Legacy herbicides in lake sediments are not preventing the growth of submersed aquatic plants in Lake Istokpoga

MARK V. HOYER, WILLIAM T. HALLER, JASON FERRELL, AND DEAN JONES*

ABSTRACT

Stakeholders concerned about the lack of submersed aquatic vegetation (SAV, primarily hydrilla [*Hydrilla verticillata* (L. F.) Royale] in Lake Istokpoga, FL, have hypothesized that legacy herbicides in sediments were the possible cause of reduced SAV growth for the past 3 yr. Bioassay experiments were conducted from sediments collected from nine stations located around Lake Istokpoga in areas identified by stakeholders in which hydrilla had previously grown. These were compared with sediments collected from three stations in similar Lake Tohopekaliga, FL, where hydrilla was currently growing. Tomato (*Solanum lycopersicum* L.) seeds were germinated in sediments from all stations in both lakes and control soils. Bare-root tomato transplants (3.8 cm tall) planted in sediments from both lakes continued to grow and, when harvested, plant dry weights were similar to transplants planted in two control soils (pure sand and 1 : 1 ratio potting soil : sand). Hydrilla tubers were also planted in sediments collected from three stations in both lakes and control soils. Tubers germinated in sediments from both lakes and control soils, and the percentage of germination was not significantly different between lake sediments and control soils. Sediment samples from all nine stations in Lake Istokpoga were sent to laboratories for chemical analyses of the nine aquatic herbicides used in Lake Istokpoga during the past 10 yr, and all results were "nondetect." Sixty cores were collected from areas with a history of hydrilla growth in Lake Istokpoga, and no hydrilla tubers were collected, suggesting little or no propagules are present for resumed growth of this SAV. Bioassays and sediment analyses indicate that legacy herbicides are not the cause of the decreased abundance of SAV in Lake Istokpoga.

Key words: aquatic plant management, herbicide, hurricanes, hydrilla, lake sediment, tomato bioassay, tuber.

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INTRODUCTION

Lake Istokpoga, Florida's fifth largest lake, at approximately 10,900 ha (26,934.5 ac), is highly productive in terms of both plant and animal life. Many different stakeholders use and rely on Lake Istokpoga, including anglers, hunters, recreational boaters, birdwatchers, and general wildlife observers; fishing, hunting, and wildlife watching–related businesses; the local hospitality industry; local residents; and a variety of civil society organizations (Greater Sebring Chamber of Commerce 2019). Many uses of the lake and the conservation of its biological resources rely on active management of its habitats, particularly with respect to control of aquatic vegetation (O'Dell et al. 1995, Alam et al. 1996). This task, however, is complex because of the dynamic, ever-changing ecology of the lake, the diversity of stakeholders, and the stakeholders' often-conflicting preferences for lake habitat characteristics and management actions.

Waterhyacinth [*Eichhornia crassipes* (Mart.) Solms], waterlettuce (*Pistia stratiotes* L.), and hydrilla [*Hydrilla verticillata* (L. F.) Royale] are the most common problematic aquatic plants in Lake Istokpoga and throughout Florida, often requiring aggressive management programs. If left alone for a growing season, one hyacinth plant can yield 1 acre of plant coverage (Joyce 1992), and one hydrilla stem can grow 486 cm (191.3 in) d^{-1} (Glomski and Netherland 2012) through production of lateral shoots and apical meristems. These plants can physically interfere with many lake uses and, in large abundance, can create oxygen deficits causing related fish kills while adding organic sediments causing expansion of littoral-emergent vegetation. The management of these plants in Lake Istokpoga and other lakes in Florida is currently conducted with an approach called "maintenance control." Florida Statute 369.22 defines *maintenance control* as "a method for the control of non-indigenous aquatic plants in which control techniques are utilized in a coordinated manner on a continuous basis in order to maintain the plant population at the lowest feasible level as determined by the department." This management strategy requires many repeated treatments on a regular basis using less herbicide, preventing problem plants from covering large areas and without greater amounts of herbicide having to be applied to achieve control.

Although herbicides are thoroughly tested and registered for use by the U.S. Environmental Protection Agency (U.S. EPA) to ensure unintended harm to lakes will likely not occur, many people are averse to using chemicals in lakes.

This can foster an adversarial environment and result in conflicts or a lack of consensus among stakeholders. These conflicts are often unnecessary and counterproductive to the extent that they are mostly based on misinformation and/or the lack of a comprehensive management policy or plan for a given lake. To promote effective, strategic habitat management for Lake Istokpoga and to reduce stakeholder conflict, the Florida Fish and Wildlife Conservation Commission (FWC) contracted with the University of Florida (UF) to engage stakeholders in the development of a Lake Istokpoga Habitat Management Plan.

Stakeholder engagement in habitat management was strategic, adaptive, and included a variety of methods to ensure the highest level of participation possible. Initially a broad-based situation analysis was conducted to assess baseline stakeholder knowledge, attitudes, and perspectives regarding the management of Lake Istokpoga as well as the stakeholders' general value orientations. A permanent advisory committee of representatives from key stakeholder groups was formed to identify objectives, develop habitat management options, assess trade-offs among objectives, and to plan for continued monitoring, review, and adaptive management. A wider array of stakeholders and the public were engaged through public meetings, and a stakeholder survey to obtain input from stakeholders at large who have not personally engaged with the committee or public meetings.

One of the main issues that emerged from stakeholder engagement sessions was the decreased abundance of submersed aquatic vegetation (primarily hydrilla) and a perceived decrease in associated fish and wildlife populations. Since 2015, little hydrilla or other submersed aquatic vegetation has been reported in Lake Istokpoga (FWC 2017). It was suggested by the Advisory Committee and many stakeholders at public meetings that the longtime use of herbicides in Lake Istokpoga had built up legacy herbicide in the sediments, which had prevented regrowth of submersed aquatic vegetation in the lake.

UF's Lake Istokpoga habitat management plan development team, with collaboration from the Istokpoga advisory committee and FWC staff, designed the following three-part sediment study to determine whether legacy herbicides in sediments were inhibiting the growth of submersed aquatic vegetation in the lake. This included 1) sediment bioassay studies, 2) analytical analysis of herbicide concentration in the sediment, and 3) a hydrilla tuber density survey within Lake Istokpoga.

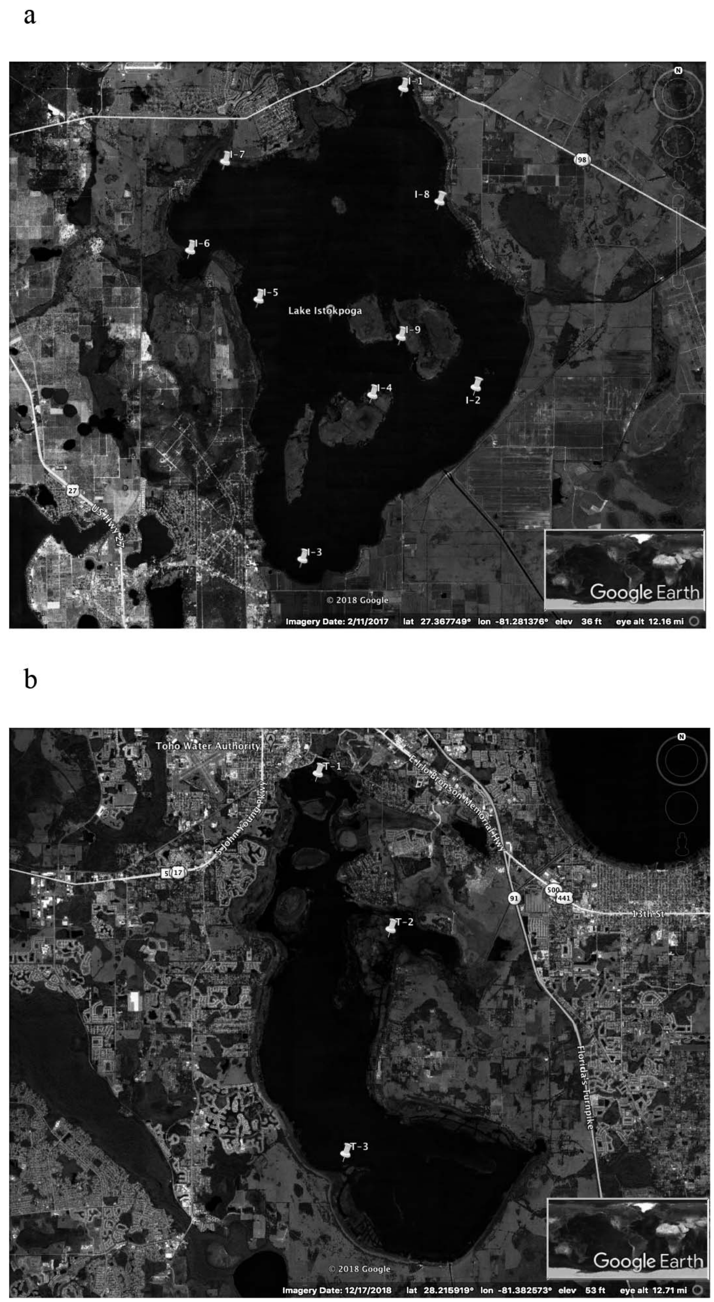

Figure 1. Google earth maps locating sediment sampling stations on Lake Istokpoga (a) and Lake Tohopekaliga (b). These lakes are of similar size and depth and located in central Florida about 200 km apart.

MATERIALS AND METHODS

Bioassay study

The specific objectives of this study section were to determine whether tomato seed germination and growth, tomato bare-root transplant growth, and hydrilla tuber germination in lake sediments collected from Lake Tohopekaliga and Lake Istokpoga are similar to each other and to germination/growth in control soils.

On May 23, 2019, a Petite Ponar sediment sampler[1] was used to collect 18.9 L (5 gal) of sediment from each of three locations identified by the Lake Istokpoga Advisory Committee as areas that historically supported hydrilla in Istokpoga (Stations I-1, I-2, and I-3, Figure 1a). Sediments were also collected from three locations (May 13, 2019) in Lake Tohopekaliga, in which hydrilla was currently growing (stations T-1, T-2, and T-3; Figure 1b). Lake Tohopekaliga was chosen for comparison to Lake Istokpoga because of similarities between the two lakes. Lake Istokpoga is a large (surface area = 10,900 ha), shallow (mean depth = 1.6 m [5.25 ft.]), eutrophic (annual mean chlorophyll ranges from 12 to 62 $\mu g\ L^{-1}$) lake, and hydrilla coverage from 1982 to 2017

TABLE 1. NUMBER OF YEARS (STARTING FROM 2009) AN INDIVIDUAL AQUATIC HERBICIDE WAS USED IN LAKE ISTOKPOGA, AND LAKE TOHOPEKALIGA LISTED WITH MEAN AMOUNT (KG AND KG HA^{-1}) OF ACTIVE INGREDIENT APPLIED DURING THOSE YEARS (KG HA^{-1} IS THE IS THE WEIGHT OF THE ACTIVE INGREDIENT DIVIDED BY THE WHOLE LAKE SURFACE AREA).

	Lake Istokpoga			Lake Tohopekaliga		
Control Method	Years	Mean (kg)	Mean (kg ha^{-1})	Years	Mean (kg)	Mean (kg ha^{-1})
Endothall	6	27,806	2.551	9	34,006	3.470
2,4-D (amine)	9	687	0.063	6	119	0.012
Glyphosate	9	624	0.057	7	734	0.075
Diquat	9	617	0.057	9	3,545	0.362
Triclopyr (amine)	4	65	0.006	2	7	0.001
Imazamox	7	45	0.004	5	52	0.005
Flumioxazin	7	45	0.004	6	36	0.004
Penoxsulam (liquid)	5	8	0.001	5	190	0.019
Imazapyr	3	1	0.000	1	1	0.000
Total annual average		29,898	2.743		38,690	3.948

averaged 19%, exceeding 90% coverage in 1996 (O'Dell et al. 1995, Florida LAKEWATCH 2018, FWC 2017). Lake Tohopekaliga is also a large (surface area = 9,800 ha), shallow (mean depth = 2.1 m), eutrophic (annual mean chlorophyll ranges from 10 to 54 µg L^{-1}) lake, and hydrilla coverage from 1982 to 2017 averaged 38%, exceeding 80% coverage in 2002 (Hoyer et al. 2008, Florida LAKEWATCH 2018, FWC 2017). Since 2009, the use of herbicides in both lakes has also been similar, with total annual herbicide applications averaging 2.743 kg ha^{-1} (2.447 lb ac^{-1})and 3.948 kg ha^{-1} in Lakes Istokpoga and Lake Tohopekaliga, respectively (Table 1).

Sediment samples were delivered to the Center for Aquatic and Invasive Plants (CAIP) for processing and all bioassay work. Sediments from each lake (Lake Istokpoga: stations I-1, I-2, and I-3; Lake Tohopekaliga: stations T-1, T-2, and T-3) were dried, sifted through a 0.6-cm screen, and put into two groups of four, 10.1-cm pots. Similarly, two control groups, one pure sand and one sand/potting soil mix (control [sand]; and control [sand and organic matter {OM}] 1 : 1 ratio by volume) were also set up. The sand controls likely hade too few nutrients to grow tomatoes so 3 g of Osmocote slow release (3 to 4 mo) fertilizer kg^{-1} of soil weight was added to all control pots, but no fertilizer was added to the lake sediment samples. Ten tomato seeds were each planted 1 to 2 cm deep in four pots from each station and the two control soils. Two- to eight-centimeter-tall tomato plants were purchased from a local nursery and all soil washed from their roots. Two of these bare-root transplants were planted in each of four pots of the two control soils and the six soil samples from lakes Istokpoga and Tohopekaliga. Tomato seeds and transplants were used for this study because they are both easy to grow and extremely sensitive to herbicides and other stresses (Fernow 1967, Neal 1991). Tomato seeds and transplants were planted on April 12, 2019, and number of seeds germinated in each pot determined on May 10, 2019. Seedlings were also harvested on May 10, 2019, dried in a drying oven (103 C) for several days and weighed (in grams).

Hydrilla tubers collected from experimental tanks located at CAIP, UF, were planted in 10.16 cm pots (six tubers per pot) using the exact experimental design mentioned above. The tubers had been held in refrigeration for several days before planting causing concern about the tubers after none had germinated for 2 wk. Therefore, using the remaining unused experimental sediments from lakes Istokpoga and Tohopekaliga, four new pots per station were prepared, and six fresh tubers from different culture tanks were planted in each. Six additional tubers were planted in each of the original control pots, yielding 12 tubers in each control pot. The second round of tuber planting occurred on June 4, 2019, and the number of tubers germinated per pot was determined on July 3, 2019.

Preliminary results (Lake Istokpoga stations I-1 to I-3, Lake Tohopekaliga T1 to T-3, and two controls) from this study were presented to multiple Lake Istokpoga stakeholders who then requested better lake-wide coverage for the bioassay work because of the lake's large surface area. Therefore, on June 6, 2019, sediment samples were collected from six additional stations in Lake Istokpoga (Figure 1a, stations I-4 to I-9) for additional bioassay tests. The sediments were processed, and the experimental design was the same as the experiments conducted with sediments from the first three stations. However, only tomato seeds were planted to evaluate seed germination. Ten tomato seeds were planted on June 24, 2019, and geminated seeds (plants) were counted on July 15, 2019.

Herbicide concentration in sediment study

FWC maintains a database called Plant Management and Accounting Retrieval System (PMARS: https://public.myfwc.com/HSC/PMARS/LoginForm.aspx), which records all the herbicides applied annually to each individual Florida public lake under their management program. Table 1 lists the number of years an individual herbicide was used in Lakes Istokpoga and Lake Tohopekaliga, and the sum of active ingredient applied during those years (kilograms and kg ha^{-1} of the lake). The Lake Istokpoga Advisory Committee requested sediments be collected from the same nine stations used in the bioassay study (Figure 1a) and have them tested for the nine aquatic herbicides listed in Table 1. The objective of this section was to identify the concentrations (if any) of the aquatic herbicides in sediments collected from nine different stations in Lake Istokpoga.

On June 6, 2019, sediment samples were collected from all nine stations (Figure 1a) using a Petite Ponar sediment sampler. Samples were placed in 7.57-L (2-gal) plastic bags, sealed, and shipped on ice to Waters Agricultural Laboratories, Inc. (Vicksburg, MI, USA) for analyses of all herbicides, except diquat and endothall. An additional set of nine sediment samples were sent to North Coast Laboratories Ltd. (Arcata, CA, USA) laboratories for analyses of diquat. We could find no laboratories that would analyze sediments for endothall because of the low partition coefficient of endothall to hydrosoil (Reinert and Rodgers 1984) and the relatively short persistence in water (half-life = 4.01 d) (Reinert et al. 1985). All analyses were conducted using standard methods.

Hydrilla tuber density in Lake Istokpoga study

Hydrilla (dioecious) plants reproduce asexually through fragmentation and production of turions and tubers (Gettys et al. 2014). Turions are small (up to 0.6 cm diam), green, and grow from the plant leaf axils, whereas tubers are larger in size (up to 1.3 cm diam), white to yellow to near black, and grow in the lake sediments. Hydrilla populations in Florida are limited to the dioecious biotype and thus can only spread and reproduce by vegetative means (Gettys et al. 2014). Turions have a longevity of roughly 1 yr (Netherland 1997), but tubers have been observed to survive in lake sediments for several years (Hofstra et al. 1999, Nawrocki et al. 2016). Thus, the primary means for regrowth and long-term persistence of hydrilla in Lake Istokpoga are sprouting from dormant tubers.

The Lake Istokpoga Advisory committee was concerned that hydrilla has not been observed in Lake Istokpoga for the previous 3 yr (2016–2019) and wished to determine whether hydrilla tubers were present in the sediments of the lake. A total of 60 sediment cores were collected on April 5, 2019, from three stakeholder-identified sampling locations (Figure 1a; stations I-1, I-2, and I-3). Twenty cores were collected in the area of each station, four subsample sites were selected (1–4), each located roughly 30 to 40 m (98 to 131 ft) in distance from each other along a north-bearing route. At each of the four subsample sites, five samples were collected from the bow of the boat.

Samples were collected using a core sampler constructed from polyvinyl chloride (PVC) pipe and fittings, a paint pole, and an air release value (modified from Sutton 1982). The PVC pipe was 15.2 cm diam, and thus, the sampling area for a single sediment core was 182.5 cm^2. Samples were collected to a depth of 20.3 cm and were washed in the field with lake water through a 0.3-cm mesh basket to remove the sediment from retained material. The retained material was then sorted by hand. and the number of tubers was counted and recorded for each sample. The objective of this section was to determine tuber density in the three identified hydrilla growth areas of Lake Istokpoga and compare with literature densities reported in other studies.

Data analyses were performed using the JMP statistical package[2] (SAS 2000). An analysis of variance was used with results to determine significance of bioassay treatments (control, Lake Istokpoga, and Lake Tohopekaliga), followed with a Tukey-Kramer honestly significant difference test for individual group differences. All statements of significance are at $P < 0.05$.

RESULTS

Tomato seeds planted in the sediments from Lake Istokpoga stations I-1, I-2, and I-3 germinated in all sediment soils (Figure 2). An analysis of variance showed significant treatment effects ($P < 0.05$). Average germination in control treatments (mean = 94% germination) exceeded mean germination in sediments from Lake Istokpoga and Lake Tohopekaliga (mean = 61% and 63% germination, respectively). However, there was no significant difference between tomato seed germination in soils from Lake Istokpoga and Lake Tohopekaliga (Figure 2). Seed germination in sample I-2 was less than the germination in other soils. This soil was extremely fine and difficult to wet and formed a "crust" after watering on the soil surface, which we suggest caused the reduced germination.

Tomato seeds planted in sediments collected from the additional Lake Istokpoga stations I-4 through I-9 also germinated in all pots (Table 2). Seed germination in the control pots for this second part of the tomato seed germination study had a mean of 88% germination, and means of Lake Istokpoga stations I-4 through I-9 ranged from ranged from 28 to 83% out of 10 seeds planted in each of the four replicates, with an overall mean of 57%.

Bare-root tomato transplants in sediments from Lake Istokpoga stations I-1, I-2, and I-3 grew well, and no plants died (Figure 3). An analysis of variance on transplant biomass showed treatment effects were significant ($P < 0.05$). Average plant biomass in controls (mean = 1.5 g dry wt) and Lake Istokpoga (mean = 1.3 g dry wt) were not significantly different, but both were significantly greater than plant biomass from transplants planted in Lake Tohopekaliga soils (mean = 0.5 g dry wt).

Hydrilla tubers in sediments from Lake Istokpoga stations I-1, I-2, and I-3 germinated in all treatments (Figure 4). An analysis of variance showed no significant treatment effects ($P < 0.05$). Average germination in controls (mean = 53% germination) was not significantly different from germination in Lake Istokpoga sediments (mean = 59% germination) and Lake Tohopekaliga sediments (mean = 44% germination). There was no significant difference in tuber germination between sediments from Lake Istokpoga and Lake Tohopekaliga.

No evidence of the eight aquatic herbicides historically used in Lake Istokpoga and analyzed for could be found in sediments at any of the nine stations identified by the Lake Istokpoga Advisory Committee (Figure 1a). No herbicides were reported from stations I-1 through I-9 by the Waters Agricultural Laboratories Inc. (Table 3). Similarly, North Coast Laboratories Ltd. reported no diquat was detected at any stations.

To put herbicide analyses in a general perspective, the label rates of herbicide concentrations for aquatic plant applications and the minimum detection limit (MDL) for laboratory analyses are also listed in Table 3. Those two values are not comparable, but they give a general perspective for ranges of herbicide concentrations. The MDLs for all herbicides (except diquat) are orders of magnitude less than the allowable application concentration. The MDL for diquat is approximately five times higher than the actual application rate. However, if diquat were

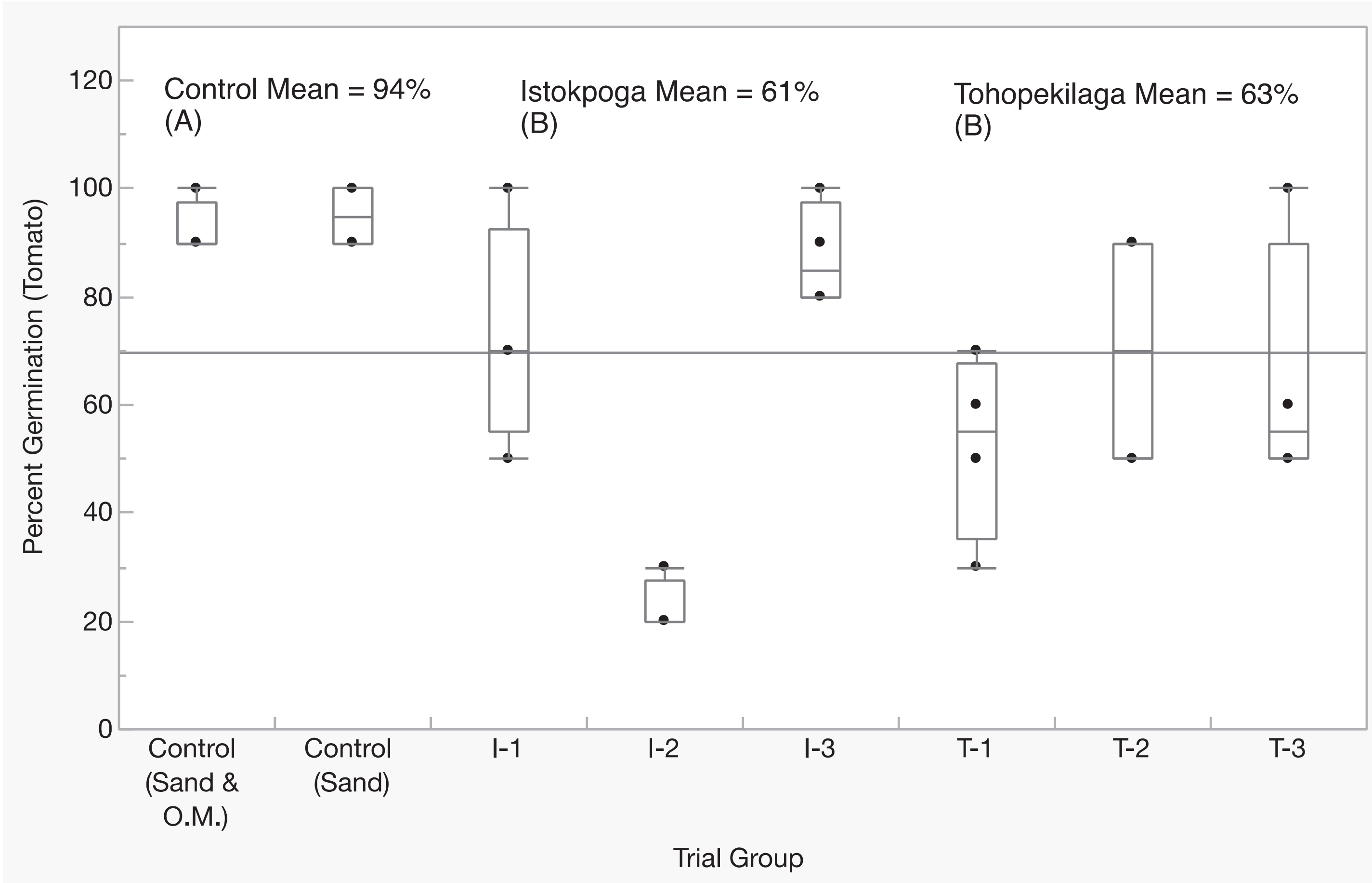

Figure 2. Box plot showing the percentage of tomato seeds germinated by the individual treatment and station. The line in the middle of the box is the median, and top and bottom edges of the box are the 25 and 75% of the data distribution. An analysis of variance was conducted using all data to determine treatment-group (controls, Lake Istokpoga, and Lake Tohopekaliga) effects and a Tukey-Kramer test was used to check for significant differences. Treatment groups with different letters are significantly different ($P < 0.05$).

accumulating in the sediments and not breaking down, it would have been found in Lake Istokpoga sediments because an average of 687 kg yr^{-1} of diquat are used in Lake Istokpoga (Table 1). Additionally, North Coast Laboratories Ltd. spiked sediments with known concentrations of diquat, and their analysis method recovered more than 80% of the spike, suggesting excellent recovery (data not shown).

No hydrilla tubers were found in any of the 60 soil core samples collected, 20 around each of stations I-1, I-2, and I-3. All samples had high levels of organic matter, especially stations I-2 and I-3 (Figure 1a). Retained material in the mesh baskets was primarily fine roots and larger fibrous plant material at station I-1, whereas material from stations I-2 and I-3 was primarily fine roots and woody material.

Table 2. Mean, minimum, and maximum percentage of tomato seed germination in second round of control pots and second round of Lake Istokpoga station research (I-4 through I-9).

Soil Sample Site	Pots	Mean	Minimum	Maximum
Control (sand and organic matter)	4	87.5	80	100
I-4	4	52.5	30	80
I-5	4	82.5	80	90
I-6	4	47.5	10	80
I-7	4	40	10	60
I-8	4	77.5	60	90
I-9	4	27.5	20	40

DISCUSSION

The Lake Istokpoga Habitat Management Planning process has identified multiple concerns, but one major concern was the hypothesis that regular use of herbicides in Lake Istokpoga was causing a buildup of legacy herbicides preventing growth of submersed aquatic vegetation (primarily hydrilla). The average annual use of herbicides in the relatively shallow Lake Istokpoga from 2009 to 2018 indicates that there was an annual application of 2.7 kg $ha^{-1}yr^{-1}$ of aquatic herbicide in this lake. Despite the reported short half-lives of less than 1 wk in the water of most of these herbicides (M.D. Netherland, chapter 11, in Gettys et al. 2014), there was a concern expressed by many that these may be accumulating in the sediment and affecting reestablishment of hydrilla and other SAVs in the lake. The sediment work conducted during this study shows that sensitive tomato seeds/transplants and hydrilla

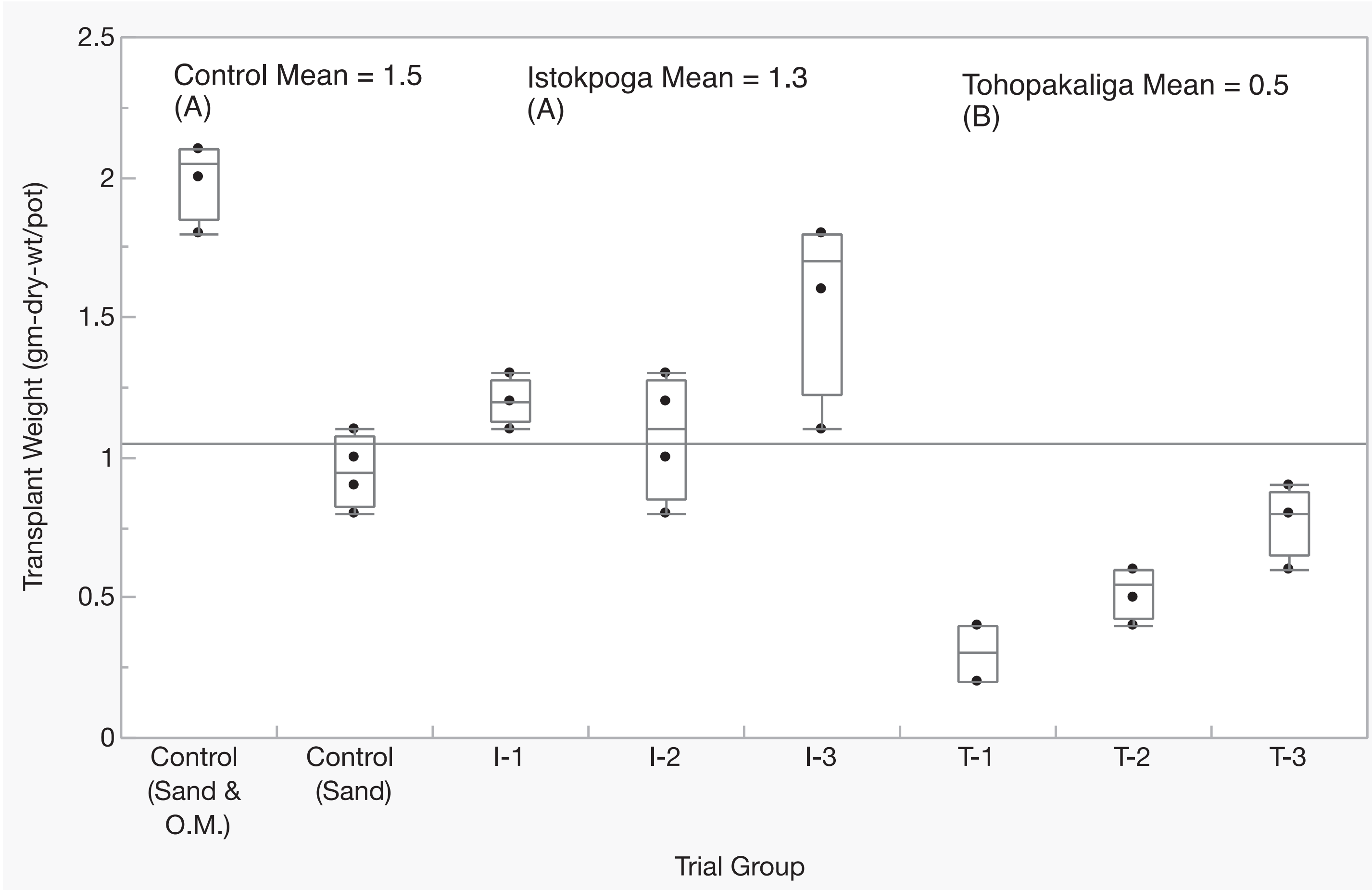

Figure 3. Box plot showing total dry weight of tomato seedings by the individual treatment and station. The line in the middle of the box is the median, and the edges of the box are the 25 and 75% of the data distribution. An analysis of variance was conducted using all data to determine treatment-group (controls, Lake Istokpoga, and Lake Tohopekaliga) effects, and a Tukey-Kramer test was used to check for significant differences. Treatment groups with different letters are significantly different ($P < 0.05$).

tubers germinate and grow well in Lake Istokpoga sediments. Analyses for nine herbicides, historically used in Lake Istokpoga during the past 10 yr, from sediments collected at nine different locations around the lake showed no detectable levels of any herbicide. These data do not support the hypothesis that legacy herbicides in the sediments of Lake Istokpoga are suppressing the growth of hydrilla.

Confusing the findings of these sediments bioassays and herbicide analyses is the fact that no hydrilla tubers were found in core samples taken from 60 stations in Lake Istokpoga. Similar sampling effort (40 to 120 cores) in six different coves of Lake Gaston, NC, yielded 31 to 293 tubers m^{-2} (Nawrocki et al. 2016), even after 7 yr of herbicide management with fluridone. Various studies have investigated the longevity of monoecious hydrilla tubers. Van and Steward (1990) conducted a long-term study with monoecious hydrilla and found tubers survived in undisturbed sediments greater than 4 yr after being produced. Other field studies have found viable tubers between 6 to 8 yr old (Nawrocki et al. 2016, Hofstra et al. 1999). Studies on dioecious hydrilla tubers by Netherland (1999) indicated that this biotype likely has similar tuber dormancy periods of several years when compared with monoecious hydrilla. Hydrilla was abundant in Lake Istokpoga approximately 3 yr before the current tuber sampling; therefore, tubers should still be present and viable in the lake sediments based on tuber longevity studies. However, the lack of hydrilla coverage, coupled with the lack tuber presence, may be an indication that there are little to no vegetative propagules left in Lake Istokpoga to facilitate hydrilla regrowth.

We do not have an explanation for why hydrilla and other SAVs appears to have vacated Lake Istokpoga. The evidence provided in these sediment studies suggest that legacy herbicides in the sediments are not the reason, and continued research will be needed to explain the hydrilla disappearance. However, this is not an isolated instance in Florida because hydrilla has disappeared from other Florida lakes in a similar manner without an explainable reason. For example, hydrilla appeared in Lake Weohyakapka (Polk County, FL) around 1992 (FWC 2017) and, by 1995, covered more than 2,428 ha (6,000 ac) of the lake (surface area, approximately 3,035 ha [7,500 ac]). Hydrilla dominated Lake

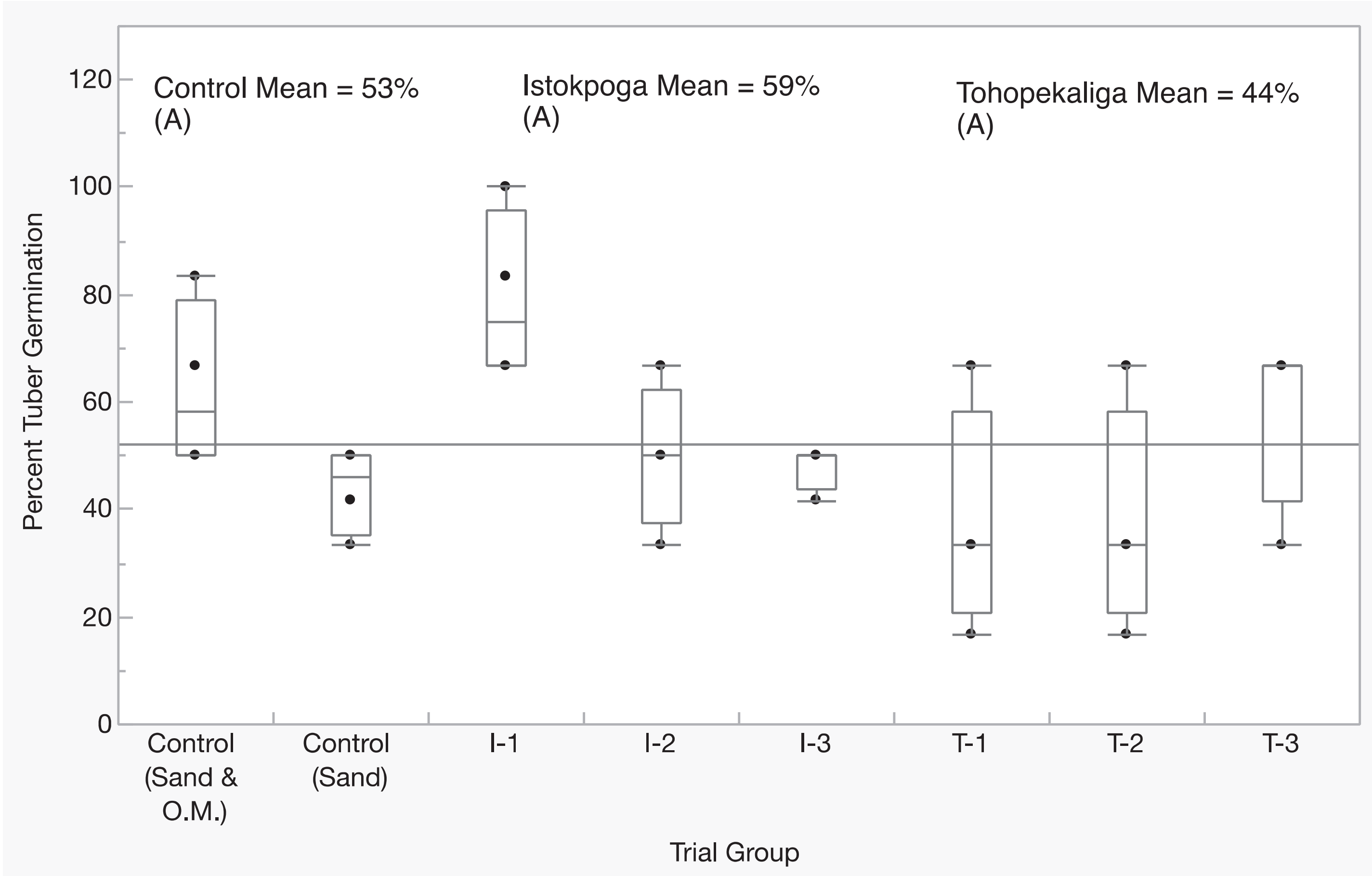

Figure 4. Box plot showing the percentage of hydrilla tubers germinated by the individual treatment and station. The line in the middle of the box is the median, and the top and bottom edges of the box are the 25 and 75% of the data distribution. An analysis of variance was conducted using all data to determine treatment-group (controls, Lake Istokpoga, and Lake Tohopekaliga) effects, and a Tukey-Kramer test was used to check for significant differences. Treatment groups with different letters are significantly different ($P < 0.05$).

Weohyakapka for the next decade, and then, after 2004, when three hurricanes passed over the lake, hydrilla disappeared and has not returned. Although hydrilla coverage was already low in Lake Istokpoga because of herbicide treatments when Hurricane Irma passed over the lake (September 10, 2017), the continued absence of hydrilla from the Lake Istokpoga may be related to hurricane activity, similar to Lake Weohyakapka. Additionally, many shallow lakes from around the world have switched from being macrophyte-dominated lakes to being algal-dominated lakes for various reasons, including changes in salinity, waterfowl grazing, water level changes, grass carp introductions, and others (Scheffer 1988). However, none of these explanations can be used to explain the situation in Lake Istokpoga.

Table 3. Concentrations of herbicides (ppb), except diquat, in sediments collected from nine locations in Lake Istokpoga on June 6, 2019, and analyzed/reported from Waters Agricultural Laboratories, Inc; samples from the nine locations were analyzed for diquat by North Coast Laboratories LTD, and all nine samples had the same results with actual aquatic plant treatment rates from herbicide labels also listed. U = undetected for each analyte reported, MDL = minimum detection limit in ppb (μg kg^{-1} of soil)

Method[1]	Analyte	Concentration	Label Rates	MDL
EPA 3540, ppb	Flumioxazin	U	100–400	20
LCMSMS, kg ha^{-1}	Glyphosate	U	6.0–9.2	50
LCMSMS, ppb	Imazamox	U	50–500	10
LCMSMS, kg ha^{-1}	Imazapyr	U	2.5–7.4	10
EPA 3540, ppb	Penoxsulam	U	10–150	10
EPA 8151A (modified), ppb	2,4-D	U	2,000–4,000	50
EPA 8151A (modified), ppb	Triclopyr	U	750–2,500	50
	Diquat	U	375	2,000

[1]The kg ha^{-1} listings are areal application rates.

Aquatic plant management has been, is, and will continue to be a major issue in Florida and around the world. Florida LAKEWATCH and CAIP have worked and collaborated with FWC for decades and understands that FWC's aquatic plant management program is sound and based on the best available science, much of which has been conducted by UF scientists. However, the difficulty comes with the diversity of stakeholders using individual lake systems and that there is no one-size-fits-all management plan. For example, the Harris Chain of Lakes Restoration Council and local stake holders are currently communicating with the State Legislature and County Government to acquire more funding for herbicides to control hydrilla in lakes under their jurisdiction, whereas stakeholders from Lake Istokpoga are loudly requesting the stoppage of all herbicide use for Lake Istokpoga.

Making the management of aquatic plants even more complicated is the fact that these two stakeholder viewpoints are moving targets depending on what the aquatic plants in each system have to "say." For example, in the early 1990s, there was little or no SAV in the Harris Chain of Lakes, and the stakeholders/anglers were advocating for SAVs (primarily hydrilla) for fish habitat, which is opposite to the current consensus. Similarly, in the late 1990s, Lake Istokpoga was covered with more than 10,117 ha (25,000 ac) of hydrilla, and at that time, the stakeholders were advocating for aggressive herbicidal management and even the stocking of grass carp. Thus, heading in the direction of individual lake management plans that can be adjusted as plants come and go in a system with a long-term goal/target of maintaining some moderate level of vegetation seems a solid approach.

Finally, this article is a small section of a much larger effort to develop a habitat management plan for Lake Istokpoga in which stakeholders and management agencies are working together to develop a plan to best manage this system for the benefit of stakeholders and the resident fish and wildlife. Although this is a small section of a bigger plan, the collaboration between stakeholders and agency personnel, working together to identify an issue, locate areas that need to be examined, and carry out studies to address the issues, is a positive step in the successful development of the Lake Istokpoga Habitat Management Plan.

SOURCE OF MATERIALS

[1]Petite Ponar. Wildco®. 86475 Gene Lasserre Blvd, Yulee, FL 32097.

[2]JMP statistical software, IBM SPSS Statistics, 1 New Orchard Road, Armonk, NY 10504-1722.

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