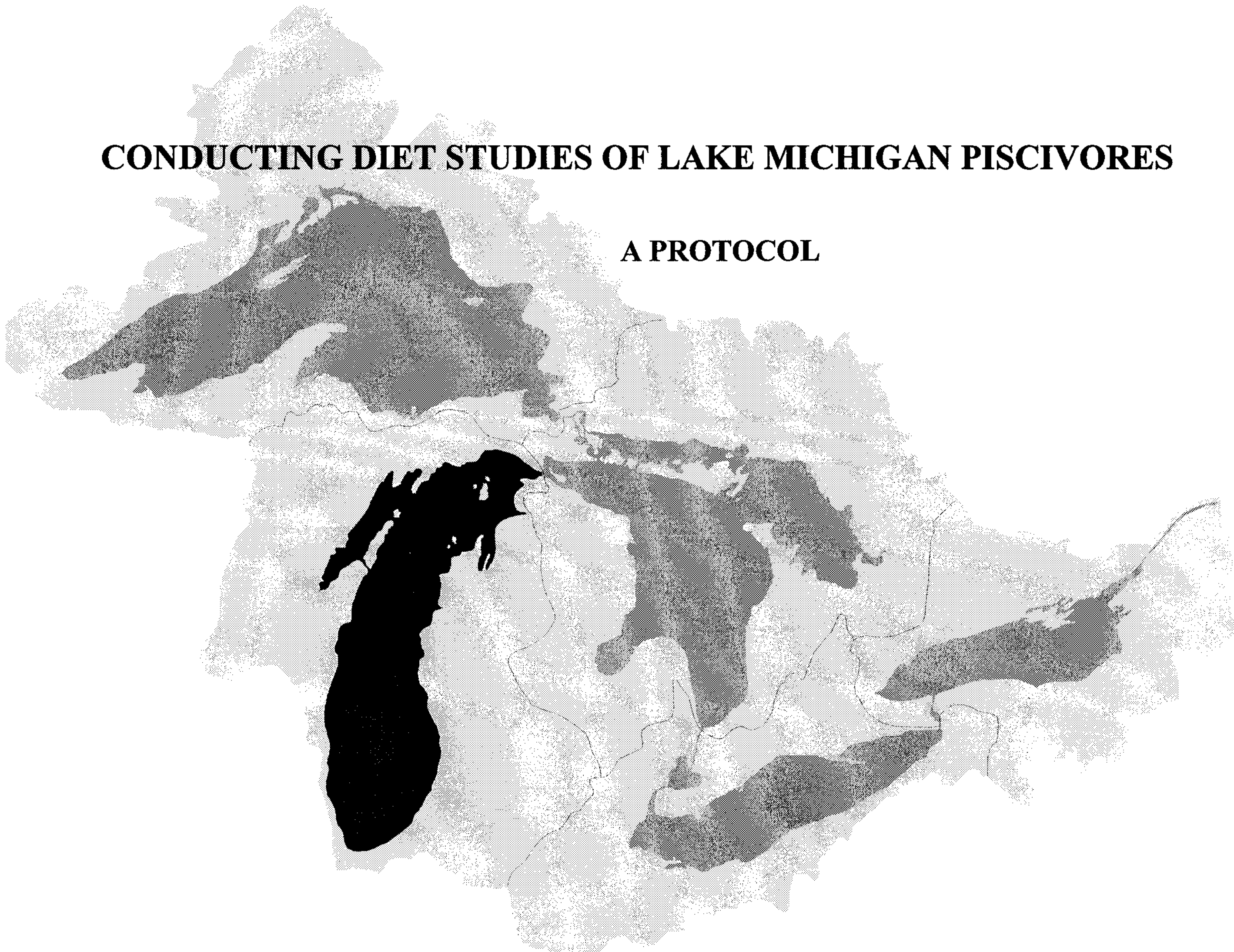
CONDUCTING DIET STUDIES OF LAKE MICHIGAN PISCIVORES

A PROTOCOL



prepared by

Robert F. Elliott
Committee Chairperson
US Fish and Wildlife Service

Paul J. Peeters
Wisconsin Department of Natural Resources

Richard J. Hess
Illinois Department of Natural Resources

Mark P. Ebener
Chippewa-Ottawa Treaty Fishery Management Authority

James T. Francis
Indiana Department of Natural Resources

Ronald W. Rybicki
Michigan Department of Natural Resources

Gary W. Eck
National Biological Service

Philip J. Schneeberger
Michigan Department of Natural Resources

Charles P. Madenjian
National Biological Service

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Lake Michigan Technical Committee

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Conducting Diet Studies of Lake Michigan Piscivores - A Protocol

Robert F. Elliott,[1] Paul J. Peeters, Mark P. Ebener, Ronald W. Rybicki, Philip J. Schneeberger, Richard J. Hess, James T. Francis, Gary W. Eck, and Charles P. Madenjian

[1]*U.S. Fish and Wildlife Service, Green Bay Fishery Resources Office*
1015 Challenger Court, Green Bay, Wisconsin 54311

ABSTRACT

Across lake and between year analysis of diet of the key predator fish is necessary to evaluate predator-prey dynamics in the Great Lakes. A lack of consistency in timing, methods, data analysis, and reporting of results has prevented meaningful comparisons between most diet studies of Lake Michigan piscivores. To address this problem, a protocol for conducting diet studies was developed by a sub-group of the Lake Michigan Technical Committee. The protocol describes the minimum data and reporting requirements necessary for diet studies to contribute fully to the lakewide data needs for Lake Michigan. Summary statistics used to describe the diet will include percent diet composition by weight for each major prey type, length frequencies of each fish species consumed, and mean total wet weight of prey per stomach (as an index of ration). The data will be stratified by predator size class, by seven collection regions, and by eight collection seasons. Results will be combined to produce lakewide reports of diet with an emphasis on identifying trends. Details of how data should be collected, stratified, analyzed, and reported are discussed, and recommendations for future work outlined.

INTRODUCTION AND BACKGROUND

Over the last 50 years there have been dramatic changes in the abundance and species composition of predator and forage fish assemblages of Lake Michigan. The timing, magnitude, and probable cause(s) of these changes has been well documented in the scientific literature. The Lake Michigan Fish Community Objectives present a good review of these changes (Eshenroder et al. 1995). Diet studies of the major piscivores have been an important information base used by fishery biologists to interpret predator-prey dynamics in the Great Lakes. However, the magnitude of forage fluxes, as determined from forage assessments, has not always been reflected in predator diets. This has lead many investigators to infer some degree of prey selectivity or preference by predators (Stewart and Ibarra 1991) and/or to question or qualify the representativeness of forage assessments (Brandt et. al. 1991; Elliott 1993).

Since predator stocks in most of the Great Lakes are greatly influenced by hatchery production, exceeding the carrying capacity of these lakes has been of significant concern and the emphasis of much research and debate. Several models have been developed that predict forage demand by the major predators and forecast population flux by the major species in the system (Stewart et al. 1983; Kitchell and Hewett 1987; Stewart and Ibarra 1991; Jones et al. 1993; Rand et al. 1993). Diet data have been an important input to these models. Forage characteristics, composition, and abundance also have commonly been topics discussed when dealing with the persistent or reoccurring problems of poor survival, disease, mortality, and reproductive failure with many of Lake Michigan's key fisheries. A clearer understanding of the predator-prey dynamics in Lake Michigan would certainly be beneficial to our understanding of these problems.

Many diet studies of Great Lakes piscivores have been conducted and reported over the last decade (Van Oosten and Deason 1938; Wright 1968; Hagar 1984; Kogge 1985; Brandt 1986; Jude et al. 1987; McComish 1989; Diana 1990; Miller and Holey 1992; Connor et al.1993; Elliott 1993). Despite the apparent abundance of diet data produced by these studies, comparing the results and drawing lakewide or basin-wide conclusions has been difficult. Results and conclusions have often appeared to be conflicting. Different studies often have had different goals, have been narrow in scope, and rarely have been carried out over a long period of time in a consistent manner. There also has been a lack of coordination among different agencies and investigators conducting concurrent or back-to-back diet studies. The stratification of data for purposes of analysis and reporting rarely has been consistent and the forms of information reported often have differed.

Results from diet studies have traditionally been reported as percent composition, a statistic that has been based on frequency of occurrence, numbers of prey, actual prey weight (both wet and dry), or reconstructed weight. While each of these measures can be very useful in determining what was eaten, they yield descriptions of diet with very different characteristics and biases (Hyslop 1980; Bowan 1983; Elliott 1993). Further, the reporting of percent data alone without the addition of some consistent quantitative measure of the amount of prey consumed (ie., actual numbers or weight of prey as an index of ration) can be misleading. Some measure or index of ration is required in order to compare the spatial and temporal variation in the quantity of food consumed.

After reviewing the current status of several diet studies in progress on Lake Michigan, the need to standardize diet studies lakewide was identified by the Lake Michigan Technical Committee. An ad- hoc committee was assigned to develop a protocol for standardizing the collection, analysis, and reporting of diet studies on Lake Michigan. This document describes the recommendations of that group in the form of a protocol for conducting diet studies of Lake Michigan piscivores.

GOALS AND OBJECTIVES

The goal of the Lake Michigan Technical Committee is to standardize the collection, analysis, and reporting of diet data for Lake Michigan.

Specific objectives include:

1. Form a consensus of what information can realistically be gathered and reported that will meet the data needs of the scientific community.

2. Describe the methods that should be used to collect, analyze, and report diet data for Lake Michigan, so that:

   - the composition of predator diets will be reported in standard units that are comparable lakewide and over time.

   - diet will be quantified in a manner that provides a measure of the amount of prey consumed to be used as an index of ration that can be compared lakewide and over time.

   - diet data can be easily input into and validate lakewide models.

DIET STUDY PROTOCOL

The following discussion outlines what needs to be considered when conducting diet studies of the major predator fish in Lake Michigan. This should not be viewed as the most comprehensive discussion of conducting diet studies on the Great Lakes. Rather, this protocol describes the procedures for generating the minimum information needed to meet the objectives set forth by the Lake Michigan Technical Committee. What is described here is expected to be attainable. Additional information beyond that called for in this protocol is certainly encouraged.

There are several dangers in trying to produce comparable lakewide results of diet for fish in lakes as large as one of the Great Lakes. Lack of sufficient resources to comprehensively sample such a large system often leads to the application of results from one study to conditions beyond those which the data are capable of representing. Another danger is the combining of heterogeneous sets of data before analysis without appropriate weighting to account for the differences. To deal with these dangers and to prevent as much as possible the introduction of bias, several levels of stratification are outlined in this protocol. The rationale behind and specifics of each stratification are discussed in the text. Levels of stratification are also presented in several tables that can serve as quick references to the critical elements of this protocol. Attached as appendices are supporting materials that will aid in following this protocol, including prey identification figures, reconstruction formula, and tables that provide a format (with optional forms) for summarizing and submitting results of individual diet studies in a consistent manner. Electronic reporting of summarized results is encouraged and the format need not conform to the example provided here. Results submitted following this protocol can then be compiled into a lakewide status report of piscivore diets in Lake Michigan and distributed for use by the Great Lakes community.

Experimental Design:

Determining an appropriate sampling design is dependent on a clear understanding of the objectives for the diet study. The diet of Great Lakes piscivores can be quite variable over space and time (Stewart et al. 1981; McComish 1989; Elliott 1993). Lake dynamics that influence predator and prey distribution also should be expected to influence diet. Location, season, time of day, and depth of capture all have been associated with differences in diet (Elliott 1993; Rybicki and Clapp in review). Although logistically difficult, lakewide descriptions of diet necessitate sample collections gathered over a broad range of times and locations, and thus involve a considerable effort. Investigators must realize that samples of fish collected from one area at one time may not provide diet information typical for that species at other times and in other locations. However, a rigorous collection of diet data throughout a season at one location may function adequately as an annual index for trend analysis at that specific location.

Sampling Gear:

The goals of a specific study will dictate the preferred sampling gear. Any sampling method can be useful in providing an index of diet over time or across regions, as long as the mechanics of its use are kept uniform. A common sampling method used in a standard way throughout Lake Michigan would facilitate lakewide comparisons of diet. Angling and use of gill nets are presently widespread in all jurisdictional waters and have been consistently used to collect samples for diet studies. Other collection methods such as trawling, seining, or impoundment gear may also be appropriate for collecting samples for diet studies, but their uniform use is generally not common enough to permit lakewide spatial, temporal, and annual comparisons. Because of the lakewide application of this protocol, gill net surveys and collecting samples from angler creels will be the current standard. Gill net sets should be 24 hours or less in duration. Netted and angler caught fish need to be well iced after removal from the water and until stomachs are sampled.

Differences in gear selectivity suggest that diet data collected using different methods should only be combined after summarized data show results from the different methods to be similar. For example, percent composition of a predator species diet may be similar for both netted and angler-caught fish, but a measure of actual prey weight might differ significantly. This could be due to diurnal differences in the collection times (day for angling, night for gill nets), to differences in depths of water sampled (bottom for gill nets, suspended for angling), to the digestion that occurs while fish are held in the nets, or to a tendency for anglers to catch more actively feeding fish. For this protocol, initial calculations of summary statistics describing the diet of predator fish will be made separately for each collection method. Once all the data is brought together, results from different methods that do not differ then can be combined when producing lakewide reports.

Stratifying by Season and Region:

Statistical districts, described in detail by Smith et al. (1961), have been used for many years to divide the Great Lakes into regions for data summary. Months have been the most common delineation of time periods. While commercial, assessment, and creel surveys often use these conventions, diet studies reported for Lake Michigan have rarely divided location and time in this manner when documenting regional and seasonal differences. While diet in Lake Michigan can differ significantly over very small spatial and temporal scales (Elliott 1993), it is broad and consistent differences that are of greater interest for lakewide applications. Broadly defined regions such as northern or southern waters of eastern or western Lake Michigan and time periods such as spring, summer, and fall have typically been used to describe diet for large regions and over long time periods (Elliott 1993; Peeters 1993; Rybicki and Clapp in review). Time and space divisions recommended by this protocol attempt to afford compatibility with other lakewide assessments while recognizing logical basin divisions where differences in diet are likely to be important or significant. For this protocol, the lake will be divided into nine regions with division lines that generally align with statistical districts (**Figure 1, Table 1**). Time periods will be months during the growing season and groups of months during the colder seasons (**Table 1**).

A spatial division not explicitly covered by this protocol is the delineation of nearshore versus offshore habitats. While diet has been shown to differ depending on water depth or distance from shore (Rybicki and Clapp in review), the initial stratification for this protocol does not attempt to differentiate these habitats beyond what can be inferred from the regions outlined. A more detailed analysis of depth specific diet data is recognized as an additional need beyond the current confines of this protocol.

Stratifying by Predator Species and Predator Size:

Differences in diet between species can vary greatly. While differences may typically be significant between species such as lake trout and steelhead, they may be insignificant between other species such as young coho and steelhead. To facilitate use of the data

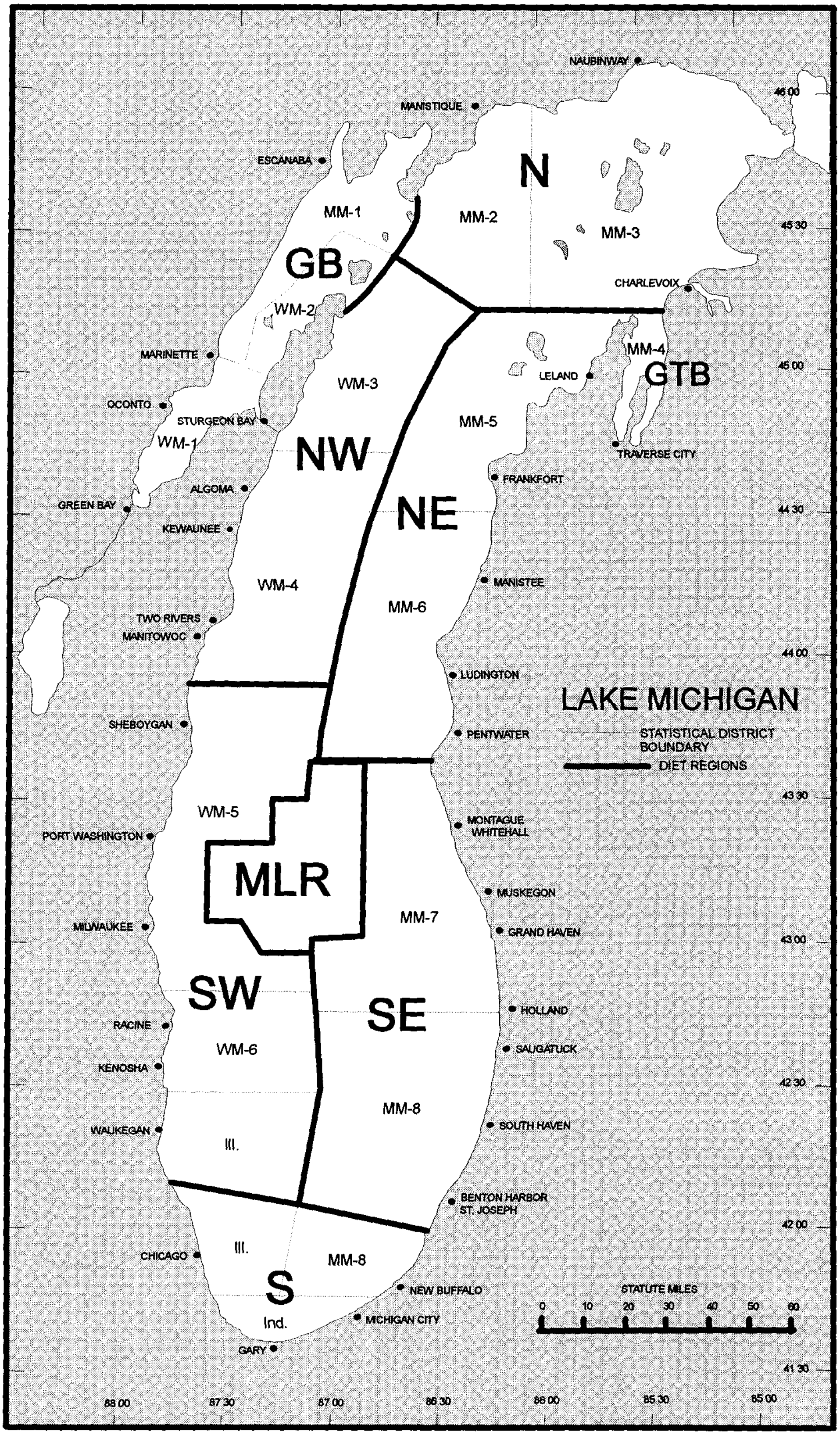

Figure 1. Region divisions for reporting diet data.

Table 1. Region and season stratification for reporting requirements.

REGIONS	Description
S = South	MM-8 south of 42°00'N (St. Joseph) Illinois waters south of 42°10'N (Waukegan) Indiana waters
SW = Southwest	WM-5 WM-6 Illinois waters north of 42°10'N (Evanston)
SE = Southeast	MM-7 MM-8 north of 42°00'N (New buffalo)
NW = Northwest	WM-3 WM-4
NE = Northeast	MM-5 MM-6
N = North (including Northern Refuge/Reef Complex)	MM-2 MM-3
MLR = Mid-lake Refuge / Reef complex	approx. 43°00'N to 43°30'N and 87°30'W to 86°45'W
GB = Green Bay	WM-1, WM-2, & MM-1 Wisconsin and Michigan waters of Green Bay including Big Bay and Little Bays de Noc
GTB = Grand Traverse Bay	MM-4 Grand Traverse Bay south of Grand Traverse Light

SEASONS
4 = March & April
5 = May
6 = June
7 = July
8 = August
9 = September
10 = October & November
1 = December, January & February

by model applications and to standardize reporting, diet should be analyzed separately for each species. The major species of interest for Lake Michigan are chinook salmon (*Oncorhynchus tshawaytscha*), coho salmon (*Oncorhynchus kisutch*), lake trout (*Salvelinus namaycush*), rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), burbot (*Lota lota*), walleye (*Stizostedion vitreum vitreum*), and yellow perch (*Perca flavescens*) (**Table 2**).

Differences in diet can also be attributed to predator age, size, or life stage. Although model inputs are often age or life stage specific, size has generally been considered a more important determinant of diet than age for Great Lakes fish. However, behavioral characteristics of different life stages can have an overriding influence on diet. For example, pre- and post-smolt juvenile salmon may be the same size but inhabit very different environments and have very different diets. Likewise, mature spawning adults may exhibit very different feeding habits from other non-spawning adults of the same size. In general, for the description of diet, each species needs to be stratified into biologically important life stages or size classes.

For this protocol, lake trout, burbot, and walleye which are relatively long lived and slow growing, will be divided into 200 mm size intervals. Yellow perch will be divided into 100 mm size intervals (**Table 2**). Because growth of these fish may vary regionally, it is expected that the typical age represented by each length interval may vary. Therefore, it is important to report the average and range of ages represented in each size group by region.

Salmon, rainbow trout, and brown trout, which are generally short lived and fast growing, will be divided into size classes typical of each major age class (lake age 0, 1, 2, and 3 and older) (**Table 2**). Because of

Table 2. Predator species size class stratification for reporting requirements.

SPECIES	SIZE GROUP	QUALIFYING DESCRIPTION
Lake Trout (LAT) Burbot (BBT) Walleye (WYE)	1 = < 200 mm (8") 2 = 200-399 mm (8-16") 3 = 400-599 mm (16-24") 4 = 600-799 mm (24-32") 5 = > 800 mm (32")	Range and average of ages and lengths (in mm) for each length interval
Chinook Salmon (CHS) Rainbow Trout (RBT) (Steelhead) Brown Trout (BNT)	representative of: 1 = lake age 1 2 = lake age 2 3 = lake age 3 and older	Range and average of lengths (in mm) for each size group
Coho Salmon (COS)	representative of: 1 = lake age 1 2 = lake age 2 and older	Range and average of lengths (in mm) for each group
Yellow Perch (YEP)	1 = < 100 mm (4") 2 = 100-199 mm (4-8") 3 = 200-299 mm (8-12") 4 = > 300 mm (12")	Range and average of ages and lengths (in mm) for each length interval

their rapid increase in size during a growing season, these separations may need to increase in size so that they represent the same cohort throughout a year. Length frequency analysis can be useful in determining appropriate size classes during a given period within a year but representative individuals should be aged to validate that the size group represents the average size of the desired age class. Elliott (1993) presents a method for determining size divisions for chinook salmon that account for the increasing size of each age class of fish observed during a season.

Sample Size and Collection Frequency:

How often to collect fish for diet analysis (a collection) and how many fish to sample (samples) during a collection depends on the variability observed in the collected data and on how representative the investigator feels that data is of the time period and area being described. Because of the spatial and temporal variability often observed in the diet of Great Lakes fish, a single collection (made at one location on one day), even when involving many fish, is unlikely to be representative of a longer time period or larger region. Based on results from previous studies, four collections made within a region per month with at least 10 fish sampled from each size class of each species per collection should produce an acceptable description of diet for that region and month. It is unlikely that agencies can afford the time and effort required to conduct annual comprehensive diet studies capable of producing a complete lakewide description of diet each year. Index sampling can be a viable alternative to producing all inclusive lakewide data. Collecting samples on an annual basis for a few predator groups at one location for selected months can be very useful in illustrating yearly changes in diet and maintaining trend data. However, this still requires a significant effort if there to be confidence in the representativeness of the data.

Data Collection:

Because of the numerous levels of stratification necessary to summarize and report diet data in an unbiased manner, several parameters that relate to the collection or analysis of each sample need to be recorded in the field and in the lab. Many of these data needs are standard procedures for most assessment work while others are specific to the collection and analysis of diet data. These data requirements are listed in **Table 3**.

Table 3. Data requirements. Items marked with an "**X**" are critical for meeting the objectives of this protocol. The other data needs are optional but will be needed for a more detailed analysis of diet data and would contribute to other lakewide data needs.

	DATA FIELD	**DESCRIPTION & SPECIFICS**
X	GEAR	-gear type and specifications -distinguish between assessment, sport, and commercial
X	DATE	-year, month, day (preferred order)
	TIME	-at least by 6 hr interval such as AM, PM, Day, Night
X	CAPTURE REGION	-see Table 1
	CAPTURE LOCATION	-statistical grid or nearest port or landmark
	CAPTURE DEPTHS	-may be a general range
	WATER TEMPERATURE	-may be a general range
X	PREDATOR SPECIES	-see Table 2
X	PREDATOR LENGTH	-total length, reported in mm (indicate dead or alive if possible)
	PREDATOR WEIGHT	-reported in grams
	PREDATOR SEX AND MATURITY	-maturity can affect feeding activity
	ABNORMALITIES	-examples include fin clips, lamprey scars, disease symptoms, physical impairments, etc. (anything that might affect feeding activity)
	CONDITION OF STOMACH	-full or empty, subjective fullness measure -indicate if appears regurgitated
X	PRESERVATION METHOD FOR STOMACH	-fresh, frozen, formalin etc.
X	TOTAL PREY WEIGHT PER PREDATOR	-actual wet weight
X	PREY CATEGORY	-see Table 4
X	PREY CATEGORY WEIGHT	-either actual weight or based on reconstructions from prey length
X	PREY ITEM LENGTH (prey fish only)	-total length in mm
	PREY CATEGORY COUNT	-a count of the number of individuals
	STATE OF PREY DIGESTION	-to indicate how recent feeding occurred

Analyzing Stomach Contents:

There are three basic steps to analyzing the stomach contents of Great Lakes predators: weighing, identifying, and measuring the contents. One of the most informative steps, yet least often done, is to weigh the entire stomach contents en masse. This measure of wet weight will provide the index of ration called for by this protocol. After determining the total weight of all contents in a stomach, determining weights for each of the prey categories can be accomplished a number of ways. This is discussed later as it pertains to determining percent composition.

Prey identification is a critical step in the analysis of predator fish diets. First, the resolution of prey identification needs to be determined so that meaningful data are generated. A prey type should be defined as the lowest taxonomic level and/or life history stage that is present in large enough quantities to contribute significantly to the diet or that is of biological importance. A core list of prey categories for Lake Michigan predators is presented in **Table 4**.

Fortunately, the number of major prey fish species in the Great Lakes is relatively few. Their general appearance and differing vertebral counts provide a good means of identification and discrimination, even when highly digested. Skeletal characteristics, particularly of vertebra and otoliths also are useful for identifying incomplete portions of prey items. To aid and document prey identification, investigators should develope a reference collection for individule diet studies that include examples of the various digested states and identifying characteristics of each prey type. Conversion formula used to reconstruct the original total length and weight of a prey item based on other measures of standard length, vertebral column length, or individual vertebra length should also be developed. Developing these conversions can usually be accomplished by using the intact prey items encountered during stomach analysis or by securing whole individuals and processing them in the same manner as the stomachs are processed. Reconstruction formula developed during studies conducted in 1994-1996 are presented in **Appendix A** along with diagrams of skeletal characteristics for many of the major prey fish species encountered in the Great Lakes.

Reducing and Analyzing Data:

Although describing diet is fairly straightforward once the data is entered into a data base, there are important considerations that need to be addressed about which predator fish to include in sample calculations, and when and how samples collected on different dates or from different areas within a region should be combined.

First, it is very important that there be consistency

Table 4. Prey categories for reporting requirements.

PREY SPECIES CATEGORIES	
PREY FISH	**INVERTEBRATES**
alewife (ALE)	Bythotrephes (BC)
bloater (BLO)	Mysis (MYS)
rainbow smelt (RBS)	Diporeia (DIP)
yellow perch (YEP)	other zooplankton (ZOO)
sculpins (slimy, deepwater, etc.) (SCL)	terrestrial insects (TRI)
sticklebacks (3-spine, 9-spine, etc.) (STK)	aquatic insects (AQI)
shiners (spottail, emerald, etc.) (SNR)	mollusks (MOL)
salmonids (salmon, trout, whitefish) (SAL)	
other	Prey categories listed above that account for less than 1% of the diet can be grouped as "other" along with prey types not listed that account for less than 5% of the diet by weight. Prey types not listed above but that account for 5% or more of the diet by weight should be added to the above list and reported as a separate prey category.

in the choice of which stomachs to included in the analysis of predator diets. In past studies, some investigators have based results only on predators having contents in their stomachs, ignoring those with empty stomachs. Other investigators have made determinations about the integrity of a predator's stomach contents, noting those that appeared to have regurgitated all or some of their stomach contents. These fish were then excluded from further calculations. While these different approaches do not generally affect the determination of percent data, they do have an important effect on the average weight or number of prey per stomach.

Determining that a stomach is completely empty as opposed to having a remanent amount of prey can be somewhat subjective and dependent on how carefully the stomach is examined. This can be difficult to do consistently across multiple investigators and studies. However, a measure of the frequency of predators that have regurgitated some or all of their prey (as evidenced by a stretched, distended, or water filled stomach) and a measure of the frequency of empty stomachs can be helpful in interpreting the results. As the standard for this protocol, all stomachs examined should be included in the data analysis, including empty stomachs. The proportion of empty and regurgitated stomachs can then be used to modify the reported results as desired.

Second, it is important that there be consistency in how results from different collections are combined when providing summary statistics. For example, suppose collections were made from one area of the lake on three different days in a one week period resulting in 100, 80, and 20 age 0.3 chinook salmon being sampled on the three days respectively. Further, assume that their diet was found to be 100% alewife (*Alosa pseudoharengus*) on the first day, 100% bloater (*Coregonus hoyi*) on the second, and 100% rainbow smelt (*Osmerus mordax*) on the third day. What would be the most appropriate description of their diet over that time period? If the samples from all collections were combined before the diet parameters were calculated, the results might indicate that their diet was approximately 50% alewife, 40% bloater, and 10% smelt (depending on the amount of each consumed). However, if the diet parameters were calculated for each day's collection separately and then weighted equally by averaging the results of the three days, the results might indicate that the diet was approximately 33% alewife, 33% bloater, and 33% smelt (again depending on the amount of each consumed). Variance estimates would also differ, as would the method used to calculate them.

The goal of data summary is to best describe the diet of the population of fish in a region over a given time period. Therefore, the most appropriate method of combining data from different collections depends on the effort expended to collect the fish and on what is known or assumed about the distribution of the population during that time period. If the samples in the above example were collected with equal effort such as with standard assessment gillnets, then unequal sample sizes might suggest different abundances of fish on the two days. Combining the samples before calculating the diet parameters would be appropriate in this case. If, however, less effort was expended on the day when fewer fish were sampled, as can often happen when sampling sportfish harvest, then averaging calculations determined separately for the three days or weighting by the effort (if known) would be appropriate.

The method of data reduction used in the analysis needs to be identified when reporting results. Method definitions and reporting codes are outlined in **Table 5**.

Table 5. Data reduction and summary methods for reporting requirements.

METHOD		DESCRIPTION
1 =	Average of Collection Means	Calculate results for all samples within each strata for each collection and then average the results of all collections within the strata (samples weighted equally regardless of sample sizes).
2 =	Grand Average	Combine data for all samples within a strata and calculate results (weighted by sample size).
3 =	Other	(Define an alternate method when reporting results).

Calculating Results:

Interpreting results of diet studies can be facilitated by determining diet using a number of different summary descriptors. Percent diet, one of the most common descriptors used, can be based on a number of parameters including the frequency of prey occurrence, the number of prey consumed, or the weight of prey consumed. Percent weight can in turn be based on actual wet weight, actual dry weight, or reconstructed weight (wet or dry).

For this protocol, percent diet by weight of prey, the length frequency of consumed prey, and an index of ration defined as the average total wet weight of all stomach contents for a given strata will be the three main descriptors of diet reported (**Table 6**). The combination of these three parameters gives a fairly good picture of the various aspects of diet. Several other descriptors that can further emphasize certain characteristics of the diet but that are not called for in this protocol are presented in **Table 7**.

The most straightforward method of determining percent diet based on weight is to directly weigh all items of a given prey type and then determine percent composition from these weights. Alternately, prey items can be identified and measured, and then their whole weight reconstructed using formula that predict whole weight (wet or dry) from various length measures. Percent composition can then be determined based on these weights.

Both methods have advantages and disadvantages. Having to directly weigh prey items involves some subjectivity in partitioning material that is not clearly associated with any one prey item. On the other hand, the uncertainty associated with measuring highly digested prey can contribute a certain degree of error that becomes accentuated when that item's weight is reconstructed. Unidentified prey items are usually highly digested and therefore are usually a fairly small portion of the actual prey weight in the diet. When reconstructed, however, unidentified prey items typically represent a larger proportion of the diet. Developing an appropriate length-weight relation for reconstruction is also difficult for unidentified items. How to quantify the contribution of invertebrates also poses some problem. Counts of each group of invertebrates can be very time consuming but are required for determining reconstructed weight. Weighing invertebrates directly is usually much easier.

What kind of weight value to measure can also vary. While it does not matter whether weights are measured as wet weight or dry weight for determining percent data, it does matter for determining the index of ration. Although dry weights may be a better measure of true food value, the time required to determine the dry weight of the contents of every stomach collected would be prohibitive. It would also require that the contents be weighed in a lab and that every lab have a drying oven. By allowing the index of ration to be measured as wet weight as called for in this protocol, it becomes possible to take the weight measurement fairly quickly and to even do so in the field.

The most time consuming portion of the stomach contents work-up is the identification and measuring of each prey item. Because spending the time to do this may not be feasible for all studies, an abbreviated method that provides average values for each predator strata for a given collection period can be used. Rather than quantifying all of the prey in each stomach, only those prey items that are easily identified and measured are quantified. Highly digested prey items are simply ignored. The assumption is that what was recently eaten and thus easily identified is representative of everything that is in the stomach. Prey weights can again be directly measured for the fairly intact prey items or reconstructed based on measured lengths. All prey from all predators of a particular strata are then combined and diet percentages determined.

The advantage of an abbreviated examination of the stomach contents is that it can be done in the field. This alleviates the need for preserving stomach contents for later laboratory analysis, saving time. There are several disadvantages however. A reliable balance is still needed for determining the total prey weight used as the index of ration and for weighing any invertebrates. Doing this in the field still takes time. This abbreviated stomach analysis also precludes the determination of some descriptive statistics such as the average number of prey consumed or the frequency of prey occurrence. In general, confidence in results from quantifying only a portion of the prey may not be as great as when all prey items are included in the analysis.

Reporting Results:

So that results from all studies conducted on Lake Michigan can be brought together and presented in one lakewide report, a suggested format for submitting results is presented in **Appendix C**. Results can be

Table 6. Reporting requirements.

PARAMETER	REPORTING UNITS	RESOLUTION	STRATIFICATION
Percent Diet Composition by prey category	% of total prey weight	1%	by Region by Season by Predator Size Class
Prey Length Frequency by prey fish species	number per length interval	10 mm intervals	by Region by Season by Predator Size Class
Index of Ration	average grams (wet weight) of prey per stomach (full & empty)	0.1 gram	by Region by Season by Predator Size Class

NOTE: Both predators with food and those with empty stomachs are to be included in the calculation of the Index of Ration.

Table 7. Optional reporting requirements that can be useful in interpreting diet data (but not required for this protocol).

PARAMETER	REPORTING UNITS	RESOLUTION	STRATIFICATION
Percent Diet Composition by prey fish category	% of total prey number (fish species only)	1%	by Region by Season by Predator Size Class
Average Number of Prey Per Stomach by prey category	numbers	1	by Region by Season by Predator Size Class
Frequency of Occurrence by prey fish category	fraction of 1	.01 (1%)	by Region by Season by Predator Size Class
Percent Empty Stomachs	% of sample number	1%	by Region by Season by Predator Size Class
Predator Length Frequency by species	number per length interval	10 mm intervals	by Region by Season by Predator Size Class
Prey Weight as a Proportion of Predator Weight	% of predator weight	1%	by Region by Season by Predator Size Class

submitted by filling in the required information directly on duplicates of these forms, by submitting hard copies of computer output or by submitting the required information in electronic form. The format does not have to follow that suggested here so long as all of the required data elements are provided and organized in an easily interpreted fashion. Responsibility for coordinating, gathering, and summarizing the data will be directed by the Lake Michigan Technical Committee.

Given the numerous stratifications required to characterize the diet (predator size, region, season, etc.) and the many categories of prey (adult, yearling, young of year groups of each prey fish etc.), it is expected that several graphical representations will be necessary to adequately portray the characteristics of the diet. Some examples are provided in **Appendix B**. Graphs should be accompanied by tables containing exact data values (with associated error when possible) and associated sample sizes for each collection when not evident from the graph.

RECOMMENDATIONS

Future data collections and analysis should address the objectives and follow the procedures outlined in this protocol. Several large scale diet studies on Lake Michigan have recently been or are soon to be completed. The effort that will be required to summarize and report all of the associated data in accordance with this protocol will be significant. There is little justification at this time to launch a new effort involving expanded field collection beyond what is currently planned. Such an effort would require more resources than agencies currently have at their disposal unless a major redirection of effort was initiated. Enough data is or will soon be at hand to produce results of greater breadth and detail than have previously been available for Lake Michigan. Continued collection of diet data during routine agency assessments is strongly recommended. Since these collections have now begun to follow this protocol, they provide the means to report some level of lakewide diet on an annual basis and accumulate the necessary index data for examining trends in predator diets. Such index sampling should be able to be incorporated into the annual assessments being planned as part of the Lakewide Assessment Plan being developed by the Lake Michigan Technical Committee. There also is a wealth of historical diet data for Lake Michigan that should be inventoried as to its usefulness and then analyzed thoroughly so that it contributes as much as possible to the objectives identified here.

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REFERENCES

Bowan, S. H. 1983. Quantitative description of the diet. In L. A. Neilson and D. L. Johnson, eds. Fisheries Techniques. pp 283-300. American Fisheries Society, Bethesda, MD.

Brandt, S. B. 1986. Food of trout and salmon in Lake Ontario. Journal of Great Lakes Research 12(3): 200-205.

Brandt, S. B., D. M. Mason, E. V. Patrick, R. L. Argyle, L. Wells, P. A. Unger, and D. J. Stewart. 1991. Acoustic measures of the abundance and size of planktivores in Lake Michigan. Canadian Journal of Fisheries and Aquatic Research 48:894-908.

Conner, D. J., C. R. Bronte, J. H. Selgeby, and H. L. Collins. 1993. Food of salmonine predators in Lake Superior 1981-1987. Great Lakes Fisheries Commission Technical Report Number 59. Great Lakes Fisheries Research Center, Ann Arbor, MI.

Diana, J. S. 1990. Food habits of angler-caught salmonines in western Lake Huron. Journal of Great Lakes Research 16(2): 271-278.

Elliott, R. F. 1993. Feeding habits of chinook salmon in eastern Lake Michigan. M. S. Thesis, Michigan State University, East Lansing, MI. 108 pp.

Eschenroder, R. L., M. E. Holey, T. K. Gorenflo, and R. D. Clark, Jr. 1995. Fish-community objectives for Lake Michigan. Great Lakes Fisheries Commission Special Publication 95-3.

Hagar, J. M. 1984. Diets of Lake Michigan salmonids: an assessment of the dynamics of predator-prey interactions. M. S. Thesis, University of Wisconsin, Madison, WI. 97 pp.

Hyslop, E. J. 1980. Stomach contents analysis -- a review of methods and their application. Journal of Fisheries Biology 17: 411-429.

Jones, M. L., J. F. Koonce, and R. O'Gorman. 1993. Sustainability of hatchery-dependent salmonine fisheries in Lake Ontario: the conflict between predator demand and prey supply. Transactions of the American Fisheries Society 122: 1002-1018.

Jude, D. J. and F. J. Tesar, S. F. Deboe, and T. J. Miller. 1987. Diet and selection of major prey species by Lake Michigan salmonines, 1973-1982. Transactions of the American Fisheries Society 116: 677-691.

Kitchell, J. F. and S. W. Hewett. 1987. Forecasting forage demand and yield of sterile chinook salmon (Oncorhynchus tshawytscha) in Lake Michigan. Canadian Journal of Fisheries and Aquatic Science 44: 384-389.

Kogge, S. N. 1985. Feeding habits of salmonids in Michigan waters of eastern Lake Michigan and southern Lake Superior. M. S. Thesis, Michigan State University, East Lansing, MI. 122 pp.

McComish, T. S. 1989. Changes in salmonine predator-prey relationships in extreme southern Lake Michigan. Illinois-Indiana Sea Grant Program Report IL-IN SC-R-89-2.

Miller, M. A. and M. E. Holey. 1992. Diets of lake trout inhabiting nearshore and offshore Lake Michigan environments. Journal of Great Lakes Research 18(1): 51-60.

Peeters, P. 1993. Salmonid diet study status report. Wisconsin Department of Natural Resources, Sturgeon Bay, WI.

Rand, P. S., D. J. Stewart, P. W. Seelbach, M. L. Jones, and L. R. Wedge. Modeling steelhead population energetics in Lakes Michigan and Ontario. Transactions of the American Fisheries Society 122: 977-1001.

Rybicki, R.W. and D. F. Clapp. In review. Diet of Chinook Salmon in Eastern Lake Michigan. Michigan Department of Natural Resources, Fisheries Technical Report, Ann Arbor, MI.

Smith, S. H., H. J. Buettner, and R. Hile. 1961. Fishery statistical districts of the Great Lakes. Great Lakes Fishery Commission Technical Report No. 2.

Stewart, D. J., D Weininger, D. V. Rottiers, and T. A. Edsall. 1983. An energetics model for Lake Trout, *Salvelinus namaycush*: application to the Lake Michigan population. Canadian Journal of Fisheries and Aquatic Sciences 40: 681-698.

Stewart, D. J. and M. Ibarra. 1991. Predation and production by salmonine fishes in Lake Michigan, 1978-88. Canadian Journal of Fisheries and Aquatic Science 48: 909-922.

Van Oosten, J. And H. J. Deason. 1938. Food of the lake trout (Cristivomer namaycush) and of the lawyer (Lota maculosa) of Lake Michigan. Transactions of the American Fisheries Society 67: 155-177.

Wright, K. J. 1968. Feeding habits of immature lake trout (Salvelinus namaycush) in the Michigan waters of Lake Michigan. M. S. Thesis, Michigan State University, East Lansing, MI. 42 pp.

APPENDIX A - Prey fish characteristics.

Table 8. Prey species characteristics and conversion formula.

SPECIES	Vertebral Count	Vertebral Length (VL) To Total Length (TL)	Standard Length (SL) To Total Length (TL)	Total Length (TL) To Wet Weight (Wwt)	Total Length (TL) To Dry Weight (Dwt)	Valid Length Range (TL)
ALEWIFE	Mean=48.0 Range=46-49	TL=1.66 VL - 3.9 r^2=.993 n=45	TL=1.26 SL - 3.6 r^2=.995 n=45	Wwt=4.020E-6 $TL^{3.108}$ r^2=.980 n=59	Dwt=57.049E-6 $TL^{2.2767}$	15-210 mm
BLOATER	Mean=54.1 Range=53-56	TL=1.52 VL + 6.8 r^2=.979 n=21	TL=1.24 SL + 2.4 r^2=.987 n=21	Wwt=3.865E-7 $TL^{3.554}$ r^2=.971 n=28	Dwt=61.253E-9 $TL^{3.6696}$	100-250 mm
RAINBOW SMELT	Mean=62.9 Range=62-64	TL=1.48 VL - 4.6 r^2=.996 n=36	TL=1.23 SL - 5.3 r^2=.995 n=36	Wwt=2.451E-6 $TL^{3.153}$ r^2=.988 n=17	Dwt=49.624E-9 $TL^{3.6297}$	40-210 mm
YELLOW PERCH	Mean=39.3 Range=37-40	TL=1.61 VL + 0.8 r^2=.994 n=50	TL=1.18 SL + 4.6 r^2=.995 n=50	Wwt=3.116E-6 $TL^{3.232}$ r^2=.991 n=50		70-190 mm
LAKE HERRING	Mean=XX.X Range=55-60	data in preperation	data in preperation	data in preperation		data in preperation
DEEPWATER SCULPIN	Mean=34.3 Range=32-36	TL=1.57 VL + 5.6 r^2=.985 n=25	TL=1.18 SL + 1.4 r^2=.993 n=25	Wwt=1.078E-6 $TL^{3.459}$ r^2=.992 n=25		50-175 mm
SLIMY SCULPIN	Mean=30.6 Range=29-32	TL=1.38 VL + 10.0 r^2=.981 n=13	TL=1.17 SL + 2.3 r2=.996 n=13	Wwt=11.482E-6 $TL^{3.013}$ r^2=.984 n=13		45-100 mm
NINESPINE STICKLEBACK	Mean=XX.X Range=XX-XX	data in preperation	data in preperation	Wwt=1.980E-6 $TL^{3.313}$ r^2=.988 n=10		30-80 mm
THREESPINE STICKLEBACK	Mean=XX.X Range=XX-X	data in preperation	data in preperation	data in preperation		data in preperation

ALEWIFE

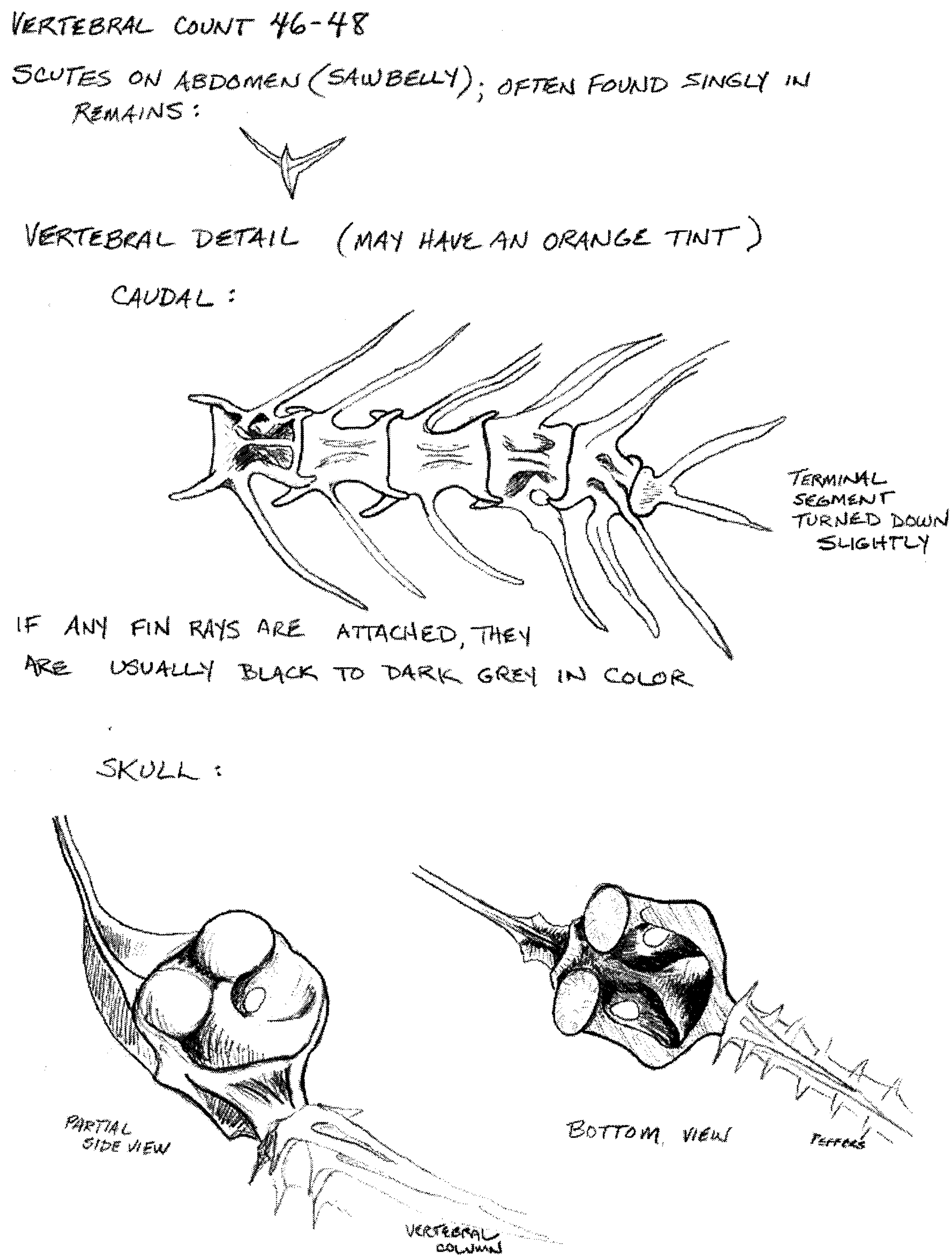


Figure 2. Skeletal characteristics of partially digested alewife.

BLOATER

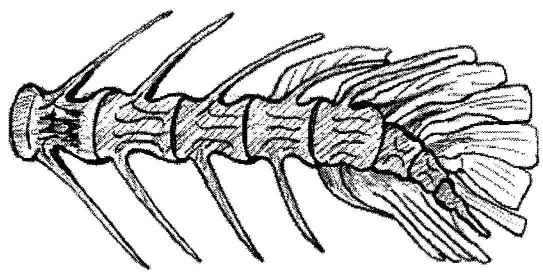
VERTEBRAL COUNT 53-56

SKIN COLORATION PINKISH. FLESH HAS SIMILAR COLORATION, COMPARED TO ORANGE OF ALEWIFE.

RETINA LINING (BLACK) PERSISTS LONGER THROUGH DECOMPOSITION, APPEARS AS FLACCID BLACK PATCHES ON HEAD

VERTEBRAL DETAIL: (VERY TRANSLUCENT WHITE)

CAUDAL;



ANY CAUDAL FIN RAYS STILL ATTACHED WILL PROBABLY BE PALE, PINKISH GRAY.

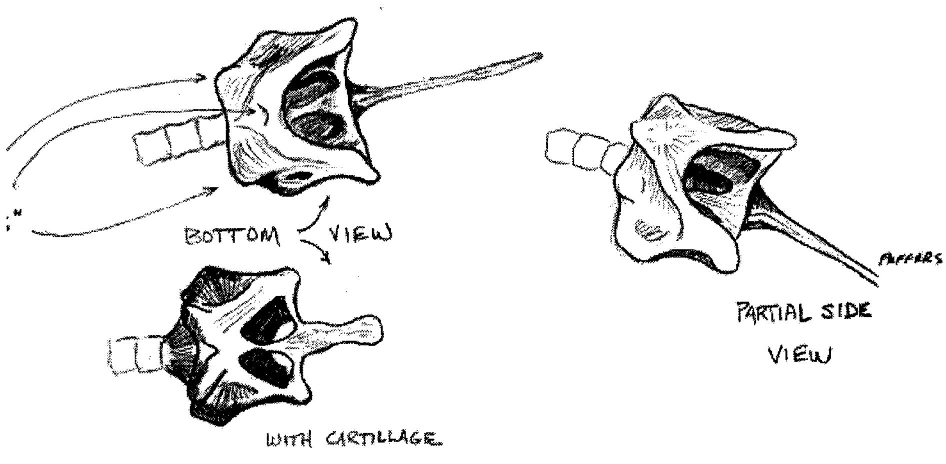
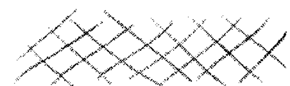


Figure 3. Skeletal characteristics of partially digested bloater.

RAINBOW SMELT

VERTEBRAL COUNT 62-64

CROSS-HATCHING PATTERN EVIDENT ON SKIN:

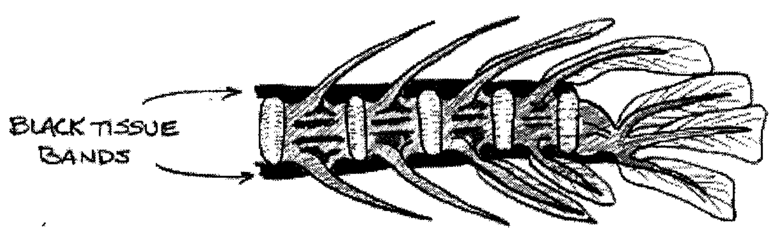


BLACK BANDS OF TISSUE PARALLEL TO VERTEBRAL COLUMN.

TEETH!

VERTEBRAL DETAIL:

CAUDAL:



SKULL:

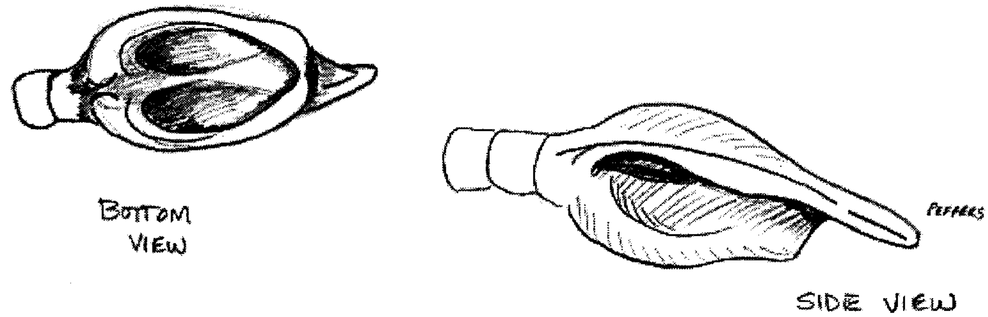


Figure 4. Skeletal characteristics of partially digested rainbow smelt.

APPENDIX B - Example graphical presentations of summarized diet data.

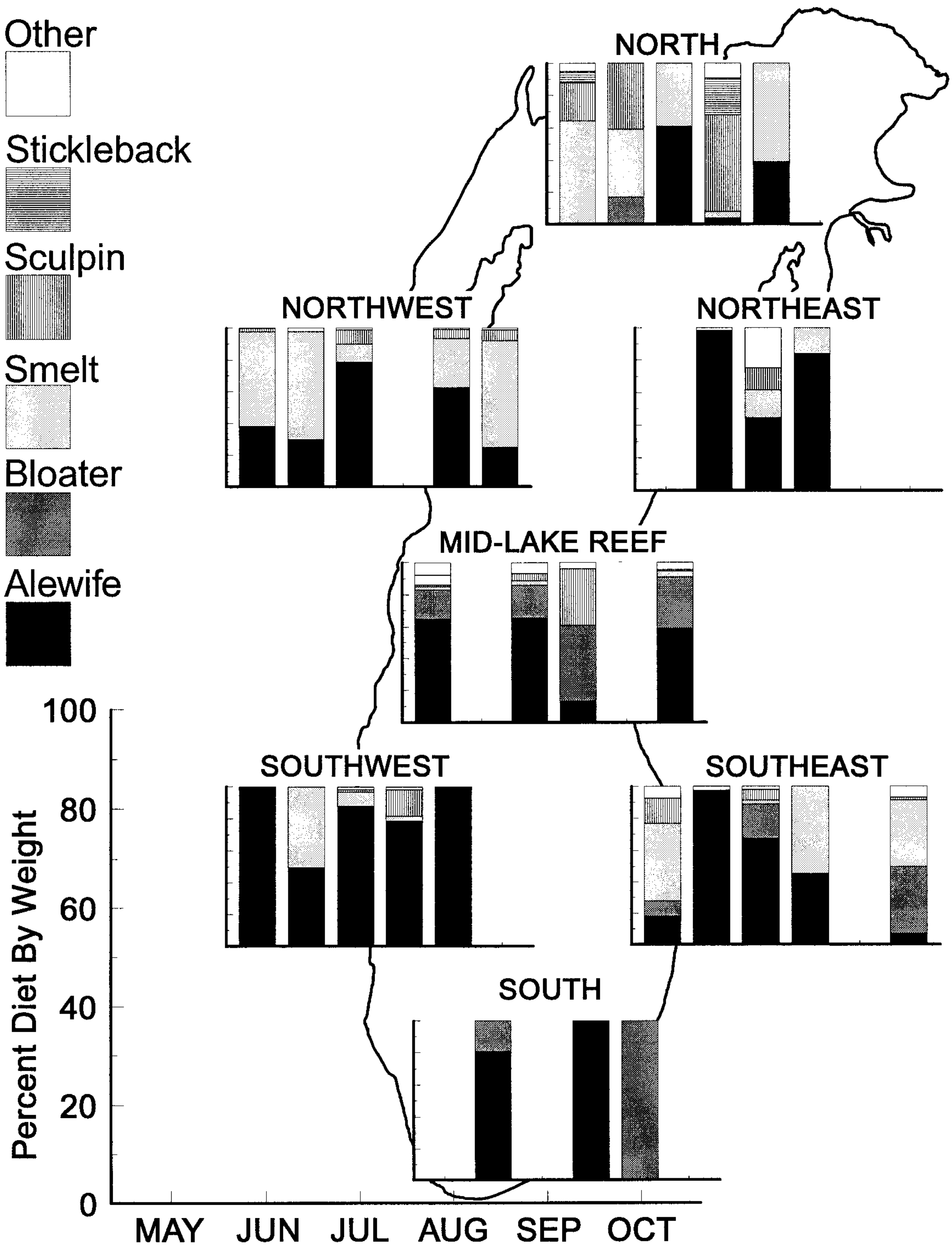


Figure 5. Summary by month and region of the percent diet composition by weight for 400-599 mm lake trout collected from Lake Michigan in 1994.

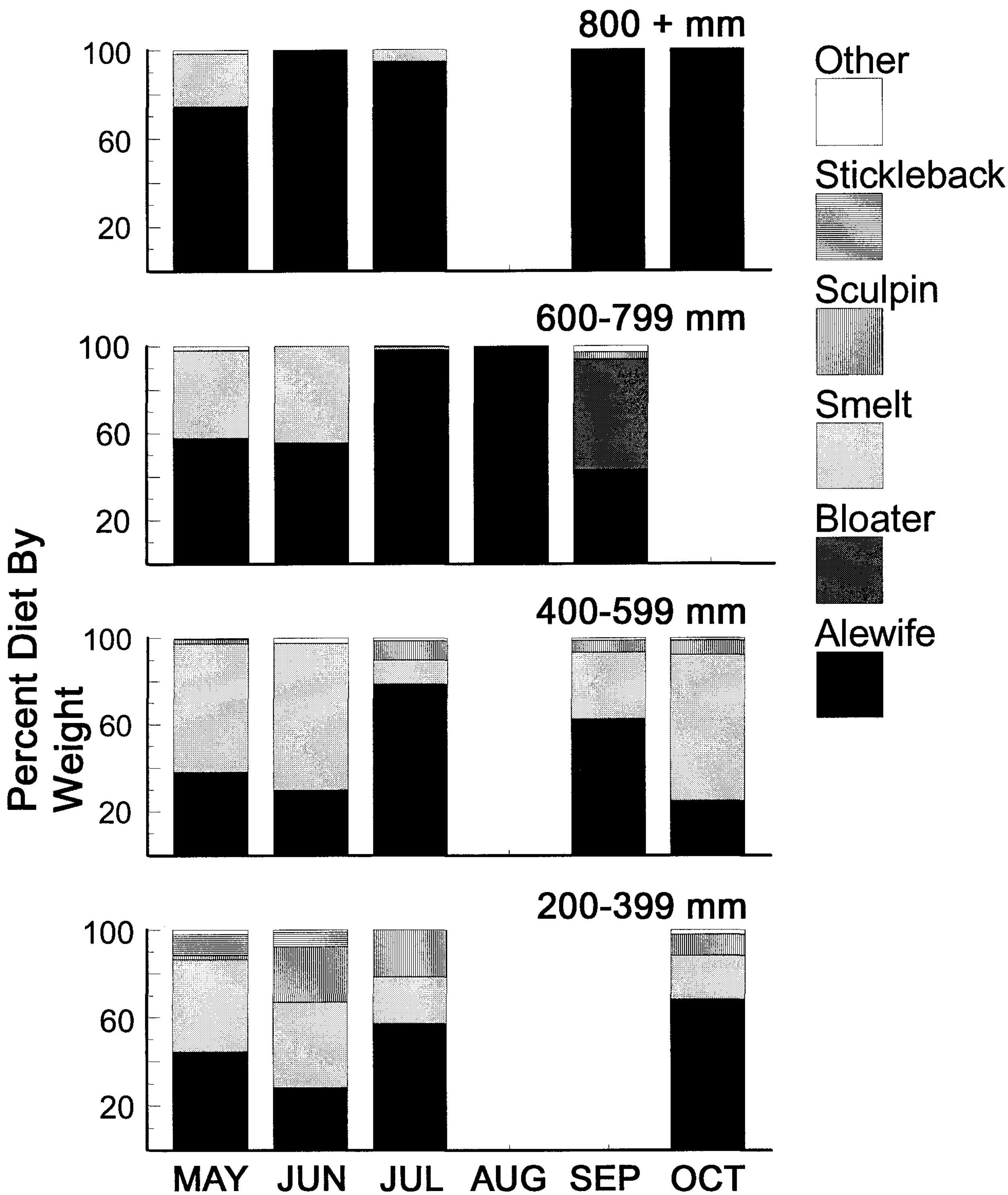


Figure 6. Summary by month of the percent diet composition by weight for four sizes of lake trout collected from northwestern Lake Michigan in 1994.

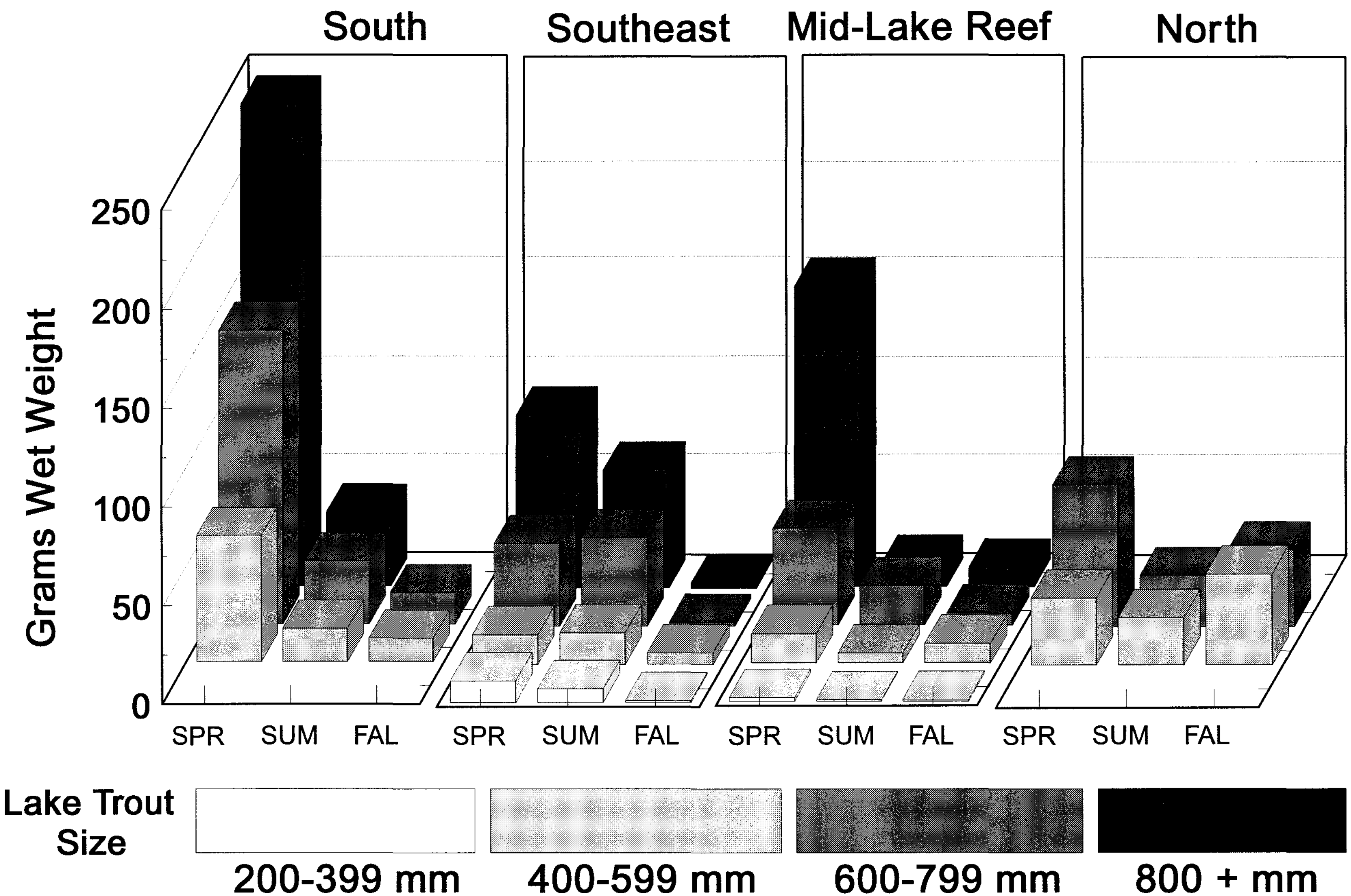


Figure 7. Summary by season and region of the average amount of prey found in the stomachs of four sizes of lake trout collected with gill nets from Lake Michigan in 1994.

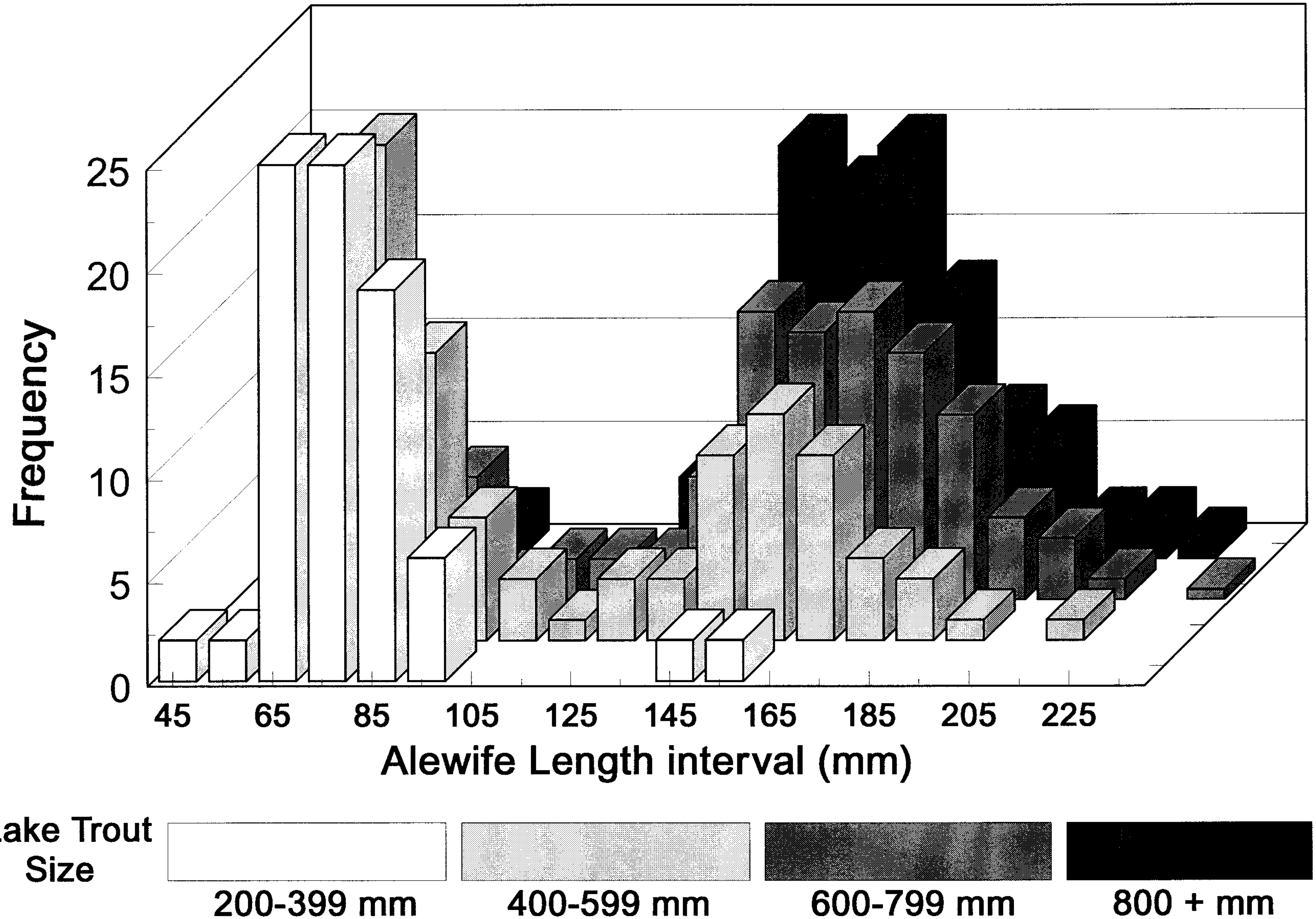


Figure 8. Lengths of alewife consumed in the spring by four sizes of lake trout collected from all regions of Lake Michigan in 1994.

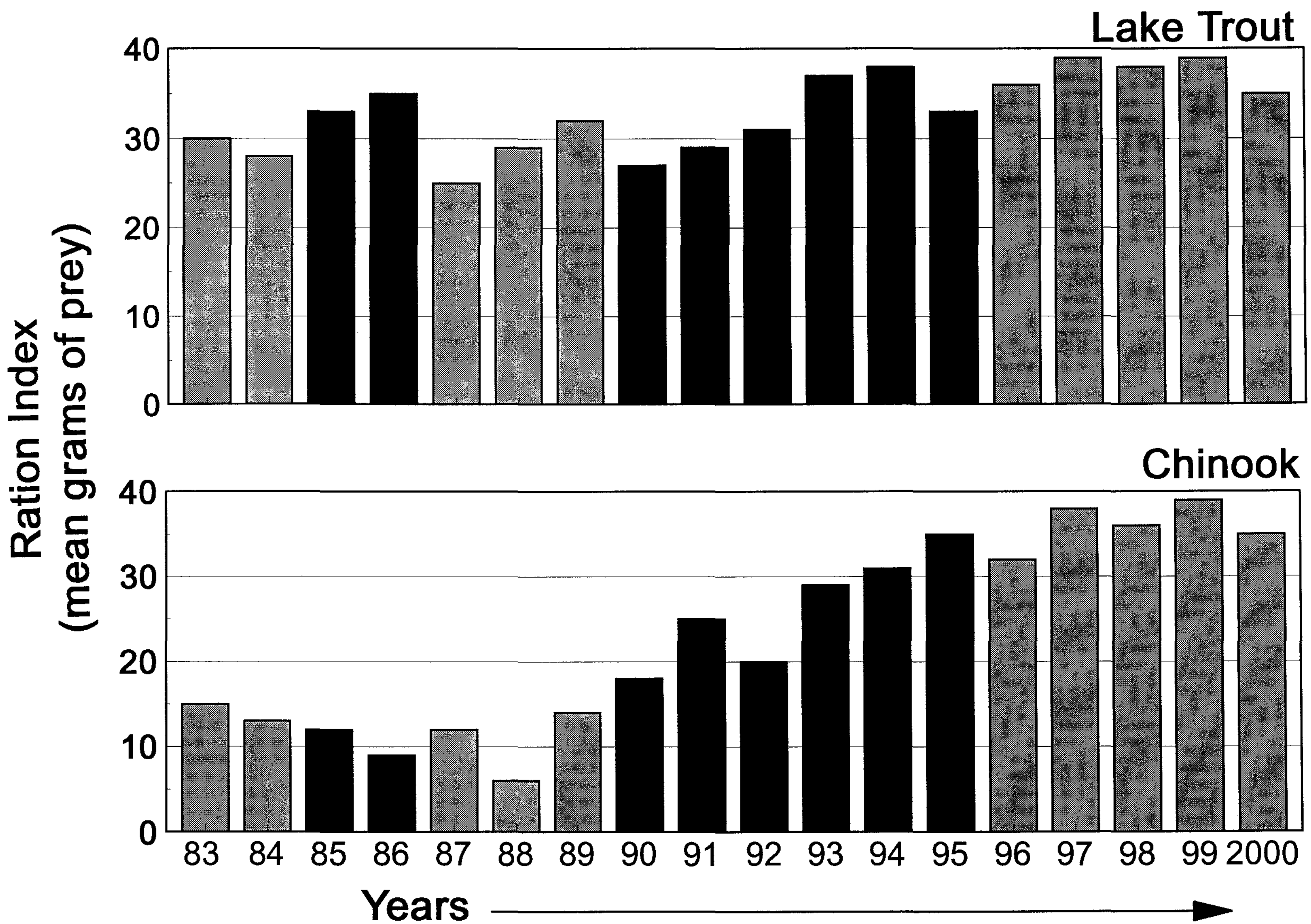


Figure 9. Hypothetical time series of an index of ration for lake trout and chinook salmon. Darker bars indicate years for which ration index data could be calculated using available data.

APPENDIX C - Reporting Forms

Table I - Description of field collection, lab analysis, and data reduction methods.

YEAR = ________ **AGENCY =** ______________ **CONTACT PERSON =** ______________

Describe in detail: -the gear used for collections (mesh sizes, length, etc.) -where and how the gear was fished (surface, suspended, bottom, in what depths of water, what locations, duration of set and times, etc.) -how the stomachs were collected (how soon after capture, if preserved and how, etc) -how the stomachs were analyzed (when done, method of identification, type of weights: reconstructed, dry, wet, detail of prey item identification, etc) -how the data was reduced and summarized (see table 5)

Table II - Results reporting form for diet composition.

YEAR=________ **AGENCY =_______________** **CONTACT PERSON =____**

LAKE=________ **GEAR TYPE =____________** **DATA REDUCTION AND SUMMARY METHOD =_______________________**

Predator Species	Size Class	Qualifying Description	Region	Season	No. of Collections	No. of Samples	No. Empty Stomachs	Ration Index (0.1 grms)	Prey Species	% Diet (wet weight)

Table III - Results reporting form for prey length frequencies.

PREDATOR SPECIES=_____________ PREY SPECIES=______________ AGENCY=_____________ CONTACT PERSON=____________________________

YEAR=___________ LAKE=_____________ REGION=______________ GEAR TYPE=________________ DATA REDUCTION METHOD=_______________

Season:	March-April					May					June					July				
Predator Size Group: Prey Lengths:	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
< 30 mm																				
30-39 mm																				
40-49 mm																				
50-59 mm																				
60-69 mm																				
70-79 mm																				
80-89 mm																				
90-99 mm																				
100-109 mm																				
110-119 mm																				
120-129 mm																				
130-139 mm																				
140-149 mm																				
150-159 mm																				
160-169 mm																				
170-179 mm																				
180-189 mm																				
190-199 mm																				
200-209 mm																				
210-219 mm																				
220-229 mm																				
230-239 mm																				
240-249 mm																				
250-259 mm																				
260-269 mm																				
270-279 mm																				
280-289 mm																				
290-299 mm																				
300 & greater																				

Table III - continued.

PREDATOR SPECIES=___________ PREY SPECIES=____________ AGENCY=___________ CONTACT PERSON=_________________

YEAR=_______ LAKE=_________ REGION=__________ GEAR TYPE=____________ DATA REDUCTION METHOD=______________

Season:	August					September					October-November					December-January-February				
Predator Size Group: Prey Lengths:	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
<30 mm																				
30-39 mm																				
40-49 mm																				
50-59 mm																				
60-69 mm																				
70-79 mm																				
80-89 mm																				
90-99 mm																				
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240-249 mm																				
250-259 mm																				
260-269 mm																				
270-279 mm																				
280-289 mm																				
290-299 mm																				
300 & greater																				

Estimating Total Vertebral Length from Measures of Partial Vertebral Length

Estimating a total vertebral length (VL) from a partial vertebral length simply involves expanding the partial length by the percent of vertebra missing, and then, when necessary, adjusting for differences in the size of anterior and posterior vertebrae. This can be done using the following formula:

$$VL = VL_P \frac{\overline{VN}}{VN_P} (A)$$

where:

VL = the total vertebral length
VL_P = the partial vertebral length
VN = the mean total number of vertebrae for that species
VN_P = the number of vertebrae in the partial vertebral length
A = an adjustment factor that corrects for the difference in size of anterior and posterior vertebra for that species.

For alewife, bloater, and rainbow smelt, there is not much, if any, difference in the length of anterior and posterior vertebrae so no adjustment factor is needed. For yellow perch, deepwater sculpin, and slimy sculpin, anterior vertebrae are larger than posterior vertebrae. When partial measures of vertebral length include only anterior or posterior vertebrae, the following adjustments should give a better estimate of the total vertebral length:

	anterior	posterior
for yellow perch:	0.95	1.05
for deepwater sculpin:	0.85	1.15
for slimy sculpin:	0.95	1.05

If the partial length is of an unknown segment of the vertebral column, or if the segment is a fairly large proportion of the total vertebral length, then it may not be necessary to use any adjustment factor.