2009 AMP LIBRARY
Fisheries Technical Appendix
FINAL

1. Introduction

The fish community of Onondaga Lake has been sampled by a number of methods to characterize species richness and diversity. Changes in the fish community are expected based on improvements in water quality (e.g., reduction in nutrients, change from a hypereutrophic to a eutrophic or mesotrophic state), which can provide additional habitats within the littoral zone as well as the pelagic zone. Such changes are being seen in the Onondaga Lake fish community, but the scale and pattern of change are often variable and difficult to explain fully due to the interaction of several phenomena occurring simultaneously in response to improved water quality. These include reduced phytoplankton abundance, expansion of exotic species populations, increases in aquatic macrophyte abundance and coverage, and competition for resources by expanding fish populations.

2. Fish Community

The AMP is designed to sample four major components of the fish community: adults, young-of-year (YOY) and juveniles, larvae, and nests (of nest-building species). Electrofishing within the littoral zone has been conducted in spring and fall since the beginning of the AMP to assess the littoral adult fish community. While juvenile fish may also be captured by this method, the gear is more selective to adults, so analysis of this data set focused on the adult fish community. The pelagic adult community has been assessed using standard gill net sets parallel to shore in both spring and fall. While this has yielded fewer species and individuals compared to the electrofishing surveys, it is a common method for assessing adult fish that spend more time in deeper water. Nest abundance and distribution is assessed by visual littoral zone surveys conducted during the spring. Larval fish are sampled by pelagic larval trawls from spring to early summer, and YOY and juvenile fish are sampled by littoral seining from spring to mid-summer. Results of the fish community surveys are presented for the 2009 sampling year, as well as a discussion of temporal trends in the fish community over the course of the AMP.

2.1 Adult Fish Community Diversity and Richness

Diversity and richness are community measures that assess both the number of species and the relative composition of the community. Richness is simply a count of the number of species within a community, while diversity accounts for the relative abundance of each species as well as the total number of species. A community dominated numerically by one or two species will have lower diversity than a community with a similar number of species that are more evenly represented. Shannon diversity was calculated for both the electrofishing and gillnetting sampling based on the following equation:

$$H' = -\sum_{i=1}^{s} P_i \ln P_i$$

Where:

s = total number of species

P_i = proportion of total individuals in the *i*th species.

2.1.1 Littoral Adults

Richness of adult littoral species within the lake was 28 species for 2009 (Library Reference 8.7.4.4.4). This is represented by 27 species in the spring sampling and 22 in the fall sampling. Looking more closely at richness by stratum shows a slight difference in composition by areas in the lake, with a high of 23 species captured from Strata 1 and 4 and a low of 20 species from Stratum 2 for the entire year (Library Reference 8.7.4.4.4). Richness was higher in the spring than in the fall within most strata. The combination of the spring and fall sampling yielded the greatest richness, indicating some species are using the lake only during certain periods of the year or, alternatively, they do not sample well with the gear used during certain times of the year. Other species may leave the lake in the spring for spawning and return during the summer and fall to overwinter in the lake. Historically, species richness declined in the fall during and following lake turnover due to increased anoxia in the epilimnion. Anoxia associated with this event has been greatly reduced in the past several years due to reductions in nutrient inputs (i.e., improving water quality). Since 2000 the number of species captured during the electrofishing events has generally increased from a low of 19 in 2001 to a high of 28 species in 2009 (Library Reference 8.7.4.4.6).

Fish species diversity in Onondaga Lake in 2009 was compared both with clupeids and without clupeids (alewife [*Alosa pseudoharengus*] and gizzard shad [*Dorosoma cepedianum*]). The abundance of these two species tends to be highly variable in New York because they are near the northern edge of their range and can experience high winter mortality. Gizzard shad are more susceptible to over-winter mortality as this species is closer to the northern edge of its range. Extremes in recruitment also play a role in the variability in abundance of these species. Both species may periodically produce very strong year classes that dominate the catch for years. Year classes can persist for a long period of time as both species can live upwards of 10 years.

Diversity was higher overall with clupeids for the whole lake and within each stratum for the whole year (Library Reference 8.7.4.4.2). Diversity was highest for the whole year in Stratum 2 with clupeids and lowest in Stratum 5 with clupeids. Diversity in the whole lake both with and without clupeids was higher in the spring than in the fall. Generally, clupeids were not as abundant in 2009 as previous years, so diversity was not as heavily influenced by these species as in past years. Overall diversity since 2000 showed greater temporal fluctuations when clupeids were included in the entire community assessment compared to when clupeids were excluded (Library Reference 8.7.4.4.3). When alewife abundance was most recently highest (in 2004), overall diversity was lowest, with an increasing trend in diversity since 2004. The trend without clupeids was not as evident, with diversity generally constant since 2000 (Library Reference 8.7.4.4.3).

2.1.2 Pelagic Adults

Richness of pelagic adults was lower than littoral adults, with 11 species captured from the whole lake in 2009. Within the whole lake, there was not a difference in richness in spring versus fall sampling, with 8 species captured during each event (Library Reference 8.7.4.4.5). Stratum 1 had the lowest richness, with only one species (white perch) captured at that location for the whole year, in both spring and fall. Within the other four strata, richness was higher in the spring than in the fall, with only one species captured in the fall in Strata 1, 2, and 3. Similar to the electrofishing results, the combination of the spring and fall sampling yielded the greatest overall richness than either season on its own (except in Stratum 2).

Shannon diversity from gill nets in 2009 was generally high for the whole lake, although differences were apparent among strata (Library Reference 8.7.4.4.1). Strata where only one species was captured in either spring or fall had a diversity value of zero, which resulted in large differences in diversity among strata. However, when pooling the strata, whole lake diversity was relatively high in both spring and fall sampling events. Generally, diversity was higher in spring than in fall in all strata, except Stratum 2 (Library Reference 8.7.4.4.1).

2.2 Adult Fish Abundance/CPUE

Direct estimates of fish population sizes have not been conducted as part of the Ambient Monitoring Program due to the amount of effort needed for such estimates. However, populations have been indirectly measured by standardizing sampling methodology and recording the amount of time each area is sampled. The catch per unit effort (CPUE) provides a reasonable measure of a fish species' abundance during each sampling event. Assessment of CPUE among species can provide an estimate of relative abundance. While some researchers disagree on the suitability of CPUE as an estimate of relative abundance, bias in the estimate should be minimized since the sampling effort typically yields fish from each location (Hinton and Maunder 2004).

Catch per unit effort is calculated for each sampling event and location by taking the number of individuals for each species and dividing by the time spent sampling (shocking seconds; gill net minutes). Mean CPUE is the sum of the CPUE for each electrofishing transect divided by the number of transects included in the mean (whole lake would be the sum of all CPUE divided by 24 transects). Relative abundance for electrofishing is calculated by taking the CPUE from each species within a transect and dividing by the sum of all species CPUE from the transect. Relative abundance for all other programs is calculated by using the number of individuals captured of a species divided by the sum of all species in the sample.

2.2.1 Littoral Adults

Catch per unit effort and relative abundance were calculated for the whole lake and by strata to assess any spatial differences within the lake both for the entire year and for spring and fall sampling periods. Whole lake electrofishing yielded the highest CPUE for pumpkinseed, followed by alewife, white perch, yellow perch, brown bullhead, gizzard shad, and largemouth bass (Library Reference 8.7.3.1.5(a)). Assessing CPUE by season, alewife had the highest CPUE during the spring sampling, followed by pumpkinseed, white perch, and yellow perch (Library Reference 8.7.3.1.5(b)). By fall, alewife CPUE dropped dramatically with only three fish captured, likely because this species prefers more pelagic habitats at that time of year. Fall CPUE was highest for pumpkinseed followed by gizzard shad, yellow perch, and white perch (Library Reference 8.7.3.1.5(c)).

Overall, the relative abundance of the littoral fish community differed only slightly with and without clupeids, due to an apparent reduction in clupeid abundance in 2009 (Library Reference 8.7.3.1.5). Pumpkinseed dominated both catches, comprising 25% and 31.5% of the overall catch in 2009 with and without clupeids, respectively. Clupeids made up 21% of the overall catch, with alewife comprising 14% of the overall catch and gizzard shad 7%.

In Stratum 1, relative abundance for the year was highest for pumpkinseed, followed by yellow perch, brown bullhead, and white perch (Library Reference 8.7.3.1.7(a)). Pumpkinseed had highest relative abundance during spring and fall sampling in Stratum 1, with higher relative abundance for white perch in spring and yellow perch in fall. Relative abundance of pumpkinseed was slightly lower in spring sampling compared to fall sampling, with more species captured in Stratum 1 during the spring. Alewife had a relative abundance of 5.6% during spring and was absent from fall samples (Library Reference 8.7.3.1.7(b,c)).

In Stratum 2, white perch had the highest relative abundance followed by alewife, gizzard shad, pumpkinseed, and brown bullhead (Library Reference 8.7.3.1.7). These five species accounted for approximately 76% of the overall relative abundance (including clupeids). Alewife had the highest relative abundance during spring sampling (29.8%), while they were much less abundant in fall samples (0.9%). White perch, pumpkinseed, and brown bullhead were the next most dominant in both spring and fall samples. Gizzard shad had an opposite pattern than alewife, with high relative abundance in fall (38.3%) compared to spring (4.5%). Sport fish other than pumpkinseed and brown bullhead had low relative abundance in both spring and fall samples.

In Stratum 3, alewife had the highest relative abundance, representing 31.5% of the sample for the year (Library Reference 8.7.3.1.7(g)). Again, this was represented by a fairly high relative abundance in spring (47.6%) and a low relative abundance in fall (none captured). Overall, CPUE was lower during fall sampling compared to spring for all species. Pumpkinseed had the highest relative abundance in fall with 27.7%, although CPUE was higher in spring with a mean CPUE of 108.59 but only representing 15.3% (with clupeids).

In Stratum 4, pumpkinseed had the highest relative abundance for the year at 28.3% (Library Reference 8.7.3.1.7(j)). Generally, pumpkinseed, yellow perch, and white perch represented the majority of the catch from this area for the year (relative abundance of all three species 56%), as well as in spring (relative abundance 48%) and fall (relative abundance 70%). Alewife were again highest in spring with relative abundance of 29.4%, while they were absent in fall samples.

In Stratum 5, pumpkinseed also had the highest relative abundance overall, representing 36.2% of the catch. Alewife were absent from samples in this stratum both during spring and fall. White perch and yellow perch followed in overall abundance with 10.4% and 13% for the year, respectively.

Generally, pumpkinseed, yellow perch, white perch, and brown bullhead were the most abundant species from within all the strata. While relative abundance varied by location, these species typically were within the top five species by abundance throughout the year. Alewife was relatively abundant in spring samples, but noticeably rare in fall samples. These patterns in fish community fluctuations within the littoral zone are indicative of a more macrophyte-dependent community, and likely are the result of increased macrophyte coverage throughout the lake in the past 10 years.

Analysis of the annual trends in catch rates of 18 of the most dominant species since 2000 indicated either an increasing or decreasing trend for many species (Library Reference 8.7.3.1.3). Catch per unit effort followed a generally increasing trend for smallmouth bass, largemouth bass, pumpkinseed, yellow perch, brown bullhead, and rock bass, while a decreasing trend was apparent for channel catfish, shorthead redhorse, and common carp (Library Reference 8.7.3.1.3). Gizzard shad and alewife trends fluctuated widely with high CPUE some years and low in other years. This pattern of abundance is typical for these species, which often produce strong year classes interspersed by weak year classes. Trends are not readily apparent for the other species. Similar to the community dynamics observed for 2009, these long term trends reflect a shift to a littoral, macrophyte-dependent fish community.

2.2.2 Pelagic Adults

Relative abundance of gill net samples was dominated by yellow perch, followed by white perch, gizzard shad, and walleye (Library Reference 8.7.3.1.4). Catch rates were higher during spring compared to fall for all strata, with yellow perch dominating the catch, followed by white perch and walleye (Library Reference 8.7.3.1.10(c)). During the fall, catch was dominated by gizzard shad and smallmouth bass with a combined relative abundance of 60% (Library Reference 8.7.3.1.10(c)).

The pelagic community has been sampled by one gill net set per stratum during one sampling event each during spring and fall (total of 5 net sets each season). These nets are set parallel to shore in 4 to 5 m water depth. Due to the increasing water clarity, the area sampled may actually be more representative of the littoral zone instead of the pelagic zone. With the apparent increasing abundance of fish species in the littoral zone, several species may be moving to the pelagic zone as they grow (e.g., larger smallmouth bass) to take advantage of improving habitat in this area. Therefore, the pelagic community may need to be sampled more intensively in the next few years with additional gill net sets, including sets during evening hours and deeper sets aligned perpendicular to shore to more accurately assess this open water community.

2.3 Fish Reproduction

An assessment of fish reproduction was conducted by several methods including a nesting survey, sampling of larval fish, and sampling of young of year (YOY) fish. Evaluation of the occurrence, abundance, and distribution of young fish provides information on the overall health of the fish community within the lake and success of reproductive efforts from year to year. Factors other than water quality, such as water temperature during and after spawning, water levels, and trophic dynamics, can affect reproductive success and complicate the interpretation of fish reproductive success.

2.3.1 Nesting Surveys

The centrarchid species in the lake (largemouth and smallmouth bass, pumpkinseed, bluegill, and rock bass), as well as bullhead, will excavate nests in the substrate of the littoral zone. Most nests are round or oval and will be guarded by the nesting male until eggs hatch and fry disperse. Nesting surveys were conducted to assess the number of nests built in 2009 and document where in the lake they were found. In 2009, 1,995 nests were observed, with a fairly even distribution between the north and south basins (Library Reference 8.7.7.3.1). A total of 1,085 (54%) nests were identified in the north basin and 910 (46%) in the south basin. This represents a more even distribution than what has been found historically. As recent as 2007, 84% of documented nests were located in the north basin. Overall, the number of nests found in 2009 was similar to the number found in other years, except 2008 in which many more nests (7,111) were found. General distribution of the nests within transects was more even with nests located within 21 of the 24 transects sampled. The two southernmost transects (transect 17 and 18 within Stratum 3) and one transect near Nine Mile Creek (transect 10) were the only locations without at least one nest observed. The southern locations are most influenced by wind/wave energy and are likely not very suitable for nesting. The area near Nine Mile Creek is located along the Wastebeds and may not have enough suitable substrate for nesting, although nesting has been observed within Stratum 2 along the Wastebeds.

Pumpkinseed nests dominated the nest count, representing over 50% of the nests observed (Library Reference 8.7.7.3.2). A large percentage (40%) of nests were not identified to species due to the lack of a fish guarding the nest during the survey. Bluegill comprised 3.5% of the nests observed, and largemouth and smallmouth bass both comprised 2%.

As evident from the temporal trends in recent years, the number of nests observed each year is highly variable. Many of the nests are located within or near the macrophyte beds, which may make accurate counts more difficult. Generally, nests are identified based on presence of a fish actively guarding the nest, or a depression that looks fresh. With the amount of macrophyte coverage increasing, timing of the nesting survey and ability to detect fresh depressions when fish are absent may become more difficult. However, the number of nests observed is becoming more widely distributed around the entire shoreline of the lake, potentially indicating the improved water quality conditions.

2.3.2 Larval Fish and YOY

Both mid-lake larval sampling and littoral zone seining were conducted throughout the spring and summer to assess reproductive success in 2009. Six species were captured in the larval fish surveys and 10 species from littoral seining surveys in 2009. Larvae present in the lake included alewife, bluegill, gizzard shad, pumpkinseed, white perch, and yellow perch; while YOY species included smallmouth and largemouth bass, brown and yellow bullhead, common carp, golden shiner, rock bass, shorthead redhorse, tessellated darter, and white sucker.

Larval samples in 2009 were dominated by alewife, which likely indicates another strong year class for this species. In recent years, the number of species captured in the larval surveys has increased, with 3 species in 2007, 5 in 2008, and 6 in 2009; and the number captured in 2009 were similar to the number captured in 2001 and 2002 (Library Reference 8.7.7.2.12(b)). Throughout the sampling, species composition is typical of time of spawning, with yellow perch dominating the catch early in the season, alewife dominating in June, and a mix of species, including bluegill and pumpkinseed, in mid-summer (Library Reference 8.7.7.1(b)).

YOY fish diversity has been increasing over the past several years (Library Reference 8.7.7.2.10). This is indicative of more species as well as a more balanced community. Diversity varied by stratum with Stratum 5 having the lowest overall diversity and Stratum 3 the highest, with no difference with or without clupeids, since alewife and gizzard shad were not collected in the littoral seines (Library Reference 8.7.7.2.9). Stratum 3 also had the highest mean CPUE over the 2009 sampling season with an average of 4.22 fish per haul (Library Reference 8.7.7.2.1). Many of the species captured in the seines are difficult to distinguish as adult or YOY, and if captured in the seines are assumed to be reproducing in the lake (see Library Reference 8.7.7.2.12(c)). In 2009, 16 species were identified as YOY and therefore considered reproducing in the lake. In 2009, the number of *Lepomis* (pumpkinseed and bluegill combined) in seine hauls was the lowest seen since 2000. Largemouth bass and smallmouth bass CPUE was also low in 2009 compared to previous years (Library Reference 8.7.7.2.12(c)). These patterns may indicate limited nesting success by centrarchids in 2009.

Relative abundance of YOY in 2009 was dominated by largemouth bass (Library Reference 8.7.7.2.7). Other relatively abundant species included common carp (14%), smallmouth bass (7%), golden shiner (7%), and *Lepomis* (6%). Relative abundance of YOY by strata differed slightly from the whole lake, with largemouth bass dominant in Strata 1, 4, and 5 while white perch was dominant in Stratum 2 and common carp was dominant in Stratum 3 (Library Reference 8.7.7.2.8).

Assessment of annual trends in CPUE of YOY for the dominant species show variable patterns (Library Reference 8.7.7.2.5). Many species have declined since 2000, including white perch, gizzard shad, yellow perch, and *Lepomis*. Both largemouth and smallmouth bass showed a peak in the mid-2000s with declines in the past several years.

Comparing the YOY trends with those of the adult littoral trends since 2000 indicates contradicting patterns (Library References 8.7.3.1.3 and 8.7.7.2.5). The CPUE from the electrofishing surveys, while incorporating both spring and fall samples, should provide an estimate of the relative numbers of adult fish potentially reproducing in that year. For example, largemouth bass adult CPUE was relatively constant from 2002 to 2007, with increases in 2008 and 2009. The YOY CPUE for largemouth bass did not follow this trend with peak CPUE in 2005 and relatively low numbers in 2008 and 2009. Similar patterns can be seen with the other centrarchids as well as yellow perch. While this may reflect poor reproductive success, an alternative hypothesis is that increasing macrophytes are making it more difficult to fully assess the YOY population, especially those that tend to prefer dense macrophyte patches. Juvenile seining is conducted in the same areas each year, with areas of low macrophyte growth preferred for a successful attempt. Macrophytes tend to disrupt the towing of the net and allow fish to escape from underneath.

3. Sport Fishery

Onondaga Lake supports a varied recreational fishery, with largemouth bass, smallmouth bass, bluegill and pumpkinseed (*Lepomis* spp.), yellow perch, and brown bullhead some of the more common sport fish present. Population characteristics of these species were investigated to assess changes in the quality of the sport fishery of the lake since the inception of the AMP. Specifically, the relative abundance of fish in various size classes available to anglers was evaluated through analysis of proportional stock density (PSD) and relative stock density (RSD). General condition with regard to weight of fish of each species across a range of size classes was also evaluated through analysis of relative weight (W_r). Finally, actual catch rates for largemouth and smallmouth bass by anglers over time were analyzed and compared to rates from other nearby waters.

3.1 PSD and RSD

Combined catch data from fall (September and October) littoral electrofishing and pelagic gill netting collections were used to calculate PSD, RSD, and W_r values. Catch from both of these gear types was combined to reduce any size-selective bias of the individual gear types. Fall catch data were used rather than spring or combined spring and fall catch data because weight of spring fish can be highly variable depending on fish reproductive status, and growth of fish between sampling periods could confound interpretation of results.

PSD is a ratio (expressed as percentage) of the number of quality-sized or larger individuals to stock-sized individuals in a fish population. Quality size and stock size vary by species, but generally correspond to the minimum size of a fish species that anglers like to catch and the minimum size that is susceptible to angling, respectively (Anderson 1980). RSD is an extension of PSD, consisting of the ratio of the number of fish of a specific size or larger to the number of fish of stock size or larger. These specific size groups also vary by species and have been defined as quality, preferred, memorable, and trophy (Gabelhouse 1984). The specific sizes for the group of sport fish of interest in this analysis are as follows.

Species	**Size Category (mm)**				
	Stock	**Quality**	**Preferred**	**Memorable**	**Trophy**
Largemouth bass	200	300	380	510	630
Smallmouth bass	180	280	350	430	510
*Lepomis**	80	150	200	250	300
Yellow perch	130	200	250	300	380
Brown bullhead	150	230	300	380	460

* The genus *Lepomis* in this analysis represents both bluegill and pumpkinseed.

There are two methods (traditional and incremental) for calculating PSD and RSD values (Gabelhouse 1984). The incremental method was used for the analysis of Onondaga Lake fish populations because this approach is best suited for long-term monitoring of changes in fish populations, including year-class strength, in a single waterbody (Gabelhouse 1984; Willis et al. 1993). The incremental approach uses the following measures.

RSD S-Q = (number of fish of stock-to-quality length/number of fish ≥ stock length) x 100
RSD Q-P = (number of fish of quality-to-preferred length/number of fish ≥ stock length) x 100
RSD P-M = (number of fish of preferred-to-memorable length/number of fish ≥ stock length) x 100
RSD M-T = (number of fish of memorable-to-trophy length/number of fish ≥ stock length) x 100
RSD-T = (number of fish ≥ trophy length/number of fish ≥ stock length) x 100
PSD = 1 - RSD S-Q

Use of the incremental approach allows for identification of changes in fish population structure due to strong or weak year-classes and provides a means for a more concise and meaningful presentation and interpretation of length-frequency data.

3.1.1 Largemouth Bass

PSD of largemouth bass has fluctuated between about 40 and 80 since 2000 (Table 1). RSD S-Q, RSD Q-P, and RSD P-M show similar patterns of variation around means of about 40, 34, and 25, respectively (Table 1, Figure 1). The proportion of stock-to-quality size (200-299 mm) largemouth bass was above average in 2009 and increased from 2008. The proportion of quality-to-preferred size (300-379 mm) fish in 2009 also increased, but was below the long-term average. The proportion of preferred-to-memorable size (380-509 mm) fish in 2009 declined from 2008 and was the lowest yet recorded. This value should begin to increase as those fish in the quality-to-preferred length range grow and exceed preferred length (380 mm). No largemouth bass exceeding memorable length (510 mm) have been captured since 2002 (when one such fish was collected), and no largemouth bass of trophy length (630 mm) have been captured since the AMP began.

The PSD/RSD analysis of largemouth bass catch indicates the size distribution of this species is skewed notably toward fish 200-379 mm in length, with fish 380-509 mm in length being relatively abundant in some years and somewhat scarce in other years. This population structure provides anglers with a consistently large proportion (~70%) of catchable-size largemouth bass of small to moderate length and a more variable proportion of fish of relatively large size. Fish exceeding 510 mm have been rarely collected during AMP sampling efforts. This suggests that fish of this size are either absent or rare in Onondaga Lake or are not susceptible to capture by the sampling gear used.

3.1.2 Smallmouth Bass

PSD of smallmouth bass has shown a distinctly different pattern than that of largemouth bass. PSD from 2000 through 2004 varied from 40 to 67 and then declined steadily beginning in 2005 and reached a low of 7 in 2007 **(**Table 1**)**. PSD remained low (10-13) in 2008 and 2009. RSD S-Q, which is the reciprocal of PSD showed an inverse relationship, increasing rapidly since 2004 and remaining high (near 90) since 2007 **(**Figure 1**)**. RSD Q-P and RSD P-M both declined from moderate levels (~20-30) in the earlier 2000s to low levels (generally <10) since 2007. RSD M-T was low (<5) from 2000-2002, spiked to 17 in 2003, and has gradually declined to <2 in 2007-2009. No smallmouth bass of trophy length have been collected since the AMP began.

The PSD/RSD analysis of smallmouth bass catch indicates that the current population is strongly skewed toward fish of small size (<280 mm). Since 2007, fish <280 mm have comprised approximately 90% of collected smallmouth bass greater than 180 mm in length. Fish of this size comprised only 33-60% of the smallmouth bass >180 mm in 2000-2004. The increase in the proportion of smaller smallmouth bass collected is due in part to an overall increase in the numbers of fish of this size but is also a response to declining numbers of fish in larger size categories. Considerably fewer fish of quality length (280 mm) or greater have been collected since 2002 and particularly since 2007. Theoretically, an increase in the number of stock-quality size fish as seen since 2003 should ultimately result in a subsequent increase in numbers of fish in larger size categories as the smaller fish grow over time. This expected increase has not been reflected in electrofishing and gill net catches from Onondaga Lake.

The relative scarcity of larger smallmouth bass and the apparent low recruitment of stock-to-quality size fish into larger size categories over time could be due to multiple factors. The possibility that there is high mortality of smallmouth bass in Onondaga Lake before they reach 280 mm is unlikely due to a lack of evidence of an annual die-off of this species and no apparent factor that would be expected to limit survival of this species (e.g., heavy predation or angling harvest). Given Onondaga Lake has a large outlet to the Seneca River, it is possible that as smallmouth bass mature, some or many of them leave the lake and take up residence in the Seneca River or elsewhere. A more likely explanation for the reduced number of larger smallmouth bass collected is a shift in habitat use by larger fish in recent years. Improving water-quality conditions in the deeper, off-shore portions of Onondaga Lake over time have made such area more inhabitable for smallmouth bass, which are known to use deeper off-shore waters in other large regional lakes such as Lake Ontario and Cayuga Lake (Webster 1954). Larger smallmouth bass may also have shifted their habitat use to deeper, off-shore areas due to increased water clarity, increased vegetative cover in the littoral zone, and to take advantage of the high abundance of alewife. Alewife was not found in Onondaga Lake prior to 2003, but has since become well established at relatively high density. Alewife can be an important component of smallmouth bass diets in lakes where both species occur (Webster 1954). The arrival of alewife in Onondaga Lake coincides with the noted decline in numbers of quality-length or larger smallmouth bass in electrofishing and gill net catches.

If quality-size and larger smallmouth bass have indeed shifted to deeper, offshore habitats, these fish would not be susceptible to capture by electrofishing, which is conducted in the lake's shallow, littoral habitat. These fish would be susceptible to pelagic gill netting, and the majority (66%) of smallmouth bass over 280 mm collected over the course of the AMP have been collected by gill net. Furthermore, 87% of smallmouth bass collected by gillnet have been quality-size or larger, indicating the susceptibility of larger smallmouth bass to this gear type. However, the effort expended in gill netting is minimal in comparison to that expended in electrofishing and given the extensive pelagic area of the lake. Consequently, fish occupying deeper pelagic habitat are under-represented in comparison to those occupying littoral habitat. This possibility is further supported by the findings of Milewski and Willis (1991) who reported that night electrofishing overestimated the proportion of smaller (<280 mm) smallmouth bass in populations from five South Dakota Lakes.

The minimal effort (one two-hour daytime set per stratum in water depths of 4-5 m) expended in pelagic gill netting also is likely insufficient for accurately documenting smallmouth bass abundance in off-shore habitats. The increasing water clarity of the lake as a result of dreissenid mussel filtering activity and low alewife abundance (resulting in reduction in phytoplankton abundance by zooplankton) further reduces the effectiveness of gill netting for smallmouth bass because fish can more easily avoid the nets. It appears that most smallmouth bass of quality length (280 mm) or greater in Onondaga Lake occupy offshore habitats during the fall sampling effort and have become relatively unsusceptible to capture by the sampling methods employed in the AMP.

3.1.3 *Lepomis* (Bluegill and Pumpkinseed)

PSD for *Lepomis* has varied greatly over the course of the AMP, ranging from 10 to 83, with no discernable pattern over time **(**Table 1**)**. The same is true for RSD S-Q and RSD Q-P **(**Figure 1**)**. RSD P-M has been consistently low (<10) for the duration of the AMP, but has remained below 3 since 2003. Memorable-to-trophy size *Lepomis* have been collected only twice, one in 2006 and one in 2008. No *Lepomis* of trophy length have been collected during the AMP.

The PSD/RSD analysis of *Lepomis* catch indicates that the population is dominated by fish of stock-to-quality size (80-149 mm) and quality-to-preferred size (150-199 mm), with the proportion of each group changing inversely with that of the other. A relatively large proportion of *Lepomis* reached stock size in 2005, resulting in a large peak in RSD S-Q that year. Catch results suggest that there were two successive poor year classes that produced relatively few stock-size fish in 2006 and 2007. RSD S-Q rose dramatically in 2008 and again in 2009, suggesting production of two consecutive good year classes. RSD Q-P declined in both 2008 and 2009 due to the greater relative abundance of stock-to-quality size fish. The number of quality-to-preferred size fish collected in 2008 and 2009 was actually well above average, but was lower in proportion to stock-to-quality size fish for those years.

The year-classes that produced few stock-to-quality size fish in 2006 and 2007 may have been a result of alewife predation on *Lepomis* larvae during previous years. Although age data specific to *Lepomis* from Onondaga Lake are not available, data from other NY lakes suggest that *Lepomis* reach stock size around age 2 (Carlander 1977). If this is the case for Onondaga Lake, catch data suggest that poor year classes of *Lepomis* were produced in 2004 and 2005. This coincides with the peak in the alewife population in the lake. Alewife prey heavily on pelagic fish larvae, such as those produced by bluegill and pumpkinseed (Madenjian et al. 2008), and alewife can also negatively affect survival of young-of-year *Lepomis* through competition for zooplankton forage (Kohler and Ney 1981). Alewife abundance has declined since 2005, and this may have allowed for production of stronger year classes of *Lepomis* since that time.

There is a marked lack of *Lepomis* greater than preferred length (200 mm) in the catch. A couple of factors may be contributing to this. It is possible that larger *Lepomis* are not being captured in proportion to their abundance by the gear being used. Reynolds and Simpson (1978) found that electrofishing underestimated the size structure of bluegill populations. Larger adult bluegill tend to be more pelagic than juveniles and smaller adults and may be captured disproportionately less than these other groups when electrofishing littoral habitats. Gill nets are not particularly effective at sampling *Lepomis*, so the limited pelagic gill netting effort conducted as part of the AMP is likely not effective in characterizing pelagic *Lepomis* in Onondaga Lake.

A second explanation for the low abundance of *Lepomis* greater than preferred length is slow growth of fish after reaching reproductive age. Redistribution of energy toward reproduction rather than somatic growth results in slower growth at larger sizes. Competition for forage may be compounding this effect in *Lepomis* from Onondaga Lake. Fish abundance in Onondaga

Lake is increasing overall, as is the abundance of *Lepomis* in recent years, so it is possible that inter- and/or intra-specific competition for invertebrate forage could be a controlling factor in the growth of *Lepomis* in Onondaga Lake. *Lepomis*, alewife, and larval gizzard shad all prey extensively on zooplankton. Adult gizzard shad may also compete with *Lepomis* for benthic macroinvertebrate forage. Competition with clupeids for forage resources has been linked to reduced growth in bluegill populations (Aday et al. 2003), and such competition could be keeping greater numbers of *Lepomis* in Onondaga Lake from reaching preferred or greater size. Relative weight analysis of adult-size fish indicates that forage is not limiting for *Lepomis* in Onondaga Lake and energy reserves of individual fish are relatively high, so it is possible that this energy is being put into reproductive effort rather than body growth. Despite the scarcity of *Lepomis* greater than 200 mm, *Lepomis* up to 200 mm are readily available to anglers and are increasing in abundance in recent years.

3.1.4 Yellow Perch

PSD for yellow perch has been highly variable from 2000 to 2009 **(**Table 1**)**. The same is true for RSD S-Q and RSD Q-P **(**Figure 1). RSD P-M has shown a generally increasing trend since the AMP began, being 1 in 2000 and exceeding 12 in the past two years. This measure spiked to 36 in 2005 as a relatively large class of quality-to-preferred size (200-249 mm) fish surpassed preferred size (250 mm). Memorable-to-trophy size yellow perch have been collected only twice, one in 2000 and one in 2009. No yellow perch of trophy length have been collected during the AMP. The scarcity of yellow perch greater than memorable size (300 mm) may again be due to larger adults of this species being more pelagic in habit than juveniles and smaller adults (Smith 1985). Larger perch also may now be attracted to the lake's pelagic habitat due to the availability of alewife as forage. Yellow perch greater than 175 mm in southern Lake Michigan will switch to feeding on alewife and do so preferentially (Truemper and Lauer 2005; Truemper et al. 2006)

The PSD/RSD analysis of yellow perch catch indicates that the population is dominated by fish of stock-to-quality size and quality-to-preferred size, with the proportion of each group changing inversely with that of the other. There is an occasional increase in the proportion of fish 250-300 mm long when a particularly large group of quality-to-preferred size fish surpasses preferred size. This occurred in 2005 and to a lesser extent in 2008. There appears to have been relatively strong year-classes of yellow perch that reached stock size in 2000, 2001, 2006, and 2009, resulting in a large peak in this size class those years. Quality-to-preferred size fish showed a peak approximately one year later as these year classes surpassed quality length. The relatively high proportion of stock-to-quality length yellow perch collected in 2009 suggests that the proportion of quality-to preferred length fish should increase in 2010.

From an angling perspective, the yellow perch fishery of Onondaga Lake is somewhat cyclic in nature. The relative abundance of larger yellow perch occasionally increases as an abundant year class ages. The overall abundance of yellow perch has been increasing, and absolute numbers of larger (>250 mm) are also increasing. This is resulting in more and larger yellow perch being available to anglers in recent years.

3.1.5 Brown Bullhead

PSD for brown bullhead has been consistently above 50 and has occasionally exceeded 90 over the course of the AMP **(**Table 1**)**. This is characteristic of a population dominated by larger adults. RSD S-Q has been variable but has not exceeded 50 in any year and has shown a generally decreasing trend since 2003 **(**Figure 1**)**. RSD Q-P and RSD P-M have generally ranged between 20 and 60 and have shown a generally increasing trend since 2003. The decreasing trend of RSD S-Q and the increasing trend of RSD for larger size groups suggest that there is reduced recruitment of fish to stock size and a stockpiling of larger, older fish. Some of these older fish are beginning to recruit to the memorable-to-trophy size class. No brown bullheads of trophy length have been collected during the AMP.

The PSD/RSD analysis of the brown bullhead catch indicates that a relatively high proportion of the stock-size population (87% in 2009) is greater than quality length (230 mm) and 51% (in 2009) exceeds preferred length (300 mm). This affords anglers an opportunity to catch relatively large brown bullhead. Overall numbers of brown bullhead have been increasing in recent years, suggesting that a high-quality brown bullhead fishery is becoming established in Onondaga Lake.

3.2 Relative Weight (W_r)

W_r compares the actual weight of a fish to a length-specific standard weight (W_s) for the species across its entire geographic range (Murphy et al. 1991). Relative weight is calculated as follows.

$$W_r = (W/W_s) \text{ x } 100$$

where

$$W_s = a(L^b)$$

W = total weight of an individual fish

L = total length of an individual fish

The constants **a** and **b** correspond to values provided by Anderson and Neumann (1996) and Bister et al. (2000). W_s represents the 75th percentile of weight for the species across its geographic range. Given this, a W_r of 100 would represent a fish with a weight equal to the 75th percentile of weight for that species. The equation for W_s applies only to those fish that exceed a specific minimum length, which corresponds to the stock length. Murphy et al. (1991) suggest evaluating relative weight for a population based on size classes since it may be important to know if the condition of smaller fish differs from that of larger fish. Therefore, W_r for each of the fish species of interest was analyzed using the length groups defined by Gabelhouse (1984) as recommended by Murphy et al. (1991).

Length and weight data for individual fish of the species of interest were examined to determine the appropriateness of the data for calculating W_r. Data from some years for some species were deemed unsuitable for calculating W_r due to questionable precision in data recording (e.g., weights were recorded in whole ounces in 2000 or only to the nearest 10 grams for small individuals in some other years). Data from years in which measurements were determined too imprecise were excluded from the W_r analysis. The remaining data were further screened to identify outliers that might be due to inaccurate recording of weight or length in the field. Data for any fish for which the calculated W_r exceeded three standard deviations from the mean were also excluded from the analysis. This resulted in exclusion of only 0.8 to 1.6% of individuals for any one species.

3.2.1 Largemouth Bass

W_r for largemouth bass collected during fall sampling efforts has been near or greater than 100 for all size groups considered **(**Table 2**)**. Values near or above 100 indicate that fish are relatively heavy for their length and suggest that forage is not limiting and energy reserves of individual fish are relatively high. High energy reserves in the fall can lead to increased overwinter survival and increased egg production the following spring (Anderson and Neumann 1996; Willis 1987). Analysis of largemouth bass W_r by size class did not indicate any distinct trends in W_r with size and suggests that forage availability is not limiting for any of the size classes of largemouth bass analyzed. From a sport fishing perspective, Onondaga Lake provides anglers an opportunity to catch largemouth bass that will generally be heavier for their length than average for this species.

3.2.2 Smallmouth Bass

W_r for smallmouth bass collected during fall sampling efforts has ranged from 65 to 116 but has typically been between 85 and 95 **(**Table 2**)**. W_r for stock-to-quality size (180-279 mm) fish has been consistently higher than larger size groups across all years. The only exception to this is 2002 when W_r for memorable-to-trophy size (430-509 mm) fish was greater, but this was based on data from only one fish of that size. W_r for fish of quality-to-preferred size (280-349 mm) and preferred-to-memorable size (350-429 mm) has generally been between 80 and 90 and was slightly above average in 2009. W_r for fish of memorable-to-trophy size has shown the greatest variation of any size group over time. This variability is likely a reflection of the low numbers (1-5) of fish collected in this size range each year. W_r for all size groups collected in 2009 was above the long-term average.

Smallmouth bass W_r has been consistently lower than that of largemouth bass (Table 2) and reflects the fact that the littoral habitat from which most of these fish were collected is more suitable for largemouth bass than smallmouth bass. Largemouth bass likely forage more effectively in the vegetated habitats of the littoral zone and have a competitive advantage over smallmouth bass. Smallmouth bass W_r values though lower than those of largemouth bass are not indicative of fish in poor condition. Crayfish are a preferred forage item in many waters that support robust smallmouth bass populations. While crayfish have recently been found in

Onondaga Lake, they are not abundant and likely do not constitute a large part of smallmouth bass diets. Smallmouth bass in Onondaga Lake therefore must feed primarily on other macroinvertebrates and fish that may provide less energy or be more difficult to capture than crayfish. W_r for stock-to-quality size smallmouth bass is likely higher than that of larger size fish because fish of this size can more effectively utilize macroinvertebrate forage.

3.2.3 *Lepomis* (Bluegill and Pumpkinseed)

W_r for *Lepomis* species collected during fall sampling efforts has been near or greater than 100 for all size groups of bluegill and generally above 100 for all size groups of pumpkinseed considered **(**Table 2**)**. This indicates that forage is not limiting for *Lepomis* in Onondaga Lake and energy reserves of individual fish are relatively high. W_r for bluegill of stock-to-quality size (80-149 mm) has been consistently greater than that of quality-to-preferred size (150-199 mm), but this trend was not seen for pumpkinseed. Relatively few *Lepomis* greater than 200 mm have been collected during the AMP, so similar trends for fish greater than preferred length could not be evaluated.

Lepomis of spawning age appear to be in good condition in the fall and this has been shown in some species to result in increased quantity and quality of eggs and increased survival and growth of newly hatched fish the following spring (Chambers et al. 1989; Brown and Taylor 1992). The increasing abundance of bluegill and pumpkinseed in recent years may in part be a reflection of relatively high W_r in the fall translating to subsequent reproductive success for these species. The relatively high W_r for *Lepomis* greater than stock length in Onondaga Lake offers anglers an opportunity to catch bluegill and pumpkinseed that are notably heavier for their length than average for these species.

3.2.4 Yellow Perch

W_r for yellow perch collected during fall sampling efforts has ranged from 69 to 92 but has typically ranged from 74 to 87 **(**Table 2**)**. W_r for stock-to-quality size (130-199 mm) fish has been consistently higher than that of larger size groups, and W_r for quality-to-preferred size (200-249 mm) fish has been consistently higher than that of preferred-to-memorable size (250-299 mm) fish since 2002. W_r for all size groups analyzed has shown a similar pattern of variation since 2005. The consistently higher W_r for stock-to-quality size fish indicates that competition for forage is not limiting for this size group. The consistent, gradual decline in W_r with increasing size suggests that forage for yellow perch becomes more limiting as yellow perch reach larger sizes. Young yellow perch feed primarily on zooplankton and midge larvae, shift to a more insect-dominated diet with increasing size, and prefer crayfish, small fish, and larger insect larvae as larger adults (Smith 1985). As noted previously, crayfish are not abundant in Onondaga Lake, and other species, largemouth and smallmouth bass in particular, may be competing with larger perch for preferred forage. Competition for preferred prey may be limiting growth of yellow perch and be a factor in the relative scarcity of large (>300 mm) yellow perch in catches from Onondaga Lake.

3.2.5 Brown Bullhead

W_r for brown bullhead collected during fall sampling efforts has ranged from 57 to 99 but has generally fluctuated between 80 and 89 (Table 2). There is no apparent trend in W_r based on fish size, and in most years W_r varied little among the various size classes analyzed. W_r values in the mid-80s indicate that brown bullhead in Onondaga Lake are in generally good condition, but not particularly heavy for their length. There is likely some competition for forage between brown bullhead and other species such as largemouth bass, smallmouth bass, and larger yellow perch, since these species consume many of the same prey items. This, along with the relatively high incidence of lesions and other abnormalities may be keeping brown bullhead in Onondaga Lake from attaining higher relative weights.

3.3 Angler Catch Rates of Bass

Largemouth and smallmouth bass are the most popular game species in Onondaga Lake. Data on angler catch rates are obtained through a volunteer angler diary program in which participating anglers record and submit standardized information on the number and species of fish caught, amount of angling effort expended, and area fished for Onondaga Lake, the Seneca River upstream of Onondaga Lake, the Seneca River downstream of Onondaga Lake, and the Oneida River. This information is used to characterize angler success in these waters and allow for assessment of how angler success in Onondaga Lake compares with other connected waters.

Largemouth bass angler catch rates in Onondaga Lake from 2001 through 2009 have ranged from 0.23 fish/hr to 0.83 fish/hr (Library Reference 8.7.2.1). The four highest annual catch rates have occurred during the last four years, with the catch rate of 0.69 fish/hr in 2009 being the second highest recorded since the inception of the AMP. Prior to 2006, largemouth bass catch rates in Onondaga Lake were typically less than those of the other connecting waters. Since 2006, Onondaga Lake catch rates of largemouth bass have consistently ranked first or second among the four connected waters, ranging from 0.48 to 0.83 fish/hr.

Conversely, smallmouth bass angler catch rates in Onondaga Lake have declined from an initial high value of 2.80 fish/hr in 2001 to a low of 0.17 fish/hr in 2009 (Library Reference 8.7.2.1). This decline was most dramatic from 2001 to 2002 (0.38 fish/hr), and catch rates of smallmouth bass have fluctuated between 0.17 and 0.75 fish/hr since 2002. Smallmouth bass angler catch rates in Onondaga Lake have declined in both of the last two years and are well below the long-term average of 2001-2007. Smallmouth bass angler catch rates for the Seneca River (upstream and downstream) and the Oneida River also have shown some considerable fluctuation (as much a two-fold increase or decrease) since 2001, but the 2009 values for these waters were near or above their long-term average.

The catch rate of smallmouth bass from Onondaga Lake in 2001 (2.80 fish/hr) was high and easily exceeds the highest value seen for the other connecting waters (2.30 fish/hr from the Oneida River in 2006). No data on catch rates for Onondaga Lake exist for prior to 2001, so it is unknown if the 2001 value is representative of angler catch rates before that time. Excluding the 2001 value from consideration, the smallmouth bass catch rate from Onondaga Lake has shown the least amount of variability among the connected waters, with a range of -56 to 61% annual change in catch rate as compared with a range of -62 to 571% change annually for the connecting waters. Thus smallmouth bass catch rates in Onondaga Lake are somewhat lower than the other three connecting waters but show less year-to-year variability.

The general decline in smallmouth bass angler catch rates in Onondaga Lake, particularly in the past two years, is likely a result of changing littoral habitat (e.g., increased distribution and abundance of aquatic macrophytes) and a subsequent increase in largemouth bass abundance. Black bass (largemouth and smallmouth combined) angler catch rates in Onondaga Lake have remained relatively consistent since 2002, ranging from 0.69 to 1.40 fish/hr. These catch rates are similar to the mean angler catch rate of black bass from nearby Oneida Lake[1] (0.69 fish/hr) for the period of 2002 through 2007 (Library Reference 8.7.2.1). Beginning in 2008, angler catch of largemouth bass has exceeded that of smallmouth bass, reflecting the shifts in abundance of these two species identified through other fish sampling programs of the AMP.

4. Fish Abnormalities

The occurrence of physical abnormalities in fish captured during AMP sampling is monitored using a standardized protocol known as DELTFM. DELTFM abnormalities are defined as Deformities, Erosions, Lesions, Tumors, Fungus, and/or Malignancies. Data are used for trend analysis and to compare fish collected from Onondaga Lake to those collected in other areas. Fish abnormalities can result from chemical contamination; biological agents such as bacteria, viruses or fungi; or interactions among multiple stressors. DELTFM abnormalities were recorded from Onondaga Lake fish only incidentally from 2000 through 2002 and systematically (all fish that were measured for length and weight) thereafter. Since DELTFM abnormalities were not consistently recorded prior to 2003, the analysis presented herein discusses findings based on data from 2003 through 2009. The discussion of DELTFM abnormalities is further limited to those recorded for adult fish since the incidence of abnormalities in juvenile fish has been comparatively low.

Seventeen species of adult fish were found with DELTFM abnormalities in 2009 (Library Reference 8.7.4.3.1). The species contributing the most to the DELTFM total in 2009 were:

- brown bullhead (48% of total)
- white sucker (12%)
- gizzard shad (9%)
- pumpkinseed (8%)
- largemouth bass (7%).

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[1] The Oneida Lake Creel Survey, 2002-2007. January 2009. Scott D. Krueger, James R. Jackson, Anthony J. VanDeValk, and Lars G. Rudstam. New York Federal Aid in Sport Fish Restoration; Study 2, Job 1 Grant F-56-R: Warmwater Fisheries .Cornell University Biological Field Station, 900 Shackelton Point Rd, Bridgeport, NY, 13030

The 17 species of fish with DELTFM abnormalities in 2009 is the highest yet recorded. Previous years ranged from 8 in 2003 to 12 in 2006 and 2008. The percent of adult fish with DELTFM abnormalities in 2009 was 7.7%, also the highest recorded to date.

Of the fish species found with abnormalities in 2009, the percentage of adults collected with DELTFM abnormalities was greatest for those species that are generally considered benthic or bottom-oriented. These species include brown bullhead, gizzard shad, white sucker, shorthead redhorse, silver redhorse, channel catfish, and bowfin. The percentage of adults collected with DELTFM abnormalities exceeded 14% for of all of these species. The percentage of adults collected with DELTFM abnormalities was 10% or less for all species not generally considered benthic in habit except northern pike and walleye.

Common carp are not included in the DELTFM analysis because carp are not actually boated during boat electrofishing sampling. Carp are only counted due to their large size and number presenting logistical problems involved with holding potentially large numbers of large fish on board. Common carp is a classic benthic or bottom-oriented species that typically feeds by rooting through bottom sediments for invertebrates. This species is also relatively long-lived. Given these characteristics, the occurrence of DELTFM abnormalities in common carp from Onondaga Lake is likely similar to that observed for other benthic species in the lake.

The majority of abnormalities in the Onondaga Lake fish community in 2009 were lesions (63%), followed by erosions and deformities (15% each) (Library Reference 8.7.4.3.1). Tumors, malignancies, and fungal infections were relatively rare (<6% combined). Brown bullhead has consistently had the highest incidence of DELTFM abnormalities of any species collected from Onondaga Lake. In 2009, lesions were the most frequent abnormality encountered in this species, comprising 61% of abnormalities observed. Deformities comprised 23% of abnormalities in brown bullhead, and erosions represented another 14% of abnormalities. In 2008, researchers from Cornell University's College of Veterinary Medicine found a variety of pathogens affecting the Onondaga Lake brown bullhead population, including *Trichodina, Saprolegnia,* and digenean infestations*, Micrococcus luteus,* and *Aeromonas sobria*. *Trichodina* is a protozoan parasite that flourishes under high bacterial loads and can cause attachment-related pathologies. *Saprolegnia* is a water mold that produces a fungal infection and is a primary or secondary pathogen. Digeneans are internal parasitic flatworms, and *Micrococcus luteus,* and *Aeromonas sobria* are bacteria, the latter of which can act as a primary pathogen in fish. Bullheads collected in the fall of 2008 appeared to be recovering from these pathogens as evidenced by healing lesions, and the incidence of lesions and tumors in brown bullhead declined from 27% of adults captured in 2008 to 16% of adults captured in 2009. This could be a sign that the causes of the outbreak of lesions in brown bullhead are subsiding.

The distribution of fish with DELTFM abnormalities showed no distinct spatial distribution in 2009. DELTFM abnormalities were most abundant in fish collected in stratum 2 along the western shore of Onondaga Lake (35% of total), followed by stratum 1 in the northwest corner of the lake (22%), and stratum 3 at the south end of the lake (18%) (Library Reference 8.7.4.3.1**)**.

The fewest (12%) DELTFM abnormalities were found in stratum 4 along the east side of the lake.

Linear regression analysis was used to test for trends over time in DELTFM abnormalities in the adult fish community with regard to 1) percent of the fish community for the whole lake and by individual lake strata; 2) percent of individual species with consistent incidence of DELTFM abnormalities; and 3) type of DELTFM abnormalities. DELTFM abnormalities for the fish community as a whole have shown a significant (α=0.05) increasing trend for the whole lake (Library Reference 8.7.4.3.2) and each of the five strata (Figure 2; Table 3). DELTFM abnormalities have ranged from a low of 0.6% in 2003 to a high of 7.7% in 2009.

The percent of individual species with consistent incidence (abnormalities recorded in at least four years from 2003-2009) of DELTFM abnormalities was analyzed to see if any species were specifically responsible for the overall increasing incidence of abnormalities. These species were bluegill, brown bullhead, channel catfish, largemouth bass, northern pike, pumpkinseed, smallmouth bass, walleye, white perch, white sucker, and yellow perch. None of these species showed a significant increase or decrease in percent of individuals with abnormalities from 2003 through 2009 (Figure 3; Table 4).

Trends in incidence of abnormalities in individual species with regard to lake strata were analyzed by looking at incidence of abnormalities by strata over time for brown bullhead, largemouth bass, and white sucker. These three species were selected because they have been collected consistently throughout the AMP and have comprised a relatively large proportion (68%) of the DELTFM abnormalities recorded during the program. Only brown bullhead in stratum 3 and stratum 5 and white sucker in stratum 4 showed a significant (α=0.05) increase in incidence of DELTFM abnormalities over time (Table 5).

The relative abundance of the various types of DELTFM abnormalities was analyzed for trends over time. The percent of DELTFM abnormalities classified as lesions has increased significantly (α=0.05) since 2003 (Table 6). Conversely, the percentage of deformities decreased significantly over time. The percentage of tumors showed a strong downward trend that was nearly significant (p=0.055).

The reason(s) for the overall increase in DELTFM abnormalities lake-wide and in individual strata since 2003 is not understood. No individual species that have consistently exhibited DELTFM abnormalities have shown a similar increase over time. Some of the observed overall increase is due to increases in the abundance of individual species over time. As an example, brown bullhead have been steadily increasing in abundance in the fish community as a whole. Because this species has a relatively high incidence of DELTFM abnormalities, an increase in the population size of brown bullhead has resulted in an increase in the total number of DELTFM abnormalities observed overall. This reasoning explains a portion of the observed increase, but it does not account for all of it.

The percent of fish of a given species with DELTFM abnormalities is highly variable from year to year, explaining why no individual species showed a significant increasing trend in DELTFM abnormalities. Notable increases in lake-wide DELTFM abnormalities have occurred in 2005, 2008, and 2009. In each of these years, different species have shown marked increases in DELTFM abnormalities from the previous year. In 2009, one such species was gizzard shad. DELTFM abnormalities were found on 24% (21 of 88) of gizzard shad collected in 2009, compared to a previous high of 0.8% (1 of 123) in 2006. Similarly, the number of pumpkinseed with DELTFM abnormalities increased from a high of 5 in 2008 (3.9% of all abnormalities) to 18 in 2009 (8.0% of all abnormalities). A large increase in the incidence of DELTFM abnormalities in a species one year may be followed by a similar decrease the following year. The inconsistent and sometimes widely fluctuating incidence of DELTFM abnormalities in individual fish species complicates identification of causes of the apparent increase in DELTFM abnormalities over time in the lake.

Reasons for the increase in the number of species with DELTFM abnormalities from a previous high of 12 in 2006 and 2008 to 17 in 2009 are also unknown. Only one of these species (silver redhorse) had not been reported with DELTFM abnormalities previously. Only one species (freshwater drum) that had previously been reported having DELTFM abnormalities was not found to have abnormalities in 2009.

The types of DELTFM abnormalities affecting fish in Onondaga Lake have changed over the course of the AMP. The incidence of deformities and tumors has declined considerably, while the incidence of lesions has increased significantly. Many factors can influence the incidence of lesions, including types and levels of various bacteria and other pathogens in the lake, physical stress on fish (such as spawning activity, elevated water temperature, water chemistry extremes), chemical exposure, and even injury or stress from fish sampling programs and angling. Further study of the types of injury or infection associated with observed lesions is required to better understand what causes the observed lesions, why the incidence of lesions is increasing and if the causes are consistent across species.

The incidence of lesions and tumors in brown bullhead in Onondaga Lake from 2000 to 2009 was compared with similar data[2] from waters in the Chesapeake Bay watershed, Great Lakes, and Cape Cod area. Prior to 2007, occurrences of lesions and tumors in Onondaga Lake brown bullhead were within the range associated with reference sites (typically <5% incidence) from this greater regional set of waters. Data since 2007 indicate a shift in occurrence to levels associated with contaminated sites from regional waters (Library Reference 8.7.4.3.4). The cause of this shift is not known, but as indicated previously, several pathogens affecting brown bullhead in Onondaga Lake have recently been identified. The incidence of lesions and tumors

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[2] The studies from regional waters were conducted independent of the AMP; as a result, the criteria used to distinguish lesions and tumors may differ somewhat between studies. To standardize the terminology between studies, the comparison to other regional waters is limited to lesions and tumors, rather than the six DELTFM categories used for the AMP.

in brown bullhead in Onondaga Lake declined in 2009, reflecting an apparent recovery (at least partially) of the population from these pathogens. Another possible explanation for the observed increase in DELTFM abnormalities in recent years is that as water quality has improved over time, more of the lake area has become inhabitable for fish. As a consequence, benthic fish may be expanding their use of areas with contaminated sediments. Increased exposure to contaminated sediment could be causing an increase in DELTFM abnormalities in benthic species.

5. Integrated Assessment of the Food Web

Changes in water quality due to improvements in the sewage treatment process and how these changes affect the various components of the aquatic ecosystem as a whole must be considered to understand more fully observed trends in the fisheries data. Fish populations are a product of their environment, and the environment of Onondaga Lake has changed dramatically since the inception of the AMP. The driving factor in this change has been improvements to water quality primarily in the form of reduced phosphorus and ammonia inputs to the lake. These two improvements have had a cascading effect on the physical and biological features of the lake. They have resulted in significant changes in water clarity and dissolved oxygen. These factors have in turn influenced growth of aquatic macrophytes and overall habitat quality in the lake. Improved habitat conditions have allowed many existing fish populations to increase and other fish and invertebrate species to become established or increase their abundance and distribution in the lake.

5.1 Changes Associated With Improved Water Quality and Clarity

Many of the observed changes in fish populations and the fish community as a whole may be attributed to improvements in water quality. One of the biggest effects of reduction in nutrients has been the increase in water clarity due to reduction of phytoplankton biomass and the elimination of nuisance algae blooms. Water clarity has been further improved by the increasing abundance of dreissenid mussels in recent years as a direct result of reduction in ammonia levels in the lake. This improved water clarity in conjunction with improved oxygen conditions throughout the summer have created expanded habitat for fish species throughout the lake, especially in deeper, pelagic areas. Improvements in water quality, particularly reduced levels of ammonia, have led to the successful recruitment of alewife in the lake, filling a niche in the pelagic community of the lake that was previously underutilized. Alewife produced a very strong year class in 2002 and has become well established in the lake with several age classes represented. Alewife comprised a large proportion of the larval samples in 2009, indicating the potential for another strong year class.

Alewife can exert strong predation pressure on zooplankton, including pelagic larval fish. There is strong evidence that, when abundant, alewife have reduced abundance of large zooplankton and affected reproduction of some fish species with pelagic larvae in Onondaga Lake. Alewife also serves as a source of prey for other pelagic fish. The presence of this pelagic prey in conjunction with improved deepwater water-quality conditions, increased macrophyte abundance in the littoral zone, and improved water clarity, may have led to larger smallmouth bass shifting to a more pelagic habitat. Larger yellow perch may similarly be foraging on pelagic alewife. The availability of abundant pelagic forage may be a reason that smallmouth bass greater than 280 mm and yellow perch greater than 300 mm currently make up a small proportion of the adult littoral catches.

Not all of the effects of improved water quality may be beneficial to the fish community. Expansion of areas used by benthic species may be a cause of increased DELTFM abnormalities as benthic fish increase use of areas with contaminated sediments. This could explain the increasing incidence of DELTFM abnormalities in recent years and may also explain some of the downward trends in abundance of some benthic invertivores (common carp, shorthead redhorse).

5.2 Changes Associated With Increased Macrophytes

Macrophyte coverage in Onondaga Lake has been increasing in response to water-quality improvements, particularly those that have resulted in increased water clarity. Increased water clarity has allowed aquatic macrophytes to grow in areas where water was too turbid for sunlight to penetrate to the bottom. This has resulted in not only an increase in the abundance of macrophytes, but also an expansion of the littoral zone so that more area of the lake bottom supports macrophyte growth. This has had significant ramifications for the fish community.

Seven of nine fish species showing a significant increase since 2000 are often associated with aquatic macrophytes during one or more life history stages. These include largemouth bass, golden shiner, yellow bullhead, pumpkinseed, rock bass (YOY), northern pike, and bowfin. Yellow perch have not shown an overall significant increase in abundance, but have shown a steady increase since 2006. Most of the above species are dependent on macroinvertebrate forage as juveniles and adults or prey on forage fish dependent on vegetated habitats. Some of these species also use aquatic macrophytes as a primary spawning substrate.

Ironically, the increased macrophytes growth in the lake over time may be making it more difficult to detect some of the positive effects this change is having on the fish community.

Increased macrophytes may be leading to sampling inefficiencies, especially with regard to the littoral YOY assessments conducted by seining. Macrophytes reduce the efficiency of seining and may allow many fish to escape capture by the net. This may be a reason that YOY trends often do not match what has been observed in the larval or adult sampling programs. Yellow perch have become more abundant in larval samples over the past several years, but the juvenile catch rates do not coincide with what would be expected later in the year when yellow perch juveniles would move into the littoral zone. Yellow perch adult abundance has also increased in recent years despite YOY catch rates to the contrary.

The design of the YOY sampling program may also be contributing to discrepancies between larval and YOY abundance now that macrophytes are providing more YOY habitat throughout the lake. YOY seine samples are collected at the same locations each year. Improved habitat conditions in the littoral zone throughout the lake have resulted in expansion of available habitat for YOY of various species. It is possible that higher levels of YOY production of species like yellow perch are not being detected in littoral seine samples because this production is occurring in areas outside of the long-established sampling locations.

5.3 Resultant Food-Web Shifts

Many food web shifts observed in Onondaga Lake can be attributed to improvements in water quality. In years of high alewife abundance, fish with pelagic larvae (such as pumpkinseed, bluegill, yellow perch, white perch) have shown reduced recruitment likely due to predation of larvae by alewife when alewife abundance is relatively high. Alewife in turn provide forage for larger, piscivorous fish, including smallmouth and largemouth bass, yellow perch, white perch, and walleye. Changes in the size distribution of smallmouth bass, in particular since 2000, suggest that larger adults of this species may have shifted to deeper, offshore habitat from shallower, littoral habitat. The availability of alewife as forage in pelagic habitats may be facilitating this shift. If such a shift has occurred, this would reflect a change in adult smallmouth bass foraging from a littoral-based food web to a pelagic-based food web.

Increased macrophyte abundance presumably has resulted in a substantial increase in production of macroinvertebrates in the littoral zone. This in turn promotes the observed increase in abundance of several littoral fish species that use macrophytes beds for foraging areas. These would include largemouth bass, pumpkinseed, yellow perch, and brown bullhead among others. YOY sport fish and forage fish species, such as golden shiner, that prefer vegetated habitats are increasing in number as a result of expanded habitat. These small fish in turn provide additional forage for larger littoral piscivores like largemouth bass. Common carp have shown a significant decline despite a preference for vegetated spawning habitat. It is possible that common carp numbers may be being controlled in recent years by increased predation of larvae and YOY by littoral zone predators such as largemouth bass, yellow perch, and rock bass.

The proliferation of zebra mussels in the early 2000s and more recently the quagga mussel may be helping to support the increased abundance and high relative weight of pumpkinseed by providing an abundant forage source for this species. Species like pumpkinseed, freshwater drum, yellow perch, and common carp that are known to feed on dreissenids and other mollusks are likely benefiting from the increasing abundance of dreissenids in the lake. Consumption of dreissenids by littoral fishes provides another connection between the littoral-based food web and the pelagic-based food web. The increasing complexity of trophic dynamics in Onondaga Lake is another sign of recovery of the lake from past environmental perturbations.

Overall, there has been an increase in the quantity and quality of habitat available to fish species in Onondaga Lake. This has resulted in a slight increase in fish species richness with a more even distribution of fish throughout the lake. Many fish species, particularly those associated with vegetated habitats, are also increasing in abundance. The aquatic food web within the lake continues to diversify, with more species becoming more interrelated. This increasing complexity with regard to energy sources and energy flow results in an ecosystem that may be more resilient to environmental stress. The results of the AMP in 2009 indicate that this is an ongoing process and that more changes are likely to occur. As water quality continues to improve, resulting in more diverse and higher quality habitats becoming established, increases in aquatic species diversity, abundance, and interrelatedness can also be expected.

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Tables and Figures

Table 1. Proportional stock density (PSD) and relative stock density (RSD) by size class of largemouth bass, smallmouth bass, *Lepomis* spp., yellow perch, and brown bullhead collected during fall electrofishing and gill net sampling, Onondaga Lake, 2000-2009.

Largemouth Bass											
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Mean**
RSD S-Q	44.0	19.2	61.8	41.3	29.5	30.9	35.6	53.7	39.4	49.4	40.5
RSD Q-P	29.4	42.3	21.3	34.8	55.2	32.1	25.3	24.1	33.3	38.0	33.6
RSD P-M	26.6	38.5	15.7	23.9	15.2	37.0	39.1	22.2	27.3	12.7	25.8
RSD M-T	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
RSD-T	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PSD	56.0	80.8	38.2	58.7	70.5	69.1	64.4	46.3	60.6	50.6	59.5
N	109	52	89	46	105	81	87	54	99	79	

Smallmouth Bass											
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Mean**
RSD S-Q	55.9	39.6	44.6	33.3	60.0	71.7	71.8	92.6	87.3	89.6	64.6
RSD Q-P	23.5	35.4	27.7	25.0	12.5	11.3	7.7	4.6	11.1	8.3	16.7
RSD P-M	17.6	22.9	26.5	25.0	22.5	11.3	14.1	0.9	0.0	2.1	14.3
RSD M-T	2.9	2.1	1.2	16.7	5.0	5.7	6.4	1.9	1.6	0.0	4.3
PSD	44.1	60.4	55.4	66.7	40.0	28.3	28.2	7.4	12.7	10.4	35.4
N	34	48	83	24	40	53	78	108	63	48	

Lepomis											
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Mean**
RSD S-Q	43.5	17.4	43.5	31.0	56.7	90.1	38.4	20.1	67.3	86.0	49.4
RSD Q-P	54.8	73.6	53.4	61.9	41.9	9.4	60.0	77.6	30.8	13.9	47.7
RSD P-M	1.7	9.1	3.1	7.1	1.4	0.6	0.8	2.3	1.7	0.1	2.8
RSD M-T	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.2	0.0	0.1
PSD	56.5	82.6	56.5	69.0	43.3	9.9	61.6	79.9	32.7	14.0	50.6
N	230	121	223	155	210	171	125	174	416	765	

Table 1. Continued.

Yellow Perch											
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Mean**
RSD S-Q	96.9	69.8	65.0	62.9	13.0	15.2	87.5	37.0	29.7	62.5	53.9
RSD Q-P	1.9	29.1	30.0	30.6	78.0	48.5	6.9	58.7	54.2	25.0	36.3
RSD P-M	0.8	1.1	5.0	6.5	9.0	36.4	5.6	4.3	16.1	12.1	9.7
RSD M-T	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.1
PSD	3.1	30.2	35.0	37.1	87.0	84.8	12.5	63.0	70.3	37.5	46.1
N	262	179	120	62	100	33	72	92	155	264	

Brown Bullhead											
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Mean**
RSD S-Q	4.5	6.3	25.0	50.0	28.6	35.0	22.6	2.1	5.7	13.2	19.3
RSD Q-P	50.0	18.8	0.0	33.3	32.1	41.7	45.3	58.3	41.5	34.2	35.5
RSD P-M	45.5	75.0	75.0	16.7	39.3	23.3	32.1	35.4	51.9	50.7	44.5
RSD M-T	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.9	2.0	0.7
PSD	95.5	93.8	75.0	50.0	71.4	65.0	77.4	97.9	94.3	86.8	80.7
N	22	16	4	6	28	60	53	48	106	152	

Table 2. Relative weight (W_r) by size class of largemouth bass, smallmouth bass, bluegill, pumpkinseed, yellow perch, and brown bullhead collected during fall electrofishing and gill net sampling from Onondaga Lake, 2000-2009. (#;#) = standard error; sample size.

Largemouth Bass

Length Range (mm)	**2000^a**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Mean**
200-299 (Stock to Quality)		101.2 (2.9;2)	102.3 (0.8;54)	113.4 (2.9;17)	102.1 (1.3;31)	110.7 (1.4;25)	100.4 (1.4;29)	101.7 (1.2;28)	108.1 (1.6;38)	108.9 (1.9;39)	105.4 (1.6;9)
300-379 (Quality to Preferred)		96.0 (1.4;6)	96.5 (2.2;19)	110.8 (3.5;16)	110.4 (1.2;56)	108.5 (1.6;26)	102.7 (3.2;22)	101.1 (4.0;12)	97.4 (1.6;33)	102.0 (1.9;29)	102.8 (1.9;9)
380-509 (Preferred to Memorable)		100.5 (1.5;13)	103.3 (3.5;14)	109.5 (3.3;11)	113.0 (2.8;16)	112.9 (1.8;30)	103.4 (1.6;34)	108.3 (2.5;12)	104.3 (2.5;27)	102.2 (2.5;9)	106.4 (1.6;9)
510-629 (Memorable to Trophy)			127.0 (NA;1)								127.0 (NA;1)
≥630 (Trophy)											
Overall Mean		**99.0**	**101.5**	**111.5**	**108.3**	**110.8**	**102.2**	**103.1**	**103.5**	**105.5**	
Standard Error		**1.1**	**1.0**	**1.8**	**1.0**	**1.0**	**1.1**	**1.3**	**1.1**	**1.3**	
Sample Size		**(21)**	**88**	**44**	**103**	**81**	**85**	**52**	**98**	**77**	

Smallmouth Bass

Length Range (mm)	**2000^a**	**2001**	**2002**	**2003^b**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Mean**
180-279 (Stock to Quality)		98.0 (0.2;2)	95.7 (1.4;36)	102.5 (5.9;8)	92.3 (2.6;24)	95.9 (1.0;36)	87.8 (1.9;55)	88.9 (1.0;100)	92.4 (1.5;52)	100.7 (1.3;43)	94.9 (1.7;9)
280-349 (Quality to Preferred)		84.0 (7.8;3)	89.6 (1.6;23)		89.5 (3.7;5)	85.6 (2.7;6)	72.6 (5.2;6)	85.4 (4.1;5)	89.1 (4.6;6)	87.3 (5.0;4)	85.4 (2.0;8)
350-429 (Preferred to Memorable)		64.7 (15.6;2)	89.9 (1.8;22)		90.5 (2.5;9)	84.4 (2.8;6)	78.7 (3.5;11)	86.5 (NA;1)		89.8 (NA;1)	83.5 (3.5;7)
430-509 (Memorable to Trophy)		73.8 (NA;1)	116.0 (NA;1)	86.4 (NA;1)	80.8 (17.4;2)	89.3 (1.3;3)	79.7 (3.7;5)	85.2 (NA;1)	75.2 (NA;1)		85.8 (4.7;8)
≥510 (Trophy)											
Overall Mean		**81.4**	**92.7**	**100.7**	**91.0**	**93.0**	**84.8**	**88.7**	**91.8**	**99.3**	
Standard Error		**6.0**	**1.0**	**5.5**	**1.9**	**1.1**	**1.6**	**1.0**	**1.4**	**1.4**	
Sample Size		**8**	**82**	**9**	**40**	**51**	**77**	**107**	**59**	**48**	

a - data excluded due to imprecise measurement

Table 2. Continued.

Bluegill										
Length Range (mm)	**2000[a]**	**2001**	**2002**	**2003[a]**	**2004[a]**	**2005**	**2006**	**2007**	**2008**	**2009**	**Mean**
80-149 (Stock to Quality)		96.8 (1.5;3)	100.4 (2.3;13)			104.0 (3.1;6)	98.4 (1.4;5)	97.8 (5.1;9)	104.5 (1.8;19)	106.7 (0.8;41)	101.2 (1.5;7)
150-199 (Quality to Preferred)		95.5 (2.2;38)	99.8 (1.1;41)			99.8 (1.4;11)	95.3 (1.3;26)	95.1 (1.1;50)	100.9 (1.0;45)	102.7 (1.3;26)	98.4 (1.2;7)
200-249 (Preferred to Memorable)		88.1 (4.4;9)	92.6 (1.1;5)			87.4 (NA;1)		85.2 (11.6;2)	101.0 (NA;1)		90.9 (2.8;5)
250-299 (Memorable to Trophy)											
≥300 (Trophy)											
Overall Mean		**94.2**	**99.3**			**100.5**	**95.8**	**95.2**	**102.0**	**106.1**	
Standard Error		**1.9**	**1.0**			**1.6**	**1.1**	**1.2**	**0.9**	**0.7**	
Sample Size		**50**	**59**			**18**	**31**	**61**	**65**	**67**	

Pumpkinseed										
Length Range (mm)	**2000[a]**	**2001[a]**	**2002**	**2003[a]**	**2004[a]**	**2005**	**2006**	**2007**	**2008**	**2009**	**Mean**
80-149 (Stock to Quality)			105.4 (1.5;43)			105.9 (0.6;144)	102.7 (1.5;38)	104.1 (2.3;24)	109.0 (0.5;257)	105.1 (0.4;511)	105.3 (0.9;6)
150-199 (Quality to Preferred)			108.1 (1.9;23)			99.8 (1.8;5)	104.3 (0.9;48)	107.8 (1.0;83)	109.4 (1.1;82)	107.6 (0.9;77)	106.3 (1.4;6)
200-249 (Preferred to Memorable)							86.9 (NA;1)	102.8 (1.1;2)	102.9 (2.3;6)	108.8 (NA;1)	100.4 (4.7;4)
250-299 (Memorable to Trophy)											
≥300 (Trophy)											
Overall Mean			**106.4**			**105.7**	**103.4**	**106.9**	**109.0**	**105.4**	
Standard Error			**1.2**			**0.6**	**0.9**	**0.9**	**0.5**	**0.4**	
Sample Size			**66**			**149**	**87**	**109**	**345**	**589**	

a - data excluded due to imprecise measurement

Table 2. Continued.

Yellow Perch

Length Range (mm)	**2000[a]**	**2001**	**2002**	**2003[a]**	**2004[a]**	**2005**	**2006**	**2007**	**2008**	**2009**	**Mean**
130-199 (Stock to Quality)		80.5 (1.2;69)	87.0 (1.2;50)			88.1 (4.3;4)	84.9 (0.9;63)	88.9 (0.9;34)	91.8 (1.1;44)	89.1 (0.5;163)	87.2 (1.4;7)
200-249 (Quality to Preferred)		73.8 (1.8;31)	85.6 (1.9;26)			83.4 (1.9;16)	79.0 (4.9;5)	83.5 (1.2;54)	86.9 (0.7;84)	85.5 (0.7;65)	82.5 (1.7;7)
250-299 (Preferred to Memorable)		87.3 (NA;1)	81.2 (2.4;3)			78.9 (2.0;12)	69.0 (2.6;4)	76.3 (4.8;4)	82.6 (1.5;25)	79.3 (1.3;31)	79.2 (2.1;7)
300-379 (Memorable to Trophy)										80.8 (NA;1)	80.8 (NA;1)
≥380 (Trophy)											
Overall Mean **Standard Error** **Sample Size**		**78.5** **1.0** **101**	**86.3** **1.0** **79**			**82.3** **1.4** **32**	**83.6** **1.0** **72**	**85.2** **0.9** **92**	**87.6** **0.6** **153**	**87.0** **0.4** **260**	

Brown Bullhead

Length Range (mm)	**2000[a]**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Mean**
150-229 (Stock to Quality)			80.1 (NA;1)	99.2 (4.9;3)	90.3 (1.7;8)	89.0 (2.0;20)	80.6 (3.4;12)		88.8 (5.5;6)	88.3 (1.2;20)	88.0 (2.4;7)
230-299 (Quality to Preferred)		81.4 (2.1;2)		93.1 (NA;1)	83.1 (2.7;9)	88.2 (1.5;24)	85.7 (1.9;24)	86.1 (1.8;28)	82.3 (1.6;44)	85.3 (1.9;51)	85.7 (1.3;8)
300-379 (Preferred to Memorable)		87.8 (1.9;8)	84.8 (11.6;3)		93.4 (2.4;11)	91.6 (3.1;14)	82.6 (2.9;17)	85.4 (1.5;17)	82.0 (1.3;55)	85.8 (1.3;77)	86.7 (1.4;8)
380-459 (Memorable to Trophy)								57.5 (21.8;2)			57.5 (NA;1)
≥460 (Trophy)											
Overall Mean **Standard Error** **Sample Size**		**86.5** **1.8** **10**	**83.6** **8.3** **4**	**97.7** **3.8** **4**	**89.2** **1.6** **28**	**89.3** **1.2** **58**	**83.5** **1.5** **53**	**84.7** **1.6** **47**	**82.5** **1.0** **105**	**86.0** **1.0** **148**	

a - data excluded due to imprecise measurement

Table 3. Results of linear regession analyses of the relationship between percent of adult fish with DELTFM abnormalities and year for the whole lake and the five individual strata of Onondaga Lake, 2003-2009. Bold = significant at α=0.05 level.

Variable	**Slope**	**p-value**	**Adjusted R^2**
Whole lake	1.008	**0.004**	0.795
Stratum 1	0.875	**0.006**	0.763
Stratum 2	1.426	**0.022**	0.621
Stratum 3	1.499	**0.003**	0.821
Stratum 4	0.541	**0.028**	0.584
Stratum 5	0.833	**0.031**	0.565

Table 4. Results of linear regession analyses of the relationship between percent of adult fish with DELTFM abnormalities and year for fish species from Onondaga Lake with consistent incidence of DELTFM abnormalities, 2003-2009. Bold = significant at α=0.05 level.

Variable	**Slope**	**p-value**	**Adjusted R^2**
Bluegill	0.204	0.264	0.088
Brown bullhead	2.737	0.142	0.253
Channel catfish	-1.089	0.675	-0.154
Largemouth bass	0.951	0.096	0.347
Northern pike	7.381	0.105	.0327
Pumpkinseed	0.234	0.120	0.296
Smallmouth bass	0.875	0.324	0.032
Walleye	1.439	0.608	-0.132
White perch	0.246	0.244	-0.110
White sucker	2.115	0.249	0.105
Yellow perch	0.149	0.510	-0.090

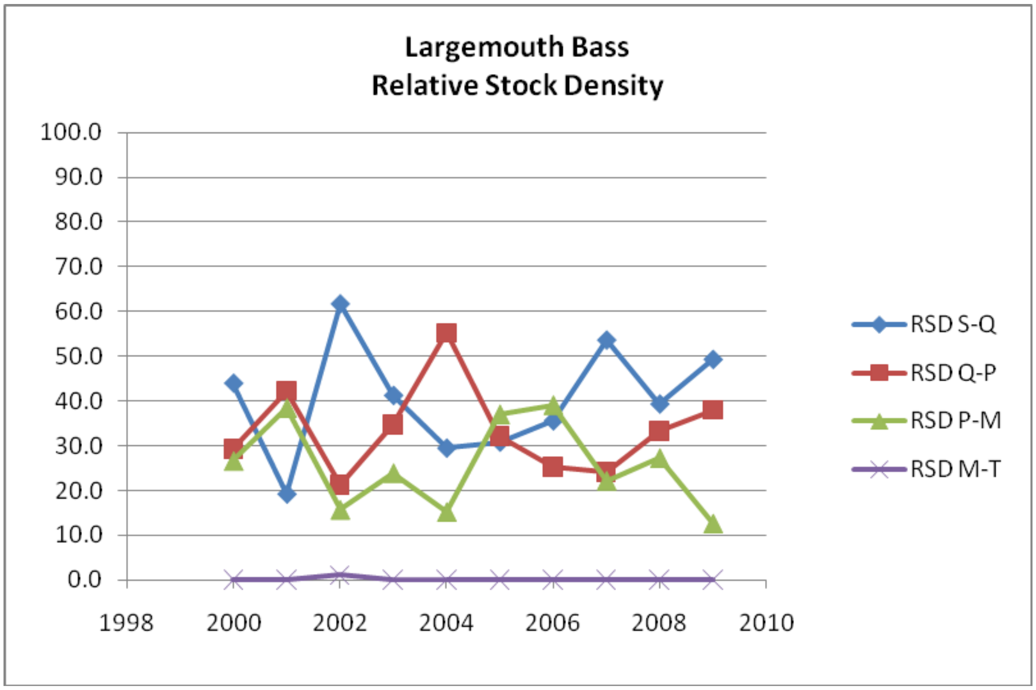
Table 5. Results of linear regession analyses of the relationship between percent of adult fish with DELTFM abnormalities by stratum for brown bullhead, largemouth bass, and white sucker from Onondaga Lake, 2003-2009. Bold = significant at α=0.05 level.

Species	Stratum	Slope	p-value	Adjusted R^2
Brown bullhead	1	1.092	0.561	-0.1138
Brown bullhead	2	1.696	0.519	-0.095
Brown bullhead	3	4.342	**0.042**	0.514
Brown bullhead	4	2.072	0.381	-0.013
Brown bullhead	5	6.903	**0.019**	0.640
Largemouth bass	1	2.117	0.090	0.3627
Largemouth bass	2	-0.600	0.690	-0.159
Largemouth bass	3	1.666	0.280	0.072
Largemouth bass	4	1.253	0.171	0.205
Largemouth bass	5	0.241	0.652	-0.147
White sucker	1	0.905	0.770	-0.1773
White sucker	2	2.194	0.333	0.024
White sucker	3	1.884	0.197	0.168
White sucker	4	5.837	**0.047**	0.494
White sucker	5	0.527	0.767	-0.177

Table 6. Results of linear regession analyses of the incidence of various DELTFM abnormalities over time from fish species from Onondaga Lake, 2003-2009. Bold = significant at α=0.05 level.

Variable	Slope	p-value	Adjusted R^2
Deformities	-3.893	**0.029**	0.578
Erosions	0.475	0.730	-0.1689
Fungal infections	0.261	0.632	-0.141
Lesions	5.746	**0.026**	0.5939
Malignancies	-0.296	0.712	-0.164
Tumors	-2.307	0.055	0.465

Figure 1. Relative stock density (RSD) by size class of largemouth bass, smallmouth bass, *Lepomis* spp., yellow perch, and brown bullhead collected during fall electrofishing and gill net sampling from Onondaga Lake, 2000-2009.



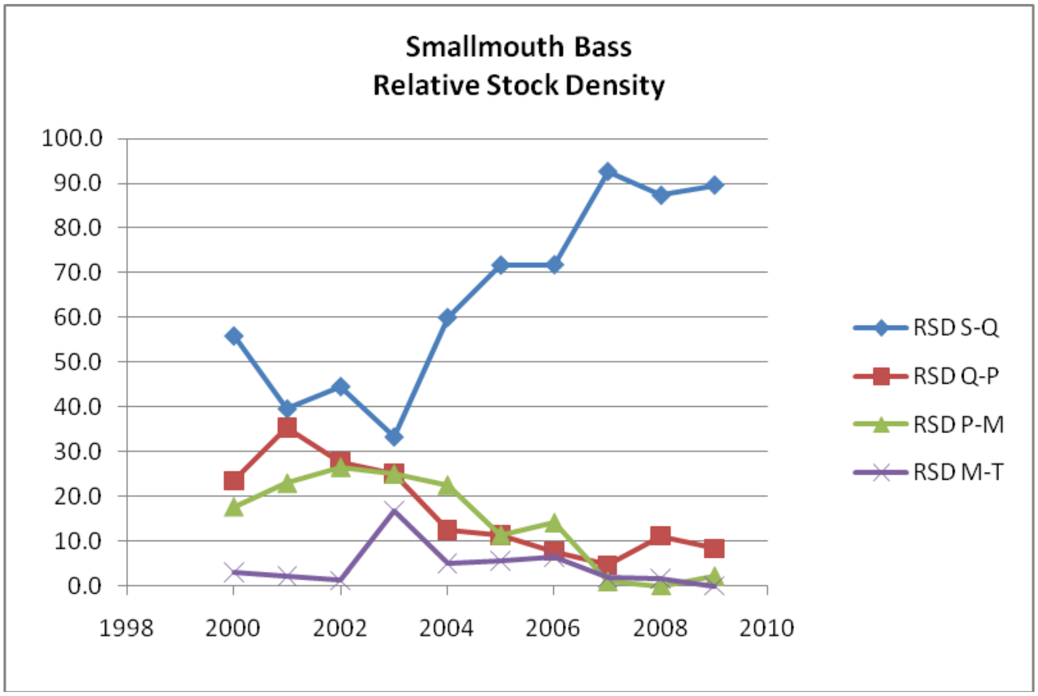
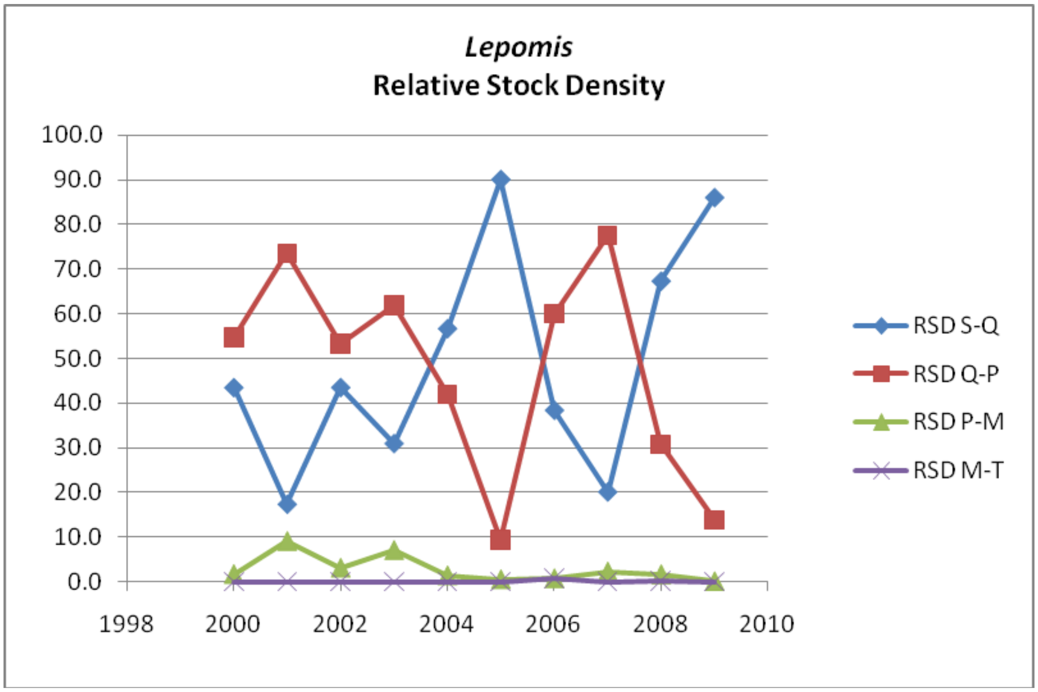


Figure 1. Continued.



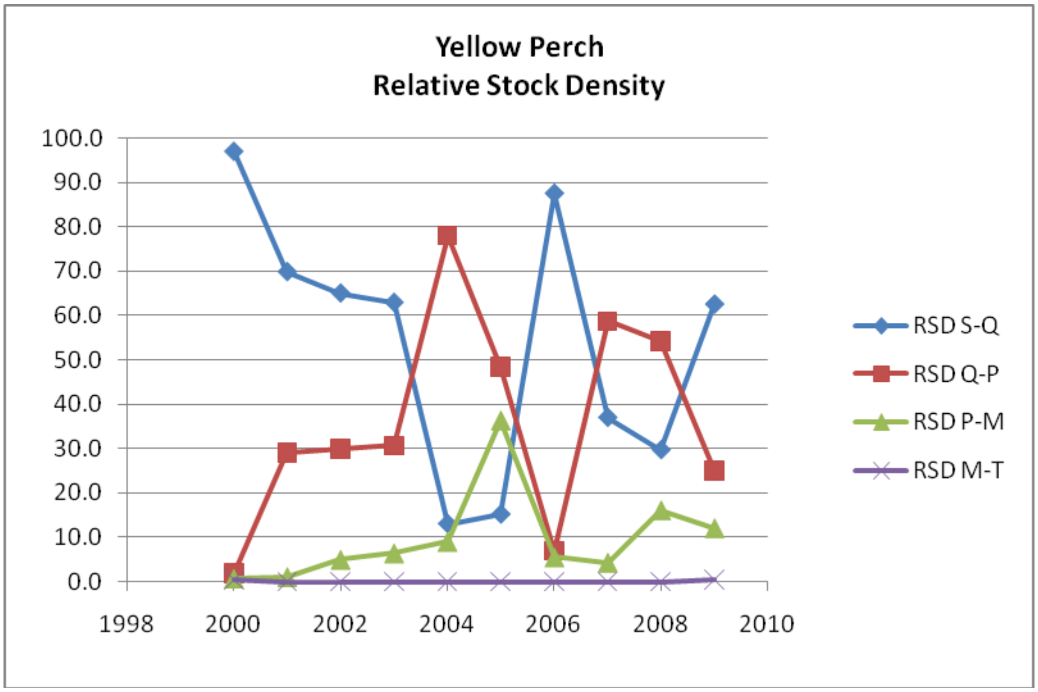


Figure 1. Continued.

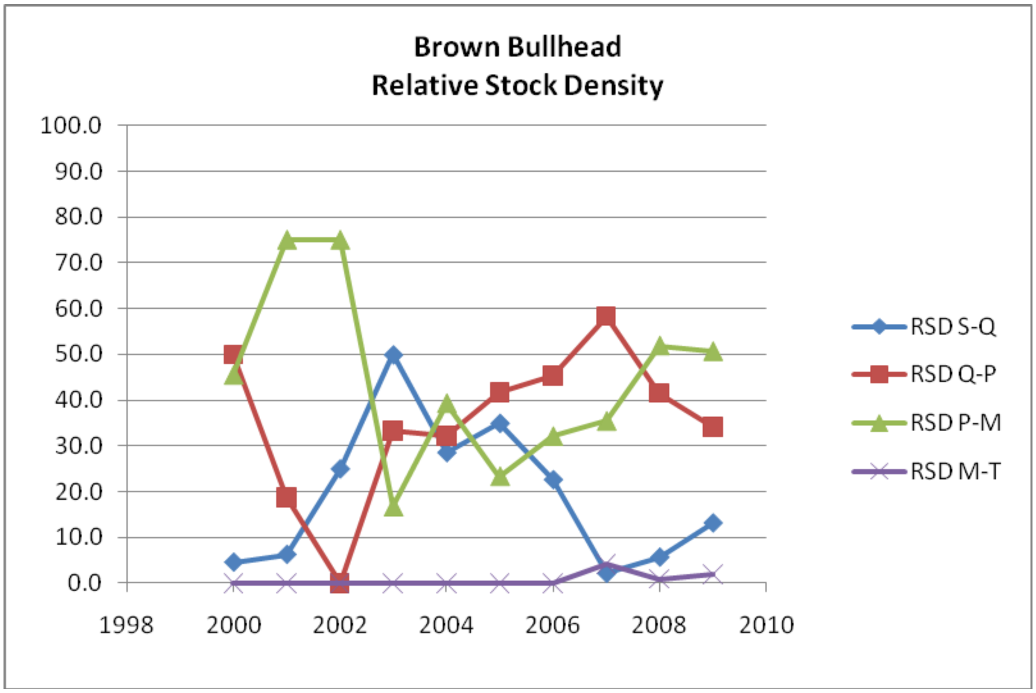


Figure 2. Percent of adult fish with DELTFM abnormalities from the five strata of Onondaga Lake, 2003-2009.

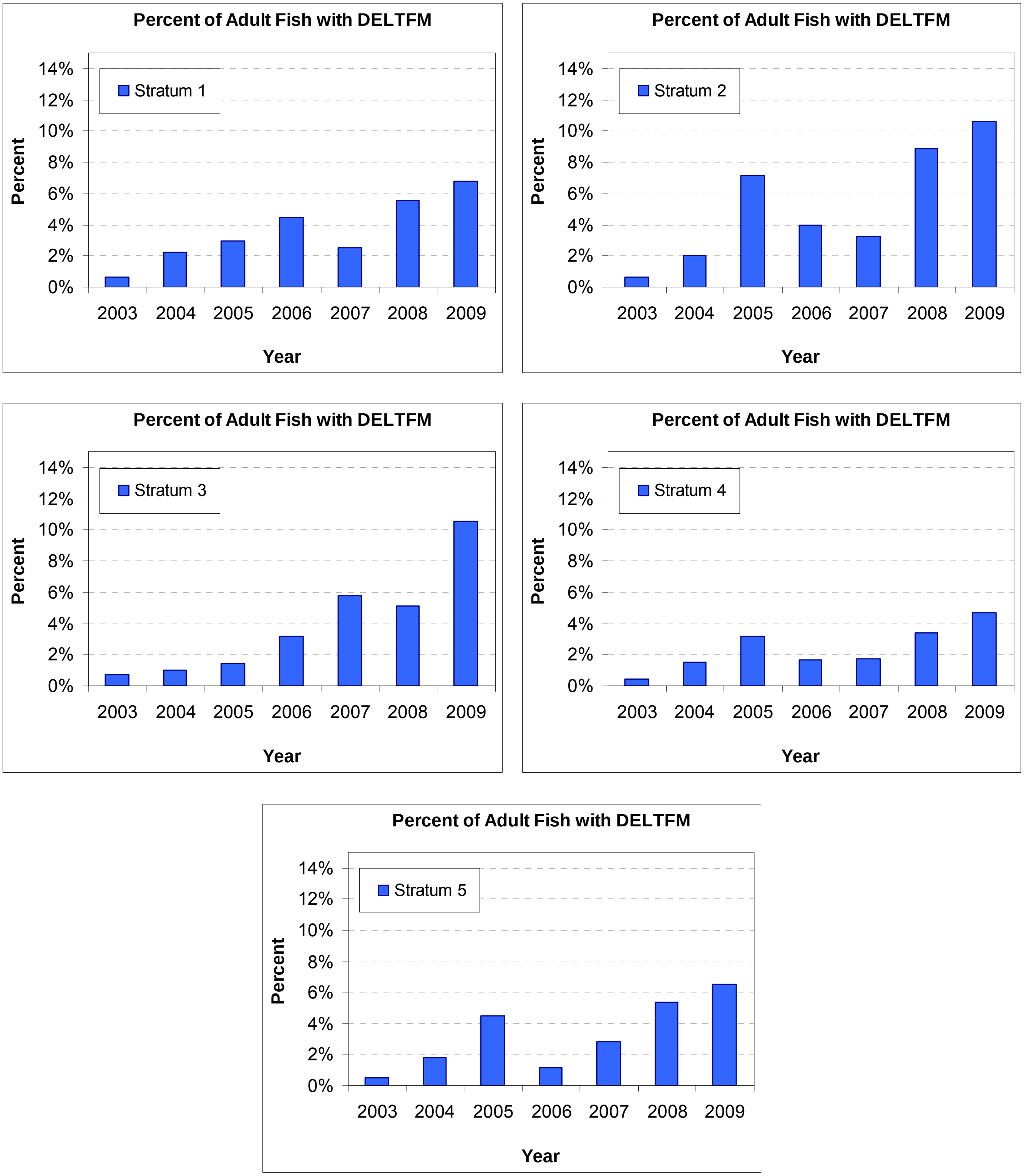


Figure 3. Percent of selected species of fish from Onondaga Lake with DELTFM abnormalities, 2003-2009.

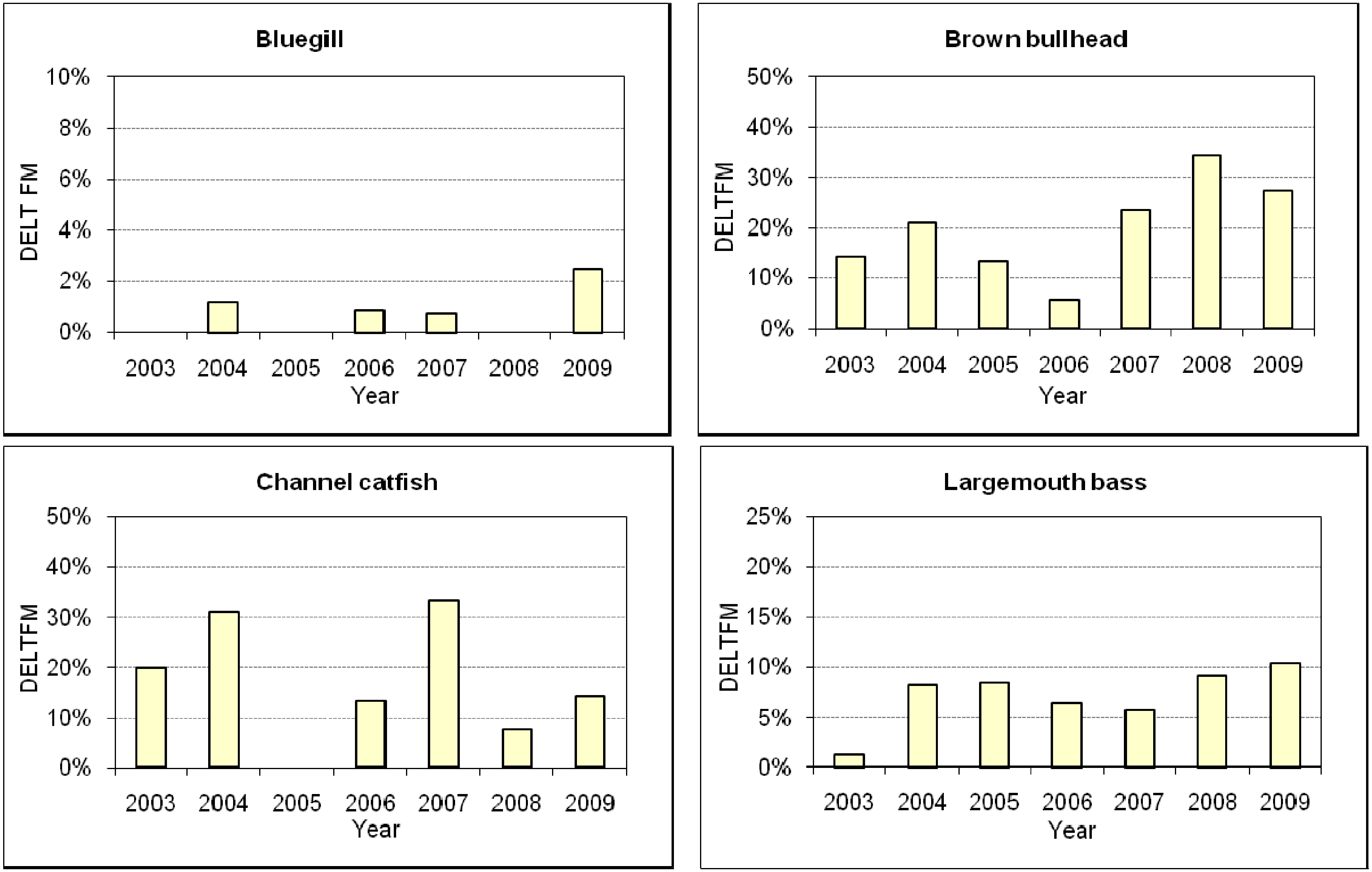


Figure 3 (continued)

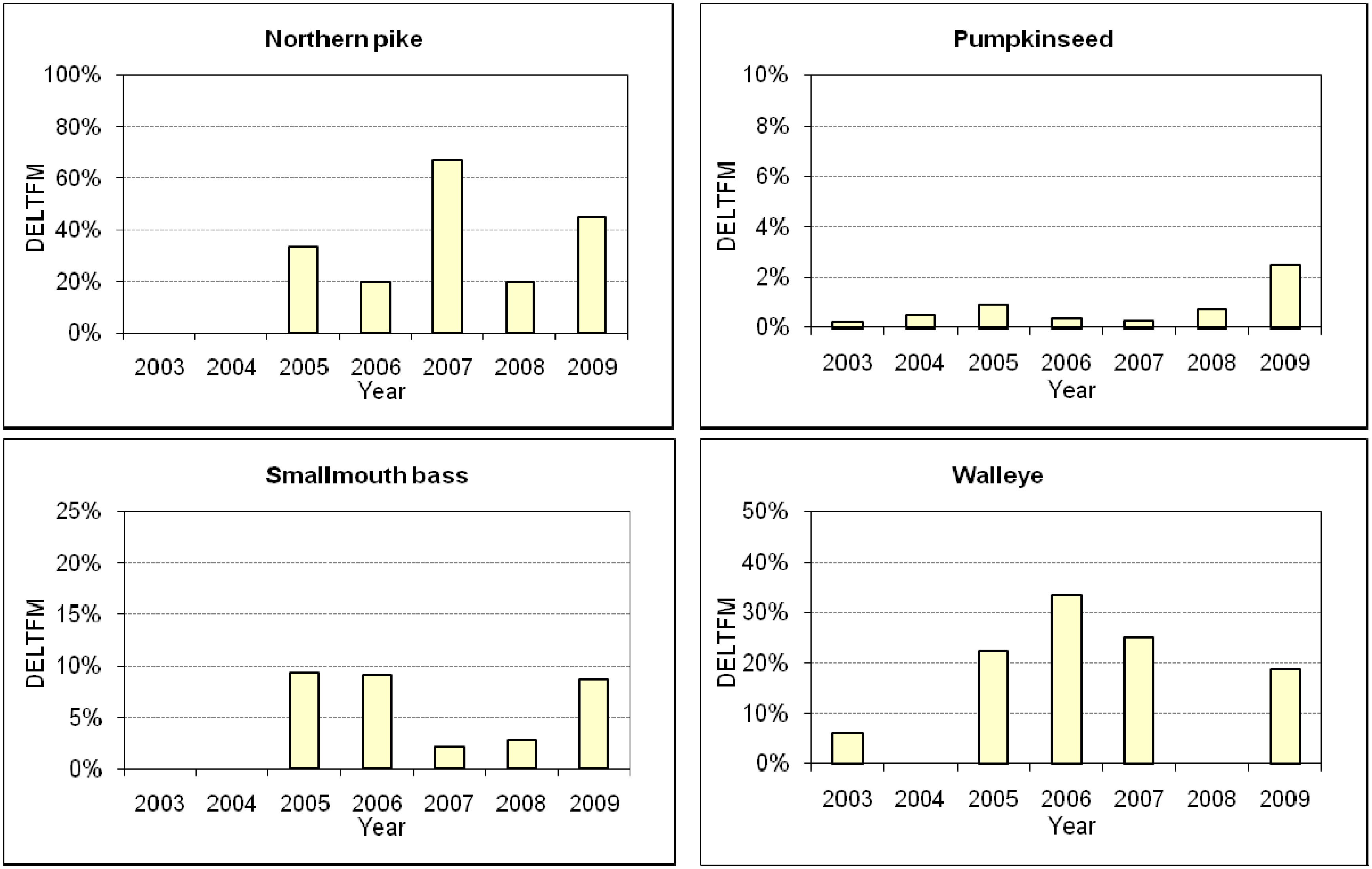


Figure 3 (continued)