Common Carp Assessment in Six Mile Creek
Summary Report: June 2014 - February 2016

Prepared for the Minnehaha Creek Watershed District

February 2016

Justine D. Koch, Reid G. Swanson & Peter W. Sorensen

University of Minnesota

Department of Fisheries, Wildlife, & Conservation Biology

Table of Contents

List of Tables

List of Figures

Purpose

To determine the abundance, seasonal movements, and recruitment patterns of common carp (*Cyprinus carpio*) in the Six Mile Creek Subwatershed to enable development of carp control strategies for restoration of the Six Mile Creek Subwatershed.

Background

Site overview

The Six Mile Creek Subwatershed is predominately agricultural and parkland, but is presently facing increasing urban development pressure. Located in the southwest corner of the Minnehaha Creek Watershed District (MCWD), it spans roughly 27 square miles and encompasses a chain of 17 lakes (Piersons, Marsh, Wassermann, Carl Krey, Kelzer's, Church, East Auburn, West Auburn, Steiger, Sunny, Zumbra, Stone, North Lundsten, South Lundsten, Turbid, Parley, & Mud) and over a dozen unnamed ponds and wetlands (Figure 1). This system flows north from Piersons Lake and eventually drains into Halsted's Bay of Lake Minnetonka.

Water quality in the Six Mile Creek Subwatershed varies by lake, but many lakes are highly degraded and devoid of healthy native submersed plant communities. Additionally, several lakes currently fail to meet state nutrient standards and are classified as impaired for excess nutrients (phosphorus). Because internal loading was identified as a significant driver of in-lake phosphorus concentrations in this system, common carp assessment and management was recommended (Wenck Associates 2013). In 2014, MCWD partnered with the University of Minnesota to initiate a three-year study to obtain a better understanding of the common carp population(s) in the Six Mile Creek Subwatershed to inform sustainable control strategies. This report summarizes the scientific findings of the first two years of this study and provides subsequent tentative management recommendations.

Common carp research & management approach

The introduction of common carp to Minnesota waters in the 1880s was one of the greatest ecological tragedies to befall our shallow lake ecosystems. Being long-lived, mobile, and extremely fecund, the common carp has come to dominate the fish biomass in many lakes in the Upper Midwest (Sorensen & Bajer 2011). Common carp disrupt shallow lake ecosystems by uprooting submersed native vegetation, altering food webs, and often negatively impacting water quality by increasing turbidity and nutrient loading (Bajer et al. 2009; Weber & Brown 2009). In deeper, thermally-stratifying lakes, carp have also been shown to decrease water clarity and reduce submersed aquatic plant growth, but their impact on nutrient cycling is less straightforward (Bajer & Sorensen 2015).

Efforts aimed at improving water quality and fish and wildlife habitat are typically futile until densities of adult carp can be sustainably reduced. Unfortunately, reducing carp densities in a sustainable manner has proven very difficult due to their complex life history strategies. For example, adult carp often exploit outlying predator-free ponds and wetlands for breeding, where young carp often thrive and can colonize connected waters. This influx of young carp can rapidly counteract any adult carp removal efforts (Bajer & Sorensen 2010; Sorensen & Bajer 2011; Osborne 2012; Koch 2014). Nevertheless, recent studies conducted by the Sorensen Laboratory are revealing a possible way forward to sustainably control carp in many watersheds. This management approach typically has three components; (1) understanding carp movement patterns to identify appropriate management units, (2) identifying carp nurseries and suppressing recruitment, and (3) quantifying adult carp abundance and reducing existing biomass.

First, appropriate management units must be defined. Identification of possible carp sub-populations by characterizing carp movements along with age structures can be used to delineate such management units. Presently, the behavior of adult carp is too poorly understood to predict when and where they will move across any particular watershed. Consequently, it is necessary to collect detailed site-specific demographic data on common carp to develop sustainable control strategies at appropriate spatial scales.

Next, the source(s) of juvenile carp (i.e. recruitment) in each management unit must be identified and subsequently remediated, isolated, and/or eliminated (Bajer & Sorensen 2010; Bajer et al. 2012; Koch 2014). Remediation may be possible if the carp nurseries can be restored to support healthy native fish communities comprised of species that consume carp eggs and young (e.g. bluegill sunfish; Silbernagel & Sorensen 2013). Alternatively, recruitment locations may be isolated from the main lakes so adults cannot reach them to breed or alternatively to prevent young from dispersing. If isolation is not feasible, control strategies such as water drawdowns or poisonings at regular intervals can be used to eliminate the young carp before significant numbers mature and disperse.

Lastly, existing adult carp must be removed in large enough numbers to make a meaningful difference to ecosystem function. A target biomass of 100 kg/ha is typically appropriate for shallow Midwestern systems (Bajer et al. 2009). Fortunately, this is often possible through the use of multiple tools such as commercial seining, trapping spawning migrants, baited traps, or piscicides. Seining can sometimes be an efficient means of removal because adult carp tend to aggregate during winter months where they may be targeted by commercial fishermen if the bottom is free of obstacles. The use of radio-tagged 'Judas' fish can increase the success rate of such seining efforts (Bajer et al. 2011). Adult carp may also form springtime spawning aggregations which can be targeted, trapped, and removed. If natural aggregations cannot be exploited, aggregation behavior can be induced by training carp to feed in a particular area using baited traps (Bajer et al. 2010).

Summary of Research Findings—June 2014 to February 2016

Deliverable 1: Estimates of adult common carp abundance in all accessible lakes

Methods

Adult common carp abundance was estimated by conducting standardized electrofishing surveys in each accessible lake (see Table 1) to calculate mean catch per unit effort (CPUE) values. Briefly, surveys consisted of sampling the entire littoral area using a boat electrofisher with pulsed DC current. CPUE measurements were used to estimate the number of carp in each lake based on the number sampled per hour, corrected by known estimates of electrofishing efficiency from similar locations (Bajer & Sorensen 2012). In lakes where multiple surveys were conducted, 95% confidence intervals were generated as a measure of precision. Carp biomass (kg/ha) was estimated by multiplying abundance by the average weight of carp in each lake and then dividing by lake surface area.

During the course of electrofishing surveys, all carp sampled were also marked with external plastic T-bar anchor tags (Hallprint co., Australia) before being released. Having these tagged fish in the system may allow for the calculation of supplemental mark-recapture population estimates if enough tagged fish are recaptured.

Results

At least two electrofishing surveys were conducted in each accessible lake between June 2014 and November 2015, with most lakes having between 6 and 8 surveys completed. Because the catch rates did not differ between years (i.e. catch rates observed during 2015 surveys fell within the 95% confidence intervals generated using 2014 data alone), we combined years to maximize sample size and thus increase the precision of abundance estimates (Table 2).

Carp biomass in the Six Mile Creek Subwatershed study lakes ranged widely from 33 to 1,129 kg/ha (Table 2). Twelve of the 15 accessible lakes surveyed were above 100 kg/ha; a threshold in which carp are known to become ecologically damaging in shallow Midwestern lakes (Bajer et al. 2009). Notably, the carp population in Halsted's Bay was estimated to contain 67,424 (61,236-73,611) individuals with a biomass of 1,129 (1,025-1,233) kg/ha based on seven whole-lake surveys. This exceeds the damaging threshold tenfold and is the highest biomass ever observed by the Sorensen Lab. In addition to Halsted's Bay, carp biomass was very high in Lakes Mud, Parley, W. Auburn, E. Auburn, Turbid, and Wassermann ranging from 259 to 529 kg/ha. Carp biomass was moderate (102-145 kg/ha) in N. Lundsten, S. Lundsten, Steiger, Sunny, and Zumbra. Carp biomass was low (≤86 kg/ha) in Piersons, Stone, and Kelzer's. It should be noted that biomass estimates for South Lundsten and Sunny Lakes are based only on two surveys and should be validated with additional electrofishing surveys next year if water levels enable access with an electrofishing boat.

During the course of all electrofishing surveys conducted across the subwatershed in 2014 and 2015, 1,384 common carp were tagged with T-bar tags and released. To date, 74 of these tagged fish have since been recaptured. Of these 74 recaptured carp, 24 were sampled relatively evenly throughout the subwatershed and thus represent low recapture rates that do not allow for the statistical computation of supplemental mark-recapture estimates in any individual lake. However, the remaining 50 of these tagged carp were recaptured during the commercial seine haul that took place in Parley Lake on March 10th, 2015. This recapture rate allowed us to calculate supplementary population estimates for Parley and Mud lakes combined (the lakes could not be separated because our movement study indicated that all carp from both lakes formed a single large aggregation in Parley Lake). In total, 6,206 carp were captured in the seine haul, of which 5,564 were individually checked for tags and 50 tagged fish were observed. Given that there were 211 carp tagged in Parley and Mud Lakes before the seining occurred, this recapture rate results in an estimated population size of 23,591 carp based on the Lincoln-Peterson method (i.e. $N=Kn/k$ where N = number of individuals in the population, K = number of marked animals in the population, n = number of animals captured, and k = number of recaptured individuals). This mark-recapture population estimate for Parley and Mud Lakes combined is comparable to the sum of estimates generated from electrofishing surveys in both lakes (i.e. 18,097-22,906) despite violating assumptions of a closed population.

Deliverable 2: Information on the seasonal distribution and movement patterns of adult carp

Methods

The seasonal distributions and movement patterns of adult carp across the Six Mile Creek Subwatershed were determined by implanting carp with radio-tags and manually biangulating their locations once per month. In fall of 2014, 102 of the 120 proposed radio-tags were implanted in carp throughout the subwatershed. Tagged fish were distributed as follows: Halsted's Bay (n=15), Mud (n=15), Parley (n=15), E. & W. Auburn (n=15), Wassermann (n=15), Piersons (n=10), Steiger (n=10), and Zumbra (n=7). In April of 2015, 13 more carp were implanted with radio-tags in Sunny (n=3), Turbid (n=5), and North Lundsten (n=5) for a total of 115 radio-tagged carp. Due to low water conditions in spring of 2015, the last 5 tags were implanted in South Lundsten Lake in July 2015 after a period of heavy rain. Each tagged carp was given a unique fish identification number ranging from 1 to 120.

In addition to tracking the radio-tagged carp, movement patterns may also be elucidated by recapturing carp previously tagged with T-bar tags during routine electrofishing surveys. As discussed above, 1,384 carp have been sampled across the subwatershed, tagged with T-bar tags, and released since the onset of the study in June 2014.

Results

To date, all of the radio-tagged carp throughout the subwatershed have been located at least once per month (See Figures 2-20) from November 2014 through February 2016. During April, May, and June, we tracked the carp twice per month to increase the resolution of our data to better capture pre-spawning migrations and spawning behavior. From November 2014 through April 2015, we were able to locate 99% of our tagged fish successfully each month. Beginning in late May 2015 and continuing to the present, an average of 8 tagged carp (7%) have been missing each month, primarily from Parley, Mud, and Halsted's Bay. One carp originally tagged in East Auburn Lake has been missing since April 2015 and one carp from Wassermann Lake has been missing since October 2015. The several missing carp from Parley, Mud, and Halsted's Bay are presumed to be somewhere in greater Lake Minnetonka, but due to time constraints, it is not feasible to search all of Lake Minnetonka. In December, we were able to search roughly half of Lake Minnetonka and we located two carp originally tagged in Halsted's bay as far east as Jenning's Bay (see Figure 18).

The first mortality of a radio-tagged carp occurred in Mud Lake in May 2015. Since then, 15 additional radio-tagged carp have died or lost their transmitters for a total mortality rate of 13.3% over 15 months which is comparable to published annual natural mortality rates in systems with high carp densities (Bajer et al. 2015). The mortalities are spread relatively evenly across the subwatershed (i.e. 2 in Halsted's Bay, 2 in Mud Lake, 4 in Parley Lake, 1 in North Lundsten Lake, 1 in East Auburn Lake, 1 in Steiger Lake, 1 in Zumbra Lake, 3 in Wassermann Lake, and 1 in Turbid Lake) and thus do not diminish the scope or resolution of the movement study.

Determining the locations of tagged carp each month provides information on both seasonal movements between study lakes and within lakes. Understanding movement between lakes is important for delineating appropriate management units and identifying heavily trafficked movement corridors to inform possible barrier and/or trapping locations. To date, of the 120 radio-tagged carp, 52 (43%) have been located in a lake other than where they were originally tagged. Most of the movement has occurred between lakes Parley, Mud, Halsted's Bay, and greater Lake Minnetonka. Of the 45 carp originally tagged in either Parley, Mud, or Halsted's Bay, 39 (87%) have moved between lakes. Most of these movements occurred from Mud Lake to Parley Lake in late fall (see Figures 2-3) or between Parley-Mud and Halsted's Bay in both directions starting in May and continuing through July (see Figures 10-13) . Additionally, 11 of the 45 carp originally tagged in Parley, Mud, or Halsted's Bay (24%) have been located in other bays of Lake Minnetonka (i.e. Priests, Cooks, West Upper, and Jennings) despite low sampling effort in greater Lake Minnetonka. This high rate of movement to and from the rest of Lake Minnetonka likely explains our inability to locate some of the tagged carp each month. There has also been carp movement between North Lundsten, South Lundsten, West Auburn, and East Auburn Lakes. Of the 25 carp tagged in these lakes, 12 (48%) have moved between two or more lakes. These movements have mainly been comprised of a couple of individuals moving between East and West Auburn lakes each month and also a few individuals moving from Auburn to Lundsten during early June (Figure 11). The only other movement of radio-tagged carp we have observed is one individual from Wassermann Lake moving to East Auburn Lake in early June and back to Wassermann in August (Figures 11-13).

There has not been any movement of radio-tagged carp in or out of Turbid, Sunny, Zumbra, Steiger, or Piersons Lakes. It should be noted that water levels were unusually low during spring of 2015 and therefore we did not observe any mass carp spawning migrations despite reports of these events in past years. It should also be noted that recaptures of T-bar tagged carp confirm the movement patterns observed during the radio-tag study and also reveal that it is possible for carp to move from Lundsten Lake through the Parley lake dam in a downstream direction. We recaptured one carp during the commercial seine in Parley Lake in March of 2015 that was originally tagged in West Auburn Lake in June of 2014. To date, there is no evidence that the dam is passable by carp in an upstream direction.

In addition to radio-tagged carp moving between lakes, there have also been strong seasonal patterns in the spatial distribution of carp within lakes. Specifically, wintertime aggregations of carp (at least 85% of radio-tagged carp located within a 10 hectare area) have formed in both 2014-15 and 2015-16 in all but one of the study sites (i.e. Steiger Lake). The timing of aggregation formation is variable between locations and years, but in general, aggregations have formed by December and persisted through February (Table 3). These aggregations have contained as many as 100% of radio-tagged carp in some lakes (i.e. Parley-Mud, N. Lundsten, S. Lundsten, Turbid, W. Auburn, E. Auburn, Sunny, Zumbra, and Wassermann), whereas in other lakes (i.e. Halsted's Bay, Piersons), multiple aggregations comprised of roughly 30-60% of tagged fish each have been observed. Interestingly, winter aggregations in some lakes formed in same spot between years (i.e. Parley, West Auburn, East Auburn, Zumbra, and Piersons) whereas they formed in different places in Wassermann Lake and Halsted's Bay (See Figures 5 and 20). The timing and locations of these winter aggregations can inform adult carp removal efforts via targeted winter seining by commercial fisherman.

Deliverable 3: Identification of sources of juvenile carp across the watershed

Relative abundance of young-of-the-year common carp

Methods

In order to assess the distribution and relative abundance of young-of-the-year carp (YOY; carp spawned that year), we conducted standardized trap-net surveys across the subwatershed. Trap-nets are a common type of sampling gear used to survey fishes in the littoral zone of lakes (e.g. panfish and YOY fishes). Trap-nets consist of a long section of net (30 ft x 3 ft wall) staked close to shore that leads out to an underwater frame that further directs fish through a series of hoops and funnels until they are 'trapped' in the rear of the net. Five nets are set equidistantly around the perimeter of each lake and are left in place overnight for approximately 24 hours. These surveys are conducted in August or September, when YOY fishes are large enough to sample. These surveys are important because they capture YOY common carp, one-year-old carp, and many other native fish species. Identifying areas with a high abundance of young carp is critical for understanding and managing common carp populations at a watershed scale as these areas have been shown to provide a source of young carp that may disperse across long distances (Koch 2014, Bajer et al. 2015).

Results

Trap-net surveys targeting juvenile common carp were completed in fall 2014 and 2015 in each accessible study lake along with numerous additional connected ponds (Table 1). In 2015, Halsted's Bay, Church Lake, and Wassermann Pond West were added to the sampling scheme. Of all of the sites sampled in 2014, YOY carp were only captured in three locations: Mud Lake (0.2 per net), Crown College Pond (1.0 per net), and Big SOB Lake (19.8 per net). Additionally, one-year-old carp were also sampled in 2 locations: Shady Pond (0.67 per net) and Carl Krey Lake (2.0 gillnet; Table 4). In 2015, YOY carp were sampled in 4 locations: Crown College Pond (332.3 per net), North Lundsten (3.2 per net), South Lundsten (311.2 per net), and Wassermann Lake (0.2 per net). Additionally, one-year-old carp were sampled in 2 locations: Big SOB Lake (1.8 per net) and Wassermann Pond West (0.3 per net). In total, juvenile carp have been sampled at 9 unique sites, but mostly in very low numbers (i.e. <3 per net). Extremely high numbers of common carp were however observed in South Lundsten Lake and Crown College Pond in 2015 (i.e. >300 per net). Follow-up surveys in fall of 2016 will be conducted to assess annual variation in catch rates.

Historical patterns of carp recruitment via ageing analysis

Methods

In order to elucidate historical trends in common carp recruitment, we have conducted aging studies throughout most of the subwatershed (Table 1). In November of 2014, otoliths were collected from Halsted's Bay (n=51), Mud Lake (n=51), Parley Lake (n=51). In 2015, otoliths were collected from North Lundsten Lake (n=31), West Auburn Lake (n=28), East

Auburn Lake (n=28), Wassermann Lake (n=37), and Piersons Lake (n=34). Common carp were sampled via electrofishing, removed from the system, and frozen for subsequent analysis following established protocols for common carp outlined in Bajer and Sorensen (2010). More specifically, the asterisci otoliths (i.e. ear bones) were extracted, embedded in epoxy, and sectioned using a slow speed saw. Annual growth rings were counted using a compound microscope by two independent readers.

Results

In total, 311 common carp were collected across the subwatershed for age determination. Carp ages ranged from 2 to 54 years old with just five year-classes (i.e. 2001-2002 and 1990-1992) accounting for 64% of total recruitment system-wide (Figure 21). The age structures of common carp sampled across the subwatershed were not consistent between all study lakes, indicating that there are multiple distinct subpopulations (Figure 22). The age structures were however similar between some groups of lakes including: 1) Parley, Mud, and Halsted's Bay, 2) East Auburn, West Auburn, and North Lundsten, and 3) Piersons and Wassermann (Figure 23). This information, coupled with the results of the movement study (see deliverable 2), suggest that there are at least three distinct management units in the Six Mile Creek subwatershed. It should be noted that carp have not been collected for age determination from Steiger, Zumbra, Sunny, or Stone Lakes, but abundance and movement results indicate that these lakes should also be considered distinct management units.

For Parley-Mud-Halsteds, 63% of all carp sampled assign to just three year classes (i.e. 1990, 1991, & 2002; Figure 23). Notably, Parley Lake appears to contain more younger carp (spawned post 2000) relative to the other lakes downstream, suggesting that carp in this subpopulation may originate from nursery areas in closer proximity to Parley Lake (i.e. Big SOB, Crown College Pond, and/or South Lundsten Lake; Figure 22). In contrast, in Lakes Auburn and Lundsten, there are relatively consistent year classes almost every year for the past 15 years and a notable absence of older individuals (Figure 23). This age structure, along with extremely high catch rates of YOY carp in South Lundsten in 2015, indicates that South Lundsten is likely an active and highly productive carp nursery for this portion of the subwatershed. In Lakes Piersons and Wassermann, the age structures suggest that there have only been two strong year classes of common carp since the 1960s (i.e. 1991 & 1992; figure 23). These two year classes account for 54% of all carp sampled in these two lakes combined. Aside from a couple of individuals every few years, there is a noticeable lack of young fish in this sub-population indicating that carp recruitment has been largely unsuccessful in recent years.

Tentative Management Recommendations

The overarching aim of the common carp assessment in the Six Mile Creek Subwatershed is to develop a rigorous scientific understanding of the carp in this system to develop sustainable control strategies. Although there is still a year of data collection remaining in the study, based on our current understanding of the common carp population(s) within the subwatershed, we can suggest some plausible strategies. It should be noted that these recommendations are preliminary and may change based on additional findings next year.

Tentative management units

Based on the abundance estimates, size structures, age structures, and movement patterns of common carp in the Six Mile Creek Subwatershed, it is clear that there are multiple sub-populations and consequently multiple management units. The boundaries of these management units and degree of connectivity between sub-populations will be better understood after two full years of tracking the radio-tagged carp. Preliminary management units are as follows: 1) Piersons-Wassermann, 2) Auburn-Lundsten, 3) Parley-Mud-Halsted's, 4) Steiger Lake, and 5) Zumbra-Sunny-Stone. It is presently unclear where the boundary falls between Piersons-Wassermann and Auburn-Lundsten (i.e. the wetland complex downstream of Wassermann that includes Carl Krey, Kelzer's Pond, and Church Lake).

Starting from the headwaters of Six Mile Creek, it appears that carp inhabiting Piersons Lake, Marsh Lake, and Wassermann Lake comprise a single population. Although it is possible for carp to move between Wassermann and downstream lakes and ponds (as evidenced by one radio-tagged carp moving from Wassermann to East Auburn and back again), movement seems uncommon given the stark contrast between the age structures of carp in Piersons-Wassermann compared to that of Auburn-Lundsten (Figure 23).

In the middle portion of the subwatershed, carp inhabiting East Auburn, West Auburn, North Lundsten, and South Lundsten Lakes should also be managed as a single population. There is evidence of radio-tagged carp moving between all four of these lakes and the age structures are also indistinguishable which supports the notion of substantial mixing. It should be noted that although there are two additional inflowing creeks to East Auburn (i.e. Steiger

Lake outflow and Sunny Lake outflow), no radio-tagged fish have been observed moving upstream or downstream in either of these creeks to date.

In the lower portion of the subwatershed, carp inhabiting lakes Parley, Mud, and Halsted's Bay should also be managed as a single population. Movement between these lakes is very common with 87% of radio-tagged fish moving between one or more lakes. This management unit presents challenges because although carp are not able to move upstream through the Parley Lake outlet structure, carp from above can move downstream as evidenced by one carp originally tagged with a T-bar tag in West Auburn Lake being captured in Parley Lake. Additionally, large numbers of carp move readily from Halsted's Bay into other bays of Lake Minnetonka and back again. Understanding and quantifying carp movement outside of the Six Mile Creek subwatershed is beyond the scope of the current study, but will be important for sustainable carp control in this management unit.

Strategies to suppress recruitment

Given the fecundity of adult common carp (2-3 million eggs per large female), suppression of recruitment is the cornerstone of sustainable long-term carp management. After two years of trap-netting for YOY carp and determining the age structure of carp in eight lakes, a few tentative carp nurseries have been identified in the Six Mile Creek Subwatershed, with South Lundsten Lake being a management priority. Strategies to suppress recruitment are less clear in Piersons-Marsh-Wassermann and Parley-Mud-Halsteds because the age structures in these lakes suggest that carp recruitment has only been successful in a few years since the 1960s (Figure 23). It is difficult to determine the precise source(s) of carp that were spawned decades ago, but it is possible to speculate on the likely sources based on our present findings, our knowledge of common carp life history, and historical climatic records. More data on springtime spawning migrations of adult carp and a third season of trap-netting will help inform the feasibility of recruitment suppression and determine appropriate management strategies for each nursery.

Based on our findings to date, it appears that South Lundsten Lake is a very productive and active carp nursery. South Lundsten supports extremely high densities of YOY carp and is well-connected to other lakes as evidenced by high catch rates of YOY carp in trapnets in 2015

(>300 per net), movement of radio-tagged carp between Lundsten and Auburn Lakes, and the prevalence of young carp inhabiting Lundsten and Auburn Lakes. Although we did sample moderate numbers of bluegill sunfish in South Lundsten Lake during fall trapnet surveys (17.4 and 34.2 per net in 2014 and 2015 respectively), the maximum dissolved oxygen content measured by MCWD staff during winter of 2014-15 was 1.5 mg/L (Table 5), a level that is lethal to bluegill sunfish. It is likely that there was at least a partial winterkill of native species in South Lundsten Lake including bluegill sunfish, but native fishes were then able to recolonize from connected waters before our fall surveys occurred. Aerating South Lundsten Lake during winter is recommended to promote the survival of a robust panfish community year-round in order to increase predation pressure on carp eggs and larvae to control recruitment.

In the Piersons-Marsh-Wassermann management unit, aside from one YOY carp sampled in Wassermann Lake and two Age-1 carp sampled in Wassermann Pond West, no juvenile carp have been sampled during the study period. Although there has not been any movement of tagged fish from Piersons or Wassermann into Marsh Lake during the study period either, past reports of mass spawning migrations to Marsh Lake from both of these lakes indicate that it likely functioned as a nursery in the past. The dissolved oxygen content in Marsh Lake remained high (>9 mg/L; Table 5) during winter of 2014-15 and 2015-16 and bluegill sunfish catch rates were also very high in fall of 2014 and 2015 (131.4 and 113.5 per net, respectively). Based on these findings, it does not appear that Marsh Lake has a tendency to winterkill in most years, but perhaps extreme climatic conditions (e.g. harsh winters, above average snowfall, drought) could cause periodic winterkills. This could explain the recruitment success of carp in 1990-91 in this system because a winterkill likely occurred in Marsh Lake in 1988-89 due to severe drought conditions across the state causing water levels to drop an average of three feet (MN DNR 1989). Winter aeration should be considered for Marsh Lake to mitigate the risk of future winterkills.

For the Parley-Mud-Halsteds management unit, juvenile carp may be coming from multiple sources including Mud Lake, South Lundsten Lake, or one or more peripheral ponds where YOY carp have been sampled during the study period (i.e. Big SOB Lake and/or Crown College Pond). Based on the age structure of carp in these lakes, with roughly half of all individuals assigning to the 1990-1991 year classes and an absence of these year classes in Auburn-Lundsten (Figure 23), it seems likely that most of these older fish were spawned below the dam at the inlet of Parley Lake. Due to the statewide drought conditions in 1988-89, it is likely that Mud Lake winterkilled in 1989-90 creating ideal carp spawning conditions the next spring for the same reasons discussed above for Marsh Lake. Specifically, water levels in Parley Lake reached record lows during 1988-1990 (2.5ft lower than average conditions; Figure 24), which would make Mud Lake approximately 1 foot deep during those years. It is also possible that these carp were spawned in one or more peripheral basins that would have also winterkilled that year, but the role that these peripheral basins have in contributing carp recruits to the sub-population of adult carp in connected lakes is unclear. Specifically, the YOY carp that were captured in SOB Lake in 2015 were likely an artifact of rotenone poisoning carried out by the property owner the proceeding fall which mimicked winterkill conditions and allowed for successful carp recruitment. It is unknown if Big SOB Lake winterkills under natural conditions, but it is now being aerated and should continue to support a healthy panfish community. Crown College Pond likely suffers partial or complete winterkills most years as evidenced by it freezing solid to the bottom in winter 2014-2015 and very low dissolved oxygen concentrations in winter 2015-16 (i.e. 1.85 mg/L) despite mild conditions (Table 5). Although very high numbers of YOY carp were sampled in Crown College Pond in fall of 2015 (>300 per net), low overwinter survival rates will likely inhibit juvenile carp from surviving for one or more years to eventually join the adult carp population downstream (Bajer et al. 2015). Roughly 20% of the carp aged from Parley-Mud-Halsted were assigned to the 2001-02 year classes (Figure 23), with these being twice as prevalent in Parley Lake compared to Mud or Halsted's Bay (Figure 22). Because these year classes are more prevalent in Parley Lake and were also well-represented in Auburn-Lundsten, it follows that these individuals may have been spawned in South Lundsten Lake. Additionally, the past occurrences of large spawning season migrations of carp trying to pass through the Parley Lake dam in an upstream direction coupled with the homing tendencies of common carp add support to this hypothesis (Koch 2014).

To avoid additional strong year classes in Piersons-Marsh-Wassermann and Parley-Mud-Halsted in the future, wintertime aeration of Marsh Lake and Mud Lake is recommended. These locales support robust populations of panfish most winters, but are very shallow and therefore vulnerable to climatic extremes.

Strategies to reduce the biomass of adult carp

After carp recruitment is better understood and ongoing recruitment is under control, it is reasonable to remove adult carp with the goal of reducing carp biomass below damaging levels. Because low numbers of adult carp (i.e. <100 kg/ha including measurement error) have not been shown to inflict significant ecological damage and their removal is likely cost-prohibitive, it critical to understand the distribution, abundance, and biomass of adult carp throughout the subwatershed to target and prioritize management efforts.

Based on multiple electrofishing surveys over two years, it is clear that there are locations within the Six Mile Creek Subwatershed that both warrant and do not warrant adult carp removal to meet a carp biomass threshold of 100 kg/ha (See Table 2). Locations that will require adult carp removal efforts include Halsted's Bay, Mud Lake, Parley Lake, West Auburn Lake, East Auburn Lake, Turbid Lake, and Wassermann Lake. Locations that will likely not require any adult carp removal include Piersons Lake, Stone Lake, and Kelzer's Pond. The rest of the study lakes (i.e. North Lundsten, South Lundsten, Zumbra, Sunny, and Steiger) have estimated 95% confidence intervals that range from less than 100 kg/ha to over 100 kg/ha. The large ranges of biomass estimates for some lakes (i.e. North Lundsten, South Lundsten, and Sunny) are due to difficultly accessing these lakes with an electrofishing boat under all water level conditions and subsequent low sample sizes. Depending on water levels during the 2016 field season, we may be able to further refine these estimates.

As for adult carp removal strategies, under-ice seining may be a viable management strategy in all lakes with the exception of Steiger Lake where wintertime aggregations never formed (Table 3). It should be noted that the feasibility and success rate of seining will be dependent on ice conditions, substrate conditions at the aggregation site, depth at the aggregation site, as well as the level of commercial fishing expertise. It is very likely that multiple seining attempts over several years will be necessary to significantly reduce existing adult biomass in most locations. Where seining is not possible or practical, trapping and removal of spawning migrants may be another viable management strategy. For example, this method has been very successful in removing adult carp from Piersons Lake where over 6,000 carp have been removed at the outlet to Marsh Lake, bringing the current estimated carp biomass below 100 kg/ha. Due to abnormally low water conditions in spring of 2015, we did not observe any mass spawning migrations of carp in the Six Mile Creek subwatershed. We will closely monitor any spawning movements in spring of 2016 to inform the most effective trapping locations. We did however observe a significant amount of movement from June through August in the Six Mile Marsh corridor between Halsted's Bay and Mud Lake and also between Mud and Parley Lakes. Bidirectional traps in these locations could be very effective in removing carp in this management unit.

Progress & Future Plans

The U of MN has completed all tasks as outlined in the Project Scope. Specifically, the U of MN has completed electrofishing surveys to estimate adult carp abundance in at least 7 study lakes (n=15), implanted radio-tags in 120 carp across the Subwatershed, located radio-tagged carp at least once per month for 16 months, conducted trap-net surveys in relevant study lakes, ponds, and wetlands (n=23), and completed two aging studies of at least 100 individuals (n=311). Additionally, the U of MN has calculated a supplemental mark-recapture population estimate for Parley and Mud Lakes, collected >1,000 tissue samples from common carp across the subwatershed for genetic analysis, and collected water and otoliths samples for microchemical analysis. Details of plans for the 2016 field season for each deliverable are outlined below.

Deliverable 1: Estimates of adult common carp abundance in all accessible lakes

Up to 2 additional electrofishing surveys will be conducted in each lake that was surveyed in 2014 and 2015 (n=15; see table 1). Lakes that have been surveyed the fewest number of times and lakes which had the highest variability in catch rates will be prioritized (i.e. North Lundsten, South Lundsten, East Auburn, & Sunny Lakes).

Due to unprecedented numbers of common carp in some of the Six Mile Creek study lakes (i.e. Wassermann, Parley, Mud, & Halsted's Bay), it would be beneficial to verify our abundance estimates that are based on catch per unit effort measurements with supplemental mark-recapture estimates. Because we have already marked hundreds of carp with T-bar tags in these lakes, supplemental mark-recapture estimates could be readily calculated if enough tagged carp could be resampled. We were able to take advantage of a commercial seine haul that occurred in Parley Lake in March 2015 to calculate such estimates and hope to do the same for Wassermann Lake in winter of 2016-17.

Deliverable 2: Information on the seasonal distribution and movement patterns of adult carp

We will closely monitor overwinter mortality of radio-tagged carp and will replace any lost tags deemed necessary. We will continue tracking all radio-tagged carp once per month. If time permits, we will obtain higher resolution tracking data during the spring spawning season in order to identify spawning habitat and thus inform where to conduct additional trap-net surveys if needed. We will also obtain higher resolution tracking data during the winter months on lakes selected for the pilot winter seining program.

Deliverable 3: Identification of sources of juvenile carp across the watershed

In order to assess annual variation in the distribution and catch rates of juvenile carp, a third fall trap-net survey will be conducted in each location. Additionally, some new locations may also be sampled; the locations of new survey sites will be determined from observations of springtime spawning movements of adult carp. To assess survival of the extremely high numbers of YOY common carp sampled in South Lundsten Lake and Crown College Pond in 2015, we will conduct additional spring trap-net surveys in these locations if time permits.

Although we have completed aging studies in eight lakes across the subwatershed, we are also interested in determining the age structure of carp in Turbid Lake. If time permits, we will collect otoliths from Turbid Lake next spring to be aged early next winter. We will also continue with genetic and microchemical analyses to try to elucidate some of the unknowns associated with carp recruitment dynamics in the subwatershed.

References

Bajer, P.G., Sullivan, G., and Sorensen, P.W. 2009. Effects of a rapidly increasing population of common carp on vegetative cover and waterfowl in a recently restored Midwestern shallow lake. Hydrobiologia 632(1): 235–245.

Bajer, P. G. Lim, H., Travaline, M. J., Miller, B. D., and Sorensen, P. W. 2010. Cognitive aspects of food searching behavior in free-ranging wild common carp. Environmental Biology of Fishes 88:295–300.

Bajer, P.G. and Sorensen, P.W. 2010. Recruitment and abundance of an invasive fish, the common carp, is driven by its propensity to invade and reproduce in basins that experience winter-time hypoxia in interconnected lakes. Biological Invasions 12, 1101–1112.

Bajer, P. G., Chizinski, C. J., and Sorensen, P. W. 2011. Using the Judas technique to locate and remove wintertime aggregations of invasive common carp. Fisheries Management and Ecology 18(6): 497–505.

Bajer, P.G., Chizinski, C. J., Silbernagel, J. J., and Sorensen, P. W. 2012. Variation in native micro-predator abundance explains recruitment of a mobile invasive fish, the common carp, in a naturally unstable environment. Biological Invasions 14(1): 1919–1929.

Bajer, P. G. and Sorensen, P. W. 2012. Using boat electrofishing to estimate the abundance of invasive common carp in small Midwestern lakes. North American Journal of Fisheries Management 32(5): 817–822.

Bajer, P. G., Parker, J. E., Cross, T. K., Venturelli, P. A., and Sorensen, P. W. 2015. Partial migration to seasonally-unstable habitat facilitates biological invasions in a predator-dominated system. Oikos 000:001–007.

Bajer, P. G. and Sorensen, P. W. 2015. Effects of common carp on phosphorus concentrations, water clarity, and vegetation density: a whole system experiment in a thermally stratified lake. Hydrobiologia 746: 303–311.

Koch, J. D. 2014. Mark-recapture and genetic evidence reveals source-sink population structure of invasive common carp in a model Midwestern watershed. M. Sc. Thesis. Department of Fisheries, Wildlife, and Conservation Biology, University of Minnesota, Saint Paul, MN.

MN DNR. 1989. Drought of 1988. Minnesota Department of Natural Resources. Division of Waters. Saint Paul, MN.

Osborne, J. B. 2012. Distribution, abundance and overwinter survival of young-of-year common carp in a Midwestern watershed. M. Sc. thesis. Department of Fisheries, Wildlife, and Conservation Biology, University of Minnesota, Saint Paul, MN.

Silbernagel, J. J., and Sorensen, P. W. 2013. Direct field and laboratory evidence that a combination of egg and larval predation controls recruitment of invasive common carp in many lakes of the Upper Mississippi River Basin. Transactions of the American Fisheries Society 142(4): 1134–1140.

Sorensen, P. W. and Bajer, P. G. 2011. The common carp. In: Simberloff D, Rejmanek M (eds) Encyclopedia of invasive introduced species. University of California Press Berkeley, CA, pp 100–103

Weber, M.J., and Brown, M.L. 2009. Effects of common carp on aquatic ecosystems 80 years after" carp as a dominant": Ecological insights for fisheries management. Reviews in Fisheries Science 17(4): 524–537.

Wenck Associates, Inc. 2013. Six Mile Creek Diagnostic Study. Wenck Associates, Inc., Maple Plain, MN.

Table 1. Overview of study design -- Attributes of study lakes in the Six Mile Creek Subwatershed and available sampling data collected by the University of Minnesota. X's denote sampling that has occurred in either 2014 or 2015 and asterisks (*) denote sampling conducted by MCWD staff.

Location	Surface Area (ac)	Max Depth (ft)	Electrofishing Survey		Trapnet Survey		Aging Studies		Radio Telmetry (# of Tags)	Winter Dissolved Oxygen*
			2014	2015	2014	2015	2014	2015		
Halsted's Bay	552	30	X	X		X	X		15	
Mud	144	6	X	X	X	X	X		15	X
Parley	257	19	X	X	X	X	X		15	
Crown College	6	3			X	X				
Big SOB	7.5	25			X	X				X
Yetzer's Pond	12	2			X					
N. Lundsten	114	7	X	X	X	X		X	5	X
S. Lundsten	77	9	X	X	X	X			5	X
Turbid	40	35	X	X	X	X			5	
Lake #2	36	N/A			X					
W. Auburn	145	80	X	X	X	X		X	7	
E. Auburn	148	40	X	X	X	X		X	8	
Shady Pond	0.5	>5			X	X				X
Sunny	48	N/A	X	X	X	X			3	X
Zumbra	193	50	X	X	X	X			7	
Stone	99	30	X	X	X	X				
Steiger	166	37	X	X	X	X			10	
Kelzer's	21	34	X	X	X	X				X
Church	16	54				X				X
Carl Krey	50	16			X	X				X
Wassermann	164	41	X	X	X	X		X	15	
N. Wassermann Pond	6	27								X
S. Wassermann Pond	13.3	27								X
W. Wassermann Pond	6.5	18				X				X
Marsh	143	5			X	X				X
Piersons	297	40	X	X	X	X		X	10	

Table 2. Attributes of study lakes, catch rates of common carp, and resulting estimates of common carp abundance and biomass in the Six Mile Creek Subwatershed shown for 2014 alone (top) and 2014 and 2015 combined (bottom).

2014

Lake Name	Area (ha)	# of Surveys	CPUE (SE) (# / hr)	Abundance N, mean (95%CI)	Average Weight (kg)	Biomass (kg/ha)
Halsted's Bay	223.4	4	61.3 (4.6)	65,225 (55,803-74,646)	3.7	1,093 (935-1,251)
Mud	37.6	6	26.3 (5.2)	4,782 (2,969-6,595	3.9	495 (307-683)
Parley	104.4	6	30.4 (1.6)	15,265 (13,709-16,820)	3.5	513(461-566)
North Lundsten	43.7	2	21.3 (9.2)	4,515 (795-8,234)	2.0	204 (36-372)
South Lundsten	29.9	1	9.7 (NA)	1,268 (NA)	2.3	97 (NA)
West Auburn	53.8	3	31.3 (3.1)	8,097(6,552-9,641)	1.9	290 (234-345)
East Auburn	46.9	3	36.6 (12.6)	8,237 (2,761-13,712)	1.8	323 (108-538)
Turbid	16.2	2	29.4 (2.1)	2,290 (1,983-2,597)	3.1	436 (378-495)
Wasserman	66.0	4	38.4 (5.2)	12,141 (8,956-15,326)	3.0	555 (409-700)
Piersons	120.1	5	3.6 (0.7)	2,400 (1,661-3,140)	3.3	66 (46-87)
Stieger	67.1	4	9.5 (3.3)	3,214 (1,175-5,254)	3.2	155 (57-254)
Sunny	19.4	1	2.8 (NA)	314 (NA)	2.6	42 (NA)
Zumbra	89.4	4	8.7 (1.8)	3,931 (2,472-5,390)	2.5	108 (68-148)
Stone	39.3	1	4.4 (NA)	924 (NA)	4.4	104 (NA)
Kelzer's	8.0	1	2.5 (NA)	118 (NA)	4.8	70 (NA)

2014 and 2015 combined

Lake Name	Area (ha)	# of Surveys	CPUE (SE) (# / hr)	Abundance N, mean (95%CI)	Average Weight (kg)	Biomass (kg/ha)
Halsted's Bay	223.4	7	66.4 (3.0)	67,424 (61,236-73,611)	3.7	1,129 (1,025-1,233)
Mud	37.6	8	26.9 (3.5)	4,874 (3,656-6,095)	3.9	504 (378-630)
Parley	104.4	8	31.1 (1.2)	15,627 (14,442-16,811)	3.5	526 (486-565)
North Lundsten	43.7	5	14.2 (4.2)	3,060 (1,355-4,764)	2.0	138 (61-215)
South Lundsten	29.9	2	8.8 (0.8)	1,332 (1,120-1,543)	2.3	102 (86-118)
West Auburn	53.8	6	31.1 (1.6)	8,045 (7,249-8,841)	1.9	288 (259-316)
East Auburn	46.9	7	29.2 (5.4)	6,599 (4,273-8,925)	1.8	259 (168-350)
Turbid	16.2	4	30.6 (1.1)	2,379 (2,213-2,544)	3.1	453 (422-485)
Wasserman	66.0	7	35.0 (3.9)	11,084 (8,701-13,468)	3.0	507 (398-615)
Piersons	120.1	8	4.8 (1.1)	3,104 (1,932-4,276)	3.3	86 (54-118)
Stieger	67.1	7	8.8 (2.2)	2,997 (1,654-4,339)	3.2	145 (80-210)
Sunny	19.4	2	10.7 (6.8)	1,035 (0-2,255)	2.6	139 (0-303)
Zumbra	89.4	7	11.6 (1.6)	5,152 (3,840-6,466)	2.5	142 (106-178)
Stone	39.3	3	1.5 (1.3)	387 (0-840)	4.4	43 (0-94)
Kelzer's	8.0	3	0.8 (0.7)	55 (3-108)	4.8	33 (2-65)

Table 3. Summary of winter aggregation occurrence and timing in the Six Mile Creek study lakes from November 2014 through February 2016. An aggregation is defined as when at least 85% of radio-tagged carp were confined to an area of less than 10 hectares. Note that radio-tags were implanted in four additional lakes in spring of 2015.

Winter 2014-2015

Location	November 2014	December 2014	January 2015	February 2015	March 2015
Halsted's Bay				X	
Mud					
Parley		X	X	X	X
W. Auburn			X	X	
E. Auburn	X	X	X	X	X
Zumbra			X	X	X
Steiger					
Wassermann		X	X	X	
Piersons	X	X	X	X	X

Winter 2015-2016

Location	November 2015	December 2015	January 2016	February 2016
Halsted's Bay		X		X
Mud				
Parley			X	X
N. Lundsten		X	X	X
S. Lundsten	X	X	X	X
W. Auburn			X	X
E. Auburn		X	X	X
Zumbra			X	X
Sunny		X	X	X
Steiger				
Wassermann		X	X	X
Turbid		X	X	X
Piersons				X

Table 4. Catch rates of young-of-year (YOY) and age-1 carp from standardized trap-net surveys conducted in the Six Mile Creek subwatershed. Asterisks (*) denote catch rates from gill net surveys. NS denotes locations that were not sampled that year.

Location	Catch Rate YOY Carp (# / Net)		Catch Rate Age 1 Carp (# / Net)	
	2014	2015	2014	2015
Halsted's Bay	NS	0.0	NS	0.0
Mud	0.2	0.0	0.0	0.0
Parley	0.0	0.0	0.0	0.0
Crown College	1.0	332.3	0.0	0.0
Big SOB	19.8	0.0	0.0	1.8
Yetzer's Pond	0.0	NS	0.0	NS
N. Lundsten	0.0	3.2	0.0	0.0
S. Lundsten	0.0	311.2	0.0	0.0
Turbid	0.0	0.0	0.0	0.0
Lake #2	0.0	NS	0.0	NS
W. Auburn	0.0	0.0	0.0	0.0
E. Auburn	0.0	0.0	0.0	0.0
Shady Pond	0.0	0.0	0.7	0.0
Sunny	0.0	0.0	0.0	0.0
Zumbra	0.0	0.0	0.0	0.0
Stone	0.0	0.0	0.0	0.0
Steiger	0.0	0.0	0.0	0.0
Kelzer's	0.0	0.0	0.0	0.0
Carl Krey	0.0	0.0	2.0*	0.0
Wassermann	0.0	0.2	0.0	0.0
Wassermann Pond W.	NS	0.0	NS	0.3
Marsh	0.0	0.0	0.0	0.0
Piersons	0.0	0.0	0.0	0.0

Table 5. Dissolved oxygen maxima (mg/L) measured by Minnehaha Creek Watershed District staff in select study sites in the Six Mile Creek subwatershed. Measurements were taken in late February just beneath the ice surface at approximately the deepest point in the waterbody. "NS" denotes locations that were not sampled that year; "Frozen" denotes locations that were frozen solid to the bottom.

Location	Dissolved oxygen (mg/L)	
	2015	2016
Marsh	12.9	9.4
Turbid	5.7	NS
Carl Krey	9.9	8.9
Crown College	Frozen	1.9
Mud	6.1	9.4
South Lundsten	1.5	10.0
North Lundsten	1.6	NS
Sunny	0.9	NS
Shady	0.8	NS
Wassermann Pond West	1.3	3.8
Kelzer's	7.2	NS
Church	1.6	NS

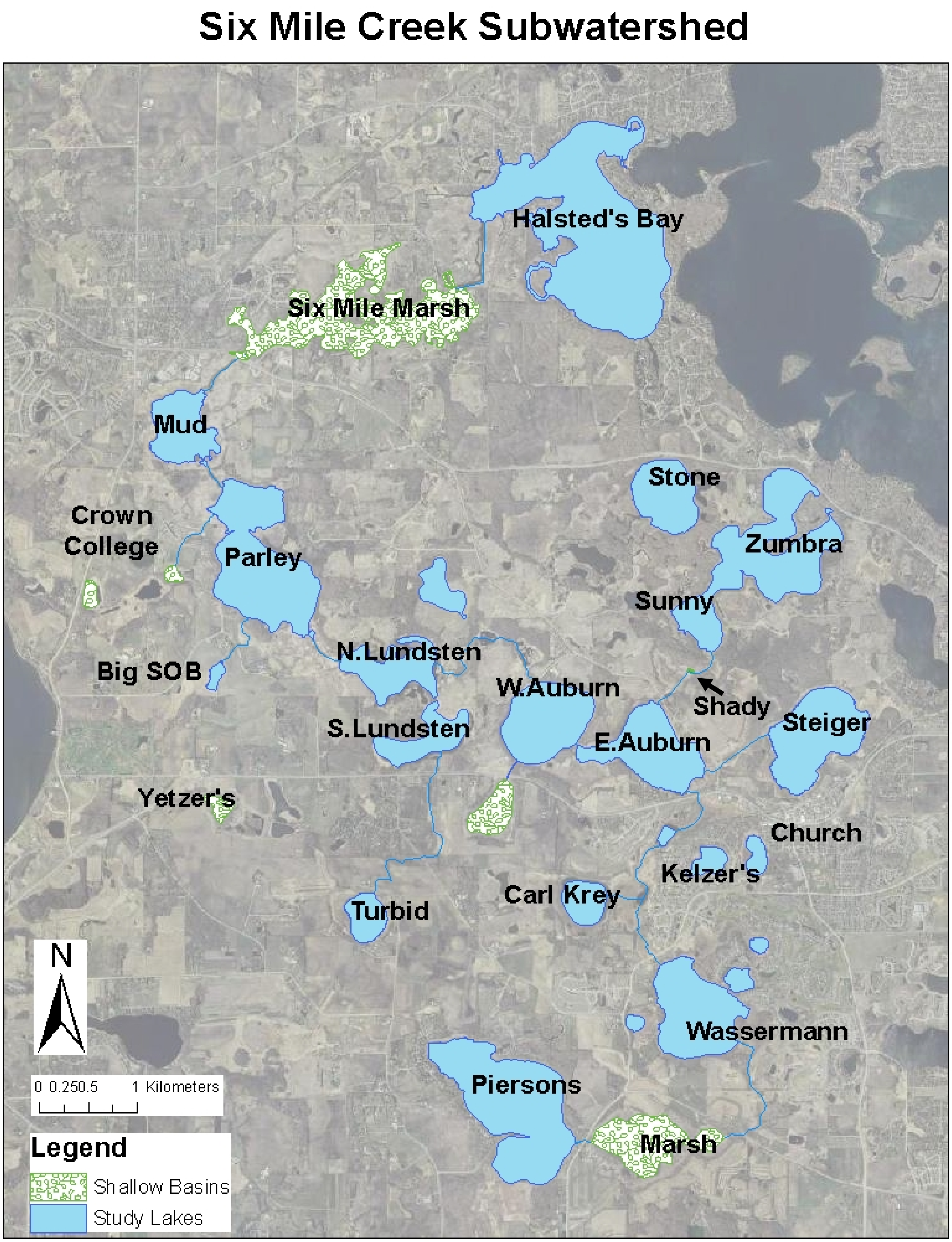

Figure 1. Overview map of Six Mile Creek Subwatershed.

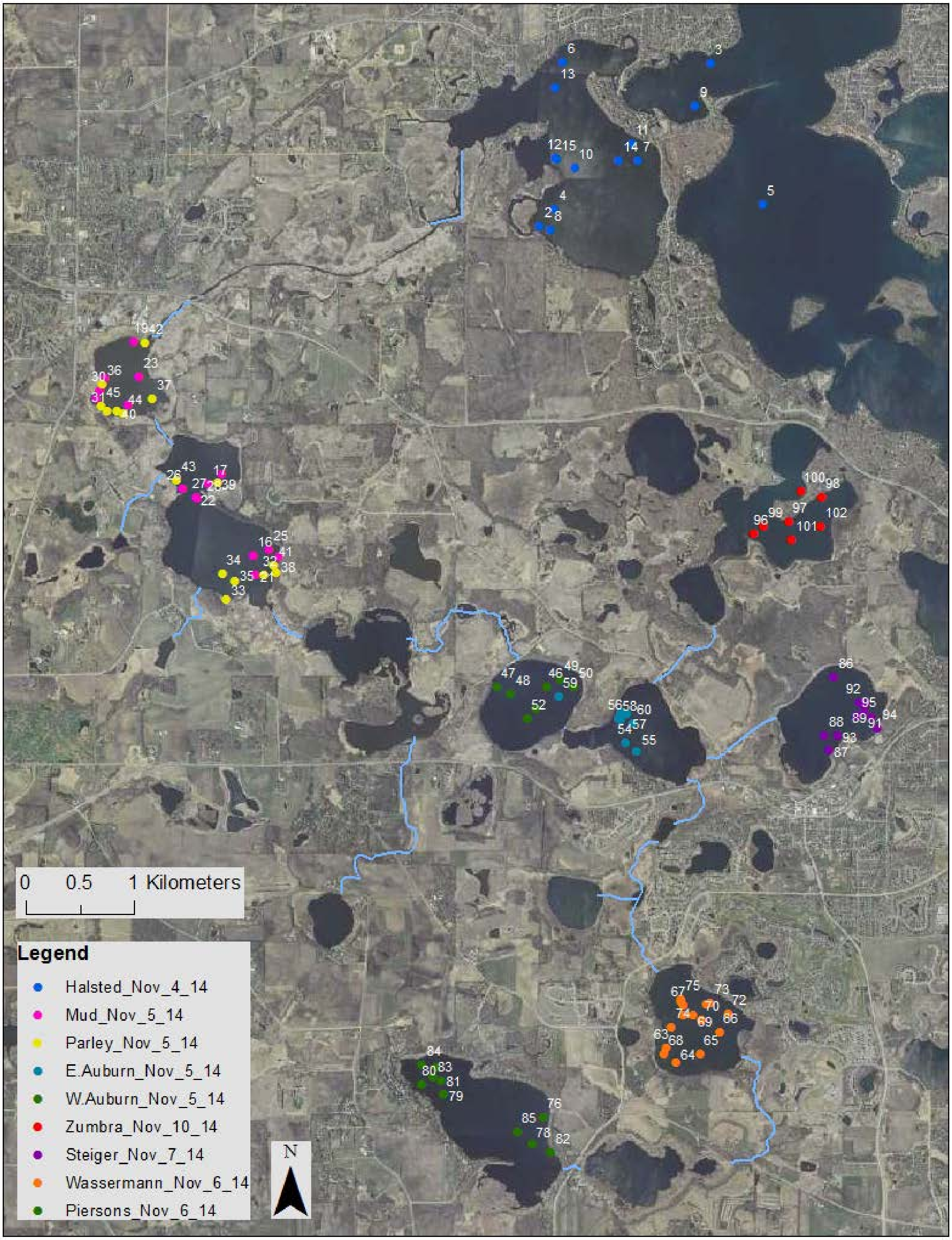

Figure 2. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in November 2014. Individuals are labeled with unique identification numbers (white).

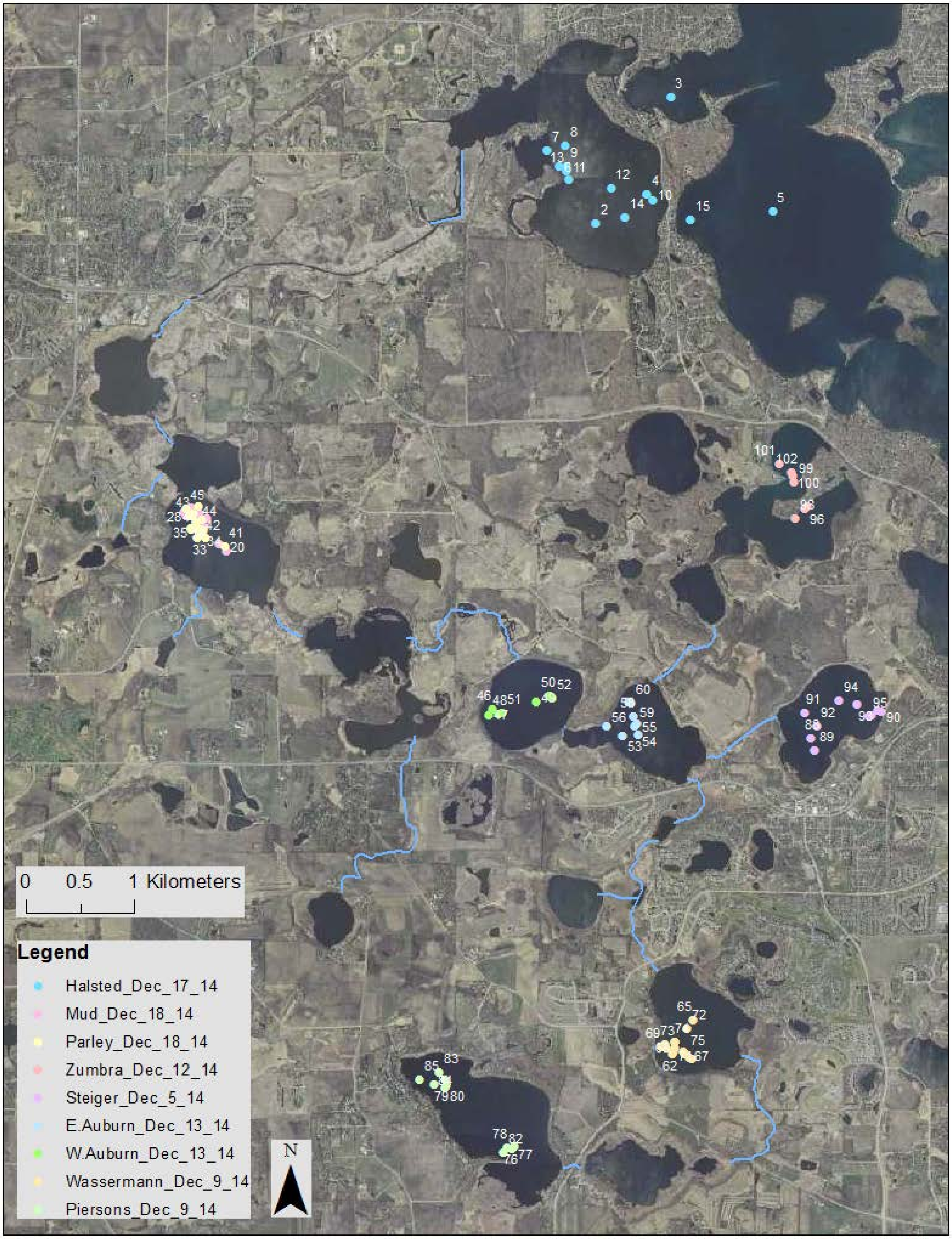

Figure 3. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in December 2014. Individuals are labeled with unique identification numbers (white).

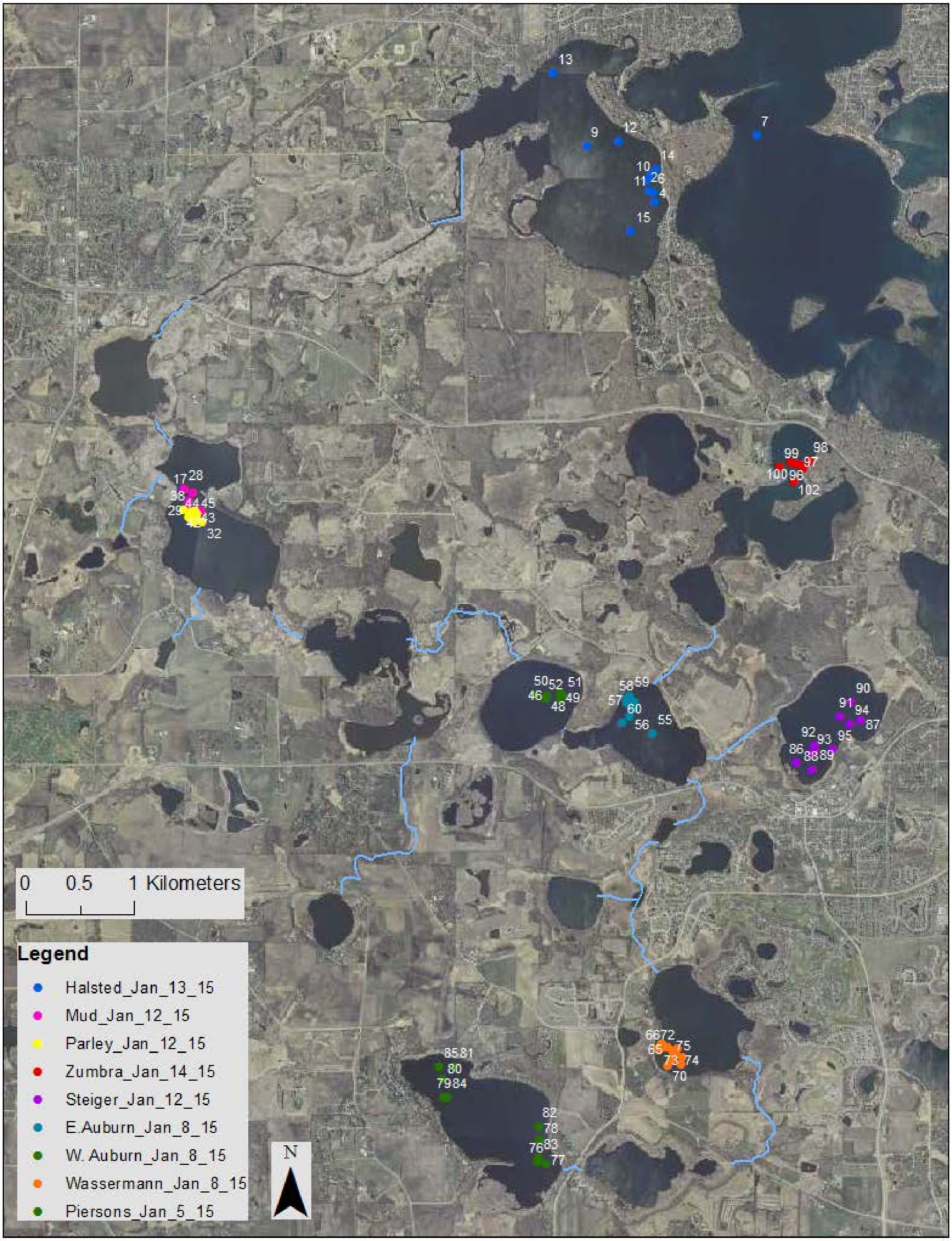

Figure 4. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in January 2015. Individuals are labeled with unique identification numbers (white).

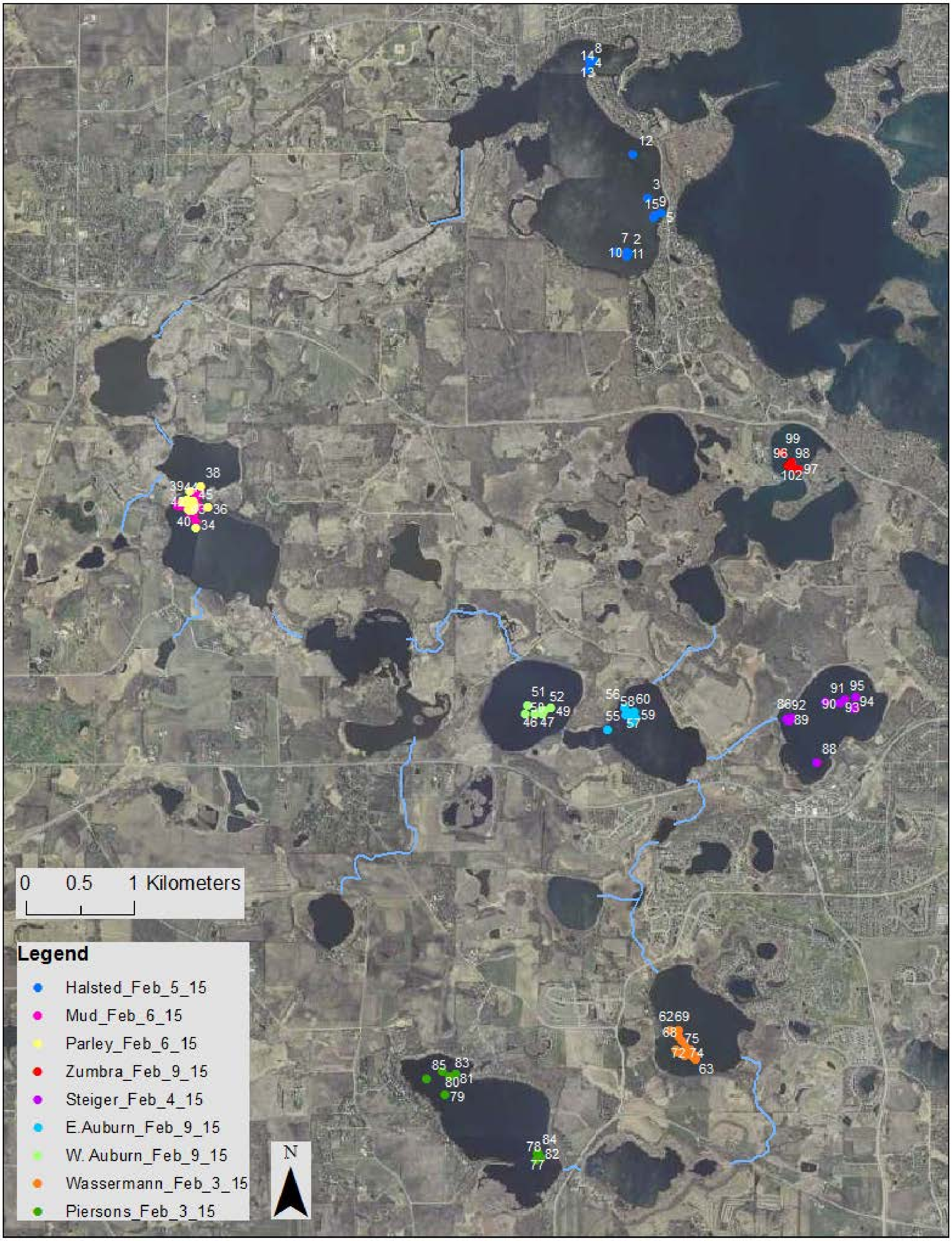

Figure 5. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in February 2015. Individuals are labeled with unique identification numbers (white).

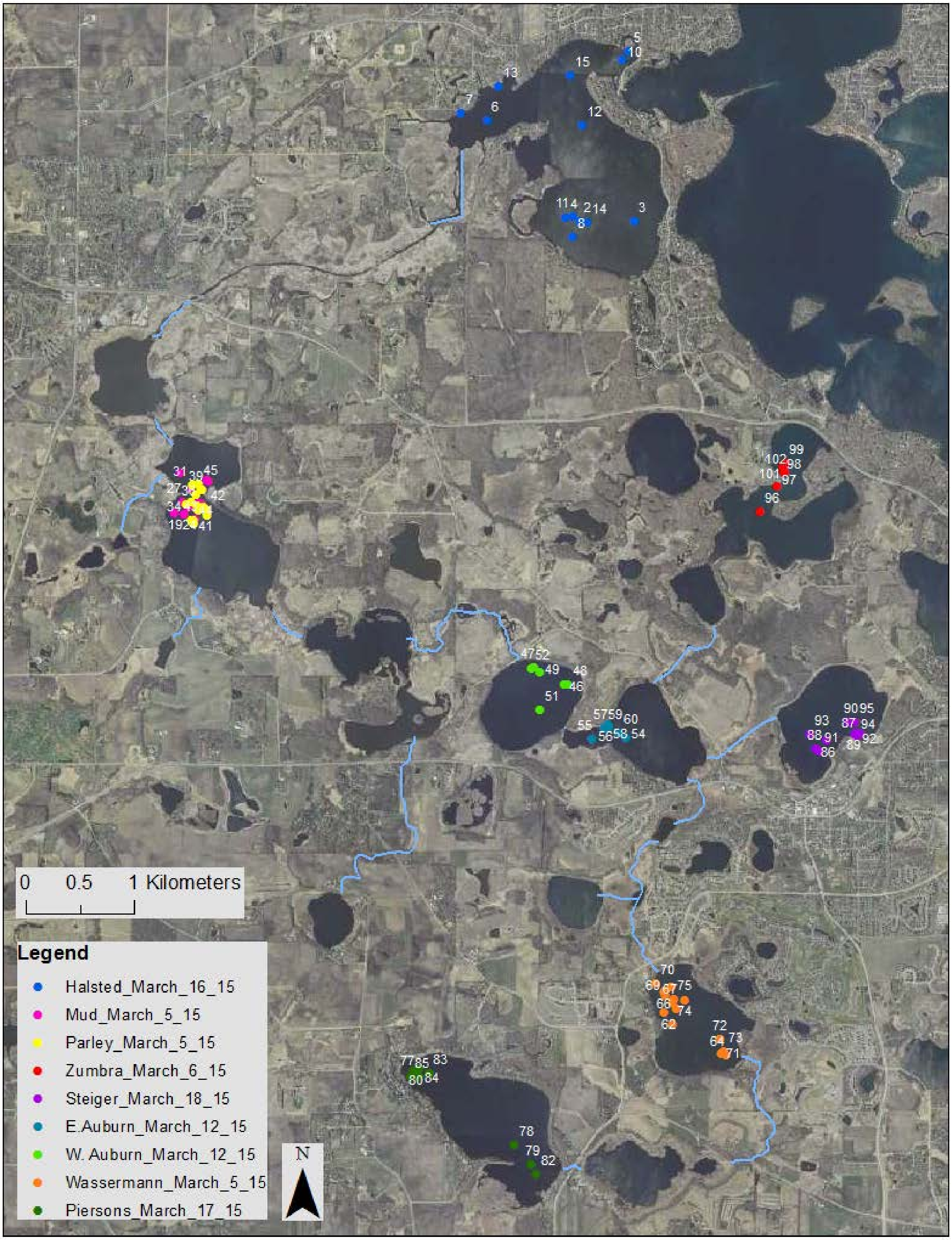

Figure 6. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in March 2015. Individuals are labeled with unique identification numbers (white).

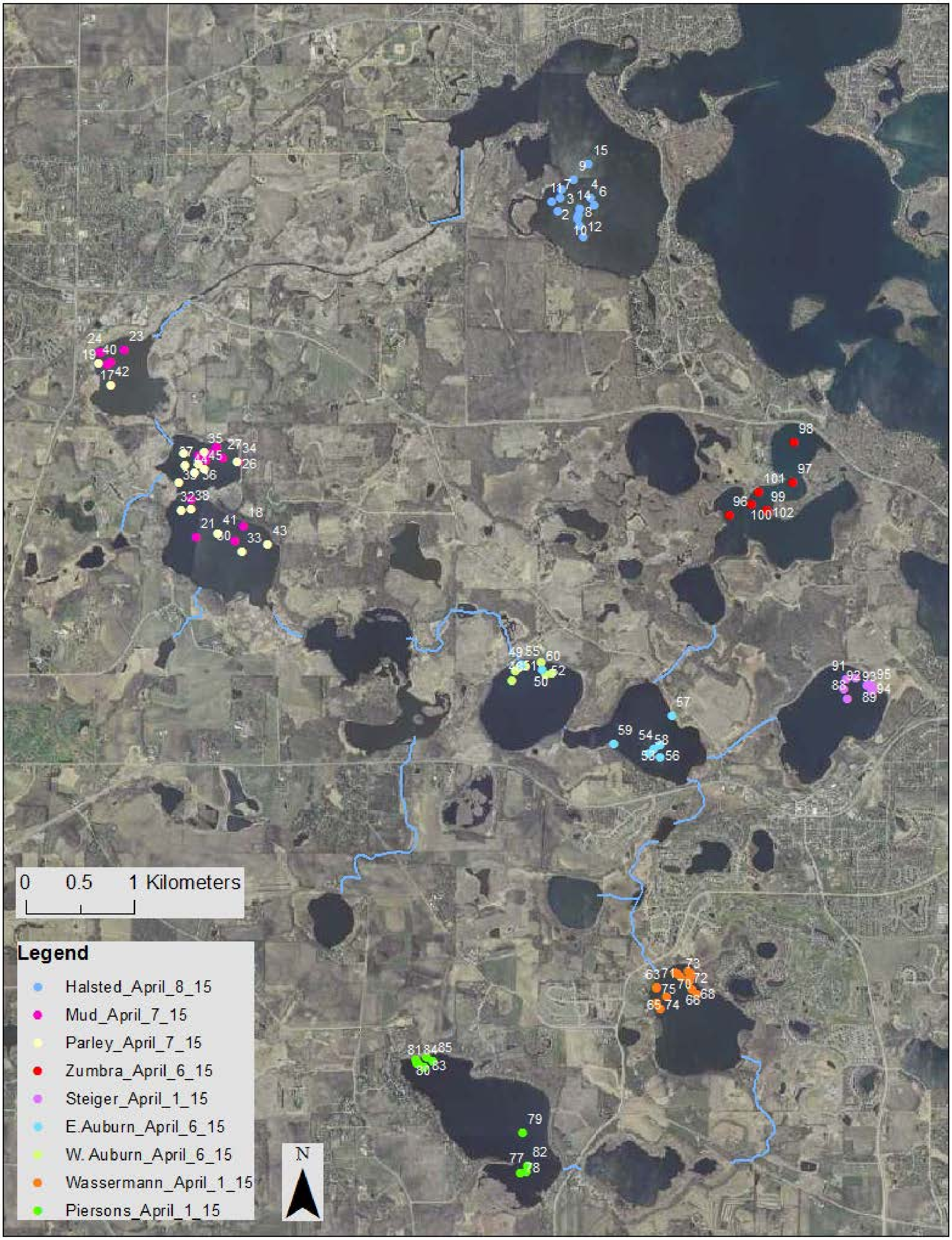

Figure 7. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in early April 2015. Individuals are labeled with unique identification numbers (white).

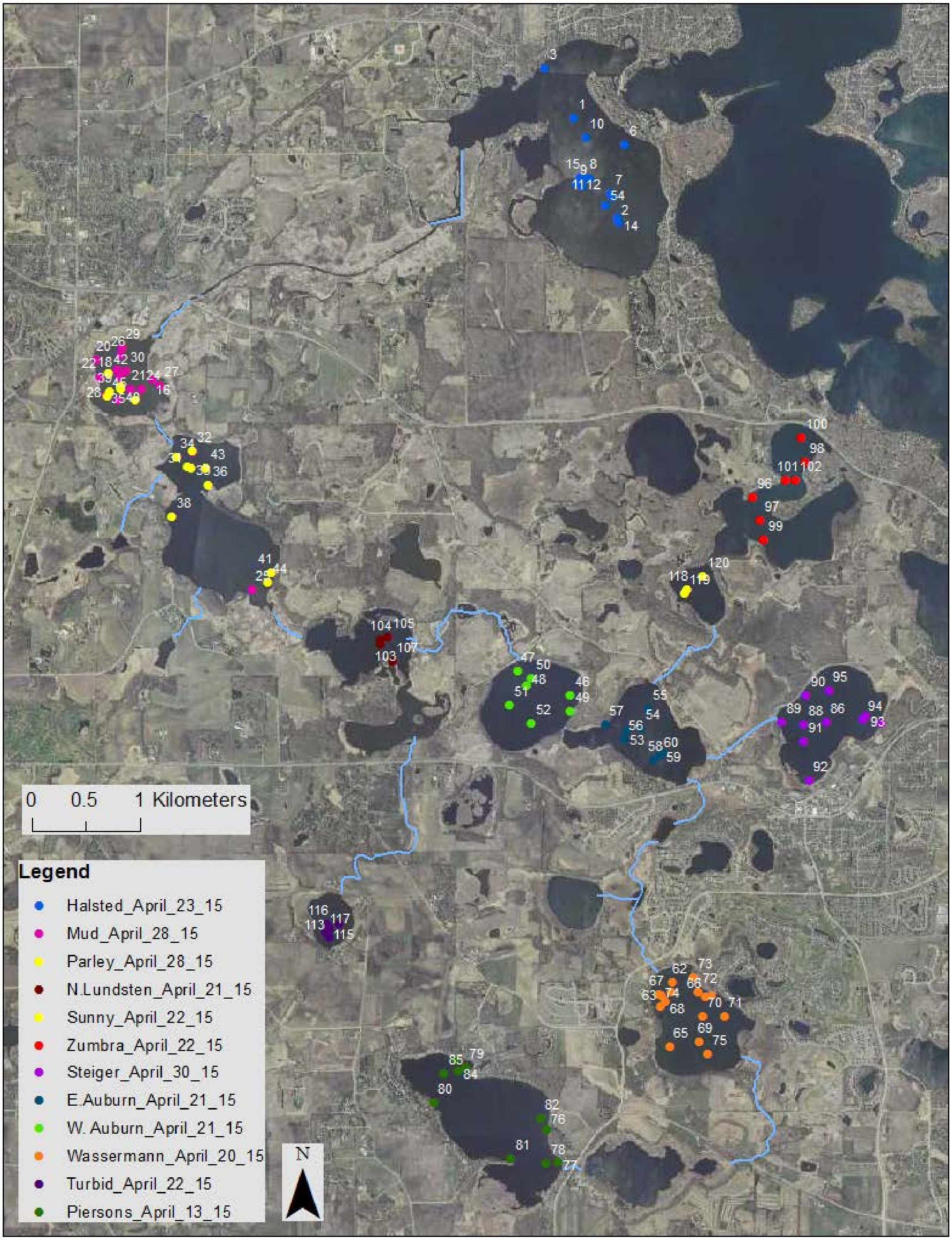

Figure 8. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in late April 2015. Individuals are labeled with unique identification numbers (white).

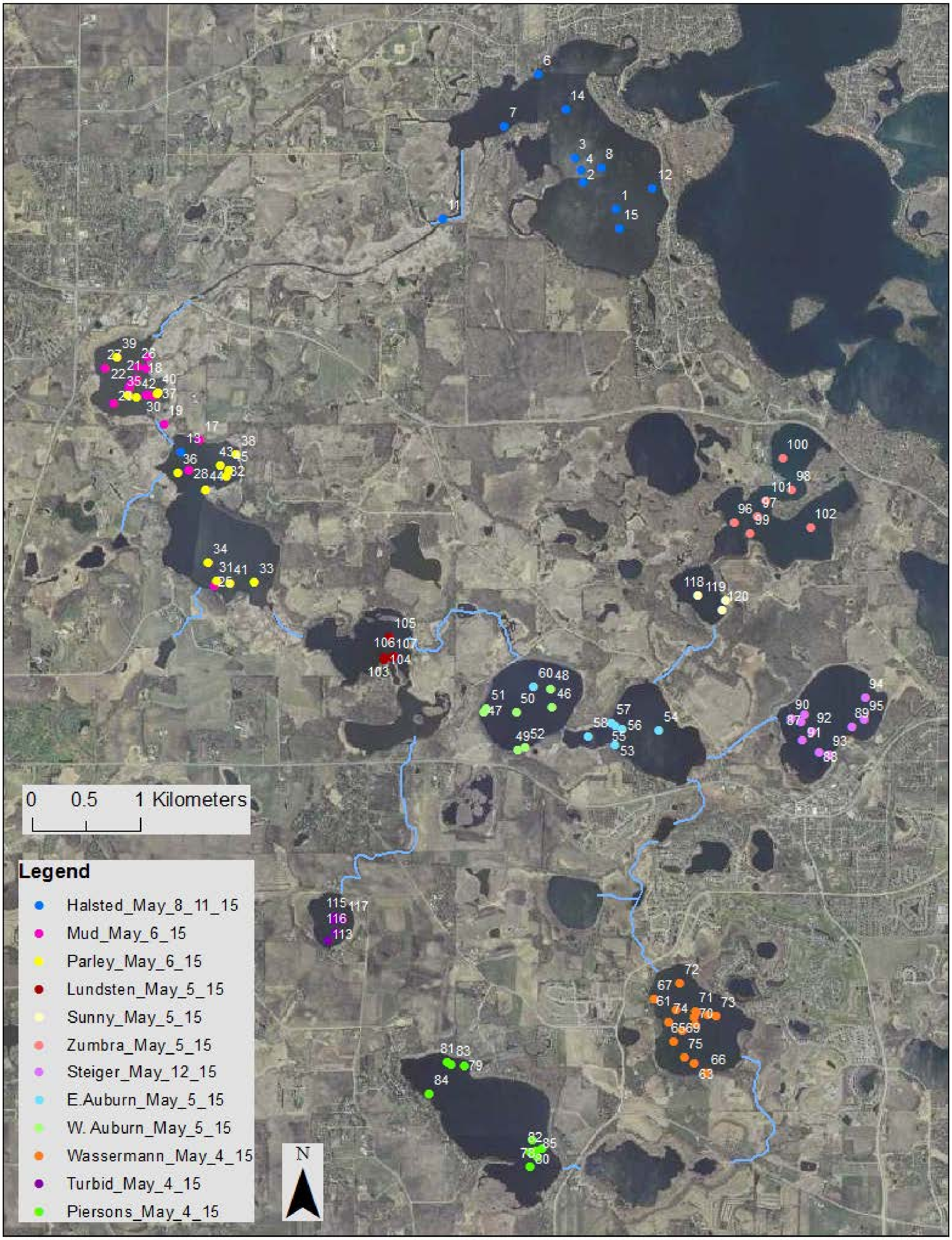

Figure 9. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in early May 2015. Individuals are labeled with unique identification numbers (white).

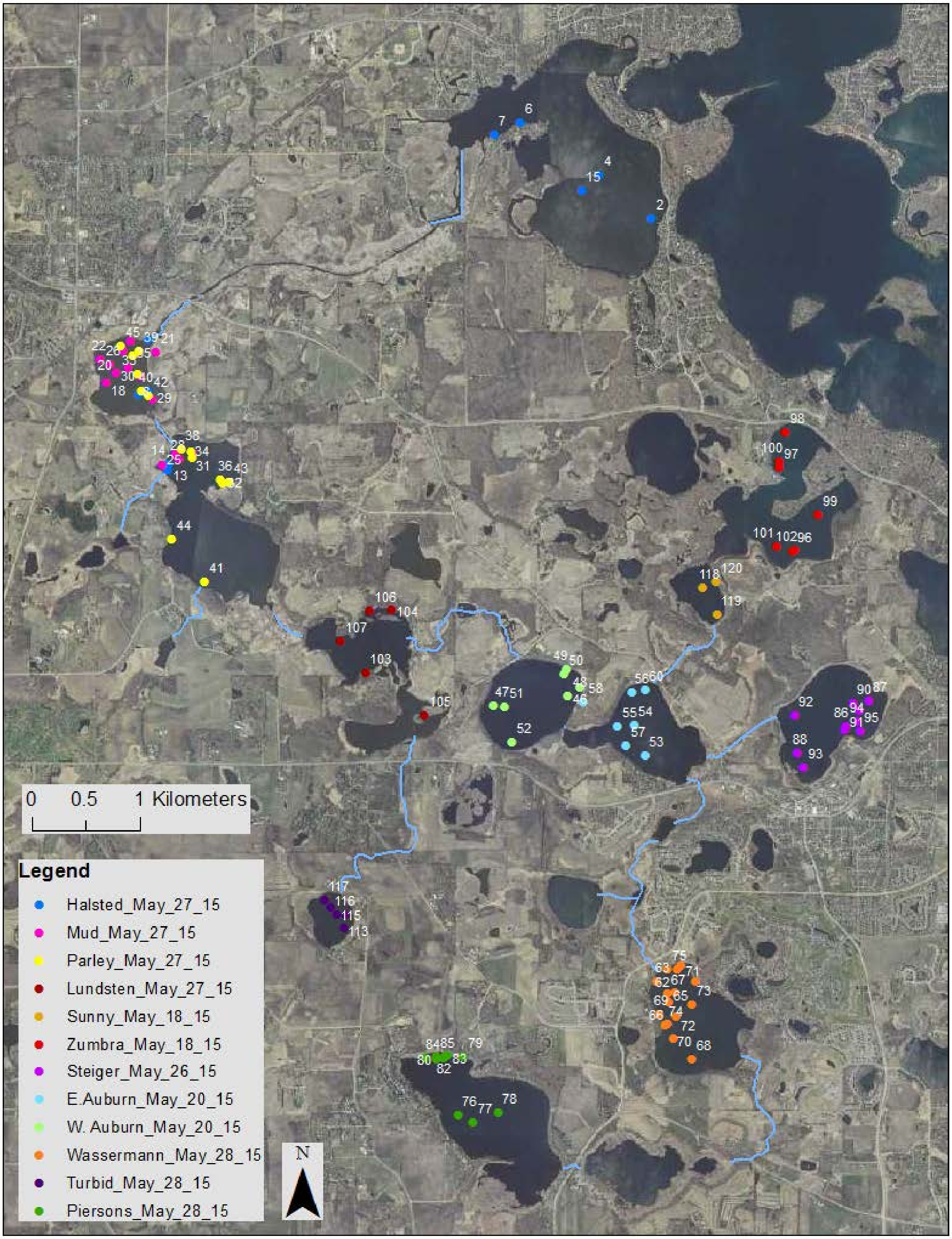

Figure 10. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in late May 2015. Individuals are labeled with unique identification numbers (white).

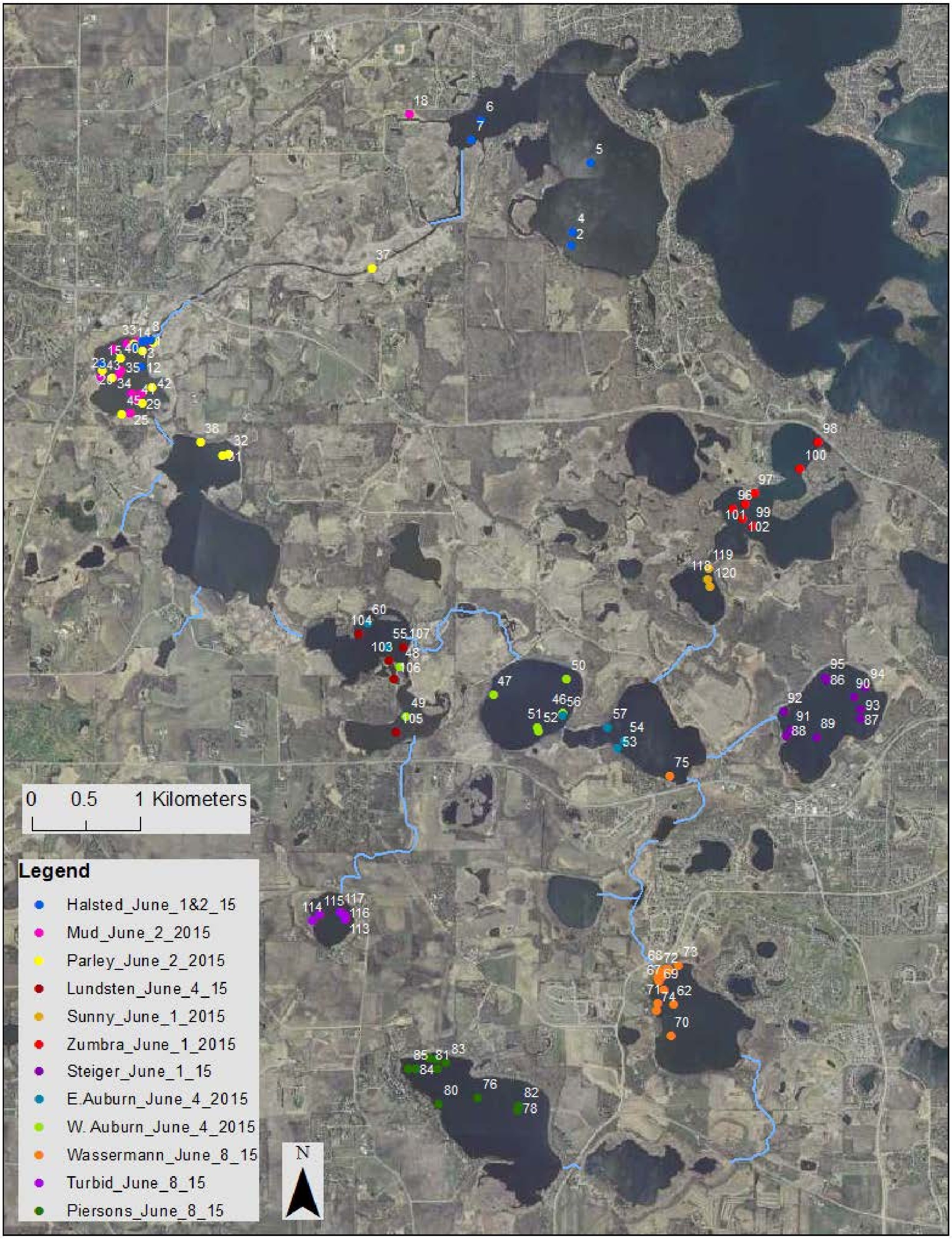

Figure 11. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in early June 2015. Individuals are labeled with unique identification numbers (white).

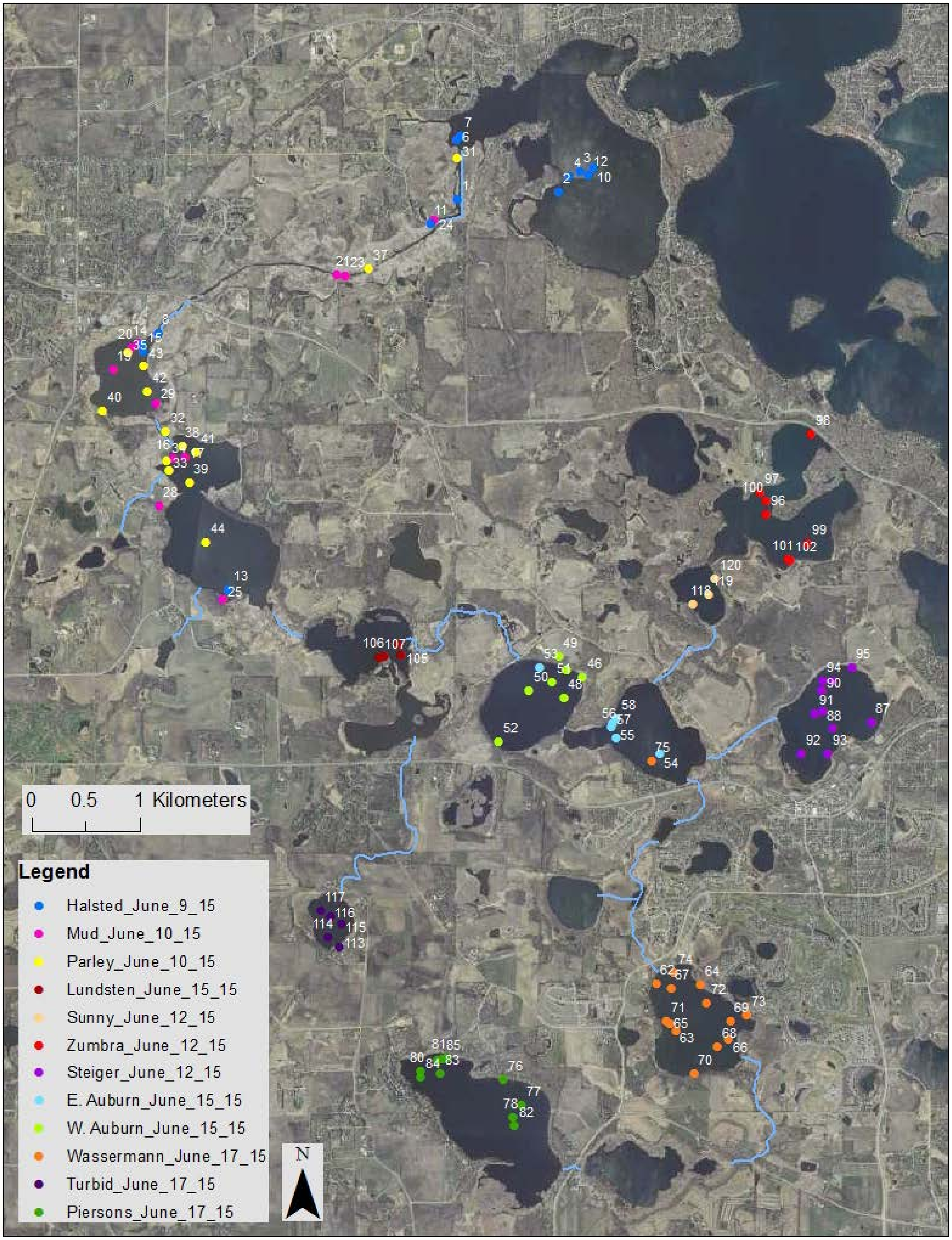

Figure 12. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in late June 2015. Individuals are labeled with unique identification numbers (white).

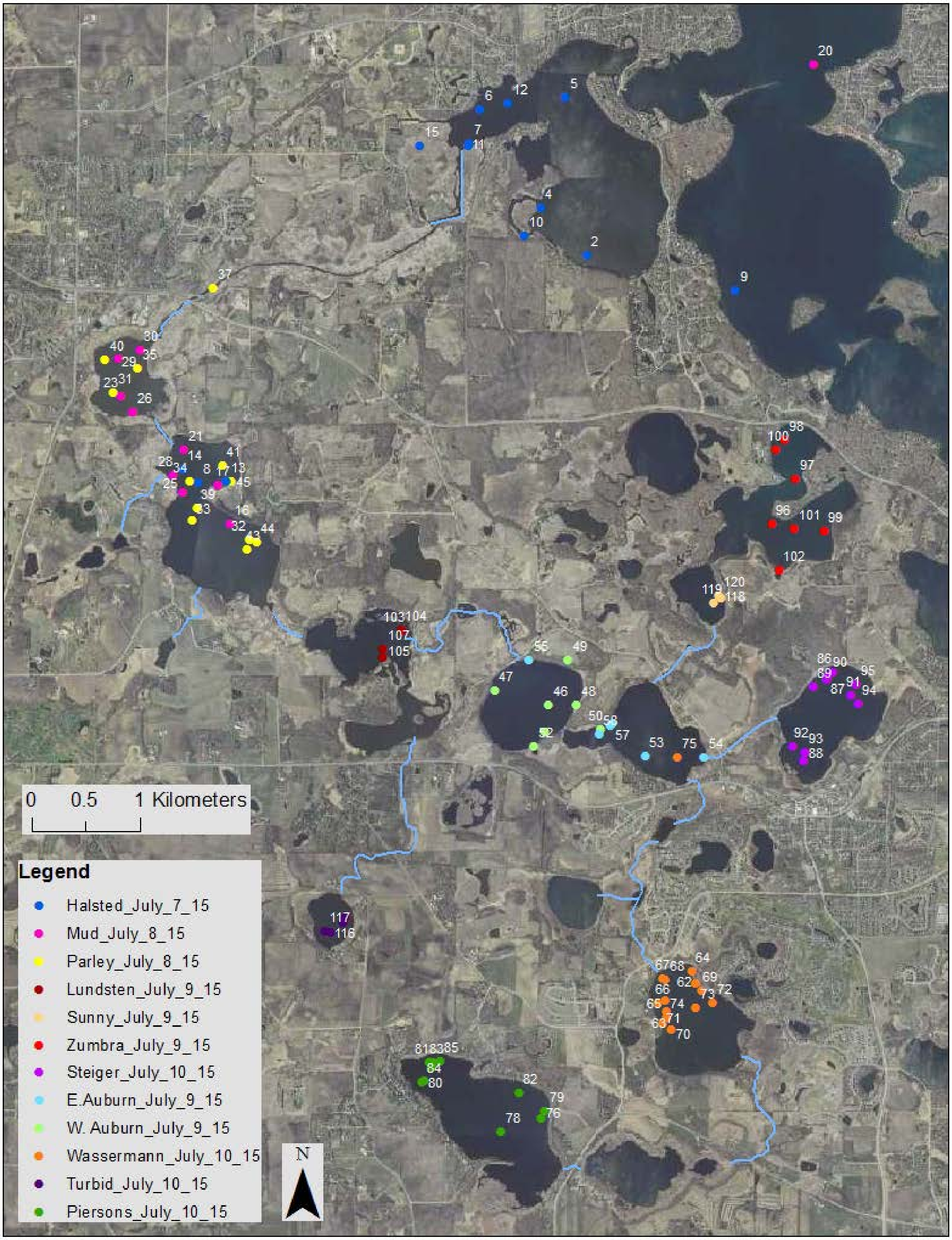

Figure 13. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in July 2015. Individuals are labeled with unique identification numbers (white).

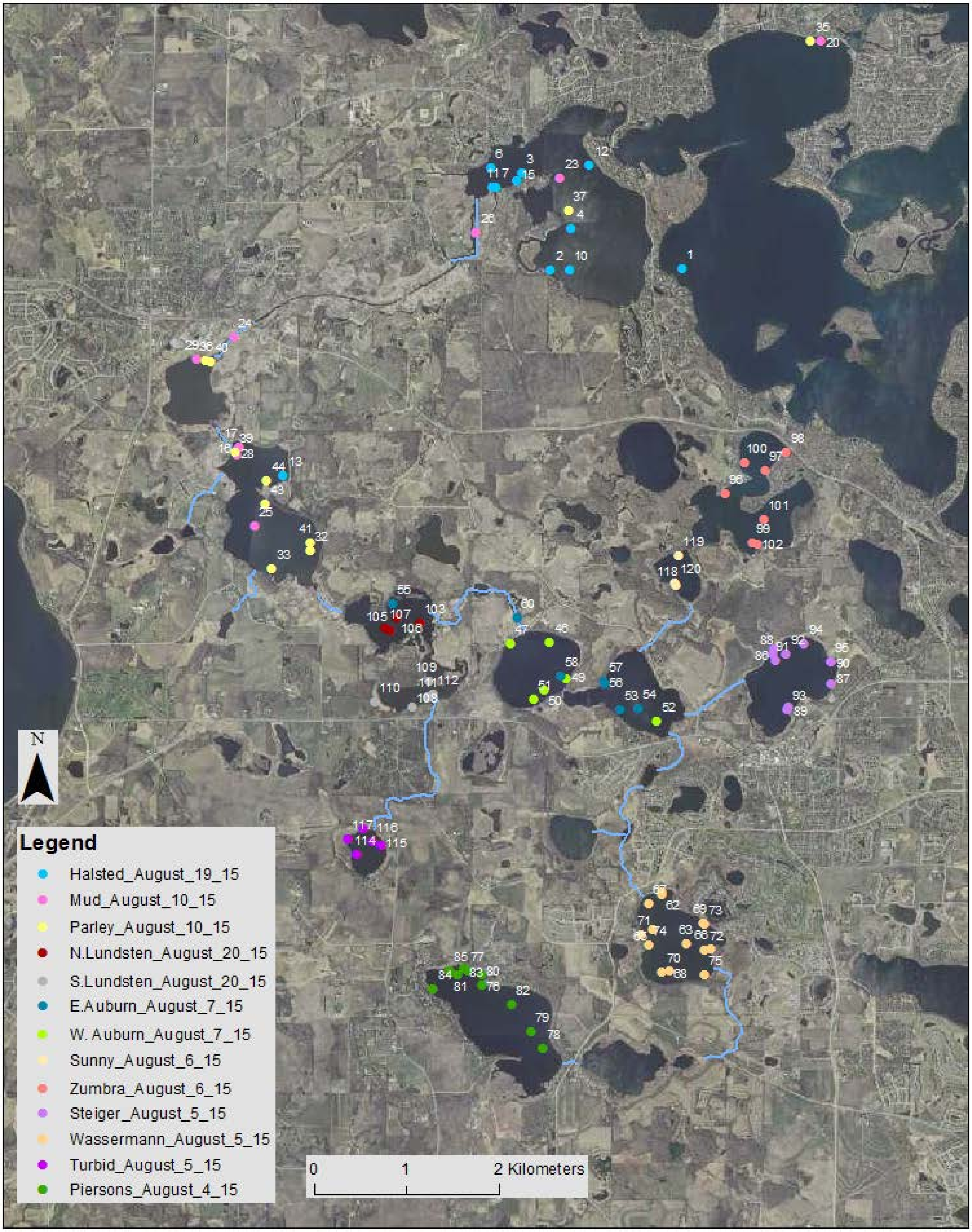

Figure 14. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in August 2015. Individuals are labeled with unique identification numbers (white).

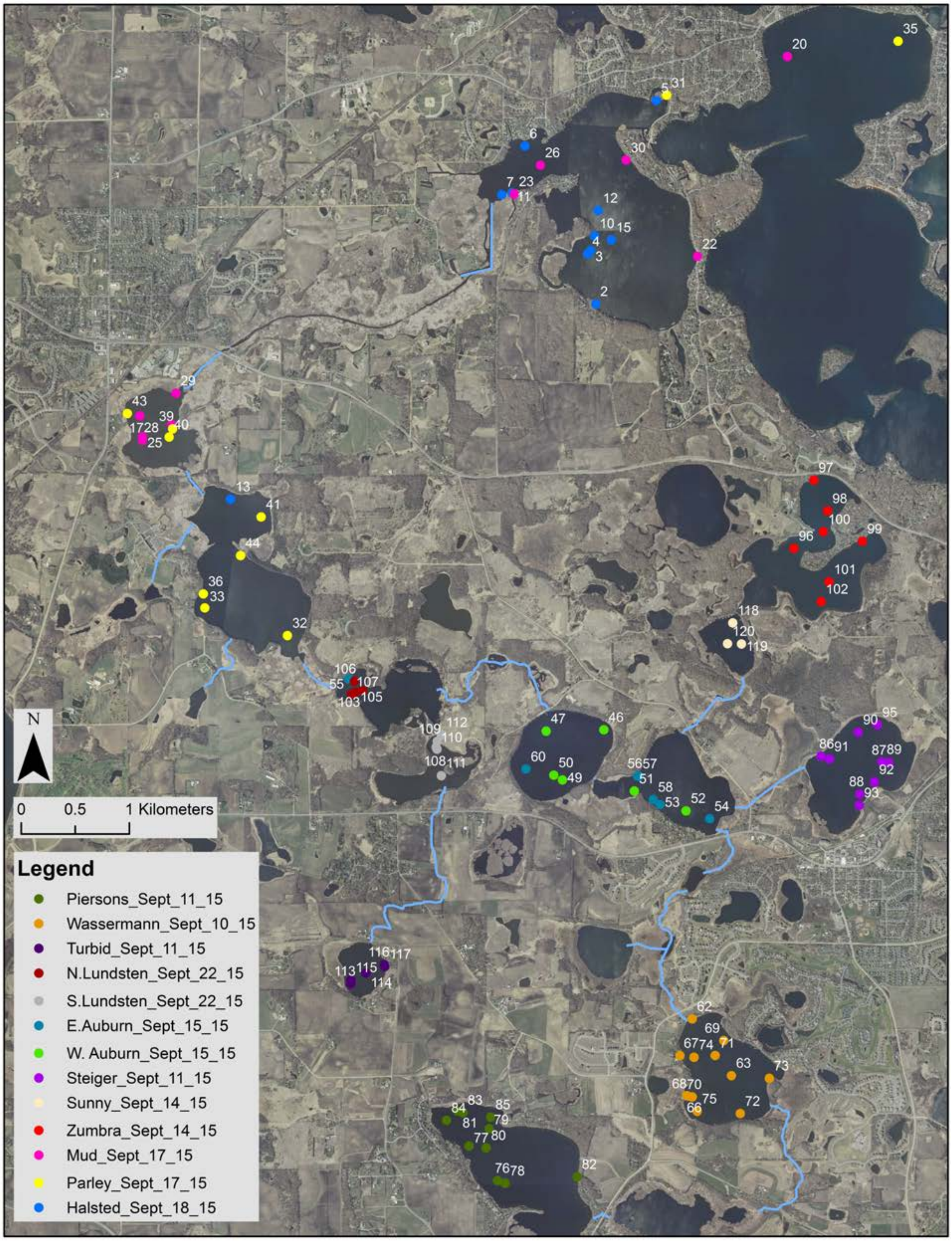

Figure 15. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in September 2015. Individuals are labeled with unique identification numbers (white).

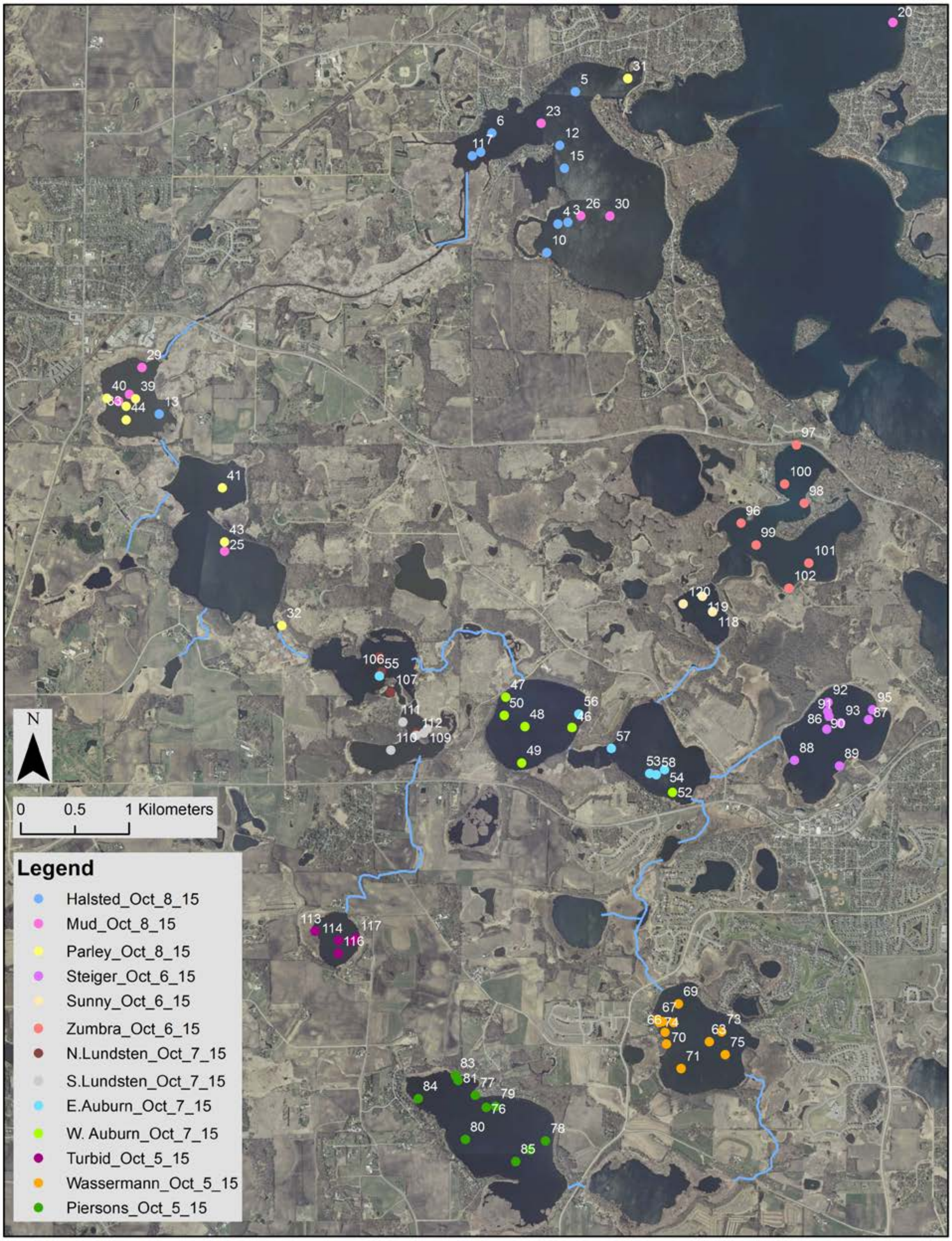

Figure 16. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in October 2015. Individuals are labeled with unique identification numbers (white).

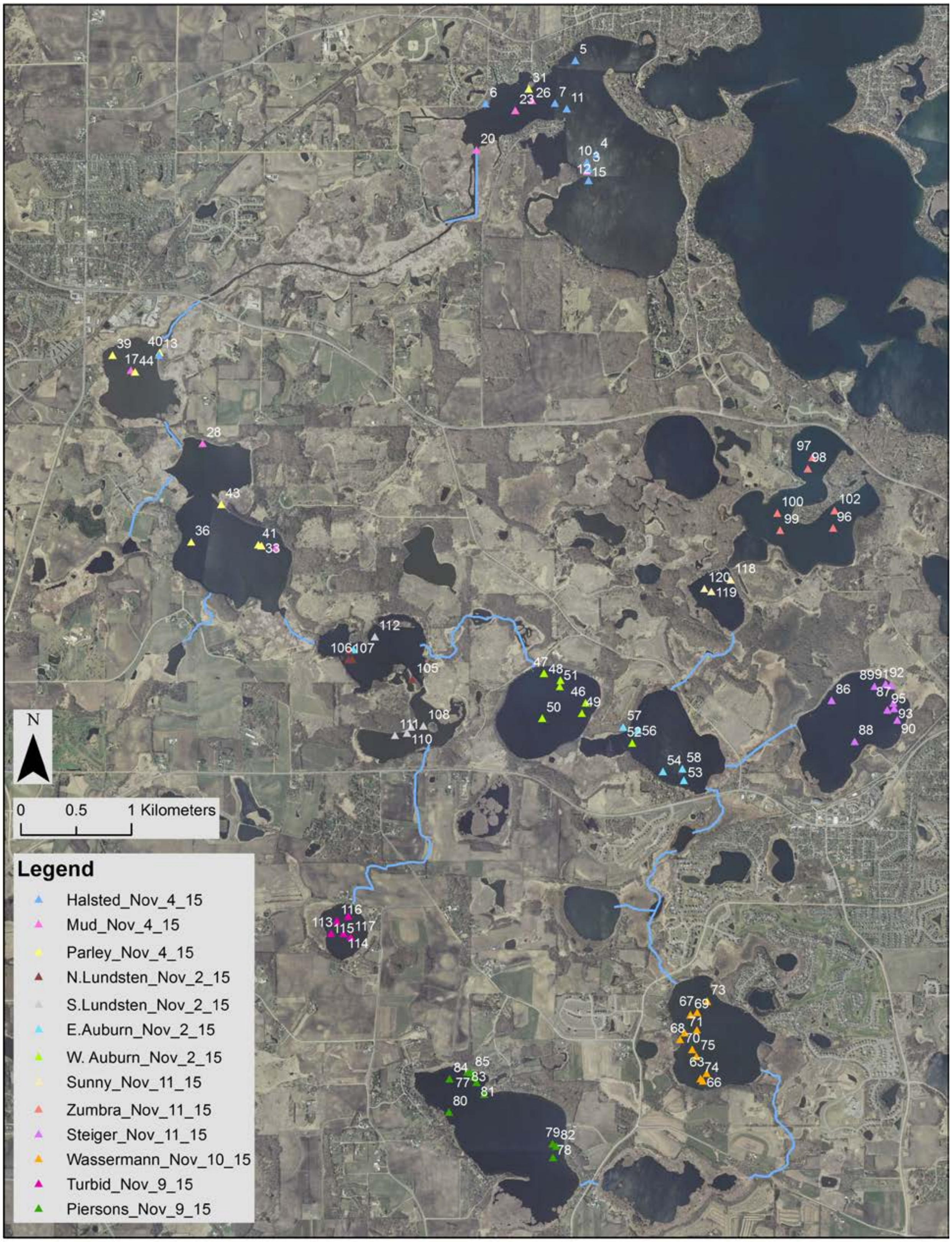

Figure 17. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in November 2015. Individuals are labeled with unique identification numbers (white).

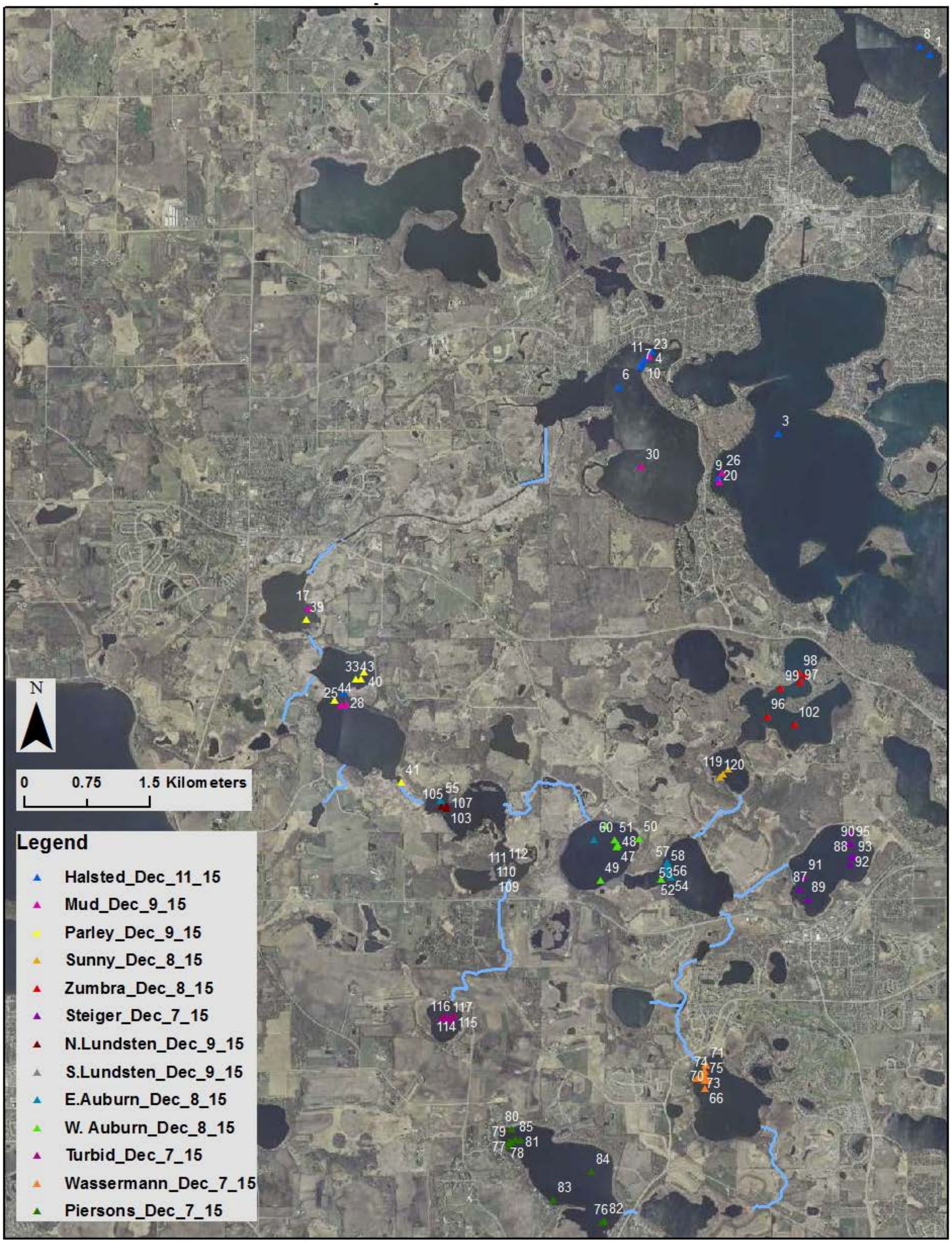

Figure 18. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in December 2015. Individuals are labeled with unique identification numbers (white).

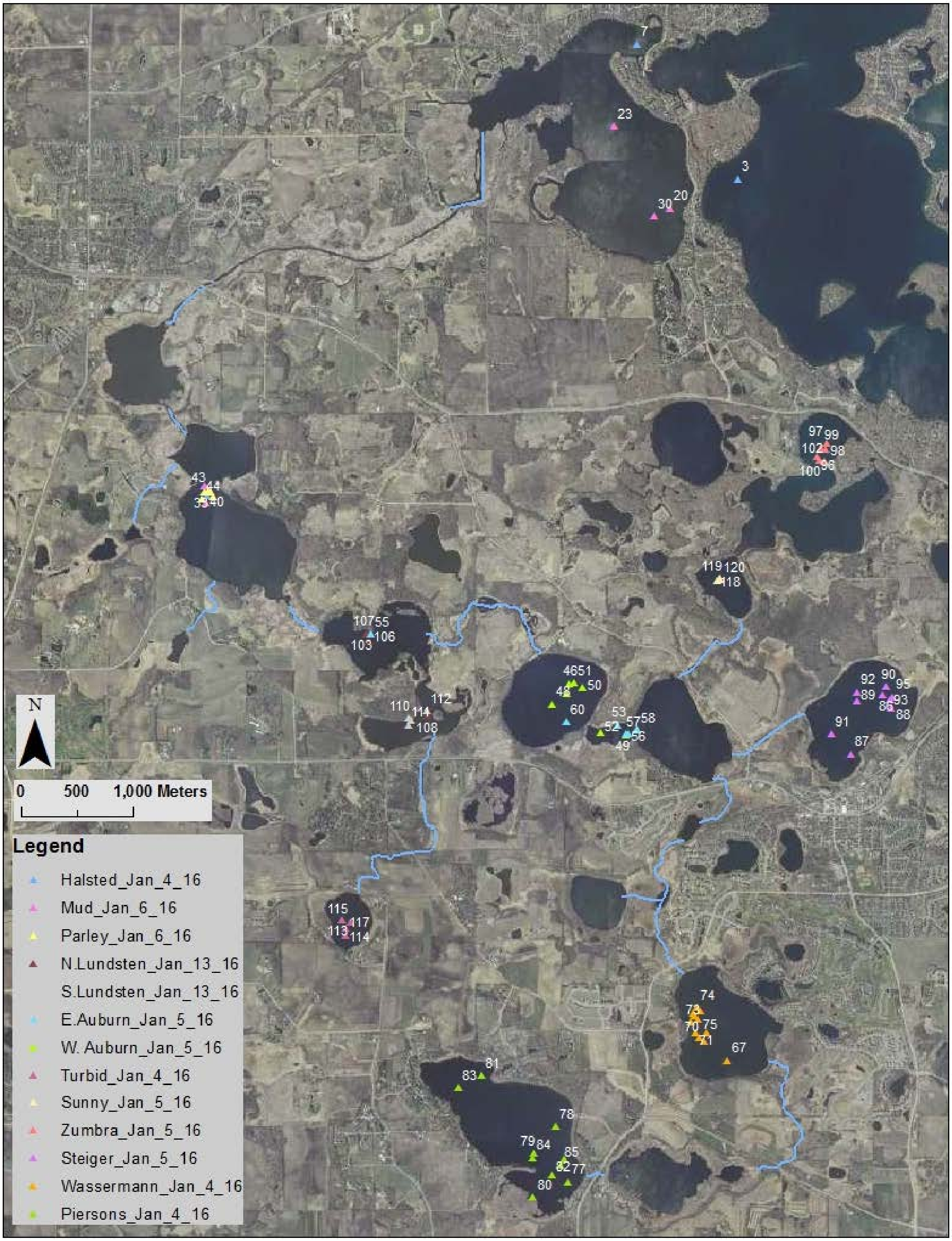

Figure 19. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in January 2016. Individuals are labeled with unique identification numbers (white).

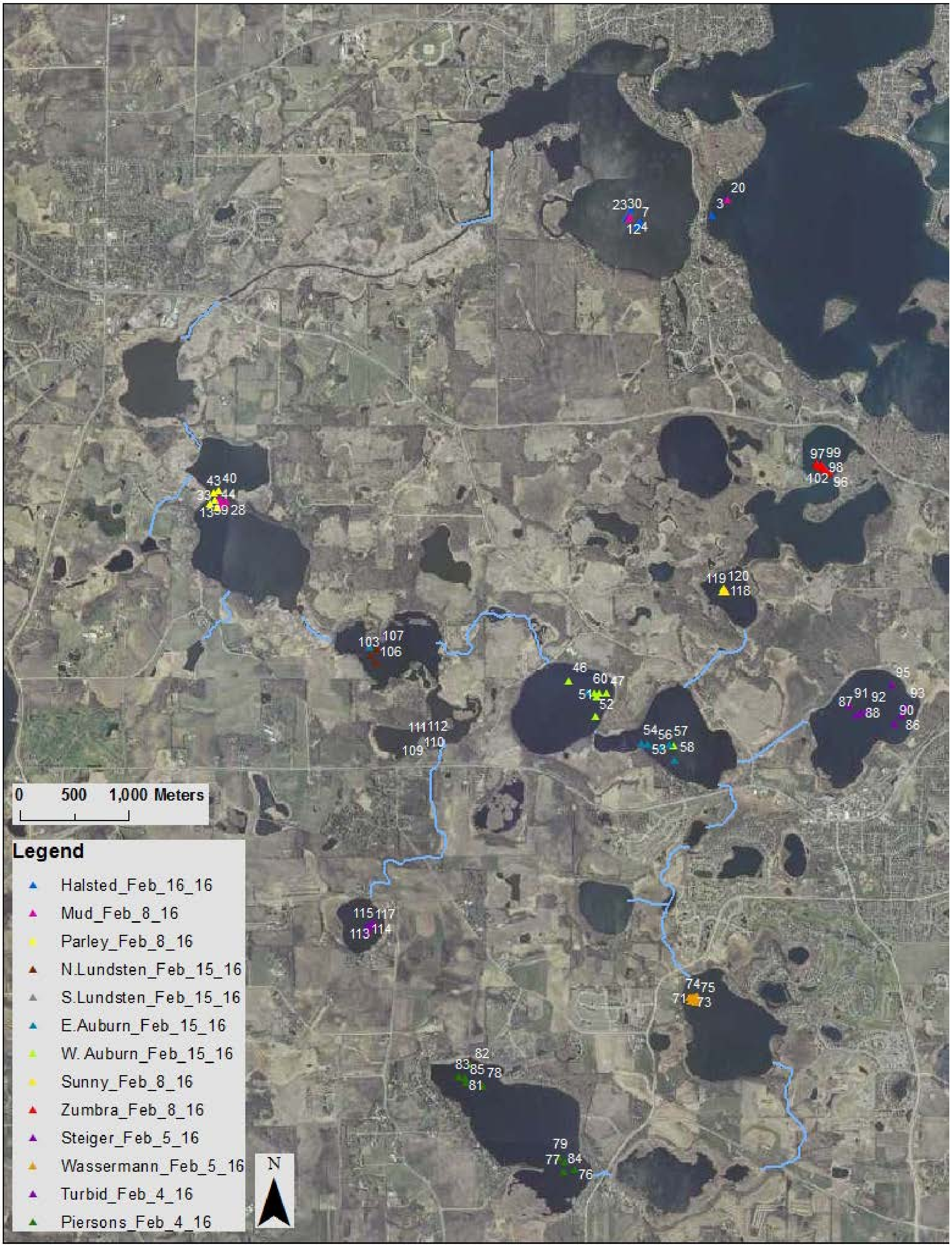

Figure 20. Locations of radio-tagged common carp in the Six Mile Creek Subwatershed in February 2016. Individuals are labeled with unique identification numbers (white).

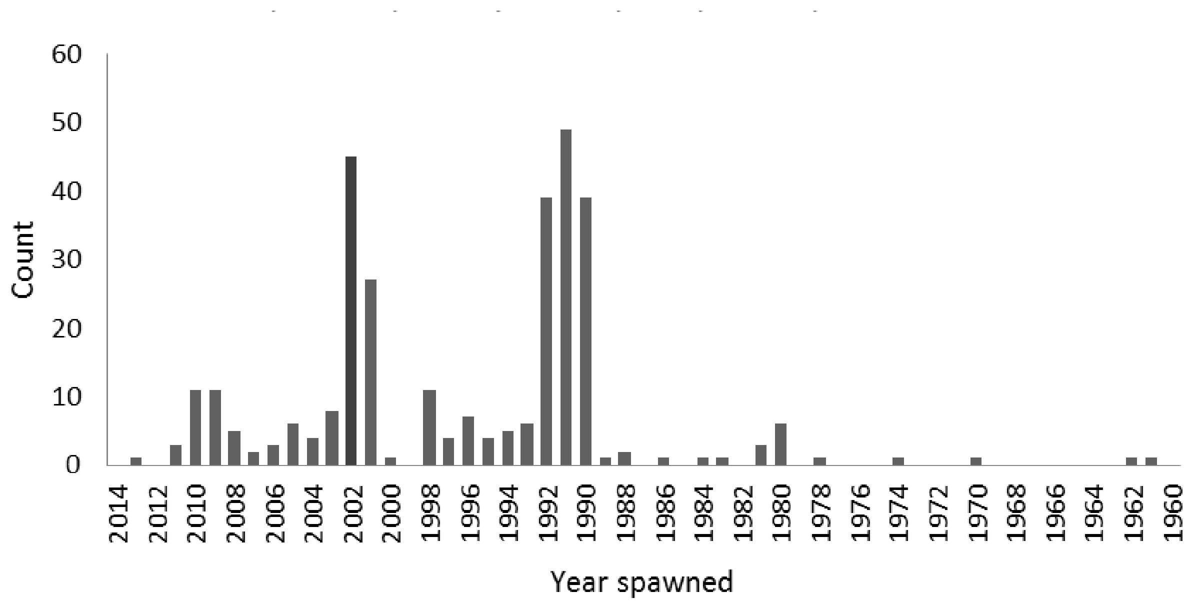

Figure 21. The age structure of common carp (n=311) across the Six Mile Creek Subwatershed. Common carp were sampled from Halsted's Bay (n=51), Mud Lake (n=51), and Parley Lake (n=51) in 2014 and North Lundsten Lake (n=31), West Auburn Lake (n=28), East Auburn Lake (n=28), Wassermann Lake (n=37), and Piersons Lake (n=34) in 2015.

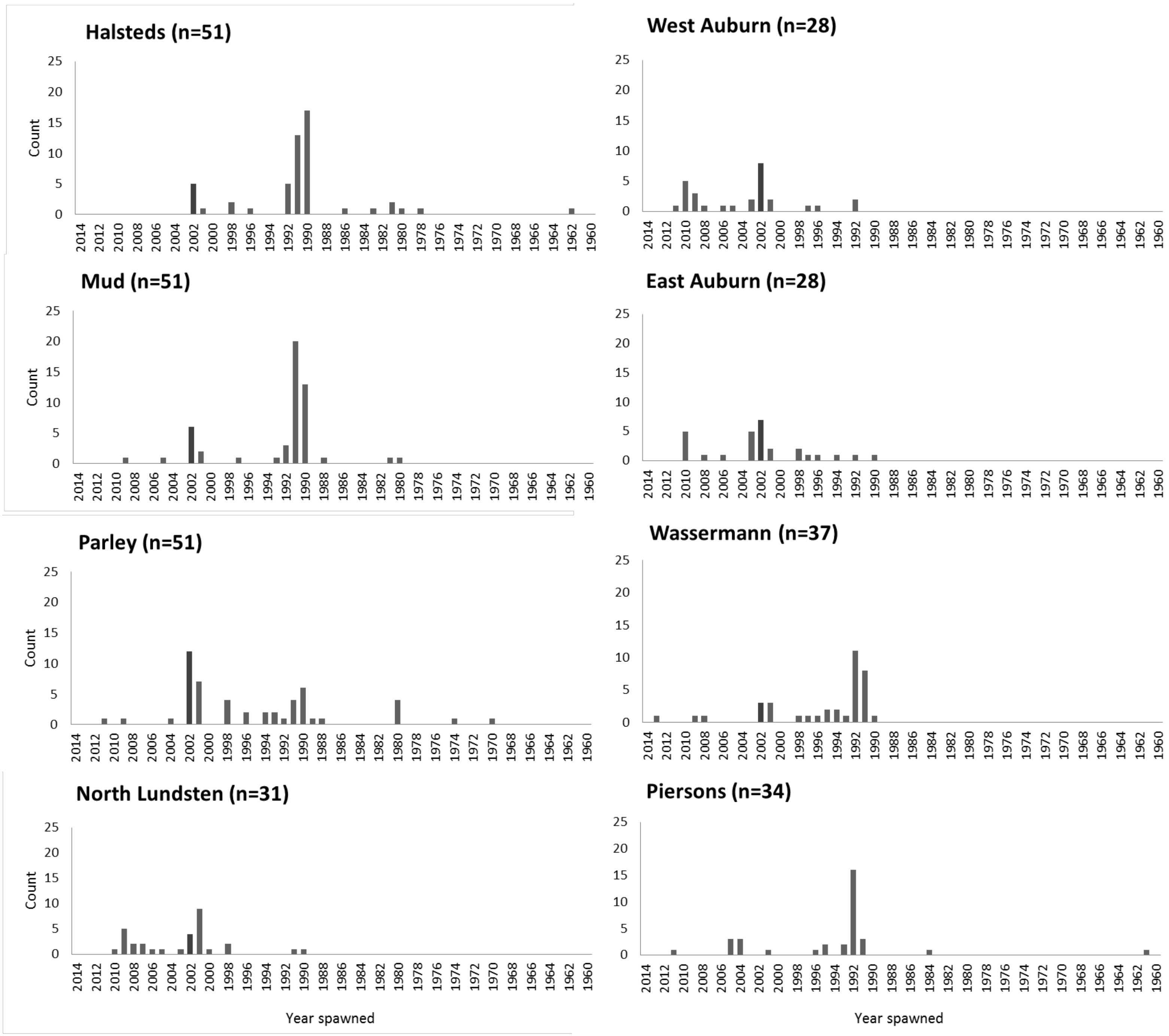

Figure 22. The age structures of common carp sampled across the Six Mile Creek Subwatershed shown individually by lake. Common carp were sampled from Halsted's Bay (n=51), Mud Lake (n=51), and Parley Lake (n=51) in 2014 and North Lundsten Lake (n=31), West Auburn Lake (n=28), East Auburn Lake (n=28), Wassermann Lake (n=37), and Piersons Lake (n=34) in 2015.

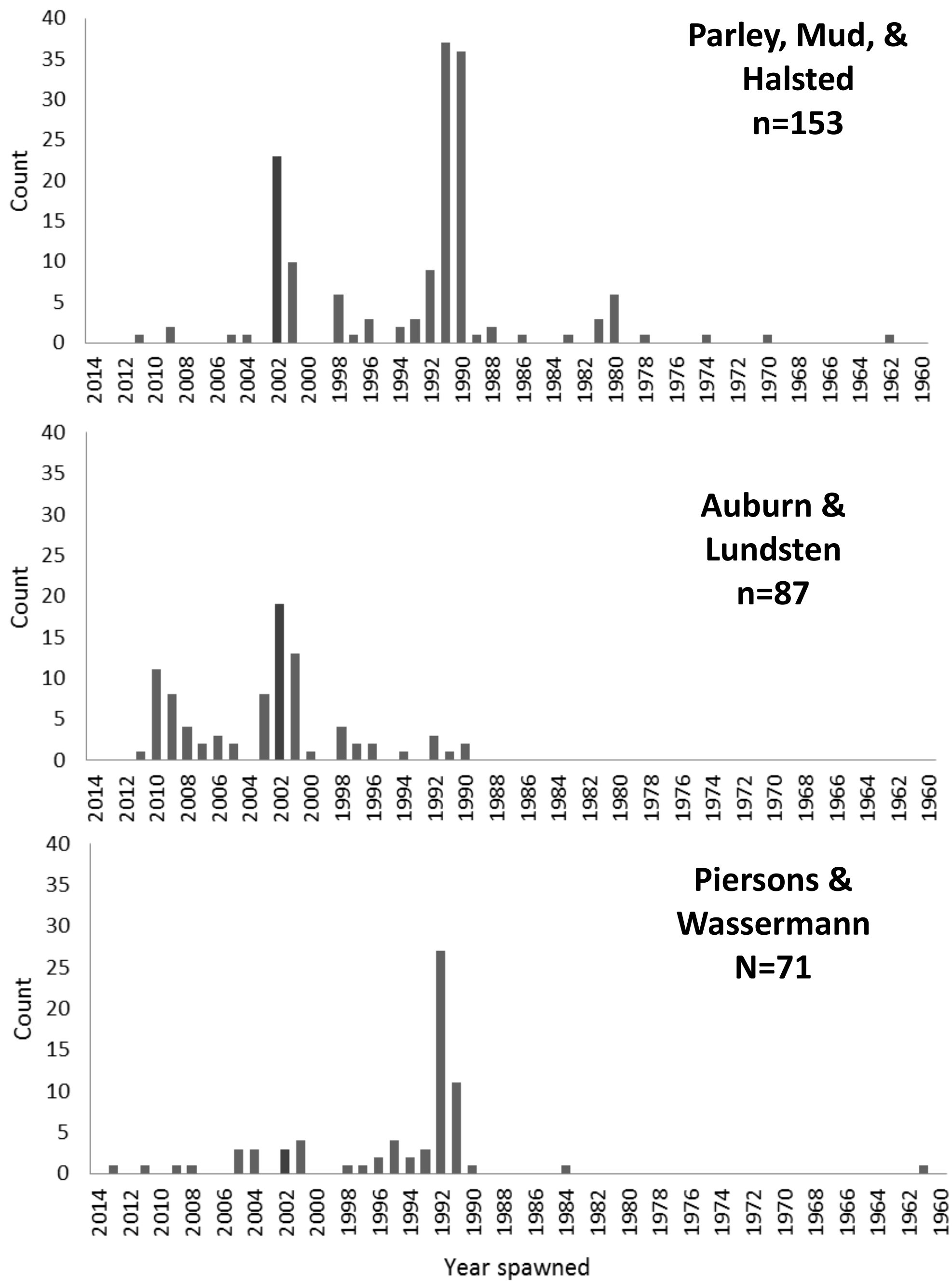

Figure 23. The age structures of common carp sampled across the Six Mile Creek Subwatershed shown by sub-population. Common carp were sampled from Halsted's Bay (n=51), Mud Lake (n=51), and Parley Lake (n=51) in 2014 and North Lundsten Lake (n=31), West Auburn Lake (n=28), East Auburn Lake (n=28), Wassermann Lake (n=37), and Piersons Lake (n=34) in 2015.

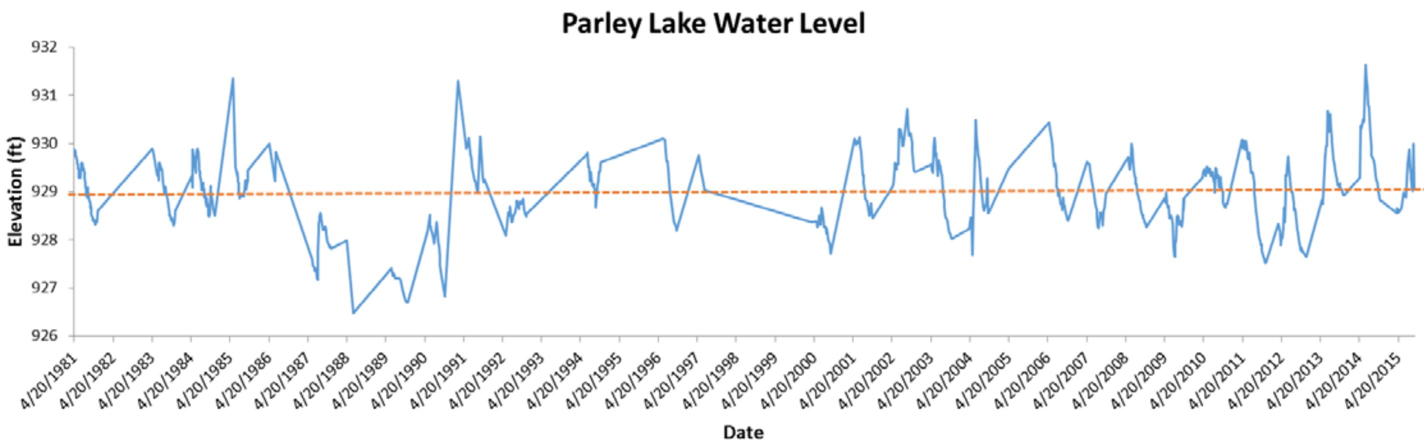

Figure 24. Parley Lake surface water elevation from April 1981 through November 2015. The average surface water elevation for this time period (929 feet) is shown by the dashed line. Source: Minnesota Department of Natural Resources; http://www.dnr.state.mn.us/lakefind/showlevel.html?downum=10004200