1982, including 250,000 pounds for waters north of Kewaunee beginning in 1981. Each year, 100,000 pounds of the Wisconsin chub TAC were reserved for assessment with graded-mesh gillnets fished for the State by some of the commercial operators.

Illinois followed suit in 1979, by setting a 250,000 pound TAC for chubs and yellow perch (Perca flavescens) in the aggregate, to be taken from April of one year through March of the next. If perch were not harvested in a given license year, which never happened, the chub TAC would have amounted to about ½ of the 1979 yield projected for Illinois waters by the Technical Committee. In 1982 Illinois increased its aggregate TAC to 350,000 pounds.

Michigan viewed the changing status of the bloater population more cautiously, and, in addition, was faced with high dieldrin concentrations in bloaters from its southern waters and the emergence of an Indian commercial fishery in waters ceded by the Treaty of 1836. Through 1982 state regulated commercial fishing for bloaters was therefore not expanded beyond the nominal assessment level established in the mid-1970s, although the Tribal fishery swelled total landings to 446,000 pounds in 1981 (Tripartite Technical Working Group 1982).

CHANGING STATUS OF THE BLOATER POPULATION

The biomass of age-1 and older bloaters, recently estimated as the sum of the products of trawl catch per unit area and total areas within geographical strata, increased almost exponentially in Lake Michigan between 1977 (4.4

million pounds) and 1981 (129.5 million pounds). The biomass available to bottom trawls in 1982 was about at the level recorded in 1963-65 (138.8 million pounds), before the severe decline that led to closure of the fishery in 1976 (Table 18). The continuing recovery has been sustained by a nearly uninterrupted annual increase in the production of young-of-the-year bloaters, which in 1982 exhibited by far the highest trawl CPE recorded for that age group in the 10 years (1973-82) that the fall surveys had been conducted lakewide. The above trawl-based estimates of age-1 and older bloaters are conservative values that could be expanded if we knew the proportions of bloaters in the water column that are intercepted and retained by the standard 39-foot (headrope) trawl, with a maximum vertical opening of only 7.9 feet (Hatch et al. 1981).

Considering this sampling bias, the 20.7 million pounds of bloaters estimated for fall 1973 agrees reasonably well with the mean value of 24.7 million pounds obtained indirectly in this study as the summation of commercial landings during the reference period divided by age-specific exploitation rates (Table 17). Despite the agreement, estimates of bloaters available to the standard trawl in the mid- 1970s depict a more severe decline in the population than do the corresponding estimates that were made by sequential projection (Table 17) or that is inferred from the annual changes in CPEs of commercial gillnets (Table

TABLE 18. Estimated fall biomass” of “adult” (≥ age I) and young-of-the-year bloaters available to bottom trawl? in Lake Michigan, based on stratified, systematic sampling lakewide in 1973-82: the mean biomass based on multi-season sampling with a larger trawl’ in 1963-65 is shown for comparison.

	Millions of pounds		
Year	Adult	YOY	Combined
1963-65	138.8	-	-
1973	20.7[d]	0.1	20.8
1974	6.3	<0.1	6.3
1975	4.7	<0.1	4.7
1976	3.9	<0.1	3.9
1977	4.4	0.2	4.6
1978	13.0	1.2	14.2
1979	31.5	1.1	32.6
1980	82.6	3.8	86.4
1981	129.5	3.8	133.3
1982	129.4	21.0	150.4

a Minimum estimates uncorrected for avoidance of or escapement from the trawl.

b Semiballoon with 39-foot headrope, 5 l-foot footrope, and cod end of ½-inch mesh, extension measure (Wells 1968, Hatch et al. 1981).

c Gulf of Mexico type with 52-foot headrope and cod end of l-inch mesh, extension measure (Reigle 1969a).

‘Brown (1974) made a preliminary estimate for 1973 of 15 million pounds of adults.

13). At the start of the period for which yields were projected in our study (fall 1978-79), biomasses estimated by these independent methods were again in closer agreement.

The overall biomass and declining growth among individual fish of the highly rejuvenated bloater population suggest that the population is now close to carrying capacity-an elusive attribute that is difficult to determine because of major changes over several decades in species composition of the fish community. Among these changes are the near disappearance of other species of deepwater ciscoes, loss of native lake trout that preyed on ciscoes, establishment of smelt and alewife populations, and buildups since 1964-65 of sizable hatchery-sustained populations of lake, rainbow *(Salmo gairdneri),* and brown *(Salmo trutta)* trout and coho *(Oncorhynchus kisutch)* and chinook *(Oncorhynchus tshawytscha)* salmon. Because there is no evidence that these salmonines are preying on bloaters in proportion to relative abundance of bloaters in the Lake, selective predation by salmonines together with abiotic environmental changes may be favoring bloaters and even smelt, which are now more abundant than in the mid-1970s, over alewives which are less abundant.

ACKNOWLEDGMENTS

Robert A. Koch, Indiana Department of Natural Resources, and Harry Wight, Illinois Department of Conservation, who with the authors composed the Lake Michigan Chub Technical Committee, contributed through discussions of that committee to the evolution of this paper. Paul Schultz and Mark Holey of Wisconsin and Bruce Muench of Illinois also worked closely with the Chub Committee in support of the joint effort. George Boyce of GLFL made all of the age determinations by the scale method, and LaRue Wells of GLFL provided data on abundance of larval bloaters in southeastern Lake Michigan. Paul Haack and Anthony Frank of GLFL provided statistical counsel and, together with Catherine Kopas of GLFL, support in computer programming. N. Robert Payne, Ontario Ministry of Natural Resources, and Stanford H. Smith reviewed the manuscript.

REFERENCES

BROWN, E. H. JR.

1968. Population characteristics and physical condition of alewives, *Alosa pseudoharengus,* in a massive dieoff in Lake Michigan, 1967. Great Lakes Fishery Commission, Technical Report No. 13, 20 p.

1970. Extreme female predominance in the bloater (Coregonus hoyi) of Lake Michigan in the 1960's, p. 501-514. In C. C. Lindsey and C. S. Woods [ed.] Biology of Coregonid Fishes. Univ. Manitoba Press, Winnipeg, Man.

1974. Estimates of biomass of principal fish species in the Great Lakes, p. 21-26. In Fisheries Res. Report No. 1813 (May 23), Fisheries Div., Mich. Dept. Nat. Res.

EMERY, LEE and E. H. BROWN, JR.
1978. Fecundity of the bloater (Coregonus hoyi) in Lake Michigan. Trans. Amer. Fish. Soc. 107(6): 785-789.
GEORGE, C. J.
1977. The implication of neuroendocrine mechanisms in the regulation of population character. Fisheries 2(3): 14-19, 30.
GULLAND, J. A.
1971. Science and fishery management. J. Cons. Int. Explor. Mer. 33(3): 471-477.
HAMLEY, J. M. and H. A. REGIER.
1973. Direct estimates of gillnet selectivity to Walleye *(Stizostedion vitreum vitreum).* J. Fish. Res. Bd. Canada 30:817-830.
HATCH, R. W., P. M. HAACK, and E. H. BROWN, JR.
1981. Estimation of alewife biomass in Lake Michigan, 1967-1978. Trans. Amer. Fish. Soc. 110:575-584.
HILE, R. and H. J. BUETTNER.
19.55. Commercial fishery for chubs (ciscoes) in Lake Michigan through 1953. U.S. Fish and Wildlife Service Special Scientific Report-Fisheries No. 163, 49 p.
HILE, R.
1962. Collection and analysis of commercial fishery statistics in the Great Lakes. Great Lakes Fishery Commission Technical Report No. 5, 31 p.
LAKE MICHIGAN CHUB TECHNICAL COMMITTEE.
1979. Final report. Great Lakes Fishery Commission, Lake Michigan Committee, Minutes of 1979 annual meeting, Michigan City, Appendix IV. 5 p. + appendices.
PATRIARCHE, M. H.
1968. Production and theoretical equilibrium yields for the bluegill *(Lepomis macrochirus)* in two Michigan lakes. Trans. Amer. Fish. Soc. 97(3):242-251.
1977. Biological basis for management of lake whitefish in the Michigan waters of Northern Lake Michigan. Trans. Amer. Fish. Soc. 106(4):295-308.
POFF, R.
1974. Status of Chubs in Lake Michigan: Chub Technical Committee. Great Lakes Fishery Commission, Minutes of 1974 Interim Meeting, Ann Arbor, Appendix XII. 6 p.
POFF, R.
1976. Interim Report Chub Technical Committee Lake Michigan. Great Lakes Fishery Commission, Minutes of 1976 Interim Meeting, Ann Arbor, Appendix XVIII. 2 p.
REIGLE, N. J.
1969a. Bottom trawl explorations in southern Lake Michigan, 1962-65. U.S. Dept. Interior, Bur. Commer. Fish. Circ. 301: iii + 35 p.
1969c. Bottom trawl explorations in northern Lake Michigan, 1963-65. U S Dept. Interior, Bur. Commer. Fish. Circ. 318: iii + 21 p.
RICKER, W. E.
1975. Computation and interpretation of biological statistics of fish populations. Dept. of the Environment, Fisheries and Marine Service, Ottawa.
SMITH, S. H.
1964. Status of the deepwater cisco population of Lake Michigan. Trans. Amer. Fish. Soc. 93(2): 155-163.

1968. Species succession and fishery exploitation in the Great Lakes. J. Fish. Res. Bd. Canada 25: 667-693.
1970. Species interactions of the alewife in the Great Lakes. Trans. Amer. Fish. Soc. 99: 754-765.
1972. Factors of ecologic succession in oligotropic fish communities of the Laurentian Great Lakes. J. Fish. Res. Bd. Canada 29:717-730.

TRIPARTITE TECHNICAL WORKING GROUP.
1982. Status of the fishery resource-1982. U.S. Department of Interior, State of Michigan, and Community of Chippewa-Ottawa Indians, Mimeo Report 3 1 p. + Appendices.

VAN OOSTEN, J.
1935. Logically justified deductions concerning the Great Lakes fisheries exploded by scientific research. Trans. Amer. Fish. Soc. 65: 71-75.

WELLS, L.
1966. Seasonal and depth distribution of larval bloaters (Coregonus *hoyi)* in southeastern Lake Michigan, Trans. Amer. Fish. Soc. 95: 388-396.
1968. Seasonal depth distribution of fish in southeastern Lake Michigan. U.S. Fish. Wildlife Serv. Fish. Bull. 67: I-15.

WELLS, L. and E. H. BROWN, JR.
1974. Status of major species in Lake Michigan. Great Lakes Fishery Commission, Lake Michigan Committee, Minutes of 1974 Annual Meeting, Milwaukee, Appendix III [a]. 12 p.

GREAT LAKES FISHERY COMMISSION

TECHNICAL REPORT SERIES

No. 1. Use of 3-trifluoromethyl-4-nitrophenol as a selective sea lamprey larvicide, *by Vernon C. Applegate, John H. Howell, James W. Moffett, B. G. H. Johnson,* and *Manning A. Smith.* May 1961. 35 pp.

No. 2. Fishery statistical districts of the *Great* Lakes, *by Stanford H. Smith, Howard J. Buettner,* and *Ralph Hile.* September 1961. 24 pp.

No. 3. Commercial fish production in the Great Lakes 1867-1977, *by Norman S. Baldwin, Robert W. Saalfeld, Margaret A. Ross,* and *Howard J. Buettner.* September 1979. 187 pp. (Supersedes 1962 edition and 1970 supplement.)

No. 4. Estimation of the brook and sea lamprey ammocete populations of three streams, *by Bernard R. Smith* and *Alberton L. McLain.* September 1962. pages 1-18.
A photoelectric amplifier as a dye detector, *by Wesley J. Ebel.* September 1962. pages 19-26.

No. 5. Collection and analysis of commercial fishery statistics in the Great Lakes, *by Ralph Hile.* December 1962. 31 pp.

No. 6. Limnological survey of Lake Erie 1959 and 1960, *by Alfred M. Beeton.* November 1963. 32 PP.

No. 7. The use of alkalinity and conductivity measurements to estimate concentrations of 3-trifluoromethyl-4-nitrophenol required for treating lamprey streams, *by Richard K. Kanayama.* November 1963. 10 pp.

No. 8. Synergism of 5,2'-dichloro-4'-nitro-salicylanilide and 3-trifluoromethyl-4-nitrophenol in a selective lamprey larvicide, *by John H. Howell, Everett L. King, Jr., Allen J. Smith,* and *Lee H. Hanson.* May 1964. 21 pp.

No. 9. Detection and measurement of organic lampricide residues, *by Stacy L. Daniels, Lloyd L. Kempe, Thomas J. Billy,* and *Alfred M. Beeton.* 1965. 18. pp.

No. 10. Experimental control of sea lampreys with electricity on the south shore of Lake Superior, 1953-60, *by Alberton L. McLain, Bernard R. Smith,* and *Harry H. Moore.* 1965. 48 pp.

No. 11. The relation between molecular structure and biological activity among mononitrophenols containing halogens, *by Vernon C. Applegate, B. G. H. Johnson,* and *Manning A. Smith.* December 1966. pages l-19.
Substituted nitrosalicylanilides: A new class of selectively toxic sea lamprey larvicides, *by Roland J. Starkey* and *John H. Howell,* December 1966. pages 21-29.

No. 12. Physical limnology of Saginaw Bay, Lake Huron, *by Alfred M. Beeton, Stanford H. Smith,* and *Frank F. Hooper.* September 1967. 56 pp.

No. 13. Population characteristics and physical condition of alewives, *Alosa pseudoharengus,* in a massive dieoff in Lake Michigan, 1967, *by Edward H. Brown, Jr.* December 1968. 13 pp.

No. 14. Limnological survey of Lake Ontario, 1964 (five papers), *by Herbert E. Allen, Jerry F. Reinwand, Roann E. Ogawa, Jar1 K. Hiltunen,* and *LaRue Wells.* April 1969. 59 pp.

No. 15. The ecology and management of the walleye in western Lake Erie, *by Henry A. Regier, Vernon C. Applegate* and *Richard A. Ryder,* in collaboration with *Jerry V. Manz, Robert G. Ferguson, Harry D. Van Meter,* and *David R. Wolfert.* May 1969. 101 pp.

No. 16. Biology of larval sea lampreys *(Petromyzon marinus)* of the 1960 year class, isolated in the Big Garlic River, Michigan, 1960, *by Patrick J. Manion* and *Alberton L. McLain.* October 1971. 35 pp.

No. 17. New parasite records for Lake Erie fish, *by Alex 0. Dechtiar.* April 1972. 20 pp.

No. 18. Microbial degradation of the lamprey larvicide 3-trifluoromethyl-4-nitrophenol in sediment-water systems, *by Lloyd L. Kempe.* January 1973. 16 pp.

No. 19. Lake Superior-A case history of the lake and its fisheries, *by A. H. Lawrie* and *Jerold F. Rahrer.* January 1973. 69 pp.

No. 20. Lake Michigan-Man's effects on native fish stocks and other biota, *by LaRue Wells* and *Alberton L. McLain.* January 1973. 55 pp.

No. 22. Effects of exploitation, environmental changes, and new species on the fish habitats and resources of Lake Erie, by W. L. *Hartman.* April 1973. 43 pp.

No. 23. A review of the changes in the fish species composition of Lake Ontario, by *W. J.* Christie. January 1973. 65 pp.

No. 24. Lake Opeongo-The ecology of the fish community and of man's effects on it, *by N. V. Martin* and *F. E. J. Fry.* March 1973. 34 pp.

No. 25. Some impacts of man on Kootenay Lake and its salmonoids, *by T. G. Northcote.* April *1973. 45* pp.

No. 26. Control of the sea lamprey *(Petromyzon* marinus) in Lake Superior, 1953-70, *by Bernard R. Smith, J. James Tibbles,* and *B. G. H. Johnson.* March 1974. 60 pp.

No. 27. Movement and recapture of parasitic-phase sea lampreys (Petromyzon marinus) tagged in the St. Marys River and Lakes Huron and Michigan, 1963-67, *by Harry H. Moore, Frederick H. Dahl,* and *Aarne K. Lamsa.* July 1974. 19 pp.

No. 28. Changes in the lake trout population of southern Lake Superior in relation to the fishery, the sea lamprey, and stocking, 1950–70, *by Richard L. Pycha* and *George R. King.* July 1975. 34 pp.

No. 29. Chemosterilization of the sea lamprey *(Petromyzon marinus), by Lee H. Hanson* and *Patrick J. Manion. July* 1978. 15 pp.

No. 30. Biology of larval and metamorphosing sea lampreys *(Petromyzon marinus)* of the 1960 year class in the Big Garlic River, Michigan, Part II, 1966-72, *by Patrick J.* Manion and *Bernard R. Smith.* October 1978. 35 pp.

No. 31. Walleye stocks in the Great Lakes, 1800-1975; fluctuations and possible causes, *by J. C. Schneider* and *J. H. Leach.* February 1979. 51 pp.

No. 32. Modeling the western Lake Erie walleye population: a feasibility study, *by B. J. Shuter, J. F. Koonce,* and *H. A. Regier,* April 1979. 40 pp.

No. 33. Distribution and ecology of lampreys in the Lower Peninsula of Michigan, 1957-75, *by Robert H. Morman.* April 1979. 59 pp.

No. 34. Effects of granular 2', 5-dichloro-4'-nitrosalicylanilide (Bayer 73) on benthic macroinvertebrates in a lake environment, *by Philip A. Gilderhus.* May 1979. pages 1-5.
Efficacy of antimycin for control of larval sea lampreys *(Petromyzon marinus)* in lentic habitats, *by Philip A. Gilderhus.* May 1979. pages 617.

No. 35. Variations in growth, age at transformation, and sex ratio of sea lampreys reestablished in chemically treated tributaries of the upper Great Lakes, *by Harold A. Purvis.* May 1979. *36* PP.

No. 36. Annotated list of the fishes of the Lake Ontario watershed, *by E. J. Crossman* and *Harry D. Van Meter.* December 1979. 25 pp.

No. 37. Rehabilitating Great Lakes ecosystems, *edited by George R. Francis, John J. Magnuson, Henry A. Regier* and *Daniel R. Talhelm.* December 1979. 99 pp.

No. 38. Green Bay in the future-a rehabilitative prospectus, edited *by* Hallett *J. Harris, Daniel R. Talhelm, John J. Magnuson,* and *Anne M. Forbes.* September 1982. 59 pp.

No. 39. Minimum size limits for yellow perch *(Perca flavescens)* in western Lake Erie, *by Wilbur L. Hartman, Stephen J. Nepszy,* and *Russell L. Scholl.* March 1980. 32 pp.

No. 40. Strategies for rehabilitation of lake trout in the Great Lakes: proceedings of a conference on lake trout research, August 1983, *edited by Randy L. Eshenroder, Thomas P. Poe,* and *Charles H. Olver.* August 1984. 63 pp.

No. 41. Overfishing or pollution? case history of a controversy on the Great Lakes, *by Frank N. Egerton.* January 198.5. 28 pp.

No. 42. Movement and capture of sea lampreys (Petromyzon *marinus)* marked in northern Lake Huron, 1981-82, *by John W. Heinrich, William C. Anderson,* and *Susan D. Oja.* February 1985. pages 1-14.
Response of spawning-phase sea lampreys *(Petromyzon marinus)* to a lighted trap, *by Harold A. Purvis, Clarence L. Chudy, Everett L. King, Jr.* and *Verdel K. Dawson.* February 1985. pages 15-25.

No. 43. A prospectus for the management of the Long Point ecosystem, *by George R. Francis,*