Review and Selection of Fish Metrics

for the Chicago Area Waterway System

Habitat Evaluation and Improvement Study

Prepared for

The Metropolitan Water Reclamation District
Of Greater Chicago

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Attachment A: CAWS Fish Data Stations and Sampling Dates Used in this Analysis

Attachment B: List of Fish Species Identified in the CAWS (2001-2007) and Their Tolerance Assignments

Attachment C: Matrix of Pearson's Correlation Values for Fish Metrics

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1. INTRODUCTION

This document summarizes the process used to select key fish metrics for the Chicago Area Waterway System (CAWS) Habitat Evaluation and Improvement Study (the Study). Selection of key fish metrics is important to the Study for two reasons:

- Sensitivity to Water Quality – Comparison of historical fish data and water quality data is important in understanding the relationship between water quality and fish communities in the CAWS. Identification of CAWS appropriate fish metrics is necessary for such data comparisons.

- Habitat Index Development – The proposed method for development of a CAWS-specific habitat index relies on the comparison of fish data to habitat variables to help define the relationship between fish and the physical habitat in the CAWS.

It was not the objective of the Study to develop a CAWS-specific index of biotic integrity (IBI), but the methods used to identify key fish metrics for the CAWS are the same as those used in current biological practice to define metrics for fish IBIs. Development of a fish IBI for the CAWS might be useful in the future, but development an IBI would require specification of a regionally appropriate, non-consumption, target condition to which the upper end of the index would be referenced (Karr 1991). This can be done in one of three ways, but is currently beyond the scope of this analysis for the CAWS as described below:

- External reference reach – An external reference reach that represents a target fisheries condition that is attainable in the CAWS could be used to establish the upper limit of the IBI. This approach is impractical for the CAWS because the CAWS consists entirely of constructed or heavily modified channels and no similar channels with high quality or reference fisheries have been identified.

- Internal reference reach – A reach within the system that represents a target fisheries condition that should be targeted for the entire CAWS could be used to establish the upper limit of the IBI. This is not currently possible because no such internal reference has been identified.

- Target use – A target fisheries use (e.g., warm water sport fishing), function (e.g., harvest prohibition) or specific target species (e.g., trophy largemouth bass) may be identified which would allow determination of target fisheries conditions to describe the upper end of the index. To date, target uses or species have not been identified.

Although it is currently impractical to establish a fish IBI for the CAWS, it is possible to determine key fish metrics for use in comparing to habitat data. This document presents the recommended list of fish metrics for the CAWS and summarizes the methodology used to arrive at that list.

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2. DATA DESCRIPTION

This section provides an overview of the fish data used in this study.

2.1 FISH SAMPLING LOCATIONS

The Metropolitan Water Reclamation District of Greater Chicago (District) has been collecting fish data annually since 1974 (with the exception of 1981 and 1982) within the CAWS. However, to focus this Study on current conditions, LimnoTech limited the fish data analysis to the data collected between 2001 through 2007 and to the area considered as the managed portion of the CAWS. The managed portion is defined by the non-wadeable waters bounded by the Wilmette Pumping Station, the Chicago River Lock and Controlling Works, the O'Brien Lock and Controlling Works and the Lockport Lock and Powerhouse. The tributaries to the CAWS are not included in this study, as their physical conditions and regulatory controls differ from the mainstems of the CAWS. The South Fork of the South Branch, also known as Bubbly Creek, is also included in this study.

During the 2001-2007 period, the District collected fish data at 34 stations within the CAWS (Figure 2.1) on a routine basis. Twenty-six of these 34 stations are part of the District's Ambient Water Quality Monitoring (AWQM) program. Seven of the AWQM stations are annually monitored (once per year), while the remainder are sampled on a four year rotation. The total number of sample events across all stations and years includes 113 sample events. The CAWS fish monitoring stations and sampling dates used in the sample description, screening and selection of fish metrics is included as Attachment A.

2.2 FISH SAMPLING METHODS

The District samples the fishery within the CAWS using boat electrofishing procedures[1], following standard and consistent protocols for this collection method. Each station is generally defined by a 400 meter reach and each bank length was sampled for fishes. The average shock time averages 800 seconds. The collected fish are counted, measured (standard and total length), weighed and released, except where difficult to identify in the field. In addition, any abnormalities such as diseases, eroded fins, lesions or tumors (DELTs) are noted. Between 2001 through 2007, all sampled stations have a single sampling event per year except Station 75, Chicago Sanitary and Ship Canal at Cicero Avenue. During the first sampling event on 7/31/2001 the field crew experienced equipment failure, which resulted in a partial fish collection sample. Later in the season, on 9/4/2001 the crew returned to the station to conduct an additional sampling. Only the 9/4/2001 data were included in this study. Finally, supplemental sampling was conducted in 2007 using Fyke nets at three stations, and those data are also summarized.

[1] In 2007, the District supplemented fish collections with Fyke net samples but, because this method is not consistent with other methods, these data were not included in this analysis.

2.3 SUMMARY DESCRIPTION OF FISH DATA

Fifty-two (52) species, including five hybrids, of fish were identified at the 34 CAWS monitoring stations between 2001 and 2007 (sample period). Attachment B provides the complete list of these fish species. For the sample period, the number of non-hybrid species collected across the CAWS stations ranged from 27 at AWQM Station 76 (Little Calumet River at Halsted Street) to only five at Stephen Street (Chicago Sanitary Shipping Canal; CSSC; Figure 2-2). The repeated, annual sampling effort did not necessarily relate to the greatest number of taxa among the sample period for an individual station. For example, the second most numerous taxa (n=23), were from the Little Calumet River at Indiana Avenue, resulting from only two sample events for the sample period. Figure 2-1 depicts the distribution of the number of non-hybrid collected taxa across the managed portion of the CAWS. Table 2-1 describes the taxa richness and total number of individuals by station, for the sample period.

Figure 2-1. Fish Sampling Stations in the CAWS.

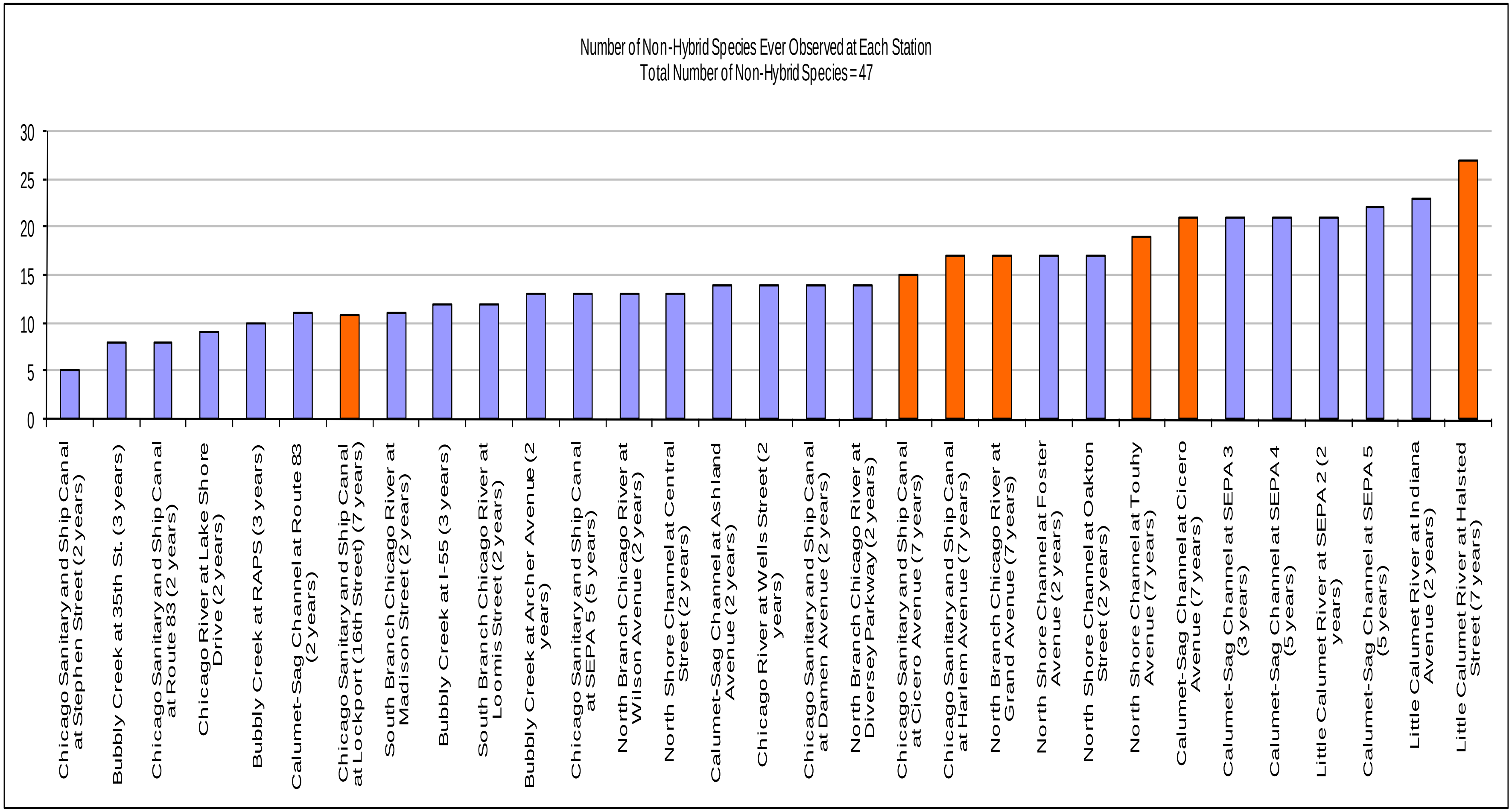


Figure 2-2. Taxa Collected among CAWS Stations for the 2001-2007 sample period. Blue bars indicate stations included in the quadrennial sampling schedule while the orange bars indicate those sampled annually.

Table 2-1 summarizes the station sample collections by station and year. Station sampling within the CAWS has ranged from as few as 12 stations (2001) to as many as 20 stations (2005) with an average of 16 stations sampled per year. Station samples vary in their taxa and total number of individuals both within stations among years, and among stations. The least number of species collected in any event occurred in 2001 at Lockport with only 2 taxa represented by 77 individuals. The greatest number of species for a single event included 22 taxa represented by 405 individuals collected on the Little Calumet River at Halsted Street in 2006.

Table 2-1. Taxa Richness and Total Number of Individuals by Station and Year.

AWQM Station Number	Station Description	Sample taxa richness (total number of individuals)						
		2001	2002	2003	2004	2005	2006	2007
35	North Shore Channel at Central Street	12 (132)				11 (139)		
36	North Shore Channel at Touhy Avenue	11 (596)	12 (147)	14 (335)	11 (249)	9 (276)	16 (496)	14 (387)
101	North Shore Channel at Foster Avenue	15 (179)				17 (273)		
102	North Shore Channel at Oakton Street	2 (2)				17 (151)		
37	North Branch Chicago River at Wilson Avenue	9 (75)				11 (122)		
73	North Branch Chicago River at Diversey Parkway	7 (58)				13 (164)		
56	Little Calumet River at Indiana Avenue			17 (452)				18 (322)
76	Little Calumet River at Halsted Street	16 (210)	17 (163)	13 (219)	17 (207)	19 (913)	22 (405)	21 (281)
SEPA2	Little Calumet River at SEPA 2					16 (529)	12 (218)	
43	Calumet-Sag Channel at Route 83			7 (43)				9 (261)
58	Calumet-Sag Channel at Ashland Avenue			13 (95)				12 (131)
59	Calumet-Sag Channel at Cicero Avenue	10 (127)	13 (174)	12 (56)	10 (147)	10 (453)	15 (214)	12 (297)
SEPA3	Calumet-Sag Channel at SEPA 3			13 (148)		16 (253)		14 (407)
SEPA4	Calumet-Sag Channel at SEPA 4			11 (93)	11 (82)	14 (663)	9 (79)	15 (417)
SEPA5	Calumet-Sag Channel at SEPA 5			12 (232)	7 (41)	16 (443)	7 (37)	17 (216)
Supplemental Survey	Calumet-Sag Channel at 104th Street							10 (92)
Supplemental Survey	Calumet-Sag Channel at Kedzie Avenue							8 (87)
Supplemental Survey	Calumet-Sag Channel at Southwest Highway							13 (127)
46	North Branch Chicago River at Grand Avenue	12 (53)	7 (28)	8 (67)	9 (88)	5 (77)	10 (158)	13 (117)
74	Chicago River at Lake Shore Drive		8 (22)				7 (83)	
100	Chicago River at Wells Street		11 (136)				10 (250)	
39	South Branch Chicago River at Madison Street		10 (138)				6 (99)	
40	Chicago Sanitary and Ship Canal at Damen Avenue		10 (148)				12 (164)	
99	Bubbly Creek at Archer Avenue		5 (21)				13 (156)	
108	South Branch Chicago River at Loomis Street		10 (76)				13 (142)	
99.2	Bubbly Creek at 35th St.			5 (39)	8 (27)	5 (26)		
99.1	Bubbly Creek at I-55			6 (31)	10 (60)	5 (31)		
99.3	Bubbly Creek at RAPS			7 (151)	10 (97)	5 (62)		
41	Chicago Sanitary and Ship Canal at Harlem Avenue	9 (88)	11 (188)	10 (225)	13 (193)	14 (758)	15 (388)	12 (282)
42	Chicago Sanitary and Ship Canal at Route 83		5 (32)				5 (10)	
48	Chicago Sanitary and Ship Canal at Stephen Street		4 (24)				5 (24)	
75	Chicago Sanitary and Ship Canal at Cicero Avenue**	10 (118)	10 (136)	9 (138)	13 (191)	7 (184)	11 (205)	13 (280)
92	Chicago Sanitary and Ship Canal at Lockport (16th Street)	2 (77)	6 (67)	7 (67)	4 (22)	9 (179)	8 (64)	6 (64)
SEPA5_CSSC	Chicago Sanitary and Ship Canal at SEPA 5			5 (18)	8 (53)	6 (306)	8 (34)	9 (178)

Figure 2-3 depicts the sample variation among years at the annual stations. The figure also includes the annual variation of species assigned to pollution tolerance categories of tolerant (to pollution), intolerant and moderately tolerant. A discussion of the categorical assignments for pollution tolerance is included later and tolerance assignments for individuals are included in Attachment B. In general, the number of taxa collected within the annual monitoring stations appears to be increasing since 2001. Tolerant species dominate all annual stations, followed by moderately tolerant species. Several stations have no intolerant species represented during any sample year, while others have a few.

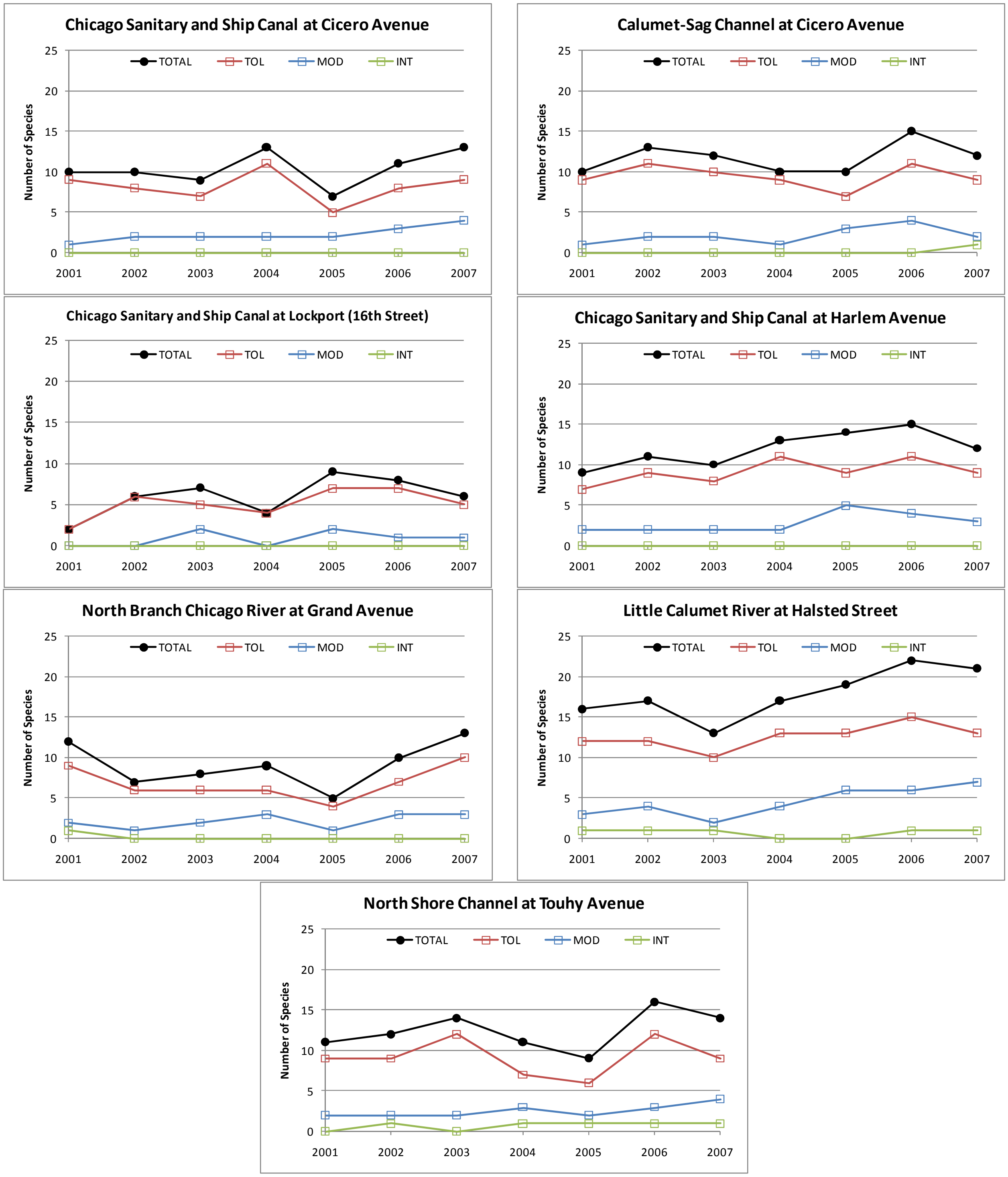


Figure 2-3. Taxonomic Abundances across the CAWS at Annual Monitoring Stations.

The most frequently observed species across all stations included gizzard shad (*Dorosoma cepedianum*), common carp (*Cyprinus carpio*), and largemouth bass (*Micropterus salmoides*), respectively (Figure 2-4). The most frequently observed species at the annual monitoring stations includes gizzard shad, common carp and pumpkinseed (*Lepomis gibbosus*), respectively (Figure 2-5). The most numerous observed species within the CAWS included gizzard shad (n=6906), emerald shiner (*Notropis atherinoides*; n=2082) and common carp (n= 2055), respectively (Figure 2-6). Eleven species are represented by only a single observation for the 2001-2007 period. Finally, gizzard shad, common carp, and largemouth bass have been observed at all stations during the sample period.

The distribution and abundance of gizzard shad in the CAWS is not unusual for large water systems and Simon and Sanders (1999) suggest not including this species in community structure comparisons as a potential source of bias in analysis. Emerald shiner is commonly found in large rivers and appears to thrive in reservoir systems (Becker 1983), so their numbers and distribution within the CAWS is not unexpected. Common carp are found turbid, warm, large river systems of the Midwest (Becker 1983) and their distribution and abundance in the CAWS is also not surprising. Largemouth bass are also abundant in large rivers of the Midwest (Becker 1983), with a presence expected in the CAWS and serve as a popular recreation target species within the system (Personal communication, Bradley 2008). Pumpkinseed also appears to thrive in impounded systems (Becker 1983) so their numbers and distributions are also not unexpected.

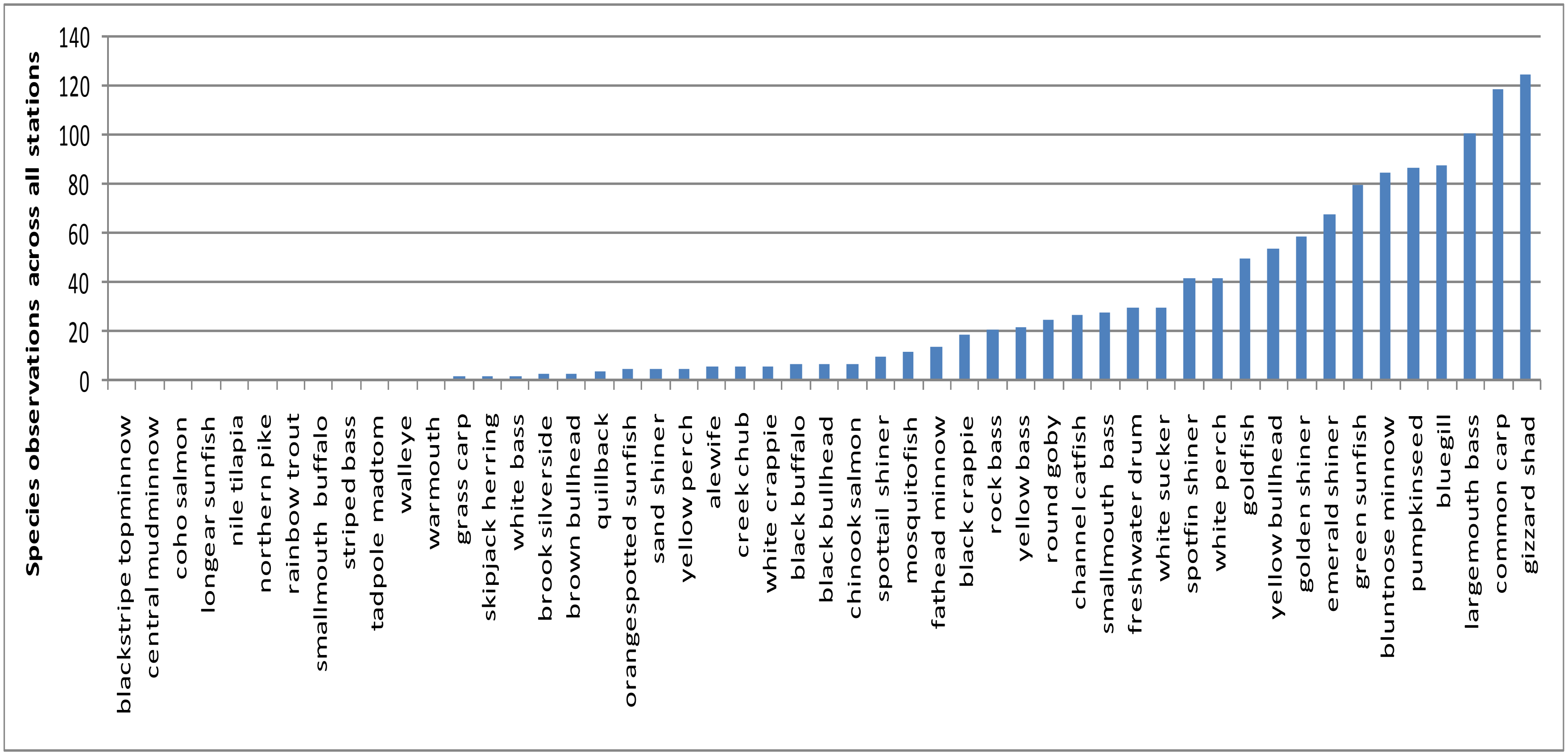


Figure 2-4. Species Observations, by Sample Event at all Monitoring Stations for the 2001-2007 Period.

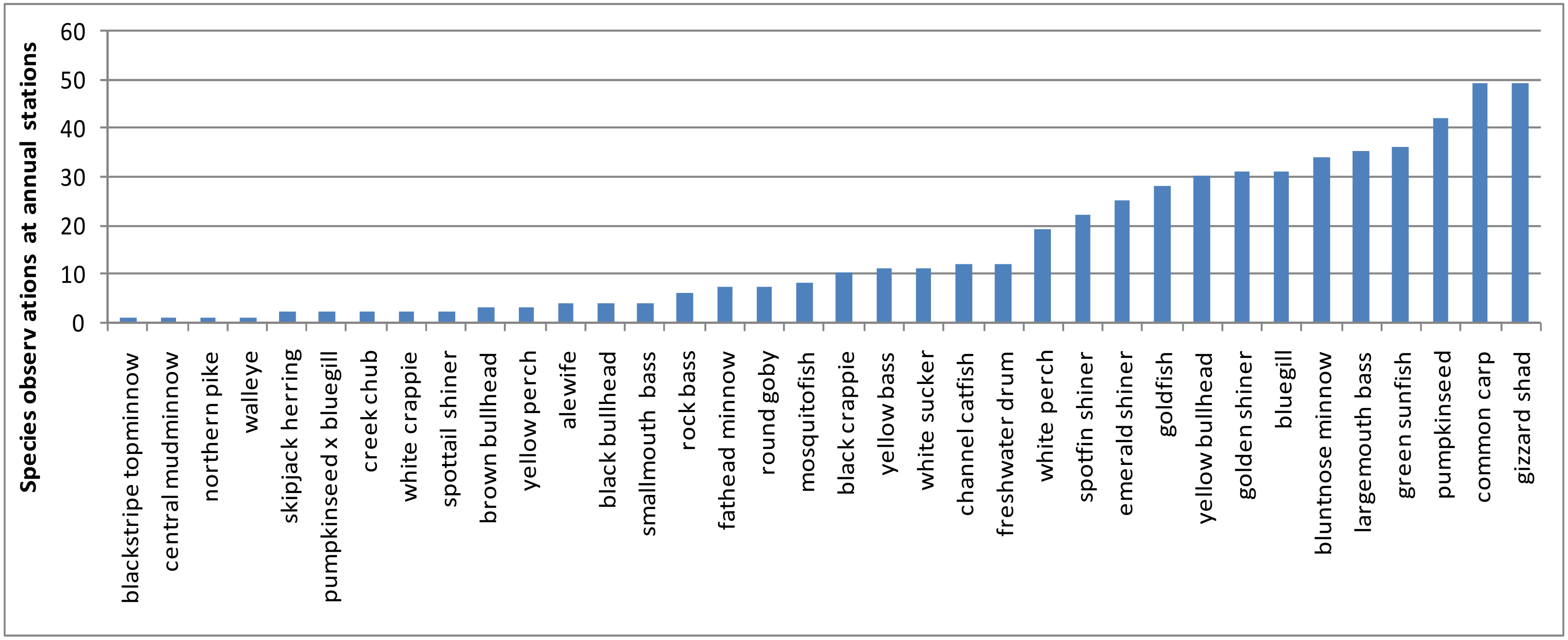


Figure 2-5. Species Observations, by Sample Event at Annual Monitoring Stations for the 2001-2007 Period.

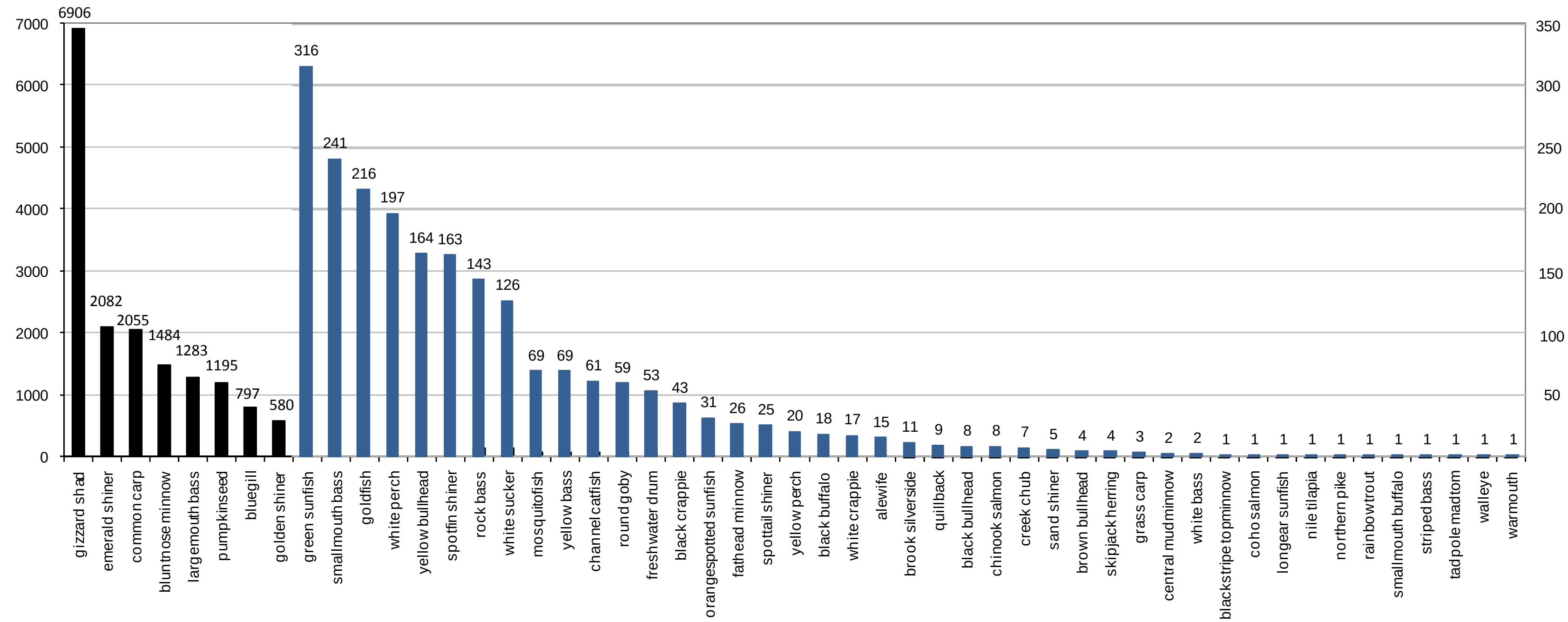


Figure 2-6. Total Number of Individuals Collected during the 2001-2007 Sample Period (black bars are referenced to the axis on the left, blue bars are referenced to the axis on the right).

Figure 2-7 describes the sample collections, among years at the annual monitoring stations. The graphs depict the variation of samples collected at the stations among years. Meador and McIntyre (2003) observed high variability (Coefficient of Variation (CV) = 0.23) in species richness from boat electrofished samples of up to +/-5 species and concluded that their variation resulted from sampling efficiency, rather than environmental variation. However, they noted that increased variation among years at a station was related to increasing station depth (Meador and McIntyre 2003). Paller (1995) suggests that a CV of 0.20 is the maximum desirable level of variability in catch per unit effort for electrofishing. The CV for the CAWS annual monitoring stations ranged from 0.16 – 0.4. The Lockport station had the highest CV (0.40), while the Cal-Sag station at Cicero Avenue had the lowest CV (0.16). The high CV at the Lockport station may be related to the site conditions of confined, deep channels, no access to shallow water areas and a species community that is dominated by mobile species such as gizzard shad, carp, and a range of sunfishes. These findings are also consistent with Meador and McIntyre (2003) in their descriptions of highly variable non-wadeable sites.

Finally, in 2007, the District deployed Fyke nets as a supplemental sampling method for three stations within the CAWS. The Fyke net collected data was compared to the closest electrofishing event in space and time in an attempt to understand how this additional collection method may be of value for use in the CAWS fishery monitoring program for capturing smaller age-class fish. Fyke nets are selective for migratory fish that follow shorelines (Hubert 1996). The 2007 samples resulted in relatively small catches compared to electrofishing and seemed biased towards smaller size classes (Figures 2-8, 2-9, 2-10). The Cal-Sag at Harlem Avenue resulted in the largest catch of 34 individuals. Of the 34 individuals, only four bluegill (total length ranging 31-37 mm) were collected with the remaining species being minnows. Only three individuals were collected at the Cal-Sag at Cicero Avenue site: two minnow and one bluegill (total length 31 mm). The Cal-Sag at Southwest Highway site found 11 individuals: 7 bluegill (total length 23-46 mm), one green sunfish (total length 48 mm), and the remaining were minnows. Overall, the catch total lengths from the Fyke net samples ranged between 23 mm and 66 mm. Little can be drawn from the small catches of the 2007 Fyke net sample data other than the samples seemed biased towards small samples of young, potentially year 1 (Becker 1983) bluegill and minnows. Future, alternative approaches may include light-traps that target young-of-year fishes to try to understand reproduction within various portions of the CAWS.

Figure 2-7. 2001 to 2007 Annual Station Fish Survey Results

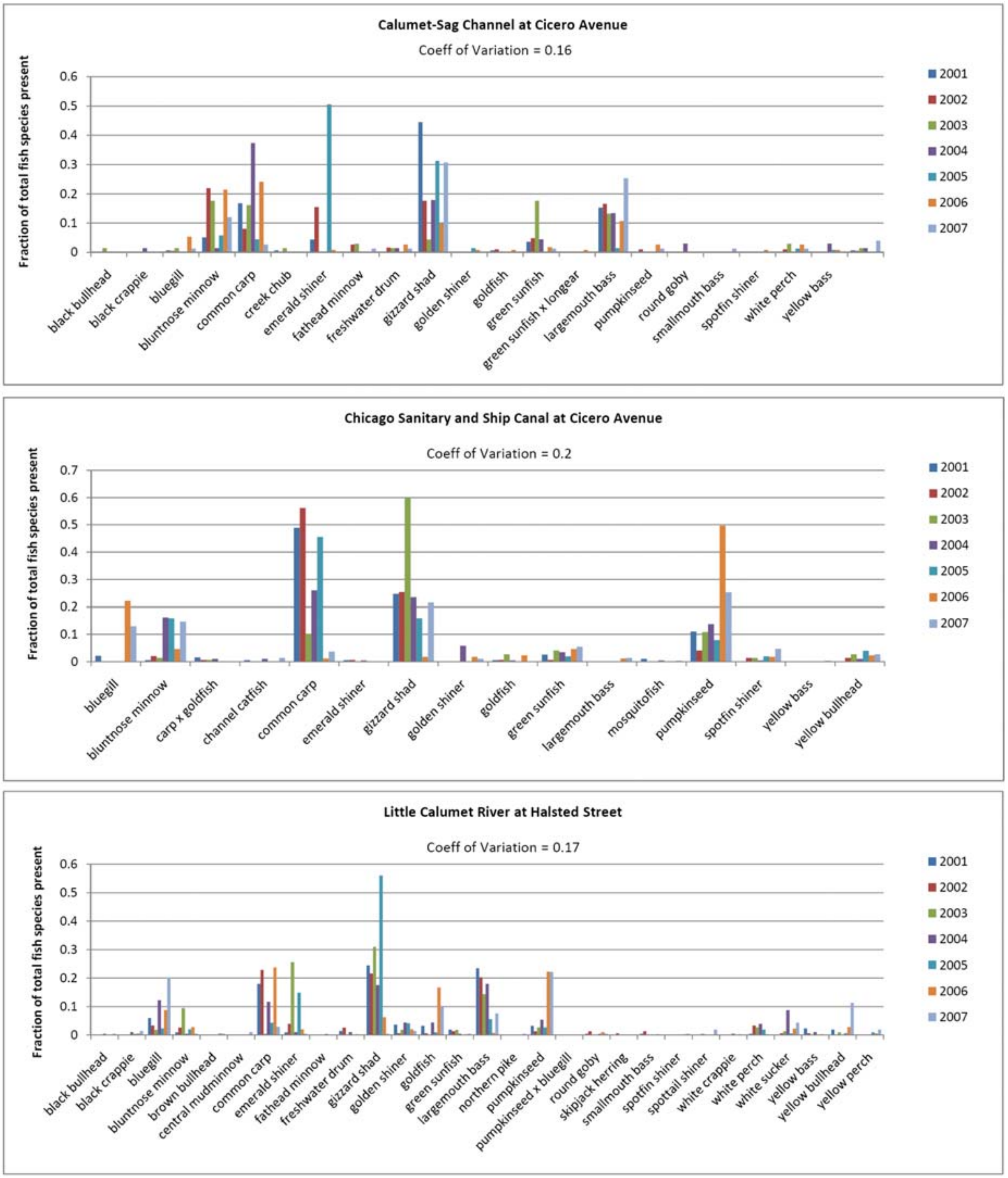


Figure 2-7. 2001 to 2007 Annual Station Fish Survey Results - Continued

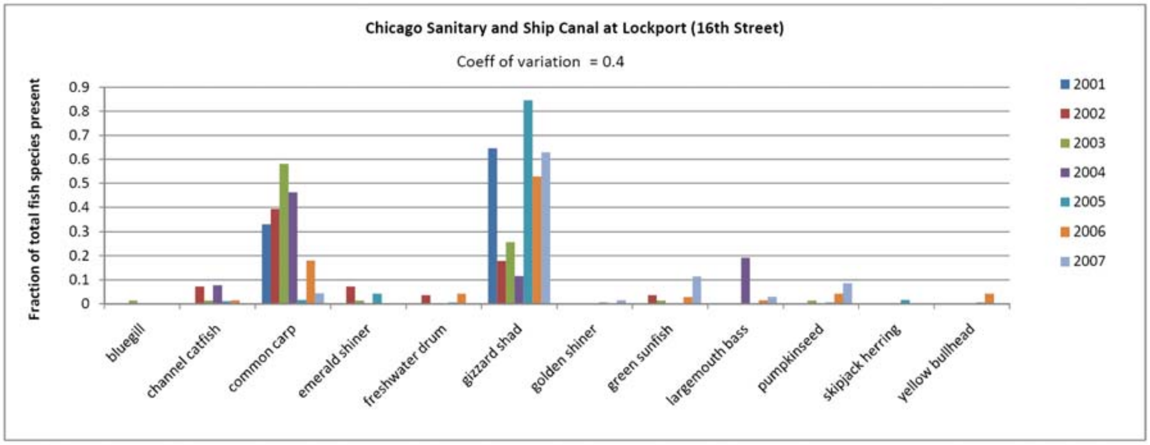
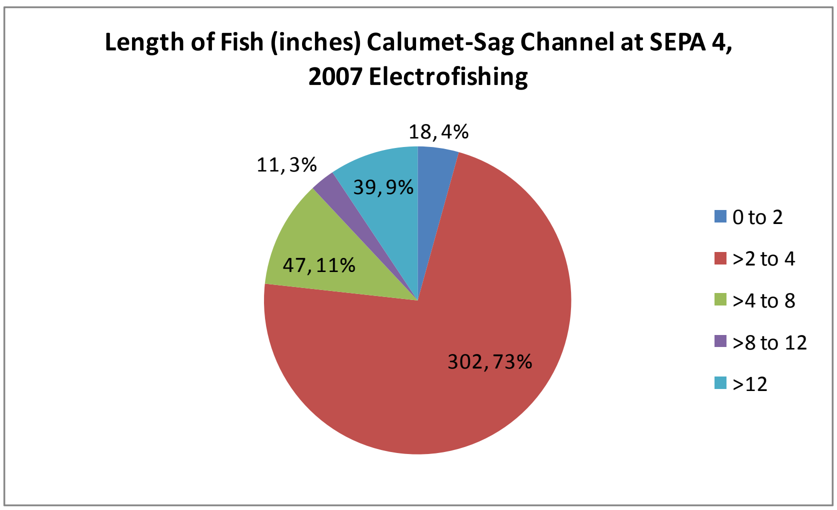


Figure 2-6. 2001 to 2007 Annual Station Fish Survey Results - Continued



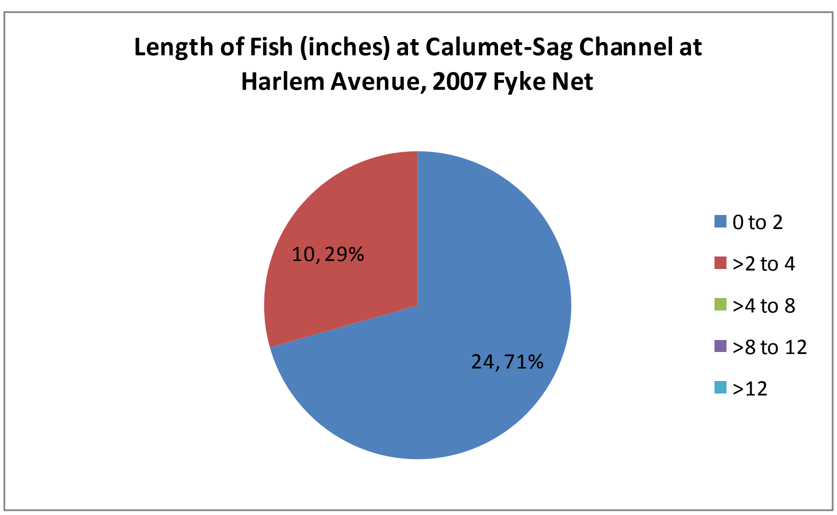
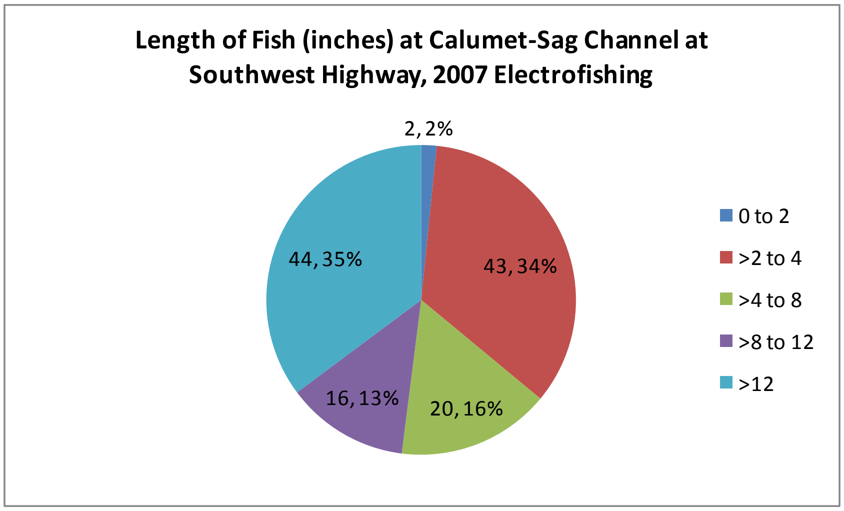


Figure 2-8. Results of Electrofishing and Fyke Net Samples by Length Interval , from 2007 Samples near Harlem Avenue on the Cal-Sag Channel.



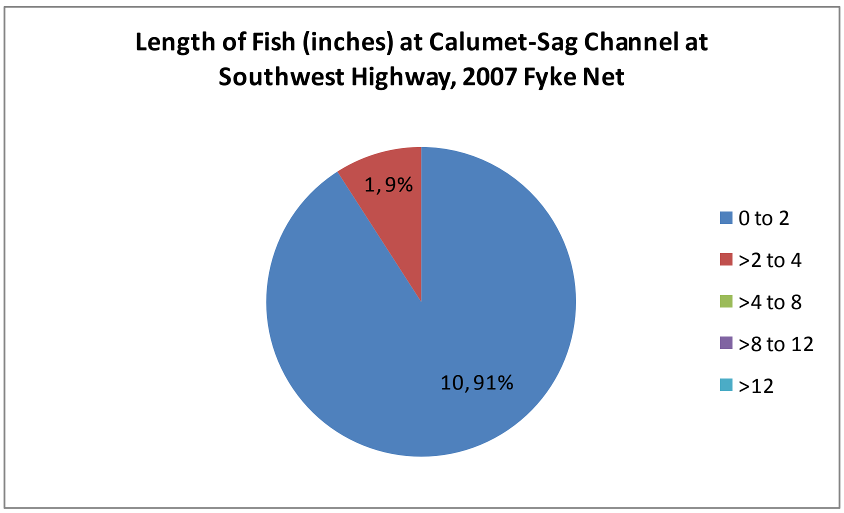
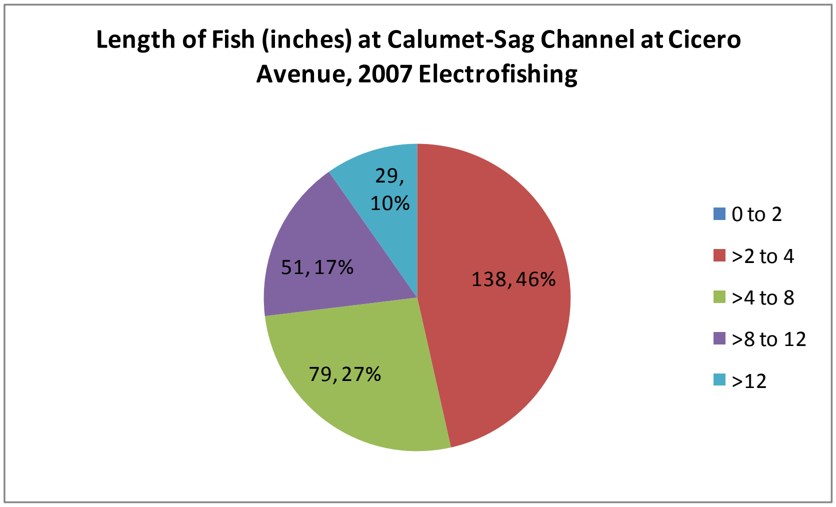


Figure 2-9. Results of Electrofishing and Fyke Net Samples by Length Interval , from 2007 Samples near Southwest Highway on the Cal-Sag Channel.



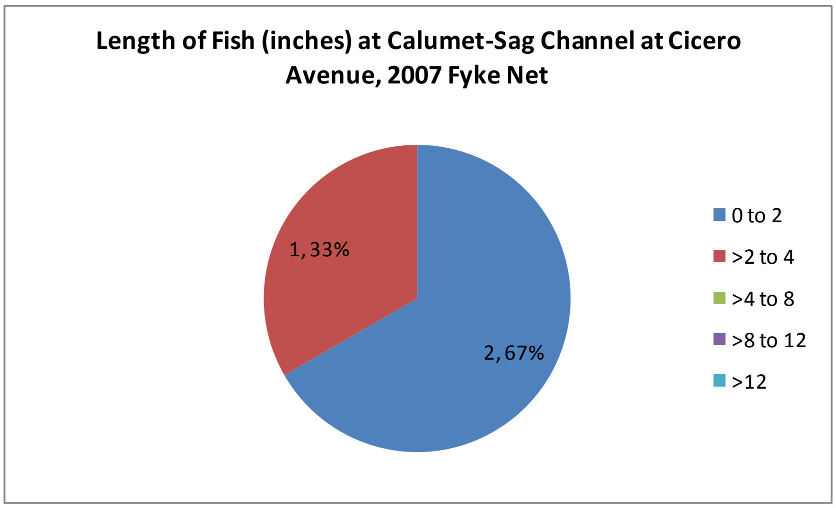


Figure 2-10. Results of Electrofishing and Fyke Net Samples by Length Interval , from 2007 Samples near Cicero Avenue on the Cal-Sag Channel.

3. SELECTION OF FISH METRICS

Fish metric selection and calculation is a common form of fish data analysis (Flotemersch et al. 2006). The general approach for screening fish metrics to determine which will be most useful and appropriate for this study follows methods applied in development of fish IBIs, as documented in peer-reviewed scientific literature. As stated in the preceding section, the objective of this study is not to develop a new IBI for the CAWS, but the process of metric development involves review, analysis, and reduction of fish metrics, so the methods used in the literature to develop IBIs provides a sound basis for screening of metrics appropriate for the CAWS.

3.1 COMPILATION OF FISH METRICS

Roset et al. (2007) suggests that starting with a large list of relevant candidate metrics increases the rigor of the system-specific metric selection process, by removing a level of *a priori* bias retained from previous studies. Lyons et al. (2001) provides a list of 26 fish metrics that were used as the starting point for the Wisconsin large warm water river IBI. The Lyons study is particularly relevant because it was developed in the Midwest for a range of larger river types, it is frequently cited, and Lyons' methodology is well-documented. Starting with Lyons' list of 26 fish metrics, LimnoTech then reviewed other relevant and significant IBI documents to identify other potentially applicable metrics:

- The Illinois IBI (IDNR 2000) was consulted as it currently provides the reference that the Illinois Environmental Protection Agency (IEPA) uses to determine attainment with aquatic life uses and may offer applicable metrics for the unique conditions within the CAWS (IEPA 2005). From this reference, ten additional metrics were added.

- The Ohio Boatable IBI (OEPA 1988) was consulted because it is frequently cited, still used after 20 years, one of the few fish IBI developed specifically for non-wadeable waters in the Midwest, and may offer applicable metrics for the unique conditions within the CAWS. Three additional metrics were included from the Ohio IBI.

- Karr's original work (Karr 1981) on fish IBIs was consulted because it was the seminal work on fish IBIs and most subsequent fish IBI work has been derived from it. No additional metrics were identified from this reference because they are included, as appropriate, in the above IBIs.

The metrics from the Illinois and Ohio IBIs increased the total number of metrics under consideration to 40. In addition to these previously used metrics, review of fish data from the CAWS and knowledge of the system suggested that some additional metrics would be worthy of consideration, including the following:

- *Percent intolerant species by number and by weight* – These metrics were added to provide additional quantification of the prevalence of pollution-sensitive individuals. This may provide information beyond the number of intolerant species.

- *Percent moderately tolerant species by number and by weight* – Previous studies have grouped species into tolerant or intolerant categories, however modifications to water quality standards recently proposed by the Illinois EPA have used the term "intermediately tolerant", so the inclusion of metrics that reflect species that are moderately tolerant to water quality impacts may be useful.

- *Number of tolerant species* – This metric was included to provide a metric of direct comparison with the number of intolerant and moderately tolerant species.

- *Number of sunfish species, excluding largemouth bass* – This metric was added because sunfish metrics used in other IBIs either included all sunfish or excluded both smallmouth and largemouth bass. Because smallmouth bass are a cool water species and are less tolerant of anthropogenic impacts, it was desirable to include them, while excluding largemouth bass because of their wide distribution across the CAWS.

With the addition of these 'custom' metrics, the list of potential fish metrics for consideration in this Study totaled 46. Review of additional scientific literature did not identify any more applicable metrics for inclusion, suggesting that the starting metric list will provide the rigor suggested by Roset et al. (2007). The 46 fish metrics and their sources are listed in Table 3.1.

Table 3-1. Initial List of Fish Metrics.

Fish Metric	Metric Name	Source
%DELT_(n)	% Diseased or with eroded fins, lesions, or tumors	Lyons et al. (2001)
CPUE	catch per unit effort	"
WPUE	weight per unit effort	"
%LRIV_(n)	% large river species by count	"
%LRIV_(wt)	% large river species by weight	"
%RIV_(n)	% riverine species by count	"
%RIV_(wt)	% riverine species by weight	"
%RNDSCK_(n)	% round sucker species by count	"
%RNDSCK_(wt)	% round sucker species by weight	"
%TOL_(n)	% tolerant species by count	"
%TOL_(wt)	% tolerant species by weight	"
INT	number of intolerant species	"
RIV	number of riverine species	"
%LTHPL_(n)	% lithophilic spawners by count	"
%LTHPL_(wt)	% lithophilic spawners by weight	"
NAT	number of native species	"
SCKR	number of sucker species	"
SR	total number of species	"
SUN1	number of sunfish species, excluding smallmouth and largemouth bass	"
SUN2	number of sunfish species, including smallmouth and largemouth bass	"
%INSCT_(n)	% insectivores by count	"
%INSCT_(wt)	% insectivores by weight	"
%OMV_(n)	% omnivores by count	"
%OMV_(wt)	% omnivores by weight	"
%TC_(n)	% top carnivores by count	"
%TC_(wt)	% top carnivores by weight	"
PRTOL	proportion of Illinois tolerant species	IDNR, 2000
LITOT	IL ratio of non tolerant coarse-mineral-substrate spawners	"
INTOL	number of IL native intolerant species	"
NFSH	number of IL native species	"
NMIN	number of IL native minnow species	"
NSUC	number of IL native sucker species	"
NSUN	number of IL native sunfish species	"
GEN	IL ratio of generalist feeders	"
NBINV	IL native benthic invertivore species	"
SBI	IL ratio of specialist benthic invertivore species	"
TNI	total number of individuals	OEPA, 1988
OH_B_Sun	number of OH native sunfish species	"
%OH_B_OMN(n)	% OH omnivores, excluding channel catfish	"
%INT_(n)	% intolerant species by count	New for this Study
%INT_(wt)	% intolerant species by weight	"
%MOD_(n)	% moderately intolerant species by count	"
%MOD_(wt)	% moderately intolerant species by weight	"
MOD	number of moderately tolerant species	"
TOL	number of tolerant species	"
SUN3	number of sunfish species, excluding largemouth bass	"

3.2 SPECIFICATION OF TOLERANCE VALUES

Several of the metrics identified for screening are intended to be relative indicators of species tolerance to pollution and other human impacts. Therefore these metrics require that species be classified according to their pollution tolerance. This is significant because proposed water quality standards for the CAWS are defined in terms of maintaining aquatic-life populations of fish species that are tolerant, intermediately tolerant, and/or intolerant. It should be noted that the proposed water quality standards do not assign fish species to these tolerance categories, nor do they refer to sources from which to derive tolerance assignments.

The classification of fishes into tolerance categories has typically been based on best professional judgment (BPJ) assignments of species based on general responses to environmental degradation (Meador and Carlisle 2007). Meador and Carlisle (2007) cited that the relative success of BPJ classifications of tolerance in the Midwest may be a result of the perceived homogeneity of regional conditions and that the assignments may have limited geographic application. Further, tolerance assignments rarely discriminate among pollutant stressors. Meador and Carlisle (2007) found that stressors such as suspended sediment, conductivity, chloride and total phosphorus provided a better measure of pollution tolerance assignment than the typically considered stressors of temperature, dissolved oxygen and pH. For example, white sucker (*Catostomus commersoni*) and fathead minnow (*Pimephales promelas*) are generally categorized as tolerant to pollutants by Illinois DNR (IDNR 2000) and Meador and Carlisle (2007), despite their intolerance to low dissolved oxygen and high temperatures (Meador and Carlisle 2007). Unfortunately, the detailed stressor assignments by Meador and Carlisle (2007) have not been developed for the Midwest region and do not consider many of the CAWS species, so their method will not be used here, but warrants future consideration.

The approach for assigning CAWS species to pollution tolerance categories of tolerant, intolerant or moderately tolerant, attempted to rely on locally derived sources, although no single source covered all species found within the CAWS. The approach started with tolerance assignments established at the state level (IDNR 2008), then for the Midwest (Lyons et al. 2001), at the national level (Meador and Carlisle 2008) and then for specific references where a species was not included in the previous documents.

The State of Illinois has developed a manual for calculating fish IBIs that is in draft form with continued updates (IDNR 2000). The manual includes pollution tolerance assignments for a range of species. The IDNR (2000) assignments only include tolerant or intolerant for those with any assignment and most species in the state list have no assignment (that is, they are given a “—“). The classifications were derived from regional fish manuals including Smith (1979), Becker (1983), Karr et al. (1986), Jenkins and Burkhead (1994), Bertrand et al. 1996, OEPA (1988) and BPJ, where information was not available (IDNR 2008). These classifications were retained as a primary reference sources.

The next level of tolerance assignment was derived from Lyons et al. (2001). The Lyons paper provided additional assignments to some species not assigned by IDNR

(2008) but also restricted species assignments to tolerant or intolerant categories only, with the remaining species assigned as "other". The tolerance assignments of Lyons stems from his earlier paper (Lyons 1992) where three qualitative criteria are used:

1) a known high degree of sensitivity to the types of environmental degradation as described by Becker (1983) and other regional fish publications;

2) areas of observed regions of decline in Wisconsin where environmental problems are known; and

3) designations used in other IBIs.

Meador and Carlisle (2007) from the U.S. Geological Survey (USGS) conducted an extensive analysis and assignment of numerous species into tolerant, moderately tolerant, and intolerant categories based on a recently published, quantified evaluation against physiochemical variables. The data set used for this effort is from the USGS national program and collected data from the USGS National Water Quality Assessment Program. These assignments were applied after the Lyons assignments. This effort resulted in a database of tolerance assignments for most remaining fish species, except for some remaining exotics. Finally, for those species not given tolerance assignments by the aforementioned efforts, species-specific papers were consulted and referenced for final pollution tolerance assignments. The tolerance values assigned for each species are included in Attachment B.

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4. SCREENING OF FISH METRICS

The procedures and rationale for screening of fish metrics are described below.

4.1 SCREENING OBJECTIVES

The process of screening the fish metrics had two primary objectives, as described below:

1. First, it was necessary to reduce the list of fish metrics to a more manageable number. Because the data corresponding to these metrics will be used for comparison to water quality and habitat data, too large a number of fish metrics would be too cumbersome. Metrics used to assess fishes vary based on the physical and biotic nature of the system (Flotemersch et al. 2006). Most fish IBIs reviewed for this study used a final set of ten to sixteen metrics (Karr 1981; OEPA 1988; Hughes et al., 1998; IDNR 2000; Lyons et al., 2001), so the goal was to reduce the list to within this range.

2. Second, the current scientific literature suggests that it is important to retain at least one metric from each major category of ecological function: species richness and composition, indicator species, trophic function, reproductive function, and individual abundance and condition (Simon and Lyons 1995; Lyons et al. 2001; Roset et al. 2007). Each category reflects a different aspect of fish assemblages that responds uniquely to aquatic ecosystem stressors (Hughes and Oberdorff 1999).

With these objectives in mind, the initial list of fish metrics was screened using the process described in the following sections.

4.2 METRICS LACKING DATA

The initial step in the screening process was to identify metrics for which there were no data available. This was essential, because the metrics will eventually be used for statistical or other quantitative comparisons to other data types (i.e., water quality and habitat) and the lack of data would preclude such quantitative comparisons.

Review of the CAWS fish data from 2001 to 2007 revealed two metrics for which no data exist in the CAWS: the percentage of round sucker taxa (genera Cycleptus, Hypentelium, Minytrema, and Moxostoma) by weight and by number (%RNDSCK_(n) and %RNDSCK_(wt)). Based on this observation, these metrics were eliminated from further consideration. This initial screening reduced the list of fish metrics from 46 to 44.

4.3 METRIC RANGE

Review of the scientific literature for fish IBI development shows that a typical method of screening fish metrics is to examine those metrics that reflect the number of species identified in a particular category or type and to screen out those that represent relatively few species (McCormick et al. 2001; Emery et al. 2003). This so-called "range test" is used to eliminate metrics for which between 0 and 2 species were identified.

The "range test" was applied to the CAWS fish data and four metrics were found for which only one or two species were identified between 2001 and 2007. These four metrics were: the number of Illinois native benthic invertivore species (NBINV), the number of Illinois native sucker species (NSUC), the number of sucker species (SCKR), and the Illinois ratio of specialist benthic invertivore species (SBI). On the basis of this observation, these four metrics were eliminated from further consideration, reducing the number of potential metrics to 40.

4.4 METRIC REDUNDANCY

A very common method of screening metrics is to analyze the metrics for redundancy with each other. This method of screening is commonly used in index development (Hughes et al. 1998; Lyons et al. 2001, Emery et al. 2003, Wilhelm et al. 2005). In this analysis, Pearson's correlation was calculated for pairs of metrics and the resulting correlation values were used to screen out statistically redundant metrics. This process is described in more detail below.

Before calculating the Pearson correlation coefficients, the metrics were evaluated for normality and several metrics were found to have skewed distributions. Some were right skewed, others were left skewed. The left skewed metrics were log transformed, resulting in near-normal distributions and include the following metrics: WPUE, TNI, TOL_TNI, CPUE, %TC_(wt), %LTHPL_(wt), %MOD_(n), and %MOD_(wt). For the right skewed metrics (mostly data representing proportions) the arcsine-square-root-transform was evaluated, but because the distribution shapes did not improve these metrics were left untransformed.

Pearson correlation coefficients were calculated between the individual metrics in order to identify metrics that are highly correlated. Correlated metrics indicate some degree of redundancy, i.e. they respond similarly to characteristics of the CAWS system and can be used to derive similar conclusions. Threshold correlation strength had to be chosen to identify the metrics with "strong" correlation, as reported in the literature. In the literature reviewed, this threshold correlation value was usually between 0.6 and 0.75 (Lyons et al. 2001; McCormick et al. 2001; Emery et al. 2003; Whittier et al. 2007). For this analysis a value of 0.6 was used, which is what Lyons used for his large warm water river IBI (Lyons et al. 2001). Thus, pairs of metrics with a correlation coefficient above the threshold were defined as redundant and only one metric of the pair was retained for subsequent analyses. The matrix of Pearson's correlation coefficients is presented in Attachment C.

Because many metrics were highly correlated with multiple metrics, some judgment was necessary in using this screening method to insure representation from each of the five ecological function categories. For example, the original list of 46 metrics only contained three reproductive function metrics and five abundance and condition metrics, therefore these metrics were, in some cases, preferentially retained.

This screening step was successful in reducing the number of metrics from 40 to 16. The list of metrics remaining after screening for redundancy is presented in Table 4-1.

Table 4-1. Fish Metrics Remaining after Screening for Redundancy.

Fish Metric	Metric Name	Ecological Function Category
%DELT_(n)	% Diseased or with eroded fins, lesions, or tumors	ACM
CPUE	catch per unit effort	ACM
%LTHPL_(n)	% lithophilic spawners by count	RFM
%LTHPL_(wt)	% lithophilic spawners by weight	RFM
%INSCT_(n)	% insectivores by count	TFM
%INSCT_(wt)	% insectivores by weight	TFM
%TC_(n)	% top carnivores by count	TFM
%TC_(wt)	% top carnivores by weight	TFM
PRTOL	proportion of Illinois tolerant species	ISM
LITOT	IL ratio of non tolerant coarse-mineral-substrate spawners	RFM
INTOL	number of IL native intolerant species	ISM
NMIN	number of IL native minnow species	SRC
NSUN	number of IL native sunfish species	SRC
GEN	IL ratio of generalist feeders	TFM
%INT_(n)	% intolerant species by count	ISM
%MOD_(wt)	% moderately intolerant species by weight	ISM

4.5 METRIC VARIABILITY

After applying the methods described above, the number of retained metrics (16) still exceeded the target number of metrics, so the retained metrics were inspected to determine whether a rational scientific basis could be identified for elimination of any of them.

It was noted that the set of metrics listed in Table 4-1 contained three pairs of metrics that represented similar fish attributes for both count and weight:

- % lithophilic spawners by count (%LTHPL_(n)) and weight (%LTHPL_(wt))
- % insectivores by count (%INSCT_(n)) and weight (%INSCT_(wt))
- % top carnivores count (%TC_(n)) and weight (%TC_(wt))

In addition, two metrics remained that represented intolerant species: %INT_(n) and INTOL. Because each of these four pairs of metrics measure the same attributes of fish assemblages, it seemed appropriate to select one metric from each pair to carry forward. To determine which metric in each pair to retain, the variability of the metrics within the data set was examined. The rationale for using metric variability as a screening measure was that preference should be given to metrics that exhibited greater variation within the system, since those metrics will be more likely to help identify relationships to other system attributes such as water quality and physical habitat.

Calculated values for each of the paired metrics were extracted from the CAWS fish database and the coefficient of variation (CV) for each metric was calculated using all data from each year from 2001 through 2007 to give a measure of data variability in each year for each metric. The CV for each metric was also calculated at each of seven annual sampling stations for all years to determine variability across the system. The results are discussed below.

The system-wide CVs for %LTHPL_(wt) and %LTHPL_(n) are depicted graphically in Figure 4-1.

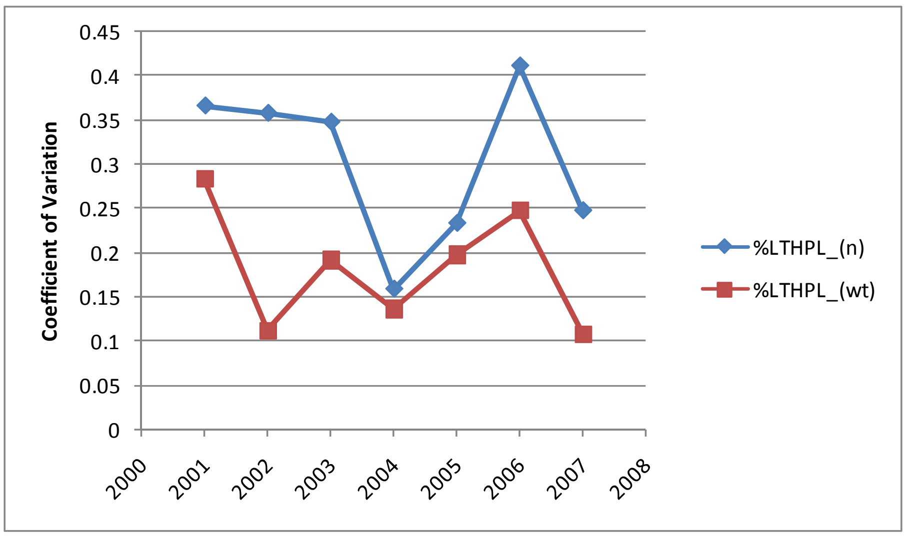

Figure 4-1. Coefficient of Variation for %LTHPL_(wt) and %LTHPL_(n), for 2001 through 2007 Data.

Although the CVs for both %LTHPL_(wt) and %LTHPL_(n) are both very low (less than 0.5 in every year), the calculated value for %LTHPL_(n) is consistently higher, in many cases double that of %LTHPL_(wt). The CVs for %LTHPL_(n) also appear to exhibit more variability over time than for %LTHPL_(wt), which is also evident from the CVs calculated for the annual sampling stations depicted in Figure 4-2. Based on these observations, %LTHPL_(n) was retained and %LTHPL_(wt) was eliminated.

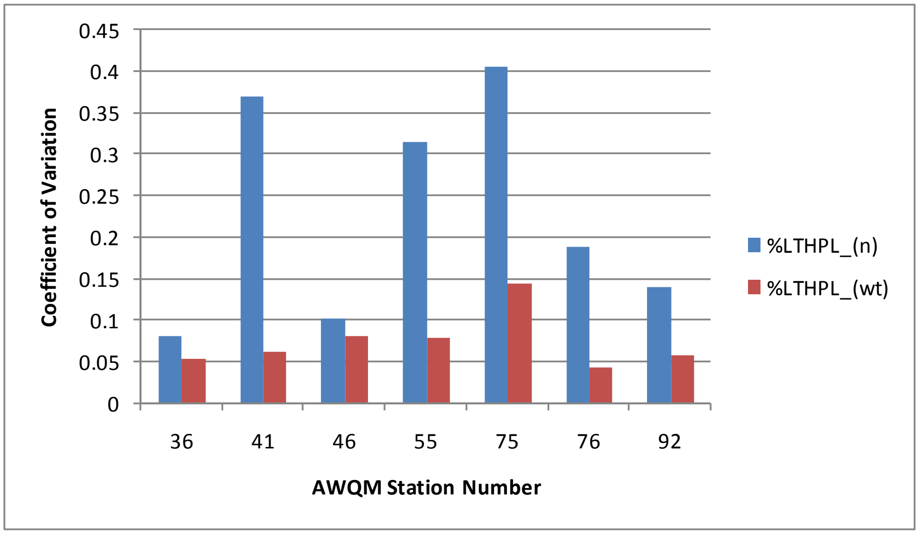

Figure 4-2. Coefficient of Variation for %LTHPL_(wt) and %LTHPL_(n) at Annual Sampling Stations.

The same comparison was made for %INSCT_(n) and %INSCT_(wt). In this case, the CV for %INSCT_(n) is consistently higher than for %INSCT_(wt), both on a system-wide basis across multiple years (Figure 4-3) as well as when compared between annual sampling stations (Figure 4-4). On the basis of these comparisons, %INSCT_(n) was retained and %INSCT_(wt) was eliminated.

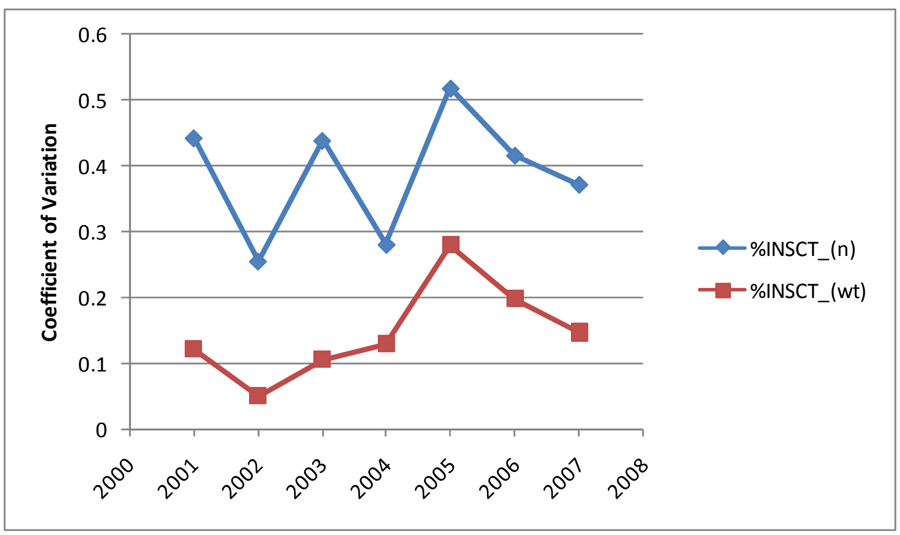

Figure 4-3. Coefficient of Variation for %INSCT_(wt) and % INSCT_(n), for 2001 through 2007 Data.

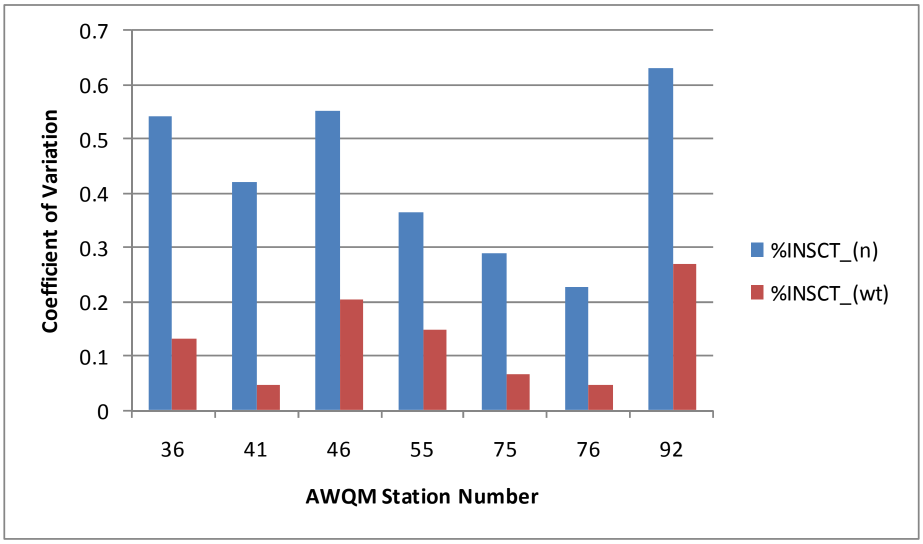

Figure 4-4. Coefficient of Variation for %INSCT_(wt) and % INSCT_(n) at Annual Sampling Stations.

Similarly, the CVs for %TC_(n) and %TC_(wt) were compared. In the case of this metric pair, most of the CVs for %TC_(wt) were above 1.0, while all the CVs for %TC_(n) were below 1.0, suggesting that %TC_(wt) has significantly higher variability (Figure 4-5). While some sampling stations exhibited similar CVs for both %TC_(wt) and %TC_(n) (Figure 4-6), three stations had significantly higher CVs for %TC_(wt). Based on these observations, %TC_(wt) was retained and %TC_(n) was eliminated.

Finally, the CVs for %INT_(n) and INTOL were compared both on a system-wide basis for each sampling year and for each annual sampling station across all years. The comparison of system-wide variability through time (Figure 4-7) clearly indicates that %INT_(n) has higher variability than INTOL, even though the inter-station comparison (Figure 4-8) shows similarity between the two metrics in terms of variability. On the basis of these observations, %INT_(n) was retained and INTOL was eliminated.

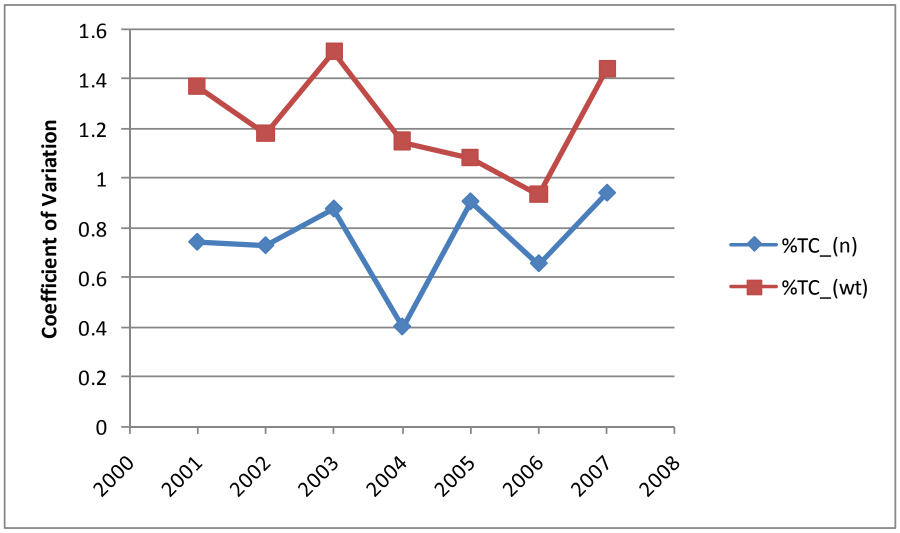

Figure 4-5. Coefficient of Variation for %TC_(wt) and % TC_(n), for 2001 through 2007 Data.

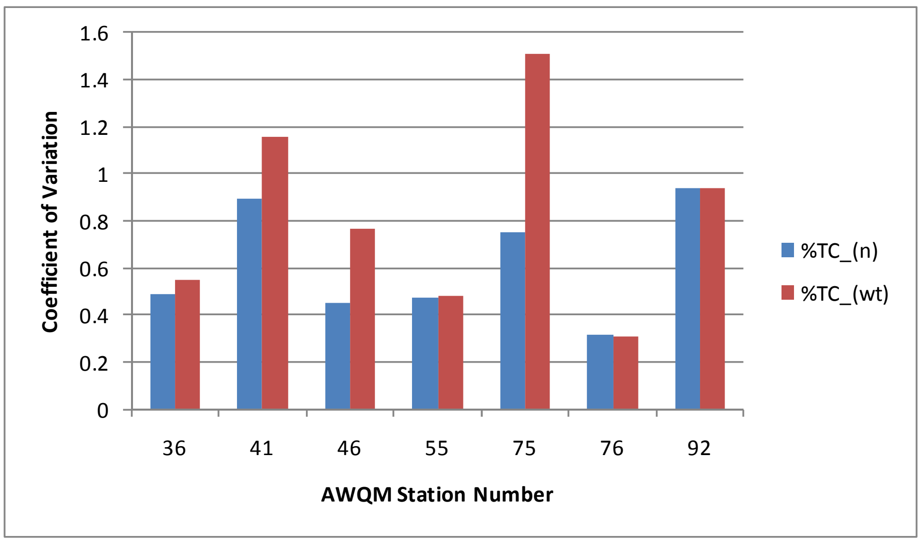

Figure 4-6. Coefficient of Variation for %TC_(wt) and % TC_(n) at Annual Sampling Stations.

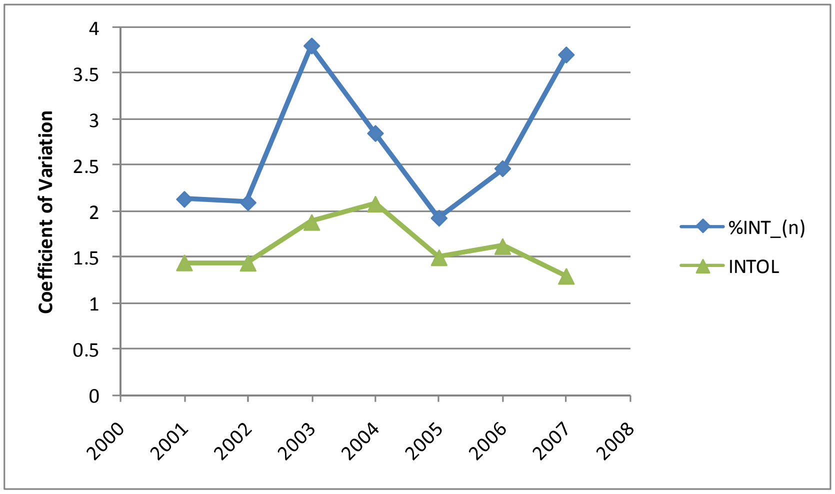

Figure 4-7. Coefficient of Variation for %INT_(n) and INTOL, for 2001 through 2007 Data.

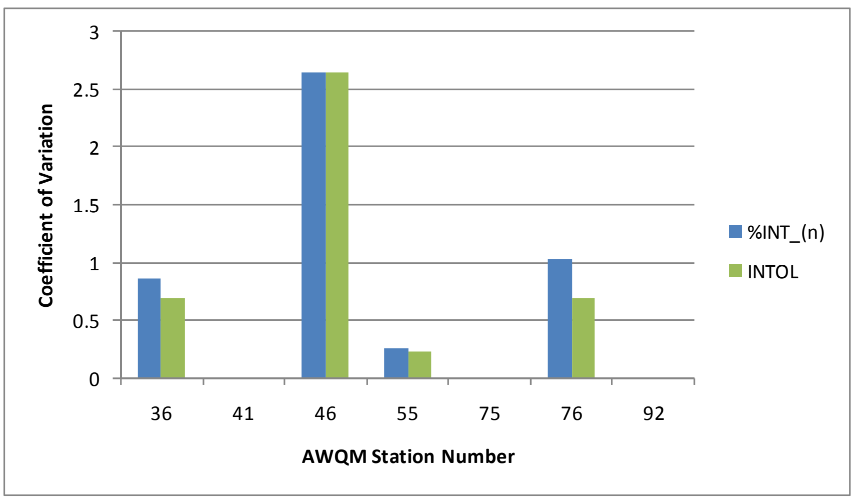

Figure 4-8. Coefficient of Variation for %INT_(n) and INTOL at Annual Sampling Stations.

In summary, based on review of metric variability as quantified by each metric's coefficient of variation, the following metric selections were made:

- %LTHPL_(n) was retained over %LTHPL_(wt);
- %INSCT_(n) was retained over %INSCT_(wt);
- %TC_(wt) was retained over %TC_(n); and
- %INT_(n) was retained over INTOL.

These selections reduced the list of metrics to 12, which are summarized in the following section.

5. FINAL RECOMMENDED LIST OF METRICS

After completion of the screening process described in the preceding section, twelve metrics were retained for use in the CAWS (Table 5-1). The retained metrics are representative of each of the five ecological function categories as recommended by Simon and Lyons (1995), Lyons et al. (2001), Roset et al. (2007): species richness and composition (SRC), indicator species (ISM), trophic function (TFM), reproductive function (RFM), and individual abundance and condition (ACM). These are further described below,

> SRC category includes two native species metrics. Species richness and composition are a measure of species diversity and Hughes and Oberdorff (1999) suggest using native species metrics for assessing physical or water quality stressors where non-natives are abundant, as found in the CAWS. Both metrics are also used by the State of Illinois and should be appropriate measures for species richness assessments within the CAWS.
>
> ISM includes three proportional metrics of tolerant, moderately tolerant and intolerant measures. Proportional measures for species have been recommended by others as well (Karr et al. 1986; Lyons et al. 1995). The current numbers of intolerant species across the CAWS is generally low and it is generally expected that the proportion of intolerant species is responding to physical and water quality stressors unique to the CAWS. However, it is expected that these species would respond positively to stressor reductions and may provide an appropriate metric for the CAWS. Both tolerant and moderately tolerant species are wide-spread across the CAWS and it is assumed that the tolerant metrics would respond negatively to physical and water quality improvements while moderately tolerant species proportions increase with the reduction of stressors. All three proportional measures are applicable measures across the CAWS.
>
> TFM includes a range of feeding metrics for the CAWS that include top carnivores, generalists and insect feeders. It is generally expected that top carnivores and insectivores would respond negatively to physical and water quality stressors, while generalists would respond positively to these stressors (Flotemersch et al. 2006). All three metrics are applicable across the CAWS, are appropriate measures of trophic function and are supported by the original work of Karr (1981) and subsequent authors (Hughes and Oberdorff 1999).
>
> RFM includes a proportion of all lithophilic species as well as intolerant lithophilic species native to Illinois. It is generally expected that lithophilic species would respond negatively to both physical and water quality stressors (Flotemersch et al. 2006). Although it is expected that lithophilic habitat is limited across the CAWS, these metrics are included because existing habitat conditions as well as future improvements within portions of the CAWS should result in a positive response by these metrics. The metrics are used within the Illinois IBI as

well as others (Emery et al. 1999; Flotemersch et al. 2006) and are appropriate for the CAWS.

ACM includes a metric for the condition of the sampled fishes as well as the efficiency of the collection methods. It is generally expected that the observed number of physical anomalies of collected fishes changes in response to a range of water quality stressors. Hughes and Oberdorff (1999) suggest including this metric where the possibility for changes in the incidence of disease and deformity exist. Hughes and Oberdorff (1999) describe sample abundance as a surrogate for system productivity but caution that nutrient and thermal enrichment may affect this metric response. Typically, it is expected that the efficiency of collected fishes decrease in response to both water quality and habitat stressors (Flotemersch et al. 2006) but the uniqueness of the CAWS conditions may warrant special consideration of the use of this metric in subsequent analysis. Both measures are commonly used measures for ACM and are appropriate for the CAWS.

In summary, the methods used for fish metric selection for the CAWS are appropriate, literature supported and robust methods. These methods have produced a final metric list that is appropriate and sensitive to responses of both physical habitat and water quality conditions within the CAWS and will be useful for further fish-habitat and fish-water quality analyses.

Table 5-1. Final Recommended Fish Metrics for Use in the CAWS.

Fish Metric	Metric Name	Ecological Function Category
%DELT_(n)	% Diseased or with eroded fins, lesions, or tumors	ACM
CPUE	catch per unit effort	ACM
%LTHPL_(n)	% lithophilic spawners by count	RFM
%INSCT_(n)	% insectivores by count	TFM
%TC_(wt)	% top carnivores by weight	TFM
PRTOL	proportion of Illinois tolerant species	ISM
LITOT	IL ratio of non tolerant coarse-mineral-substrate spawners	RFM
NMIN	number of IL native minnow species	SRC
NSUN	number of IL native sunfish species	SRC
GEN	IL ratio of generalist feeders	TFM
%INT_(n)	% intolerant species by count	ISM
%MOD_(wt)	% moderately intolerant species by weight	ISM

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ATTACHMENT A:

CAWS FISH DATA STATIONS AND SAMPLING DATES

USED IN THIS ANALYSIS

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IEPA Station Description	Station ID	Station Description	2001	2002	2003	2004	2005	2006	2007	Total Count
North Shore Channel	35	North Shore Channel at Central Street	9/24/01				7/20/05			2
	36	North Shore Channel at Touhy Avenue	9/26/01	7/31/02	7/24/03	9/29/04	7/21/05	7/10/06	7/12/07	7
	101	North Shore Channel at Foster Avenue	9/27/01				9/8/05			2
	102	North Shore Channel at Oakton Street	9/25/01				7/20/05			2
North Branch Chicago River from its confluence with North Shore Channel to the south end of the North Avenue Turning Basin	37	North Branch Chicago River at Wilson Avenue	10/1/01				9/7/05			2
	73	North Branch Chicago River at Diversey Parkway	10/3/01				9/6/05			2
Little Calumet River from its confluence with Calumet River and Grand Calumet River to its confluence with Calumet-Sag Channel	56	Little Calumet River at Indiana Avenue			9/29/03				7/30/07	2
	76	Little Calumet River at Halsted Street	9/12/01	9/16/02	9/29/03	9/30/04	9/27/05	7/21/06	7/31/07	7
	902,SEPA2	Little Calumet River at SEPA 2					10/20/05	10/20/06		2
Calumet-Sag Channel	43	Calumet-Sag Channel at Route 83			7/30/03				9/14/07	2
	58	Calumet-Sag Channel at Ashland Avenue			9/5/03				8/1/07	2
	59	Calumet-Sag Channel at Cicero Avenue	9/14/01	9/17/02	7/31/03	8/31/04	9/29/05	7/24/06	8/2/07	7
	903,SEPA3	Calumet-Sag Channel at SEPA 3			10/6/03		10/20/05		10/31/07	3
	904,SEPA4	Calumet-Sag Channel at SEPA 4			10/3/03	10/19/04	10/18/05	10/30/06	10/29/07	5
	905,SEPA5	Calumet-Sag Channel at SEPA 5			10/1/03	10/18/04	10/18/05	10/17/06	10/23/07	5
		Calumet-Sag Channel at 104th Street							9/14/07	1
		Calumet-Sag Channel at Kedzie Avenue							9/13/07	1
		Calumet-Sag Channel at Southwest Highway							9/13/07	1
North Branch Chicago River from the south end of the North Avenue Turning Basin to its confluence with South Branch Chicago River and Chicago River	46	North Branch Chicago River at Grand Avenue	10/2/01	8/1/02	7/23/03	8/27/04	7/18/05	7/11/06	7/11/07	7
Chicago River	74	Chicago River at Lake Shore Drive		8/2/02				7/26/06		2
	100	Chicago River at Wells Street		8/21/02				7/27/06		2
South Branch Chicago River and its South Fork	39	South Branch Chicago River at Madison Street		8/27/02				7/28/06		2
	40	Chicago Sanitary and Ship Canal at Damen Avenue		8/19/02				8/30/06		2
	99	Bubbly Creek at Archer Avenue		8/20/02				9/5/06		2
	108	South Branch Chicago River at Loomis Street		8/26/02				9/12/06		2
	99.2	Bubbly Creek at 35th St.			9/30/03	10/20/04	8/10/05			3
	99.1	Bubbly Creek at I-55			9/30/03	10/20/04	8/10/05			3
	99.3	Bubbly Creek at RAPS			9/30/03	10/20/04	8/10/05			3
Chicago Sanitary and Ship Canal	41	Chicago Sanitary and Ship Canal at Harlem Avenue	9/7/01	9/3/02	7/21/03	8/24/04	8/26/05	8/21/06	7/16/07	7
	42	Chicago Sanitary and Ship Canal at Route 83		8/28/02				8/31/06		2
	48	Chicago Sanitary and Ship Canal at Stephen Street		9/10/02				8/28/06		2
	75	Chicago Sanitary and Ship Canal at Cicero Avenue**	9/4/01	8/29/02	7/18/03	8/23/04	8/22/05	8/29/06	7/17/07	7
	92	Chicago Sanitary and Ship Canal at Lockport (16th Street)	9/4/01	9/11/02	7/29/03	8/30/04	9/15/05	7/25/06	7/10/07	7
	905.1,SEPA5_CSSC	Chicago Sanitary and Ship Canal at SEPA 5			10/1/03	10/18/04	10/18/05	10/17/06	10/23/07	5
	Total Stations: 34		12	15	17	13	20	19	17	113

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ATTACHMENT B:

LIST OF FISH SPECIES IDENITIFIED IN THE CAWS (2001-2007) AND THEIR TOLERANCE ASSIGNMENTS

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Scientific Name	Common Name	Tolerant	Intolerant	Moderate
Alosa pseudoharengus	alewife	X[4]		
Alosa chrysochloris	skipjack herring			X[5]
Dorosoma cepedianum	gizzard shad	X[3]		
Oncorhynchus mykiss	rainbow trout		X[3]	
Umbra limi	central mudminnow	X[2]		
Esox lucius	northern pike			X[3]
Carassius auratus	goldfish	X[1]		
Cyprinus carpio	common carp	X[1]		
Notemigonus crysoleucas	golden shiner	X[1]		
Semotilus atromaculatus	creek chub	X[1]		
Cyprinella spiloptera	spotfin shiner			X[3]
Pimephales promelas	fathead minnow	X[1]		
Pimephales notatus	bluntnose minnow	X[1]		
Notropis atherinoides	emerald shiner	X[3]		
Notropis hudsonius	spottail shiner		X[2]	
Notropis stramineus	sand shiner			X[3]
Ictiobus niger	black buffalo		X[2]	
Catostomus commersoni	white sucker	X[1]		
Ictalurus punctatus	channel catfish	X[3]		
Ameiurus natalis	yellow bullhead	X[1]		
Ameiurus melas	black bullhead			X[3]
Ameiurus nebulosus	brown bullhead			X[3]
Noturus gyrinus	tadpole madtom			X[3]
Fundulus notatus	blackstripe topminnow	X[3]		
Gambusia affinis	mosquitofish	X[3]		
Labidesthes sicculus	brook silverside			X[3]
Morone saxatilis	striped bass			X[6]
Morone chrysops	white bass	X[3]		
Morone mississippiensis	yellow bass			X[9]
Morone americana	white perch	X[7]		
Pomoxis nigromaculatus	black crappie	X[3]		
Pomoxis annularis	white crappie	X[3]		
Ambloplites rupestris	rock bass		X[2]	
Micropterus salmoides	largemouth bass	X[3]		
Micropterus dolomieu	smallmouth bass		X[1]	
Lepomis gulosus	warmouth			X[3]
Lepomis cyanellus	green sunfish	X[1]		
Lepomis macrochirus	bluegill			X[3]
Lepomis gibbosus	pumpkinseed			X[3]
Lepomis humilis	orangespotted sunfish	X[3]		
Stizostedion vitreum	walleye			X[3]

Scientific Name	Common Name	Tolerant	Intolerant	Moderate
Perca flavescens	yellow perch			X[3]
Aplodinotus grunniens	freshwater drum	X[3]		
Neogobius melanostomus	round goby	X[8]		
Cyprinus spp.	carp x goldfish	X[11]		
Oncorhynchus tshawytscha	chinook salmon		X[9]	
Oncorhynchus kisutch	coho salmon		X[9]	
Lepomis spp.	green sunfish x bluegill	X[11]		
Lepomis spp.	green sunfish x longear	X[11]		
Lepomis spp.	green sunfish x pumpkinseed	X[11]		
Oreochromis niloticus	nile tilapia	X[10]		
Lepomis spp.	pumpkinseed x bluegill	X[11]		

References

X[1] - IDNR 2000
X[2] - Lyons et al. 2001
X[3] - USGS 2008
X[4] - FWS 1986
X[5] - Barbour et al. 1999
X[6] - EPA 2008
X[7] - FWS 1983
X[8] - Corkum et al. 2004
X[9] - Plafkin et al. 1989
X[10] - Popma and Masser 1999
X[11] - LTI 2008

ATTACHMENT C:

MATRIX OF PEARSON'S CORRELATION VALUES FOR FISH METRICS

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Pearson Coefficient Matrix

	%DELT_(n)	%INSCT_(n)	%INSCT_(wt	%INT_(n)	%INT_(wt)	%LRIV_(n)	%LRIV_(wt)	%LTHPL_(n)	%LTHPL_(wt	%MOD_(n)	%MOD_(wt)	OH_B_OMV_	%OMV_(n)	%OMV_(wt)	%RIV_(n)	%RIV_(wt)	%TC_(n)
%DELT_(n)	**1**	0.265	0.351	0.036	-0.177	-0.053	0.287	-0.010	0.321	0.128	-0.203	0.306	0.313	0.323	0.012	0.280	0.237
%INSCT_(n)	0.265	**1**	0.557	0.162	0.144	-0.527	-0.133	-0.522	-0.028	0.336	0.230	-0.385	-0.384	0.005	-0.416	-0.049	0.504
%INSCT_(wt)	0.351	0.557	**1**	-0.062	0.000	0.021	0.425	0.022	0.409	0.087	-0.141	0.072	0.078	0.483	0.055	0.434	0.351
%INT_(n)	0.036	0.162	-0.062	**1**	0.269	-0.195	-0.249	-0.111	-0.168	0.108	0.111	-0.105	-0.111	-0.171	-0.147	-0.186	0.194
%INT_(wt)	-0.177	0.144	0.000	0.269	**1**	0.078	-0.321	0.121	-0.098	-0.077	0.056	-0.362	-0.363	-0.347	0.057	-0.316	-0.002
%LRIV_(n)	-0.053	-0.527	0.021	-0.195	0.078	**1**	0.582	**0.955**	0.515	-0.426	-0.494	0.371	0.377	0.407	**0.873**	0.482	-0.517
%LRIV_(wt)	0.287	-0.133	0.425	-0.249	-0.321	0.582	**1**	0.563	**0.888**	-0.167	-0.513	0.518	0.523	**0.906**	0.574	**0.900**	-0.185
%LTHPL_(n)	-0.010	-0.522	0.022	-0.111	0.121	**0.955**	0.563	**1**	0.530	-0.471	-0.543	0.328	0.329	0.395	**0.826**	0.458	-0.489
%LTHPL_(wt)	0.321	-0.028	0.409	-0.168	-0.098	0.515	**0.888**	0.530	**1**	-0.128	-0.485	0.421	0.410	**0.808**	0.521	**0.810**	-0.166
%MOD_(n)	0.128	0.336	0.087	0.108	-0.077	-0.426	-0.167	-0.471	-0.128	**1**	0.589	0.041	0.026	-0.049	-0.107	-0.024	0.581
%MOD_(wt)	-0.203	0.230	-0.141	0.111	0.056	-0.494	-0.513	-0.543	-0.485	0.589	**1**	-0.236	-0.237	-0.407	-0.249	-0.322	0.386
%OH_B_OMV_(n)	0.306	-0.385	0.072	-0.105	-0.362	0.371	0.518	0.328	0.421	0.041	-0.236	**1**	**0.997**	0.513	0.375	0.476	-0.099
%OMV_(n)	0.313	-0.384	0.078	-0.111	-0.363	0.377	0.523	0.329	0.410	0.026	-0.237	**0.997**	**1**	0.518	0.376	0.479	-0.090
%OMV_(wt)	0.323	0.005	0.483	-0.171	-0.347	0.407	**0.906**	0.395	**0.808**	-0.049	-0.407	0.513	0.518	**1**	0.425	**0.831**	-0.066
%RIV_(n)	0.012	-0.416	0.055	-0.147	0.057	**0.873**	0.574	**0.826**	0.521	-0.107	-0.249	0.375	0.376	0.425	**1**	**0.609**	-0.277
%RIV_(wt)	0.280	-0.049	0.434	-0.186	-0.316	0.482	**0.900**	0.458	**0.810**	-0.024	-0.322	0.476	0.479	**0.831**	**0.609**	**1**	-0.070
%TC_(n)	0.237	0.504	0.351	0.194	-0.002	-0.517	-0.185	-0.489	-0.166	0.581	0.386	-0.099	-0.090	-0.066	-0.277	-0.070	**1**
%TC_(wt)	-0.352	0.096	-0.101	0.167	0.245	-0.274	-0.536	-0.283	-0.581	0.159	0.539	-0.344	-0.333	-0.523	-0.215	-0.447	0.455
%TOL_(n)	0.015	-0.230	0.247	-0.132	0.057	**0.625**	0.499	**0.708**	0.455	-0.672	-0.591	0.320	0.330	0.434	0.385	0.372	-0.296
%TOL_(wt)	0.203	0.028	0.466	-0.061	-0.255	0.428	**0.726**	0.443	**0.636**	-0.119	-0.374	0.508	0.512	**0.740**	0.371	0.551	0.040
CPUE	-0.072	0.210	0.068	0.164	0.102	-0.224	-0.064	-0.236	-0.013	**0.794**	0.485	-0.045	-0.059	0.035	0.035	0.025	0.409
GEN	0.313	-0.384	0.078	-0.110	-0.363	0.377	0.523	0.329	0.411	0.026	-0.237	**0.997**	**1.000**	0.518	0.376	0.480	-0.090
INT	-0.083	0.112	0.017	0.596	0.420	0.096	-0.099	0.174	0.001	-0.079	-0.013	-0.255	-0.259	-0.094	0.092	-0.082	0.084
INTOL	0.016	0.125	0.021	**0.647**	0.223	0.031	-0.043	0.107	0.032	-0.029	0.020	-0.161	-0.168	-0.024	0.044	-0.018	0.130
LIT0T	0.049	0.131	-0.066	**0.983**	0.154	-0.189	-0.198	-0.113	-0.146	0.111	0.094	-0.066	-0.072	-0.124	-0.143	-0.141	0.192
MOD	-0.114	0.129	0.071	0.041	0.117	-0.035	-0.003	-0.029	0.023	0.570	0.345	-0.032	-0.047	0.073	0.126	0.069	0.251
NAT	-0.122	0.184	0.183	0.113	0.155	-0.028	0.056	0.033	0.077	0.312	0.180	-0.073	-0.082	0.132	0.068	0.114	0.301
NFSH	-0.122	0.184	0.183	0.113	0.155	-0.028	0.056	0.033	0.077	0.312	0.180	-0.073	-0.082	0.132	0.068	0.114	0.301
NMIN	-0.275	0.156	0.146	0.014	0.240	0.101	0.088	0.135	0.115	0.077	0.115	-0.174	-0.186	0.071	0.147	0.141	-0.022
NSUN	0.065	0.152	0.072	0.347	0.000	-0.169	-0.087	-0.116	-0.068	0.473	0.206	0.078	0.064	0.063	-0.056	-0.063	0.474
OH_B_SUN	0.091	0.123	0.029	0.285	-0.038	-0.215	-0.096	-0.166	-0.081	0.544	0.240	0.151	0.135	0.063	-0.073	-0.045	0.404
PRTOL	0.191	0.089	0.382	-0.294	-0.141	0.154	0.354	0.181	0.297	-0.401	-0.266	0.267	0.285	0.331	0.065	0.317	0.006
RIV	-0.057	0.099	0.224	0.018	0.100	0.179	0.276	0.230	0.269	0.233	0.000	-0.039	-0.046	0.284	0.270	0.300	0.204
SR	-0.107	0.183	0.220	0.077	0.186	0.025	0.097	0.096	0.128	0.282	0.100	-0.104	-0.115	0.155	0.096	0.127	0.274
SUN1	0.091	0.123	0.029	0.285	-0.038	-0.215	-0.096	-0.166	-0.081	0.544	0.240	0.151	0.135	0.063	-0.073	-0.045	0.404
SUN2	0.065	0.152	0.072	0.347	0.000	-0.169	-0.087	-0.116	-0.068	0.473	0.206	0.078	0.064	0.063	-0.056	-0.063	0.474
SUN3	0.088	0.134	0.057	0.350	-0.026	-0.175	-0.063	-0.118	-0.047	0.487	0.203	0.100	0.083	0.083	-0.047	-0.019	0.398
TNI	-0.187	-0.100	0.129	0.016	0.187	0.356	0.337	0.390	0.345	0.093	-0.027	0.107	0.096	0.377	0.434	0.341	-0.072
TOL	-0.076	0.167	0.264	-0.044	0.110	0.029	0.156	0.107	0.165	0.142	-0.019	-0.073	-0.079	0.200	0.054	0.160	0.241
WPUE	-0.052	0.238	0.057	0.058	0.394	-0.172	-0.151	-0.135	-0.032	0.390	0.411	-0.271	-0.276	-0.101	0.004	-0.098	0.273

NOTE: This matrix does not include:
1. %RNDSCK_(n) or %RNDSCK_(wt) because there were no data for these metrics (no fish identified in these categories).
2. NBINV, NSUC, and SCKR because each of these species metrics had insufficient numbers of species associated with them in the dataset (2 or fewer).

Pearson Coefficient Matrix

	%TC_(wt)	%TOL_(n)	%TOL_(wt)	CPUE	GEN	INT	INTOL	LIT0T	MOD	NAT	NFSH	NMIN	NSUN	OH_B_SUN	PRTOL	RIV	SR	SUN1
%DELT_(n)	-0.352	0.015	0.203	-0.072	0.313	-0.083	0.016	0.049	-0.114	-0.122	-0.122	-0.275	0.065	0.091	0.191	-0.057	-0.107	0.091
%INSCT_(n)	0.096	-0.230	0.028	0.210	-0.384	0.112	0.125	0.131	0.129	0.184	0.184	0.156	0.152	0.123	0.089	0.099	0.183	0.123
%INSCT_(wt)	-0.101	0.247	0.466	0.068	0.078	0.017	0.021	-0.066	0.071	0.183	0.183	0.146	0.072	0.029	0.382	0.224	0.220	0.029
%INT_(n)	0.167	-0.132	-0.061	0.164	-0.110	0.596	**0.647**	**0.983**	0.041	0.113	0.113	0.014	0.347	0.285	-0.294	0.018	0.077	0.285
%INT_(wt)	0.245	0.057	-0.255	0.102	-0.363	0.420	0.223	0.154	0.117	0.155	0.155	0.240	0.000	-0.038	-0.141	0.100	0.186	-0.038
%LRIV_(n)	-0.274	**0.625**	0.428	-0.224	0.377	0.096	0.031	-0.189	-0.035	-0.028	-0.028	0.101	-0.169	-0.215	0.154	0.179	0.025	-0.215
%LRIV_(wt)	-0.536	0.499	**0.726**	-0.064	0.523	-0.099	-0.043	-0.198	-0.003	0.056	0.056	0.088	-0.087	-0.096	0.354	0.276	0.097	-0.096
%LTHPL_(n)	-0.283	**0.708**	0.443	-0.236	0.329	0.174	0.107	-0.113	-0.029	0.033	0.033	0.135	-0.116	-0.166	0.181	0.230	0.096	-0.166
%LTHPL_(wt)	-0.581	0.455	**0.636**	-0.013	0.411	0.001	0.032	-0.146	0.023	0.077	0.077	0.115	-0.068	-0.081	0.297	0.269	0.128	-0.081
%MOD_(n)	0.159	-0.672	-0.119	**0.794**	0.026	-0.079	-0.029	0.111	0.570	0.312	0.312	0.077	0.473	0.544	-0.401	0.233	0.282	0.544
%MOD_(wt)	0.539	-0.591	-0.374	0.485	-0.237	-0.013	0.020	0.094	0.345	0.180	0.180	0.115	0.206	0.240	-0.266	0.000	0.100	0.240
%OH_B_OMV_(n)	-0.344	0.320	0.508	-0.045	**0.997**	-0.255	-0.161	-0.066	-0.032	-0.073	-0.073	-0.174	0.078	0.151	0.267	-0.039	-0.104	0.151
%OMV_(n)	-0.333	0.330	0.512	-0.059	**1.000**	-0.259	-0.168	-0.072	-0.047	-0.082	-0.082	-0.186	0.064	0.135	0.285	-0.046	-0.115	0.135
%OMV_(wt)	-0.523	0.434	**0.740**	0.035	0.518	-0.094	-0.024	-0.124	0.073	0.132	0.132	0.071	0.063	0.063	0.331	0.284	0.155	0.063
%RIV_(n)	-0.215	0.385	0.371	0.035	0.376	0.092	0.044	-0.143	0.126	0.068	0.068	0.147	-0.056	-0.073	0.065	0.270	0.096	-0.073
%RIV_(wt)	-0.447	0.372	0.551	0.025	0.480	-0.082	-0.018	-0.141	0.069	0.114	0.114	0.141	-0.063	-0.045	0.317	0.300	0.127	-0.045
%TC_(n)	0.455	-0.296	0.040	0.409	-0.090	0.084	0.130	0.192	0.251	0.301	0.301	-0.022	0.474	0.404	0.006	0.204	0.274	0.404
%TC_(wt)	**1**	-0.128	-0.153	0.179	-0.333	0.194	0.145	0.134	0.167	0.260	0.260	0.068	0.302	0.224	0.002	0.121	0.216	0.224
%TOL_(n)	-0.128	**1**	**0.641**	-0.504	0.330	0.061	0.016	-0.131	-0.274	-0.027	-0.027	0.056	-0.182	-0.236	**0.625**	0.099	0.024	-0.236
%TOL_(wt)	-0.153	**0.641**	**1**	-0.046	0.512	-0.044	0.000	-0.026	-0.012	0.102	0.102	0.012	0.141	0.096	0.563	0.214	0.142	0.096
CPUE	0.179	-0.504	-0.046	**1**	-0.060	0.205	0.203	0.137	**0.781**	**0.658**	**0.658**	0.435	0.584	**0.634**	-0.448	0.567	**0.647**	**0.634**
GEN	-0.333	0.330	0.512	-0.060	**1**	-0.259	-0.168	-0.071	-0.047	-0.082	-0.082	-0.186	0.064	0.135	0.286	-0.047	-0.116	0.135
INT	0.194	0.061	-0.044	0.205	-0.259	**1**	**0.932**	0.529	0.156	0.342	0.342	0.218	0.376	0.221	-0.354	0.366	0.369	0.221
INTOL	0.145	0.016	0.000	0.203	-0.168	**0.932**	**1**	**0.602**	0.142	0.348	0.348	0.196	0.448	0.297	-0.332	0.361	0.338	0.297
LIT0T	0.134	-0.131	-0.026	0.137	-0.071	0.529	**0.602**	**1**	0.001	0.057	0.057	-0.056	0.343	0.280	-0.280	-0.009	0.022	0.280
MOD	0.167	-0.274	-0.012	**0.781**	-0.047	0.156	0.142	0.001	**1**	**0.775**	**0.775**	0.567	0.544	0.571	-0.495	**0.629**	**0.752**	0.571
NAT	0.260	-0.027	0.102	**0.658**	-0.082	0.342	0.348	0.057	**0.775**	**1**	**1.000**	**0.747**	**0.670**	**0.642**	-0.172	**0.869**	**0.967**	**0.642**
NFSH	0.260	-0.027	0.102	**0.658**	-0.082	0.342	0.348	0.057	**0.775**	**1.000**	**1**	**0.747**	**0.670**	**0.642**	-0.172	**0.869**	**0.967**	**0.642**
NMIN	0.068	0.056	0.012	0.435	-0.186	0.218	0.196	-0.056	0.567	**0.747**	**0.747**	**1**	0.170	0.167	-0.085	**0.687**	**0.720**	0.167
NSUN	0.302	-0.182	0.141	0.584	0.064	0.376	0.448	0.343	0.544	**0.670**	**0.670**	0.170	**1**	**0.940**	-0.293	0.563	**0.645**	**0.940**
OH_B_SUN	0.224	-0.236	0.096	**0.634**	0.135	0.221	0.297	0.280	0.571	**0.642**	**0.642**	0.167	**0.940**	**1**	-0.284	0.527	**0.606**	**1.000**
PRTOL	0.002	**0.625**	0.563	-0.448	0.286	-0.354	-0.332	-0.280	-0.495	-0.172	-0.172	-0.085	-0.293	-0.284	**1**	-0.099	-0.139	-0.284
RIV	0.121	0.099	0.214	0.567	-0.047	0.366	0.361	-0.009	**0.629**	**0.869**	**0.869**	**0.687**	0.563	0.527	-0.099	**1**	**0.901**	0.527
SR	0.216	0.024	0.142	**0.647**	-0.116	0.369	0.338	0.022	**0.752**	**0.967**	**0.967**	**0.720**	**0.645**	**0.606**	-0.139	**0.901**	**1**	**0.606**
SUN1	0.224	-0.236	0.096	**0.634**	0.135	0.221	0.297	0.280	0.571	**0.642**	**0.642**	0.167	**0.940**	**1.000**	-0.284	0.527	**0.606**	**1**
SUN2	0.302	-0.182	0.141	0.584	0.064	0.376	0.448	0.343	0.544	**0.670**	**0.670**	0.170	**1.000**	**0.940**	-0.293	0.563	**0.645**	**0.940**
SUN3	0.222	-0.206	0.110	**0.609**	0.083	0.368	0.449	0.349	0.549	**0.658**	**0.658**	0.174	**0.970**	**0.970**	-0.323	0.573	**0.632**	**0.970**
TNI	0.020	0.230	0.337	0.567	0.095	0.285	0.234	-0.019	0.578	**0.730**	**0.730**	**0.612**	0.427	0.434	-0.041	**0.733**	**0.765**	0.434
TOL	0.177	0.146	0.210	0.484	-0.080	0.216	0.195	-0.086	0.538	**0.895**	**0.895**	**0.679**	0.553	0.521	0.113	**0.865**	**0.945**	0.521
WPUE	0.240	-0.296	-0.154	**0.693**	-0.277	0.356	0.251	-0.018	**0.612**	0.588	0.588	0.461	0.318	0.325	-0.274	0.488	**0.609**	0.325

Pearson Coefficient Matrix

	SUN2	SUN3	TNI	TOL	WPUE
%DELT_(n)	0.065	0.088	-0.187	-0.076	-0.052
%INSCT_(n)	0.152	0.134	-0.100	0.167	0.238
%INSCT_(wt)	0.072	0.057	0.129	0.264	0.057
%INT_(n)	0.347	0.350	0.016	-0.044	0.058
%INT_(wt)	0.000	-0.026	0.187	0.110	0.394
%LRIV_(n)	-0.169	-0.175	0.356	0.029	-0.172
%LRIV_(wt)	-0.087	-0.063	0.337	0.156	-0.151
%LTHPL_(n)	-0.116	-0.118	0.390	0.107	-0.135
%LTHPL_(wt)	-0.068	-0.047	0.345	0.165	-0.032
%MOD_(n)	0.473	0.487	0.093	0.142	0.390
%MOD_(wt)	0.206	0.203	-0.027	-0.019	0.411
%OH_B_OMV_(n)	0.078	0.100	0.107	-0.073	-0.271
%OMV_(n)	0.064	0.083	0.096	-0.079	-0.276
%OMV_(wt)	0.063	0.083	0.377	0.200	-0.101
%RIV_(n)	-0.056	-0.047	0.434	0.054	0.004
%RIV_(wt)	-0.063	-0.019	0.341	0.160	-0.098
%TC_(n)	0.474	0.398	-0.072	0.241	0.273
%TC_(wt)	0.302	0.222	0.020	0.177	0.240
%TOL_(n)	-0.182	-0.206	0.230	0.146	-0.296
%TOL_(wt)	0.141	0.110	0.337	0.210	-0.154
CPUE	0.584	**0.609**	0.567	0.484	**0.693**
GEN	0.064	0.083	0.095	-0.080	-0.277
INT	0.376	0.368	0.285	0.216	0.356
INTOL	0.448	0.449	0.234	0.195	0.251
LIT0T	0.343	0.349	-0.019	-0.086	-0.018
MOD	0.544	0.549	0.578	0.538	**0.612**
NAT	**0.670**	**0.658**	**0.730**	**0.895**	0.588
NFSH	**0.670**	**0.658**	**0.730**	**0.895**	0.588
NMIN	0.170	0.174	**0.612**	**0.679**	0.461
NSUN	**1.000**	**0.970**	0.427	0.553	0.318
OH_B_SUN	**0.940**	**0.970**	0.434	0.521	0.325
PRTOL	-0.293	-0.323	-0.041	0.113	-0.274
RIV	0.563	0.573	**0.733**	**0.865**	0.488
SR	**0.645**	**0.632**	**0.765**	**0.945**	**0.609**
SUN1	**0.940**	**0.970**	0.434	0.521	0.325
SUN2	**1**	**0.970**	0.427	0.553	0.318
SUN3	**0.970**	**1**	0.445	0.534	0.327
TNI	0.427	0.445	**1**	**0.721**	0.511
TOL	0.553	0.534	**0.721**	**1**	0.477
WPUE	0.318	0.327	0.511	0.477	**1**