Aquatics

SUMMER 2022

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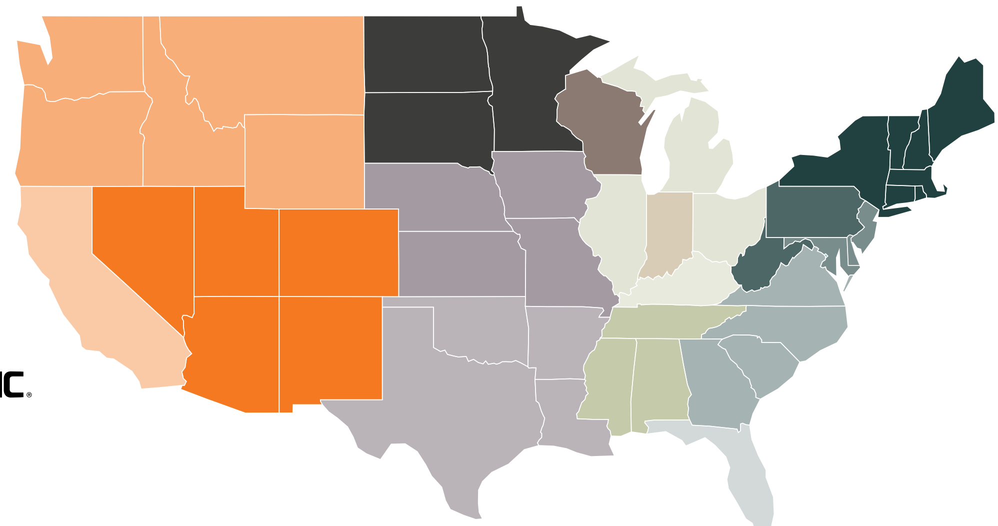

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This glossy ibis (*Plegadis falcinellus*) is in search of a tasty meal among the aquatic vegetation along the Lake Apopka Wildlife Drive, Apopka, Florida. Photo submitted by Margie Sullivan. Margie has enjoyed learning about photography and nature since September 2016. On weekends during the pandemic, there were many new outdoor birding and nature adventures. She believes the opportunity to be outdoors and be in the present moment are priceless.

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In memoriam: Vernon V. Vandiver, Jr.

February 1944-May 2022

I'm sad to report that Vernon Vandiver passed away on May 26, 2022. He went peacefully into that good night and services will be announced in the future. He is survived by his wife Fran Vandiver. Vernon was a wonderful man and a big part of the aquatic weed world, so I wanted to share this information with his FAPMS and APMS family.

Dr. Vernon V. Vandiver, Jr. was an Associate Professor Emeritus at the University of Florida and he was based at the Fort Lauderdale Research and Education Center in Davie until his retirement in 2002. He was a quintessential southern gentleman who never met a stranger and always had a kind word for anyone he encountered. Vernon was a great contributor to the field of aquatic plant management; he was a Charter Member of FAPMS, as well as becoming an FAPMS Honorary Lifetime Member in 2006, receiving the 2009 FAPMS President's Award, and serving as FAPMS President in 2011. He received the APMS Max McCowen Friendship Award in 2012 and became an APMS Honorary Member in 2018. In addition to his scientific pursuits, Vernon was well-known for his Extension efforts – most notably, for creating the UF/IFAS Aquatic Weed Control Short Course. In addition to his efforts to advance the field of aquatic plant research, Vernon served his country and was a Colonel in the United States Air Force.

I first met Vernon when I started working for Dr. Dave Sutton at the Fort Lauderdale REC in 1996. Dave and

Vernon shared a lab and I remember that nearly all of the bench space in the lab was populated with Short Course materials. Vernon was always kind and good-natured and made me feel welcome. Jay Ferrell stated that Vernon was one of the most genuine individuals he had ever met and agreed that he was a true southern gentleman. Ken Langeland mentioned that Vernon taught him to drive an airboat and Jim Cuda agreed that Vernon was a really good guy. Joan Dusky wrote, "Vernon was a gem. I know that he took me under his wing when I first came to Belle Glade and taught me a lot".

He will be missed by all who knew him.

Vernon's biography on APMS: https://apms.org/vernon-vandiver/

Press release about the 2002 UF/IFAS Aquatic Weed Control Short Course (Vernon started the Short Course in 1976): https://blogs.ifas.ufl.edu/news/2002/05/17/annual-aquatic-weed-control-short-course-at-ufs-fort-lauderdale-research-and-education-center-may-19-24/

Submitted by Lyn Gettys

Lake Trophic State and Eutrophication

Mark V. Hoyer and Daniel E. Canfield Jr.
Florida LAKEWATCH, School of Forest, Fisheries and Geomatics Sciences, UF/IFAS

Preface

This manuscript was initiated by many questions directed toward Florida LAKEWATCH (volunteer water quality monitoring program) staff regarding the definition and use of the terms "lake trophic state" and "eutrophication." We hope this Information Circular will address these questions in clear, understandable detail.

LAKEWATCH staff demonstrating how to measure chlorophyll concentrations that are used to estimate trophic state of lakes (Credits: Mark Hoyer).

Introduction

Most limnologists consider François-Alphonse Forel (Figure 1, February 2, 1841 – August 7, 1912), a Swiss physician and scientist who pioneered the study of lakes, to be the founder and father of limnology. Simply stated, limnology is the study of inland freshwaters. Not so simply, limnology in the 21st century incorporates many scientific, sociological, and political disciplines that impact inland waters including, but not limited to, geology, hydrology, chemistry, biology, physics, human dimensions, and others. As technology advances, the disciplines used in limnology continue to expand. For example, geomatic sciences are now used by limnologists incorporating satellite/drone imagery to monitor and understand water clarity and algal blooms in lake systems.

Trophic State Concept

While limnology continues to evolve, lake trophic status and eutrophication are core concepts that underlie or are related to most limnological investigations and aquatic system management. Einar Naumann (Figure 2), a Swedish limnologist, first developed what is now thought of as the trophic state concept (Naumann 1919, Naumann 1929), a lake classification system based on a lakes productivity, which is primarily limited by nutrients that are delivered to the lakes from the lake's watershed. Naumann's concept of trophic state can be summarized by the following four statements (Carlson and Simpson 1996):

- The amount of algae (production) in a lake is determined by several factors, primarily by the concentration of phosphorus and nitrogen.
- Regional variations in algal production correlate with the geological structure of the watershed with lakes in agricultural, calcareous regions being greener than lakes in forested, granitic watersheds.
- The amount of production in a lake affects lake biology as a whole.
- There are certain evolutionary (ontological) connections between lakes of the various types; lakes become more productive as they age.

Understanding the significance of

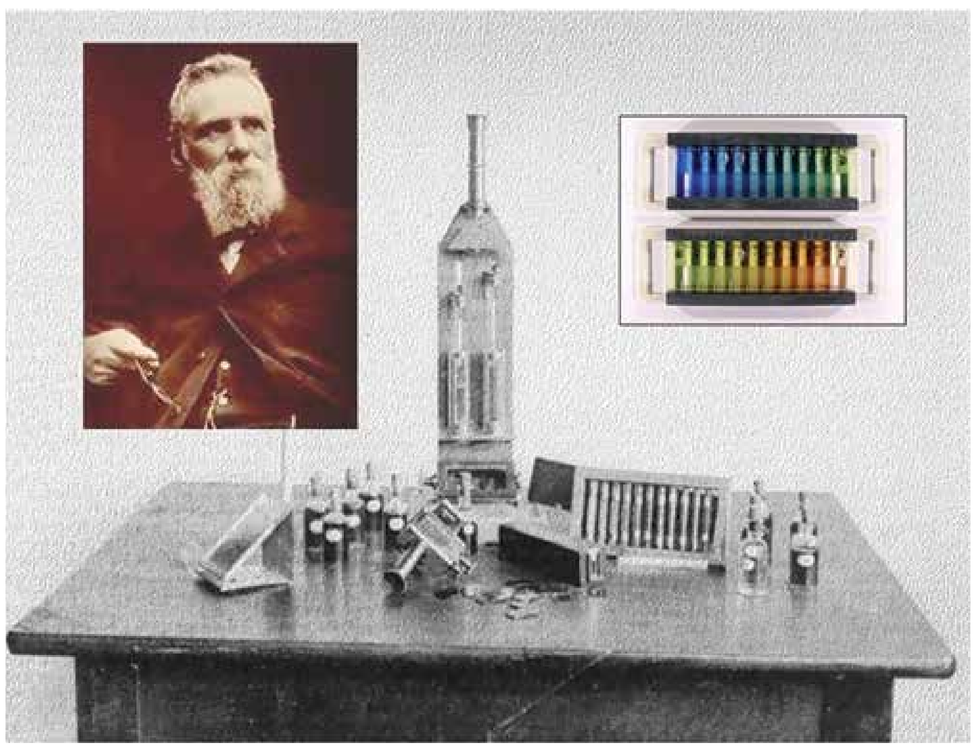

Figure 1. Portrait: François-Alphonse Forel, the initiator of the colour comparator scale. On his laboratory table are all the ingredients needed to use his new Forel scale (ca. 1905). Marcel R. Wernand (https://www.researchgate.net/figure/Portrait-Francois-Alphonse-Forel-the-initiator-of-the-colour-comparator-scale-On-his_fig1_254886155).

Figure 2. Photograph of Einar Naumann (https://en.wikipedia.org/wiki/Einar_Naumann).

these four propositions is fundamental to understanding how the trophic state concept is or should be applied in the 21st century. So, let's delve into each proposition:

Proposition 1 - The amount of algae (production) in a lake is determined by several factors, but primarily by the concentration of nitrogen and phosphorus.

Naumann emphasized that the trophic classification of a water body was based on the production of phytoplankton (defined as algal biomass). In contemporary times, chlorophyll has been used as a surrogate for algal biomass and algal production because it is highly correlated with algal biomass. Naumann also developed the common trophic state terminology based on quantitative production of phytoplankton that is still used today. Oligotrophic lakes are those with low nutrients and algal production and eutrophic lakes have high nutrients and high algal production. Carlson and Simpson (1996) describe how others have since added additional classification terms commonly used today; mesotrophic (production between oligotrophic and eutrophic) and hypereutrophic (production above eutrophic). While Naumann's primary classification system was based on algal/plant production he understood factors other than nutrients (temperature, light, and chemical factors such as calcium, humic content, iron, pH, oxygen, and carbon dioxide) could also impact algal production, thus he added additional classification terminology (lake types) to account for these factors. These extra classifications have since fallen into disuse, but limnologists still understand that environmental factors other than nutrients can limit algal production in some lakes.

Proposition 2 - Regional variations in algal production correlate with the geological structure of the watershed; lakes in agricultural, calcareous regions were greener than lakes in forested, granitic watersheds.

Naumann recognized that agriculture existed in areas where there were abundant nutrients available in the soil and that forested areas remained in rockey regions where nurients were not very available in the thin soils. Recognition of the importance of a region's geological structure in determining algal production stimulated many studies in the United States during the rest of the 20th century. These works ultimately lead to the establishment of Ecoregions that the U.S. Environmental Protection Agency (USEPA) used to establish regional water chemistry expectations.

Here in Florida, the first statewide study to specifically assess the chemical and trophic state characteristics of Florida lakes in relation to regional geology was conducted in 1979 and 1981 (Canfield 1981). This study confirmed that there were regional patterns due to geological structure, but Florida's geology was so complex that multiple regions would be needed for establishing in-lake nutrient concentrations for lake protection and management.

USEPA and many Florida scientists agreed that USEPA's level III Ecoregions for the United States were too broad to encompass the diversity of Florida lakes and that subregions were needed for water quality management purposes. Consequently, a collaborative project between the USEPA, the Florida Department of Environmental Protection (FDEP), and the University of Florida's LAKEWATCH program was initiated in the 1990s, resulting in the establishment of 47 Florida Lake Regions (Figure 3).

Lakes within a specific region were grouped together because there were

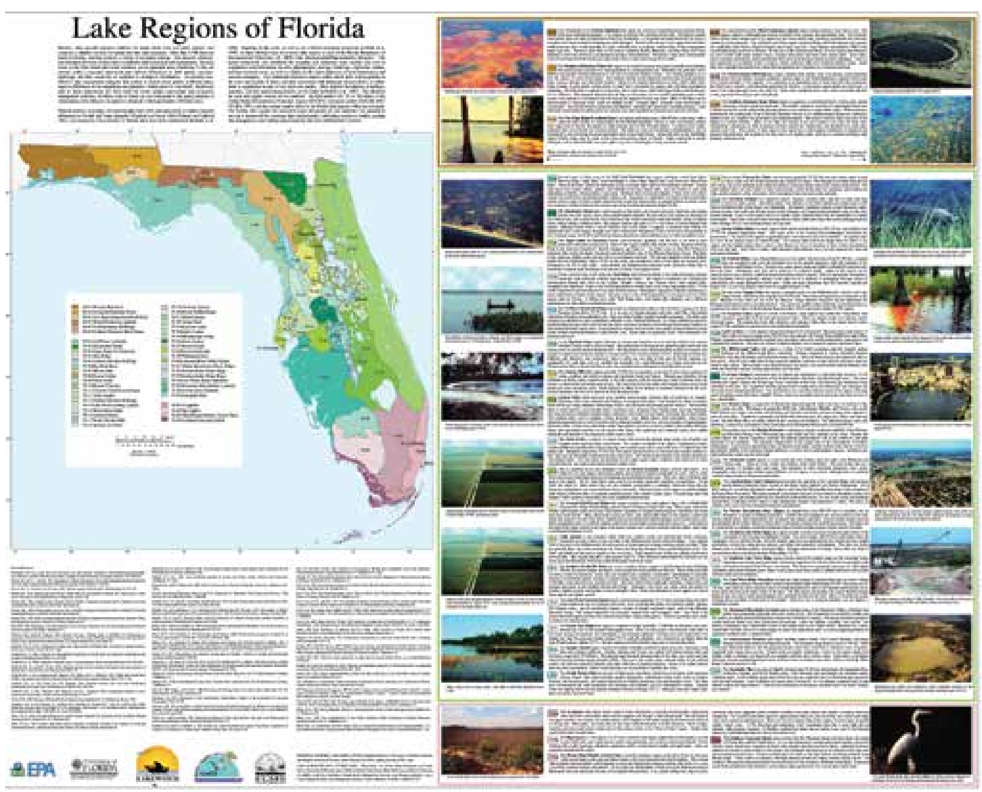

Figure 3. Lake Regions of Florida (https://floridadep.gov/sites/default/files/fl_lkreg_front.pdf).

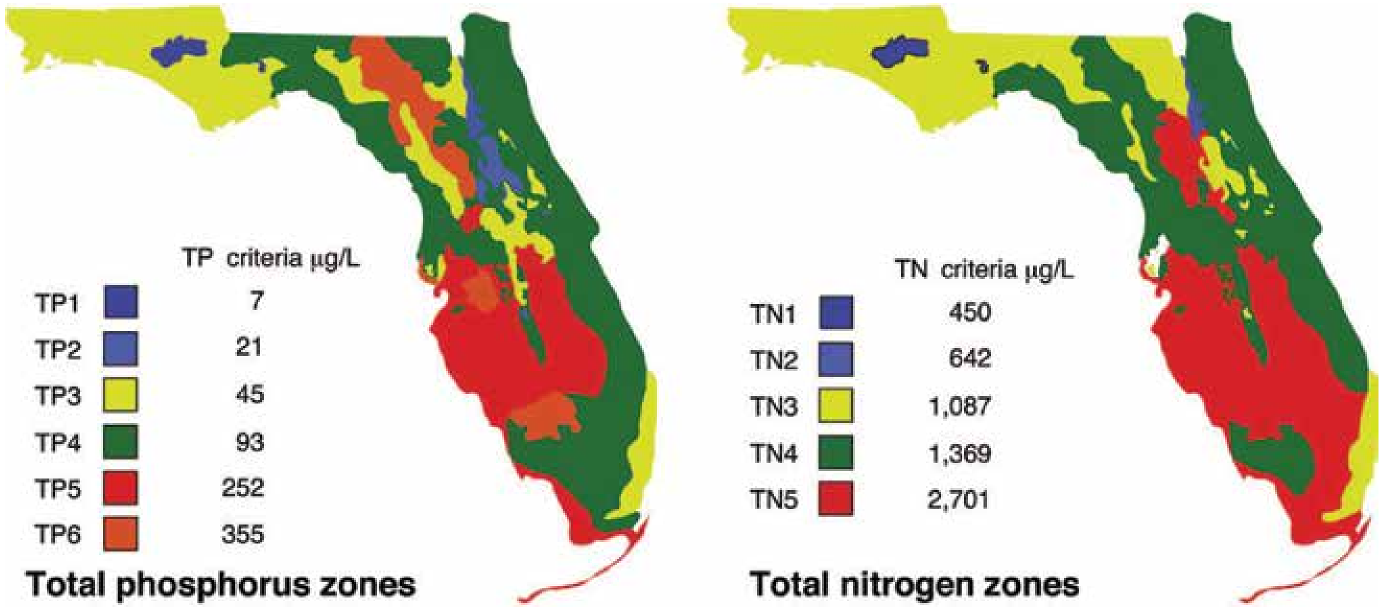

Figure 4.Maps showing the phosphorus and nitrogen zones and the proposed numeric criteria for TP and TN (Bachmann et al. 2012b).

similarities in the types and quality of lakes and their associations with landscape characteristics. The boundaries between the regions also generally followed those on soil maps. Thus, the different regions represented a manifestation of the differences in geology, soils, and hydrology from one part of the state to another, resulting in a patchwork appearance when the lake regions were represented on a map.

In the 21st century USEPA was establishing Numeric Nutrient Criteria (NNC) for Florida lakes. They defined NNC as a tool for protecting and restoring a waterbody's designated uses related to nitrogen and phosphorus pollution. USEPA decided not to use the Florida Lake Regions directly in their approach because of the high number of regions and the limited data for some regions. This led to a study of the factors determining the distributions of total phosphorus, total nitrogen, and chlorophyll a in Florida lakes (Bachmann et al. 2012a). Knowing the lake region where a lake was located still was the best predictor of its trophic state, but statistically different nutrient zones for the primary nutrients of concern (six phosphorus zones and five nitrogen zones) were established to reduce the number of regions that had to be considered as regulations were developed (Figure 4). This added to the development of Florida's NNC for lakes (Bachmann et al. 2012b).

Figure 4 shows the 6 nutrient zones for TP and the 5 nutrient zones for TN. Each color zone represents areas where lakes have similar nutrient concentrations and the listed concentrations represent the value where 95% of the lakes in the region have lower nutrient concentrations. While mean values for each nutrient zone are statistically different from each other, the range of values demonstrate the diversity of nutrient concentrations in Florida lakes, even within individual nutrient zones.

These nutrient zones are now incorporated in Chaper:62-302 (Surface Water Quality Standards) of the Florida Administrative Code & Florida Administrative Register Rule. Reference to the nutrient zones is specifically found in 62-302.200(19) where they are used to define what natural background conditions, which is the condition of waters in the absence of man-induced alterations.

Proposition 3 - The amount of production in a lake affects the lake biology as a whole.

One of the most noticeable impacts of the amount of algal production on lakes was the influence on the quantity of aquatic organisms. Soon after Naumann's work, limnological surveys clearly showed numerous lakes with additions of domestic drainage over and above the normal geologic influences showed marked biological changes. Lakes with additions of nutrients by humans (cultural eutrophication) led to increases in the biomass of fish. In Florida, research has also shown similar positive relations between the amount of chlorophyll (estimate of algal abundance) and zooplankton abundance, fish abundance, aquatic bird abundance and even the abundance of top predators like alligators. Thus, as the bottom of the food chain increases (plant biomass), food becomes more available for all levels of aquatic organisms and abundances increase.

While the total abundance of organisms increases with trophic state, species composition also changes. In the northern regions, when nutrient inputs became too great in thermally stratified waterbodies, their bottom water (hypolimnion) lost oxygen and there was the elimination of "desirable" cold-water fish (e.g., trout and salmon). There was also a decline in the percentage of "desirable" cold-water fish" within a water body due to an increase in "rough" or "course" fish (carp and shad) numbers and biomass.

Florida waters, however, do not show the same changes in fish populations often described for northern lakes. Florida waters do not have cold hypolimnia (bottom waters), and do not support cold-water fish species. Species richness of fish (total number of fish species in a lake) in Florida is also directly related to the waterbody's surface area and not trophic state. Additionally, the absolute biomass of Florida's premier sportfish the largemouth bass (*Micropterus salmoides*) shows increases with trophic state, but their percentage of the total biomass becomes less abundant at higher trophic states. On average the percentages of large¡mouth bass by weight in oligotrophic, mesotrophic, eutrophic, and hypereutrophic lakes were 20, 17, 16, and 4%, respectively, of the total biomass. Smaller centrarchids (i.e., bluegill Lepomis macrochirus and redear sunfish *Lepomis auritus*), likewise showed higher total biomass in lakes with higher trophic state but the centrarchids represented a lower percentage of total fish biomass in lakes of higher trophic states. With these changes come increases in bottom and filter feeding fish like gizzard shad (*Dorasoma cepedianum*) and threadfin shad (*D. petenense*).

Another transition that can happen to shallow waterbodies as the water becomes more productive is a change from a clear-water macrophyte (aquatic plants) dominated water to an algal dominated system (Brönmark and Weisner 1992). Naumann's original idea was to classify the trophic status of lakes based on plant production (biomass). He focused on phytoplankton production for the practical reason that his study lakes were large, deep, and only had a fringe of aquatic macrophytes that were confined to small littoral areas (nearshore areas that have enough sunlight penetrating to the sediment to support aquatic plant growth). As regional limnological studies examined shallower lakes, the presence of large amount of macrophytes made limnologist realize these plants play an important role in providing fish habitat and overall lake-wide production. Visual observations clearly indicated that the presence of aquatic macrophytes were indicative of great levels of production, but measures of nutrients, chlorophyll and Secchi disk transparency suggested the macrophyte-dominated water bodies were not productive.

This causes additional difficulties when classifying the trophic state of lakes with abundant aquatic macrophytes, especially when using open water measures of water chemistry (Carlson and Simpson 1996). Open water measures of chemistry in lakes with abundant aquatic plants miss the plant production associated with aquatic macrophytes and attached periphytic algae. Errors in trophic state assessment would be small where macrophytes were confined to small littoral areas, but large errors would result in macrophyte-dominated lakes. This problem was emphasized when aquatic weed control efforts removed large amounts of plants as described previously. When abundant aquatic plants in lakes are killed by management activities or by natural events, nutrients are released and plant production shifts from aquatic plants and associated periphyton (algae attached to plants) to open-water algae. Xiong and Hoyer (2019) suggested that there are three mechanisms that can contribute to increases in nutrient concentrations and thus chlorophyll concentrations of a lake when abundant aquatic plants (> 30% area covered with aquatic macrophytes; Canfield et al. 1983) decrease in a lake either naturally or through management. First, nutrients within the plant and attached algae (periphyton) are released, making it available to open-water algae. Secondly, when macrophytes are removed wave action increases, potentially increasing resuspension of sediment-associated nutrients to the water column. Finally, particles like phytoplankton containing nutrients are not allowed to settle without calm water, keeping them in the surface water where there is sufficient light for growth (photic zone).

Lake Weohyakapapka also known as Lake Walk-in-Water is a good Florida example of a long-term shift in chlorophyll values based on a large change in aquatic macrophyte abundance. Walk-in-Water is a large shallow lake in Polk County, Florida with a surface area of 3050 ha and a mean depth of 1.25 m. From 1990 to 2004, Walk-in-Water was dominated by the non-native submersed aquatic plant hydrilla (*Hydrilla verticillata*). During that time, hydrilla coverage averaged 640 ha with a range from 24 ha to 2600 ha. In 2004 hurricanes Charlie, Francis and Jeanne traveled almost directly over Lake Walk-in-Water. After the storms ripped up all submersed aquatic vegetation, releasing nutrients, and allowing continued wind resuspension, algae populations dominated plant production from 2005 to 2019. Chlorophyll levels during the pre- and post-hurricane years averaged 10 µg/L and 23 µg/L, respectively (Figure 5).

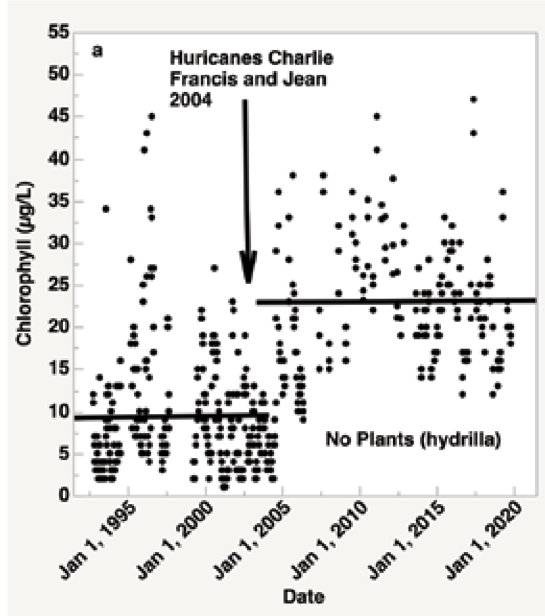

Figure 5. Plot of chlorophyll concentrations versus date from Lake Walk-in-Water. Horizontal lines indicate average chlorophyll concentrations before and after hurricanes Charlie, Francis and Jeanne crossed central Florida in 2004.

Proposition 4 - There are certain evolutionary connections between lakes of the various types; lakes become more productive as they age.

Naumann's trophic state concept began with the watershed. Nutrients and other chemicals from the watershed, together with factors such as temperature and light, were seen as factors influencing the abundance of algae in a lake. It was also recognized that the watershed delivered sediments and other biological material produced within the watershed to the lake. These materials, over geological time, would shallow a lake providing less dilution capacity for incoming nutrients. The reduction in dilution capacity would then lead to increased nutrient concentrations and increased in-lake biological production; hence lakes would become more productive as they aged.

It is to Naumann's credit that he also insisted that in-lake production would affect the system's biological structure, and thus the ontogeny of the lake itself. However, many limnologists began to consider the evolution of lakes as a unidirectional process. They also accepted the notion that the addition of nutrients by human activities (cultural eutrophication), which enhances in-lake algal production, contributed directly to the aging of lakes by delivering organic sediments to deeper waters.

Understanding the ontogeny of lakes, however, becomes more complicated once exotic aquatic macrophytes began to dominate a shallow water's biological production, especially in Florida's shallow lakes. Increases in aquatic vegetation results in a rapid accumulation of organic matter on the bottom of water bodies in a relatively short period of time, especially for exotic aquatic plants like water hyacinth (*Echhornia crassipes*) or torpedo grass (*Panicum repens*). Expansive monocultures of native emergent vegetation, such as pickerelweed (*Pontederia cordata*) and cattails (*Typha spp.*) also produce tremendous amounts of leaf litter that allows for the expansion of the littoral zone, often within an individual's lifetime.

The extensive accumulation of organic matter on the bottom of water bodies can lead to expensive muck removal programs (Figure 6, Hoyer et al. 2008). In Florida, the stabilization of water levels with dikes and other water control structures have also eliminated the natural self-cleaning processes that minimized muck accumulation prior to settlement. High water levels and wind activity would permit resuspended fine-grain organic particles to be swept out of the basin and deposited downstream. Organic matter trapped in stem and root structures of emergent and floating-leaved plants such as spatterdock (*Nuphar luteum*) provided another mechanism for organic matter removal by creating tussocks (floating plant islands with an organic base).

Figure 6. Muck removal and in-lake disposal creating islands of muck at Lake Tohopekaliga in 2003 (Credits: Mark Hoyer).

Tussocks, occur globally in many wetland and aquatic ecosystems, and are also formed when anaerobic gasses accumulate on the bottom, causing mats to break loose and float to the surface. Formation of tussocks results in hydropattern changes that can significantly alter the structure and function of pre-existing biological communities and influence ontological development. Prior to the building of water control structures in Florida, high water and wind could deposit the floating islands outside the normal water bodies basin (Hoyer et al. 2008), Floating island and sediment deposition onto normally dry floodplain when water levels receeded also resulted in organic sediments drying and oxidizing. This mechanism would efficiently remove large amounts of muck, leaving behind sandy shorelines in many Florida lakes, thus reversing the ontological process.

Another feature of Florida lakes that can reset the ontological clock is extreme low water during drought conditions. Organic sediments are again exposed to drying and oxidation (process where organic matter is broken down by oxygen using/stealing electrons that form those organic compounds) only this time on the lake bottom. When thoroughly dry, wind can remove the dry oxidized sediments from the basin. Additionally, in some lakes sediments can catch on fire from lighting strikes among other causes, creating large muck fires. All of these mechanisms functioned to reduce the accumulation of organic matter and create a diverse, dynamic, aquatic plant community in the littoral zone (Hoyer et al. 2008).

Trophic state classification systems

It is important to clarify distinctions between the terms trophic status and eutrophication, which are often used interchangeably by both professionals and lay persons. Defining a lake's trophic state is a static exercise, placing a lake somewhere along Naumann's gradient of lake production from low production (oligotrophic) to high production (eutrophic). Eutrophication on the other hand, is the movement from a lower trophic state to a higher trophic state. There is a natural long-term eutrophication process due to continued accumulation of particulate organic matter (Wetzel 1975) and an anthropogenic accelerated eutrophication due to increased additions of nutrients to aquatic systems (Smith et al. 1999). Additionally, oligotrophication is the reduction of nutrient loading to systems causing a decrease in trophic state, which can also be natural or cultural (Anderson et al. 2005).

There are many different published lake trophic state classifications systems (Carlson and Simpson 1996 and scientists continue to rethink these indices (Farnez et al. 2019). Being true to Naumann's original intent would mean basing indexes solely on some measures of plant abundance (production). However, scientists have developed multiple trophic state indices including those based on a chain of empirical models (Hoyer and Canfield 2022), which assume phosphorus limitation, to give discrete values for predicted chlorophyll concentrations using other variables like total phosphorus, and water clarity that are correlated with chlorophyll (Carlson 1977).

Staying with Naumann's intent and using only chlorophyll concentration, Florida LAKEWATCH follows the trophic state classification system published by Forsberg and Ryding (1982). Others can use any of the published trophic state indexes because they all divide the trophic state continuum (oligotrophic, low plant productivity to eutrophic, high plant productivity) into different discrete units. However, we recommend using only the chlorophyll aspects of any index and cite specifically which index you are using so everyone can compare apples with apples. We also advise that the abundance of aquatic macrophytes be considered when classifying the trophic status of aquatic systems.

Conclusions

From the beginning Naumann (Naumann 1919, Naumann 1929) and others understood that most lakes follow patterns that could be used for classification of trophic status and/or management of eutrophication. However, then as now limnologists understand that many lakes are individuals having characteristics that make them unique, to some extent. Certainly, algal populations are nutrient limited in many of the world's lakes and control of phosphorus inputs can be a successful strategy for curbing lake eutrophication. Unfortunately for managers of aquatic systems, phosphorus while being the major limiting nutrient is not always the limiting environmental factor. Unless phosphorus can be made both the limiting nutrient and the limiting environmental factor expensive lake management programs can be implemented without great success.

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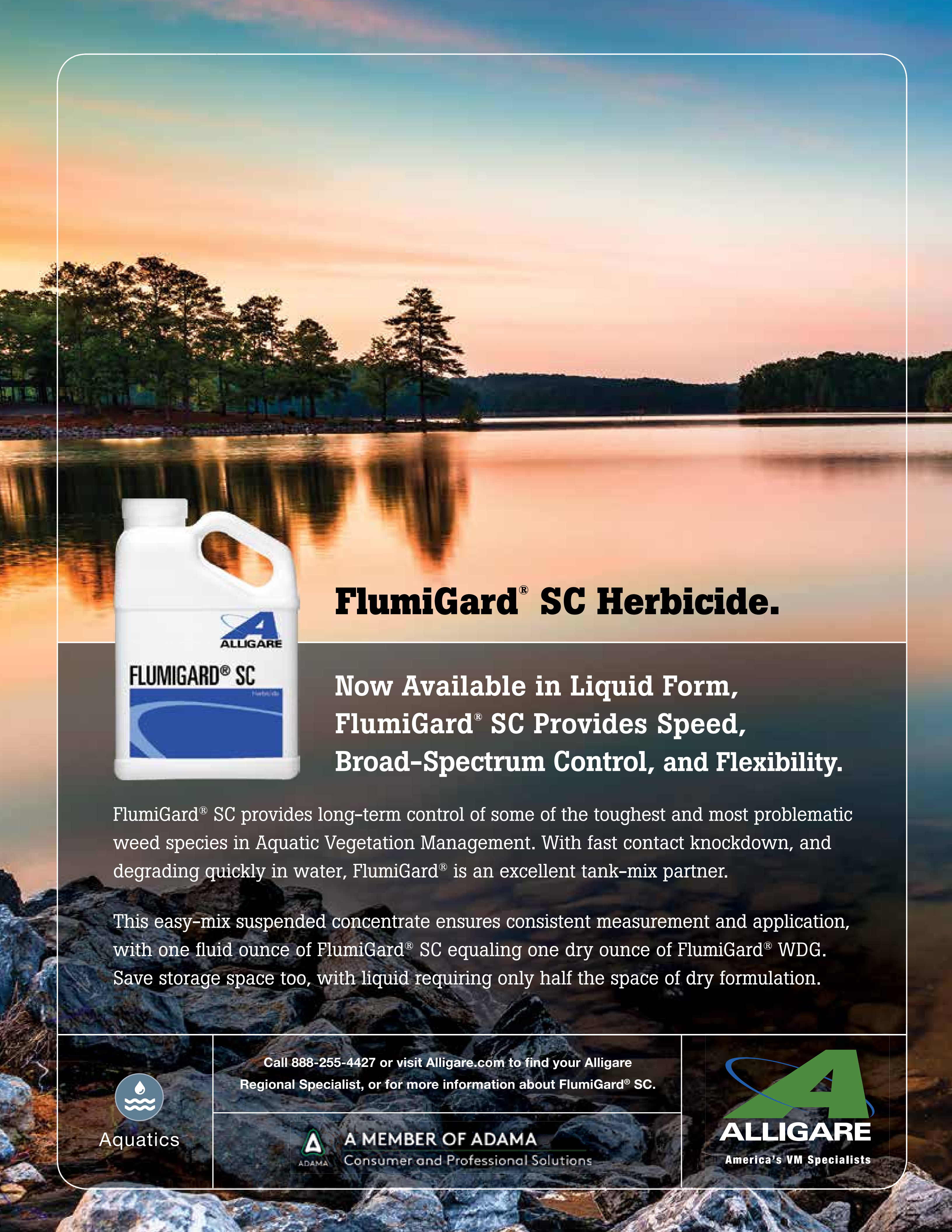
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Natural herbicides for aquatic weed control – *is that an option?*

Lyn A Gettys, Kyle L Thayer, Joseph W Sigmon and Jennifer H Bishop

Background

Invasive aquatic weeds can interfere with natural resources in many ways. Overgrowth of introduced species can have negative impacts on our use of waters by disrupting flow in stormwater canals, hindering navigation, tangling fishing lines, boat propellers and watercraft, trapping swimmers, and ruining aesthetics. Aquatic weeds can also affect aquatic organisms like fish and turtles by outcompeting native plants to create monocultures (large populations of a single species), lowering dissolved oxygen levels, limiting light penetration through the water column, and reducing the plant diversity needed to support aquatic life.

Figure 1. Kyle Thayer and Joey Sigmon applying natural herbicides to waterhyacinth and broadleaf sagittaria.

Aquatic vegetation management is a multi-million dollar industry in Florida. The Florida Fish and Wildlife Conservation Commission (FWC) oversees and tracks all aquatic herbicide applications in the state and produces an annual report outlining target plants, areas treated and funds spent throughout Florida, along with a National Pollution Discharge Elimination System (NPDES) report detailing the volume of herbicides applied to state waters. The FWC reports that annual spending for aquatic weed control in Florida ranges from $14 to $17 million dollars per year, with around $4 million of that used for floating weed (waterhyacinth and waterlettuce) control.

In 2019 the FWC enacted a "pause" in aquatic vegetation management operations to allow public comments on statewide weed control efforts. One of the goals developed from that pause was to seek alternatives to the synthetic herbicides that have been used for decades. In this paper, we describe studies that we conducted to evaluate efficacy and selectivity of two "natural" products—acetic acid and d-limonene—on common aquatic plants in Florida. We also compared the cost of promising treatments to the cost of using synthetic herbicides.

Why acetic acid and d-limonene?

Acids and oils are sometimes used as non-selective, contact foliar sprays for terrestrial weed control. Both types of products work by destroying cell membranes and disrupting the waxy cuticle on leaves, which can lead to cell leakage, foliage burn, and plant death. Household vinegar is a weak (3% solution) form of acetic acid. Stronger concentrations—sometimes referred to as "horticultural vinegar"—are used for weed control by homeowners and some organic systems. The Organic Materials Review Institute (OMRI) allows the use of acetic acid at concentrations of up to 8% in organic production, and the US Environmental Protection Agency (USEPA) considers acetic acid to be a "Minimum Risk Pesticide" that is exempt from FIFRA registration requirements when its concentration is 8% or less. Nonsynthetic (naturally derived) citric acid and d-limonene (orange oil) can be used as a crop management tool in OMRI-certified organic operations without restrictions, but d-limonene is also used as a degreaser, an adjuvant, and as an aroma enhancer for a variety of products.

Experiment details and setup

All of these experiments were conducted in 68L mesocosms (those rope-handle tubs you can find at big-box stores) in the research greenhouse at the University of Florida Ft. Lauderdale Research and Education Center in Davie, FL. We tested a total of six invasive species (to evaluate efficacy—how well the treatments controlled the target weeds) and six native species (to evaluate selectivity—how much damage these treatments caused to desirable plants). Plants were tested in pairs of one invasive species and one native species. Our invasive species were waterhyacinth (*Eichhornia crassipes*), waterlettuce (*Pistia stratiotes*), feathered mosquitofern (*Azolla pinnata*), common salvinia (*Salvinia molesta*), crested floatingheart

(*Nymphoides cristata*) and rotala (*Rotala rotundifolia*). Our native species were broadleaf sagittaria (*Sagittaria latifolia*), pickerelweed (*Pontederia cordata*), cattail (*Typha latifolia*), Gulf Coast spikerush (*Eleocharis cellulosa*), bulrush (*Schoenoplectus californicus*) and spatterdock (*Nuphar advena*). Native plants were grown in fertilized sand in 2L plastic pots without holes on greenhouse benches and received overhead irrigation twice per day, and invasive plants were grown out directly in the water-filled mesocosms.

Treatments

When invasive plant growth covered at least 80% of the water surface, we inserted a single potted native plant into each mesocosm and prepared the treatments. Our treatments were acetic acid at 5%, 7.5%, 10%, 15% and 20% (base material Green Gobbler 30% Vinegar Home and Garden from EcoClean Solutions in Copiague NY) ; d-limonene at 10%, 15%, 20% and 30% (base material 100% Pure Technical Grade D-Limonene, also from EcoClean Solutions); and all combinations of these treatments (for example, 5% acetic acid + 10% d-limonene, 5% acetic acid + 15% d-limonene and so on). We also included "synthetic standard" treatments of diquat at 0.5%, 1% and 2% (base material Tribune Herbicide from Syngenta Crop Protection LLC in Greensboro NC) and an untreated check of water only. All treatments included a 1% by volume non-ionic surfactant (Induce from Helena Agri-Enterprises LLC in Collierville TN) to aid with treatment mixing and penetration. We set up four replicates of each treatment in a completely randomized arrangement and applied 50mL of treatment solution to each mesocosm using a foliar spray-to-wet technique. We used portable shields to ensure that the treatments only reached the plants in the mesocosm being treated and did not drift onto the mesocosms adjacent to the one receiving an application.

Evaluations and comparisons

All plants were grown out for eight weeks after treatment, then scored for visual quality using a scale where 0 = dead; 5 = fair quality, acceptable, somewhat good form and color, little to no yellow or dead plant material; 10 = excellent quality, perfect condition, healthy and robust, excellent color and form. After visual scoring, we collected all live material of floating plants and all live aboveground shoots of emergent plants, placed these in paper bags and moved them to a forced-air oven maintained at 65°C for two weeks before weighing them. We then analyzed the average visual quality and dry weight values of natural and synthetic treatments to evaluate efficacy [whether treatments reduced invasive plant quality and weight by at least 80% compared to untreated (sprayed with water only) check plants] and selectivity [whether treatments reduced native plant quality and weight by no more than 50% compared to untreated check plants].

Cost analysis

After we completed the analyses outlined above, we calculated the cost of natural treatments that were effective and selective and compared those to the cost of synthetic treatments that produced similar results. Cost estimates were based on bulk purchase pricing of the three products in these trials as follows: Green Gobbler 30% Vinegar Home and Garden = $8.00 per gallon (275-gallon tote); 100% Pure Technical Grade D-Limonene = $31.82/gal (4 x 55-gallon drums); Tribune Herbicide = $35.50 per gallon (FWC's contract pricing in 2018). These costs are based on 2018/2019 pricing and were used throughout this three-year study for consistency, but it is extremely likely that all prices have increased since then.

Efficacy and selectivity results

As mentioned above, we tested plants in pairs of one invasive species and one native species, so these results are organized based on plants that were treated and evaluated together. Although a goal of these experiments was to compare the efficacy of natural products to the synthetic herbicide diquat, it quickly became clear that most natural treatments were much less effective than any diquat concentration. We realized that comparisons between natural treatments and untreated check plants would be more informative, so we removed the diquat treatments from datasets before continuing with our statistical analyses.

Invasive waterhyacinth and **native broadleaf sagittaria:** treated on November 12, 2019, harvested on January 7-9, 2020

Single-product treatments: The only single-product treatments that provided good control of waterhyacinth were the three diquat concentrations (0.5%, 1% and 2%), and all three concentrations completely eliminated waterhyacinth. Unfortunately, broadleaf sagittaria was killed by these treatments as well. Waterhyacinth weight was affected by single product natural treatments, but no treatment reduced weight by more than 50% or affected visual quality. Single natural products had no effect on broadleaf sagittaria dry weight or visual quality.

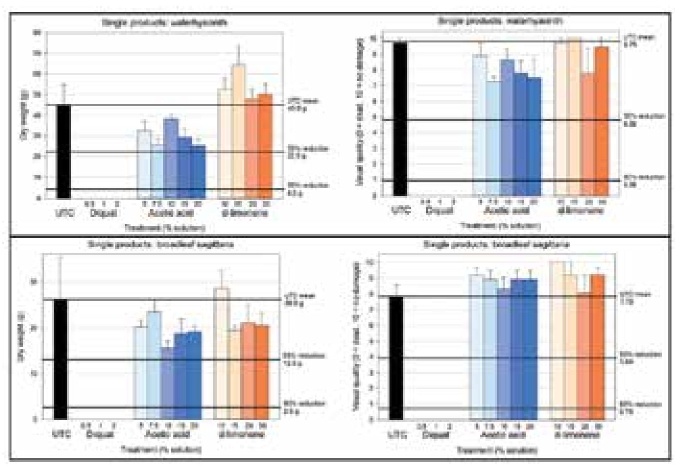

Figure 2. Dry weight and visual quality of waterhyacinth and broadleaf sagittaria treated with single natural products. Top rule in each graph = average of untreated check plants; middle and lower rules = 50% and 90% reduction from untreated check plants.

Acetic acid and d-limonene mixes: In contrast to single-product natural herbicide treatments, some combinations of acetic acid and d-limonene had good efficacy on waterhyacinth. The most promising combinations were 15% acetic acid plus 15%, 20% or 30% d-limonene and 20% acetic acid with any concentration of d-limonene; these treatments reduced dry weight by > 80% and visual quality by > 60% compared to untreated check plants. There was no difference among broadleaf sagittaria weights treated with mixes of acetic acid and d-limonene; visual quality of sagittaria differed among plants treated with mixes, but treated plants were not different from untreated check plants (all differences occurred among treatment combinations).

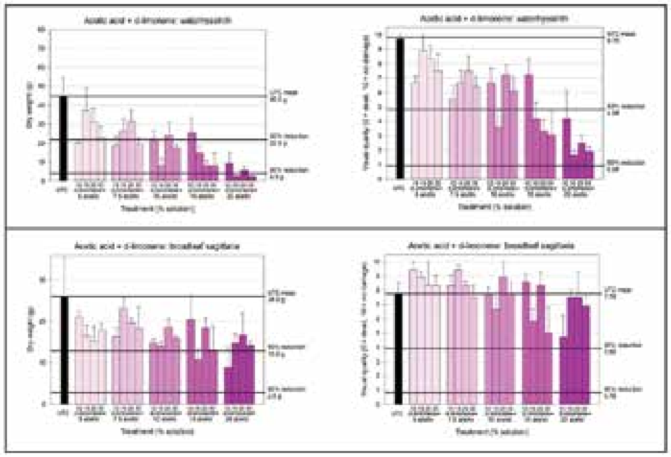

Figure 3. Dry weight and visual quality of waterhyacinth and broadleaf sagittaria treated with mixes of natural products. Top rule in each graph = average of untreated check plants; middle and lower rules = 50% and 90% reduction from untreated check plants.

Invasive waterlettuce and **native pickerelweed:** treated on January 15, 2020, harvested on March 11-13, 2020

Single-product treatments: As with waterhyacinth, all three diquat concentrations completely eliminated waterlettuce, but these treatments killed pickerelweed as well. Single product natural treatments affected waterlettuce weight and visual quality, which were reduced by more than 90% and more than 75%, respectively, after treatment with 20% or 30% d-limonene, but no other single-product treatments differed from untreated check plants. Pickerelweed dry weights were reduced by most single-product treatments compared to untreated check plants, but none reduced weight by more than around 60% and visual quality was unaffected.

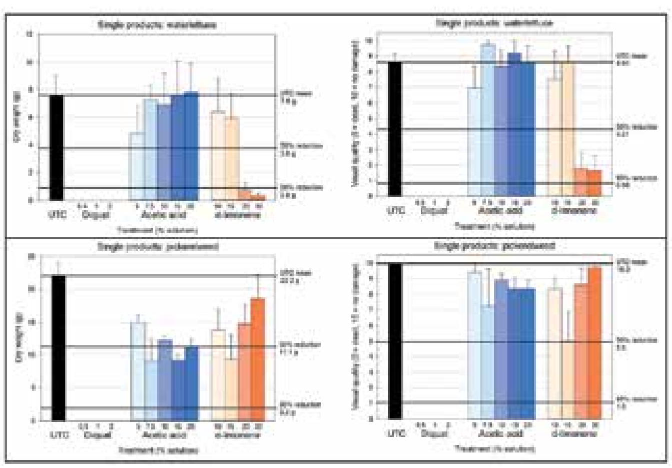

Figure 4. Dry weight and visual quality of waterlettuce and pickerelweed treated with single natural products. Top rule in each graph = average of untreated check plants; middle and lower rules = 50% and 90% reduction from untreated check plants.

Acetic acid and d-limonene mixes: Most combinations of acetic acid and d-limonene had good efficacy on waterlettuce weight and visual quality, which were reduced compared to untreated check plants. Only five of the 20 treatment mixes failed to reduce weight by at least 90% compared to untreated check plants, and only two mixes failed to reduce visual quality by at least 50%. Pickerelweed weight and quality were also affected by mixes of acetic acid and d-limonene; plants treated with any mix weighed less than untreated check plants and visual quality was reduced in 13 of the 20 treatments.

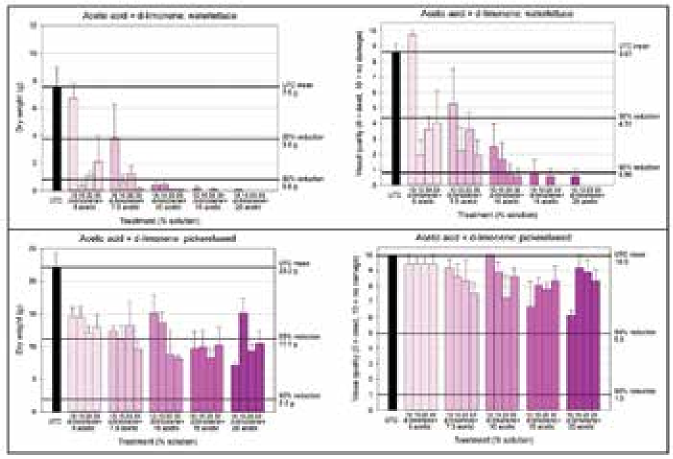

Figure 5. Dry weight and visual quality of waterlettuce and pickerelweed treated with mixes of natural products. Top rule in each graph = average of untreated check plants; middle and lower rules = 50% and 90% reduction from untreated check plants.

Invasive feathered mosquitofern and **native Gulf Coast spikerush:** treated on September 10, 2020, harvested on November 5-7, 2020

While collecting live plant material at the end of this experiment, we realized that visual quality alone might not accurately reflect treatment efficacy on feathered mosquitofern. For example, some mesocosms had very few live plants remaining, but the plants that were still alive were in excellent condition. To compensate for this, we also recorded percent coverage of this small floating species in each mesocosm to describe this observation. We then multiplied visual quality by percent coverage to calculate "VC", to better describe treatment effects on feathered mosquitofern.

Single products: As with waterhyacinth and waterlettuce, all three diquat concentrations completely eliminated feathered mosquitofern and Gulf Coast spikerush. Most single-product natural treatments provided good control of feathered mosquitofern, and the only single-product natural herbicide treatments that failed to reduce weight and VC by at least 90% were 5% and 7.5% acetic acid. Gulf Coast spikerush was less affected by these treatments than was feathered mosquitofern. Most single-product natural herbicide treatments reduced weight by around 50% and reductions in visual quality ranged from around 20% to 45%.

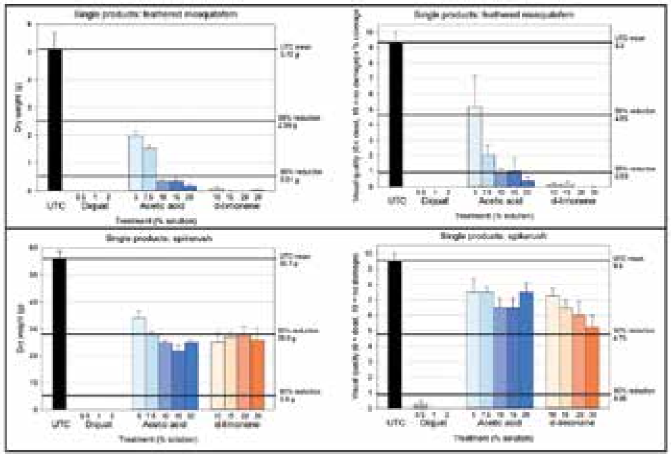

Figure 6. Dry weight and visual quality of feathered mosquitofern and spikerush treated with single natural products. Top rule in each graph = average of untreated check plants; middle and lower rules = 50% and 90% reduction from untreated check plants.

Acetic acid and d-limonene mixes: All combinations of acetic acid and d-limonene had good efficacy on feathered mosquitofern. Biomass and VC were reduced by greater than 90% compared to untreated check plants. Most treatments reduced biomass of Gulf Coast spikerush by between 50% and 75%, but only two combinations reduced visual quality by more than 50%.

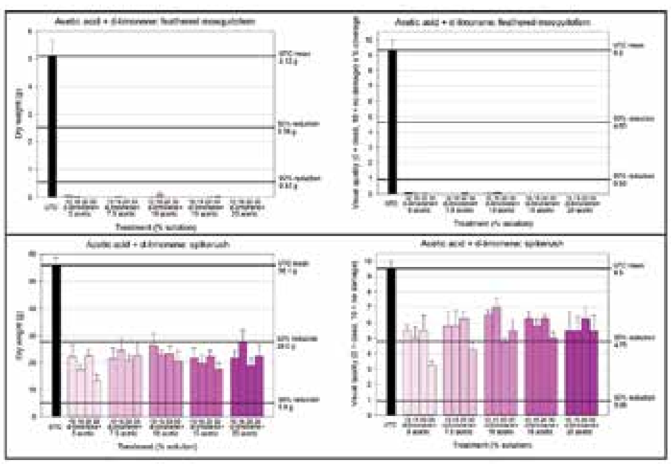

Figure 7. Dry weight and visual quality of feathered mosquitofern and spikerush treated with mixes of natural products. Top rule in each graph = average of untreated check plants; middle and lower rules = 50% and 90% reduction from untreated check plants.

Invasive common salvinia and **native cattail:** treated on January 28, 2021, harvested on March 25-27, 2021

As with feathered mosquitofern, we recorded percent coverage of common salvinia in each mesocosm and calculated VC to describe treatment effects on this small floating species.

Single products: As with waterhyacinth, waterlettuce and feathered mosquitofern, all three diquat concentrations completely eliminated common salvinia and cattail. In contrast to feathered mosquitofern, most single-product natural treatments failed to provide good control of common salvinia in respect to biomass and VC, and the only single-product natural treatments that reduced these measures by at least 90% were 20% and 30% d-limonene. Also, dry weight and VC of common salvinia treated with any concentration of acetic acid was equal to (or greater than) untreated plants. All single-product treatments reduced cattail weight by at least 50% compared to untreated plants. Cattail was much more sensitive to acetic acid and less sensitive to d-limonene than was common salvinia, and concentrations of acetic acid that were 7.5% or stronger reduced weight by at least 80%, whereas only the highest d-limonene concentration (30%) reduced weight by at least 90% compared to untreated check plants, although visual quality was less affected by all treatments.

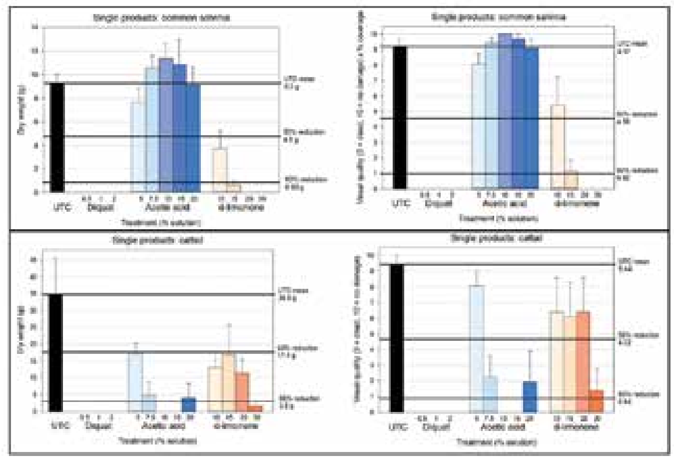

Figure 8. Dry weight and visual quality of common salvinia and cattail treated with single natural products. Top rule in each graph = average of untreated check plants; middle and lower rules = 50% and 90% reduction from untreated check plants.

Acetic acid and d-limonene mixes: Virtually all combinations of acetic acid and d-limonene had good efficacy on common salvinia. With the exception of plants treated with 5% acetic acid + 10% d-limonene, weight and VC were reduced by at least 85% compared to untreated common salvinia. Unfortunately, cattail weight was affected by treatments in a similar manner, although visual quality was less affected.

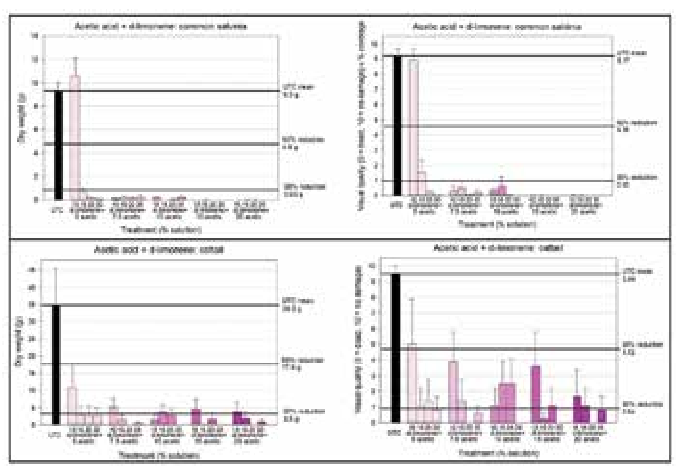

Figure 9. Dry weight and visual quality of common salvinia and cattail treated with mixes of natural products. Top rule in each graph = average of untreated check plants; middle and lower rules = 50% and 90% reduction from untreated check plants.

Invasive rotala and **native spatterdock:** treated on December 6, 2021, harvested on January 31, 2022

Single products: As with the previous species, rotala was completely killed by any concentration of diquat. In contrast, spatterdock survived treatment with diquat, although reductions in weight and quality compared to untreated check plants ranged from 20% to 60%. No single-product natural treatments reduced rotala weight and visual quality by more than 50%, and only two treatments—15% acetic acid and 30% d-limonene—reduced weight and quality of spatterdock by more than 50% compared to untreated check plants.

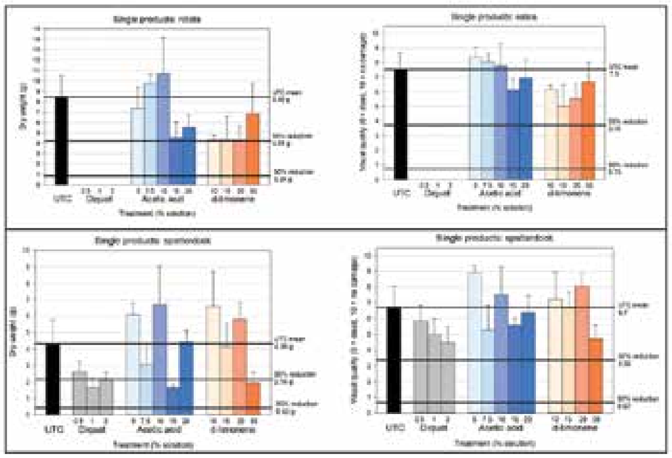

Figure 10. Dry weight and visual quality of rotala and spatterdock treated with single natural products. Top rule in each graph = average of untreated check plants; middle and lower rules = 50% and 90% reduction from untreated check plants.

Acetic acid and d-limonene mixes: All combinations of acetic acid and d-limonene reduced weight and visual quality of rotala by at least 50%; 13 of the 20 mixes reduced weight by around 90% or more and seven reduced visual quality by around 90% or more compared to untreated checks. Only one mix—20% acetic acid + 10% d-limonene—reduced spatterdock weight by more than 50% and no mixes reduced visual quality by more than 30% compared to untreated check plants.

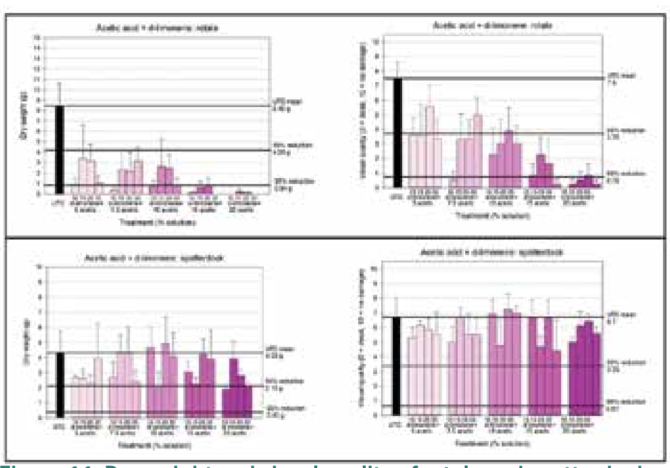

Figure 11. Dry weight and visual quality of rotala and spatterdock treated with mixes of natural products. Top rule in each graph = average of untreated check plants; middle and lower rules = 50% and 90% reduction from untreated check plants.

Invasive crested floatingheart and **native bulrush:** treated on March 28, 2022, harvested on May 23-24, 2022

Single products: As with the previous species, crested floatingheart was completely killed by any concentration of diquat, as was nearly all bulrush. No single-product natural treatments reduced weight or visual quality of either species by more than 50%, and in fact bulrush dry weights were much greater in plants treated with any concentration of d-limonene than in untreated check plants.

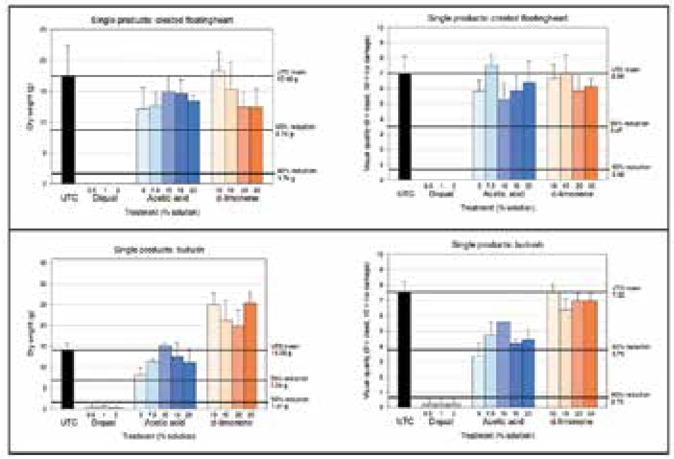

Figure 12. Dry weight and visual quality of crested floatingheart and bulrush treated with single natural products. Top rule in each graph = average of untreated check plants; middle and lower rules = 50% and 90% reduction from untreated check plants.

Acetic acid and d-limonene mixes: Only one combination (20% acetic acid + 20% d-limonene) reduced weight and visual quality of crested floatingheart by at least 50%, but biomass was only reduced by 34% compared to untreated check plants, which is unacceptable. No combinations reduced bulrush dry weight by more than 50% and only one combination reduced visual quality by more than 50%.

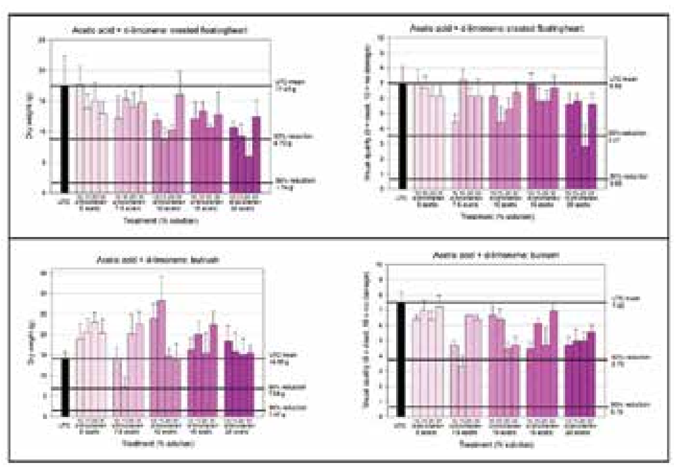

Figure 13. Dry weight and visual quality of crested floatingheart and bulrush treated with mixes of natural products. Top rule in each graph = average of untreated check plants; middle and lower rules = 50% and 90% reduction from untreated check plants.

Conclusions

Our goal was to identify natural products that had good efficacy (significant reductions in invasive plant biomass) and good selectivity (minimal or acceptable damage to native plants). We were able to do that with five of the six weed species we studied, with crested floatingheart being the exception. So is that it? Are we done? No, there's more to the story—we need to consider the cost of these natural treatments. Stay tuned and watch for the next issue of Aquatics to get the REST of the story!

Acknowledgements

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Limnology– **The Basics**

Frank M. Wilhelm

Our LakeLine editor invited me to write a readily accessible introduction to "limnology" for this issue of LakeLine that includes "everything" — basically to distill volumes of textbooks into an article — a formidable task. Reflecting on how to tackle this "small" task, I have chosen to focus on what I would consider most important to know as background if I were a member of the public attending a seminar or technical presentation regarding some aspect concerning my local lake. I will start with some basic definitions, then move from the formation of lakes to physical, chemical, and biological processes. Hopefully, you'll make it to the end, and emerge with an appreciation for the beauty and complexity that is the aquatic realm — something that has captivated me since chasing salamanders and tadpoles in creeks and quarry ponds during my childhood. I consider myself fortunate to have lakes and reservoirs as my "office" and to be able to work on them regularly. However, it comes with the burdensome insight that we are rapidly approaching a reckoning: an expanding human population that needs access to clean water and a finite quantity of such water available on earth. Thus, it is imperative that each of us becomes informed and takes appropriate actions to protect this life-giving resource. Thanks for joining me, let's get started.

Limnology – is the study of inland water; it includes some waters more saline than the ocean, ponds, streams, rivers, to lakes and reservoirs — large and small. Basically, if the aquatic system is inland or drains to the ocean, it is encompassed in limnology. So, what do limnologists study? There is a myriad of physical, chemical, and biological processes that occur in our lakes (I'll primarily focus on lakes here) that make them function. Considered as a whole, lakes are living ecosystems.

Nutrients – includes a wide variety of elements necessary to fuel life. In the case of freshwater, nitrogen (N) and phosphorus (P) are typically the nutrients in shortest supply — this is termed a limiting nutrient — and hence our overwhelming focus on them because adding just a little can have large effects (Schindler 1971). Realize that N and P are only two of a plethora of nutrients. For example, silica may limit the growth of diatoms (small algae) in some lakes seasonally.

Eutrophication – is the presence of excess nutrients that stimulate high plant biomass; it comes in two flavors — natural and cultural. The former is the typical process for all waterbodies as they evolve to solid land over geologic time periods. As soon as a lake is created, it's on a death march to solid land — stick around for 10,000-plus years and you'll see your favorite lake change. Cultural eutrophication is the acceleration of this process shortening it to tens of years so that ecosystem changes become noticeable during a human lifetime. It is the result of human activities that increase the rate of sediment and nutrient transport to our aquatic ecosystems.

Trophic state – is a classification system devised by limnologists based on the productivity (amount of plant growth) in a lake. While trophic state is a continuum (Figure 1), you will encounter the following terms — Oligotrophic (low nutrients, low algal biomass, high transparency); Eutrophic (high nutrients, high algal biomass, low transparency); and Mesotrophic (intermediate conditions). Trophic state can be assigned based on the concentration of nutrients in the water column, the amount of plant biomass, or the depth to which light penetrates (Carlson 1977; Carlson and Simpson 1996).

Secchi disk – is a 0.2-m diameter weighted disk with opposing white and black quadrants that limnologists use to

Trophic state boundaries

	Oligo-	Meso-	Eutrophic
Total Phosphorus	<6 µg/L	12-24	24-48
Chlorophyll a	<0.95 µg/L	2.6-7.3	7.3-20
Secchi Depth	>8 m	4-2	2-1

Figure 1. Trophic state boundaries from oligotrophy to eutrophy for total phosphorus, chlorophyll a, and Secchi depth based on Carlson 1977, and Carlson and Simpson 1996.

measure the depth to which light that plants use to photosynthesize penetrates into a lake. Because light needs to reflect off the disk for you to be able to see it, the actual depth to which useable light penetrates is approximately two times the Secchi depth. NALMS is the coordinator of the Secchi Dip-in program which encourages citizens to measure the Secchi depth on their lake during the month of July each year and enter the data into an online database. You can find more information here: https://www.nalms.org/ secchidipin/ and I encourage you to participate.

Algae – are small plants that are suspended in the water column and for which one usually requires a microscope to see them properly. When light is present, they photosynthesize turning light energy into chemical energy in the form of sugar. They form the basis of the food chain, similar to grass on land.

Macrophytes – are large plants that are easily seen with the naked eye, like lily pads and cattails. Similar to algae, they also photosynthesize, and are usually found around the margin of lakes which is called the "littoral zone." The littoral zone is defined by the depth to which macrophytes grow along the bottom of water bodies.

Zooplankton – are small animals that typically graze algae and other small bits and pieces in the water column. They in turn are food for larger organisms such as fish. It's interesting to note that even the most voracious fish predators such as pike or bass feed on small zooplankton when they first start life. Zooplankton density changes seasonally, with high densities in early to mid-summer, and low densities over winter.

Microinvertebrates – are easily seen denizens such as dragon-, May-, or Damselflies, or amphipods (scuds) or shrimp. Beware, some such as giant water bugs can deliver a memorable bite and regularly capture and consume small fish!

Catchment – is the land area from which water drains into a particular water body. It is identified from elevation maps or rectified photographs. Catchment size changes with scale of interest. For example, the catchment of Lake Ontario is composed of many small catchments of individual lakes, whereas most of us on smaller lakes look to the high points around our own lake and use those to draw in the boundary of the land that drains to the lake. Lakes represent the drain of the landscape where water accumulates. It serves us well to remember this, as the health of a lake will be reflective of what is happening in its catchment. It's easy to add something to a lake but much harder, if not impossible to remove it again.

Lake formation

Lakes can be classified by their basin type and the way in which they were created. Many lakes result from catastrophic geologic events, be it shifts in faults, volcanism, or the wandering of glaciers (think Great Lakes of North America, African Rift Valley lakes, or the lakes in the Sierra Nevada Mountains) that create divots in the landscape which fill with water. For example, consider one of my favorite types —kettle lakes —aptly named for their near vertical-sided basin shapes that are like a kettle. Each is formed upon burial of a sizeable chunk of ice that broke off from a retreating glacier. When the ice melts, it leaves behind a kettle-shaped depression. Interestingly, quaking bogs often occur atop kettle lakes after vegetation from the sides has gown inward in a floating mat to entirely cover the top of the kettle lake. Other examples of lake types include reservoirs created by dams —debris, landslides, beavers, and humans, and oxbow lakes formed from the pinching off of part of a meander river during a flood event. How was your favorite lake formed?

Water chemistry

Just as interesting as how a lake's basin is formed, is the geologic setting in which it occurs as this predominantly controls the water chemistry in the lake. A mnemonic I give to my students is that "Hard Rock equals Soft Water, and Soft Rock equals Hard Water." Soap or shampoo in the shower at the lake cabin will quickly reveal your geologic setting. A good lather indicates soft water, while a poor lather indicates hard water.

A geology of "soft" rocks such as sedimentary or limestone is readily weathered and materials are easily transported to a receiving water body; calcium and magnesium are chief among dissolved elements. In contrast, "hard" rocks such as granites and feldspar resist weathering and result in little transport of materials to lakes.

An accurate determination of the constituents in the water requires a laboratory analysis. A rough generalization is that hard water lakes tend to be more productive than soft water lakes. Another generalization is that certain organisms such as those requiring calcium for incorporation into body parts like shells will not occur in soft water lakes because of inadequate underlying base chemistry. Hence some lakes are thought to be less susceptible to hosting populations of the highly invasive zebra and quagga mussels (e.g., Karatayev et al. 2015; Mellina and Rasmussen 1994).

Base chemistry is also important in determining a lake's resistance to change under assaults of human inputs such as acid precipitation —soft water lakes such as those in the Adirondack Mountains. are highly susceptible (Driscoll and Newton 1985) compared to hardwater lakes elsewhere. It should also be noted that depending on the aquatic life present and their density, they can seasonally influence chemistry as well (e.g., Lehman 1980). While not readily apparent to us, water chemistry varies widely in different lakes across the landscape which has consequences for what we find in them.

Temperature and lake stratification

Perhaps one of the most striking features in moderately deep to deep lakes is the occurrence of temperature stratification, where a layer of warm, low-density water (termed the epilimnion) is atop a layer of cold, high-density water (termed the hypolimnion) throughout the summer (Figure 2; 3A). This is called "direct stratification" and is the result of differential heating of the water column. It has important consequences for the biotic communities in lakes. Because the epilimnion is in constant contact with the atmosphere gas exchange is good; it also contains the algae that produce oxygen via photosynthesis, which means that the dissolved oxygen saturation in this layer is typically near or above 100 percent. This is not necessarily the case in the hypolimnion.

In oligotrophic lakes, biotic biomass (aquatic life) is low and therefore oxygen consumption via respiration is low in the hypolimnion (bacteria consuming decomposing aquatic life in the bottom of the lake), which is cut off from gas exchange with the atmosphere during the stratified period when the top and bottom layer do not mix. Consequently, many oligotrophic lakes retain good concentrations of dissolved oxygen during stratification, allowing communities of cold-water fish to exist.

In contrast, in eutrophic lakes, there tends to be more aquatic life, and thus more organic material accumulates at the bottom of the lake. Its decomposition plus the respiration of biota in the deep water can consume all of the dissolved oxygen resulting in anoxia (lacking oxygen; Figure 3b). This absence of oxygen in the hypolimnion explains why eutrophic lakes typically only have fish species tolerant of warm water; fish requiring cold water are unable to survive in the hypolimnion due to the lack of dissolved oxygen. This is an excellent example of the interconnectedness among chemical (heat and oxygen), physical (temperature/density), and biological (type of fish) phenomena in our lakes.

The occurrence of low oxygen in the bottom waters has further chemical consequences that can affect nutrients, especially dissolved phosphorus, the biotic community (algae), and subsequently our ability to use a lake. Low or no oxygen in the hypolimnion can lead to chemistry changes in the lake sediment, that result in changing phosphorus from an immobile phase in the lake sediments to a phase that dissolves into the water column, a process known as internal loading of phosphorus.

When internal loading occurs, it is not uncommon for very high concentrations of dissolved phosphorus to build up in the hypolimnion (Figure 3C), some of which can be transferred to the epilimnion by wind and wave action, diffusion and/or the movement of organisms from deep in the lake to the upper water layer. Should this occur, algae in the epilimnion receive a phenomenal boost of nutrients that stimulates a spurt of growth termed a bloom. Because of the overabundance of phosphorus, nitrogen now becomes the limiting nutrient which provides a competitive advantage to cyanobacteria, a group of algae capable of fixing their own nitrogen from the atmosphere, *and* also capable of producing some of the most potent toxins known to humans (Chorus and Bartram 1999). In such cases the bloom is termed a "harmful algal bloom" (HAB), especially if toxins are present that results in the issuing of no-contact advisories for the duration of the bloom. Obviously, such an occurrence detracts greatly from the value of our aquatic resources at multiple levels.

This temperature-chemistry relationship again demonstrates the interconnectedness of the physical, chemical, and biological relationships that occur in aquatic ecosystems. As you can imagine with such interconnectedness, managing lakes is not a trivial task. It also demonstrates that we must consider lakes holistically before undertaking any actions to avoid any unintended consequences.

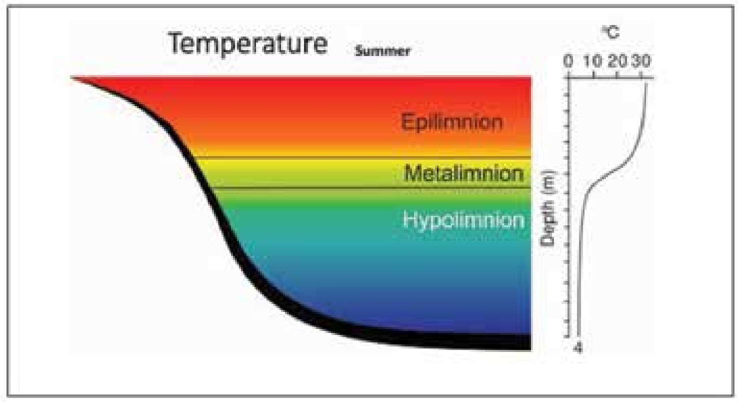

Figure 2. Temperature zonation for a directly stratified deep lake showing warm less dense water in the epilimnion atop the hypolimnion with cold and high-density water at the bottom.

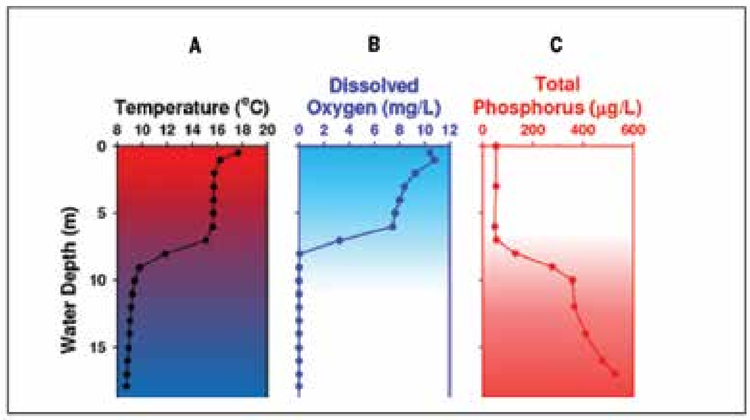

Figure 3. Profiles of Temperature (A), Dissolved oxygen (B), and Total phosphorus (C) as a function of depth in Willow Creek Reservoir, OR, on September 24, 2018, showing anoxia below the thermocline and high internal loading of phosphorus (data from Figure 3C courtesy of S. Burnet).

Further Reading

While I've only touched on some common relationships and connections that occur in lakes, they should serve to illustrate the complexity of what happens under the water surface. It's a fascinatingworld, and I encourage you to dive in deeper to learn more. A plethora of resources exist for your further exploration of our aquatic ecosystems.

NALMS has a series of easily accessible guides, starting with Your Lake and You (https://www.nalms.org/product/ your-lake-you-2nd-edition/), and The Lake Pocketbook (https://www.nalms.org/ nalms-publications/). More technical reference texts include Limnology: Lake and River Ecosystems (R.G. Wetzel, 3rd ed. Elsevier), Freshwater Ecology (W. Dodds and M. Whiles, Elsevier), Textbook of Limnology (Cole and Weihe, Waveland Press), Limnology (Horne and Goldman 2nd ed) and Lake and Reservoir Restoration (Cooke et al. Elsevier).

Great resources are also available on the web such as Water on the Web (https:// www.waterontheweb.org/), and the U.S. Geologic Survey (https://www.usgs.gov/ special-topic/water-science-school/ science/ lakes-and-reservoirs?qt-science_ center_ objects=0#qt-science_center_ objects)

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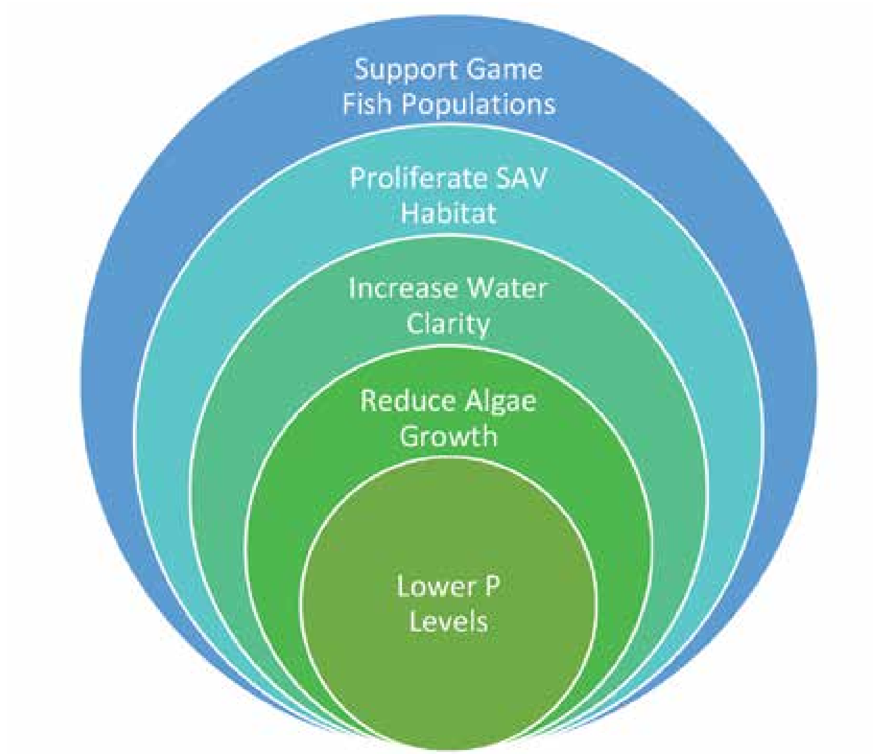
Lake Apopka: A Wickedly Big Problem

James Leary, Center for Aquatic and Invasive Plants, University of Florida.

Did you hear the news! Lake Apopka recently exploded with over 10,000 acres of submersed aquatic vegetation (SAV); Plant coverage of this scale has not been seen on this lake in 75 years. Unfortunately, and maybe not surprisingly, this plant recolonization is almost exclusively hydrilla (*Hydrilla verticillata*), an invasive species that has been a huge problem in Florida and the US for over 50 years. It seems we have a conundrum of epic proportion. Is this a good thing, knowing SAV are finally coming back to Lake Apopka or a bad thing that the SAV is primarily an invasive non-native species? This situation is what can be referred to as a wicked problem, which is a large, often expensive, problem that is difficult or impossible to overcome due to a diversity of stakeholder interests and possibly competing missions.



A conceptual cascade of events predicting how restoration efforts to reduce phosphorous levels can achieve a productive game fish habitat. Adopted froma 2016 SJRWMD Technical Report (https://www.sjrwmd.com/static/reports/Coveney-2016-Water-Quality-Lake-Apopka-SJRWMD-TechMemo56.pdf)

How did we get here?

At over 30,000 acres, Lake Apopka is the fourth largest freshwater body in Florida. In the early 20th century, it was renowned as a world-class bass fishing destination and reputed to be one of the original tourist destinations in Florida. In the 1920s, ingenuity and agricultural enterprise transformed large tracts of surrounding wetlands into highly productive muck farms, creating an economy for a growing population and ultimately supporting the war effort in the 1940s. As a consequence, cultural eutrophication of Lake Apopka started to dramatically transform from a clear-water lake with abundant submersed macrophytes providing fish habitat into a turbid, algal-dominated water unable to support native SAV such as pepper grass (*Potamogeton* sp.) and tape grass (*Vallisneria* sp.). Many local experts claim that the hurricane of 1947 was the trigger which switched the lake from a macrophyte-dominant to algal-dominant system. This eventually resulted in a complete collapse of the bass fishery that no one at the time had foreseen nor wanted. For several generations, Lake Apopka has been known as a "green" lake with no personal memories of what it used to be.

Can we get it back?

Scientists at the University of Florida and across the globe have theorized and debated this phenomenon of ecological change between "alternate stable states". The theory of alternate stable states suggests that nutrient rich (eutrophic) ecosystems can shift between multiple states of biological equilibrium (algal vs. macrophyte dominance) that can be triggered by environmental (biotic or abiotic) tipping points. After the hurricane of 1947 ripped up the majority of aquatic macrophytes in Lake Apopka, historical increases in nutrients (e.g., phosphorus) allowed for the proliferation of algae further reducing light levels making the aquatic environment unsuitable for SAV survival. With that in mind, a logical approach to ecological restoration would be to stop nutrient inputs in order to suppress algal dominance. This inspired a grassroots effort by the Friends of Lake Apopka in 1996 to endorse the Lake Apopka Restoration Act giving mandate to the St. Johns Water Management District (SJRWMD) to purchase over 13,000 acres of agricultural lands north of the lake to reestablish the wetlands and cease inputs of nutrient-rich waters into Lake Apopka. This inspired additional partnerships among state and local governments including the Florida Department of Environmental Protection (FDEP) and the Lake County Water Authority (LCWA). In collaboration, they developed state-of-the-art restoration projects such as the Lake Apopka Marsh Flow-Way (2003) and the Apopka-Beauclair Canal Nutrient Reduction Facility (2009) that are both contributing directly to phosphorus reduction in Apopka and downstream lakes.

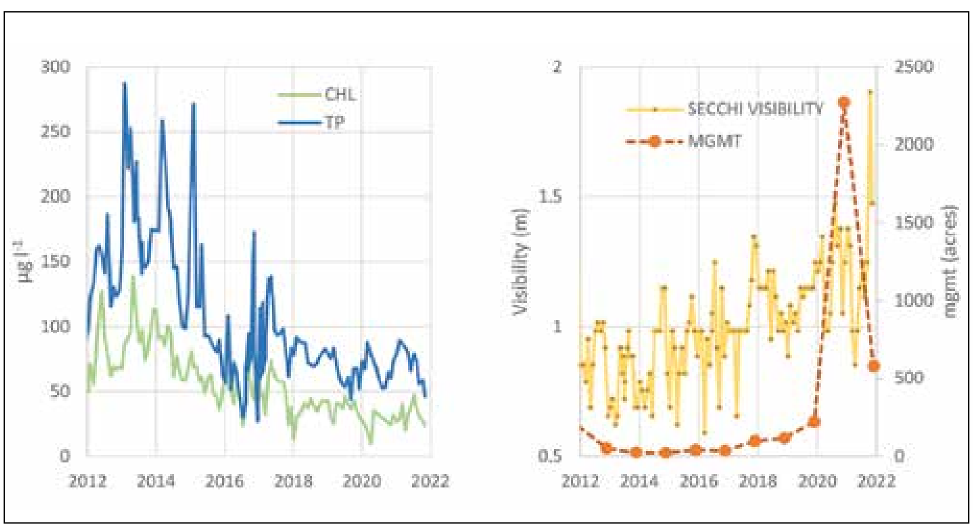
Lake Apopka from Sentinel-2 satellite image from 10/30/2021 using multi-spectral band composition to highlight the large hydrilla infestation (emerald green) in the water column.

If you build it, will they come?

Dramatic environmental and ecological changes are occurring on Lake Apopka. In the last decade, total phosphorous concentrations have decreased by over a half and for the first time in recorded history, total phosphorous has held below 100 parts per billion (ppb; $\mu g\ l^{-1}$) over a four-year period, which has further driven a parallel reduction of algae with concentrations reaching below 50 ppb over the same period. These stabilizing conditions have not been experienced on this lake in the last 75 years and are the fruits of the heroic efforts of our state and local governments. This has further cascaded to an increase in water clarity that is now measuring over 3 feet deep, which is substantial for a 30,000-acre lake with an average depth that is less than 6 feet.

Who invited Cousin Eddie?

These changes in water quality were envisioned when restoration efforts began 30 years ago and plantings of native SAV are showing great promise over hundreds of acres. Hydrilla infestations have persisted on the surrounding Harris Chain of Lakes and other smaller public water bodies and, truth be known, small patches of hydrilla have been monitored and managed on Lake Apopka for the last two decades, averaging less than 100 acres annually. Then, in 2020, hydrilla demonstrated how aggressive it can be, obligating management to over 2000 infested acres and another 580 infested acres in 2021. Just the last two years of management alone are triple to the total management over the previous twenty years combined. Despite these ramped up efforts, hydrilla continues to expand. The total infested area measured in 2021 exceeded 10,000 acres, which includes another 6000 acres of an expanding front. Left unchecked, we are predicting that hydrilla may occupy over half of the lake in 2022. This is an unprecedented event with lots of uncertainty to future outcomes. The restoration efforts to reduce nutrient loads have clearly succeeded with improving the environment for the reestablishment of SAV. The consensus, however, was hoping it was the native species that could have taken advantage. Alas, it was an exotic species with a competitive advantage for light that has so far exploited this change in environment.



Water analyses for total phosphorous (TP) and chlorophyll a (CHL; a proxy for algae). Data archives sourced from the SJRWMD Hydrological Data Portal (webapub.sjrwmd.com/agws10/hdsnew/map.html) and the FWC What's Happening On My Lake Portal (https://ipm-myfwc.shinyapps.io/whoml/)

Can we have our cake and eat it too?

While hydrilla was not a part of the original restoration plan, it can exhibit favorable qualities such as further reducing phosphorous levels, increasing water clarity, consolidating sediments and provide habitat for game fish. It may also serve as a nurse plant to the establishment of the other desirable native SAV, again with water clarity improving light penetration and reduction of wind fetch and wave actions that can uproot new plantings. However, with all of these possible benefits, we must also weigh the ancillary risks for considering hydrilla becoming a keystone species inhabiting Lake Apopka. If hydrilla is left to grow unchecked it will establish large surface mats that can disrupt water conveyance and navigation. As biomass accumulates in the water column, natural decomposition can consume oxygen at rates exceeding the levels of oxygen evolved from photosynthesis, which becomes more susceptible to dissolved oxygen crashes and significant fish kills. We would anticipate the frequency of these events to accelerate with dominant surface growth of hydrilla. While hydrilla might facilitate the establishment of desirable SAV, it is also likely to compete for space in the water column. Thus, limiting the full potential of the desirable species to expand and thrive in Lake Apopka. Ultimately, this would be taking two steps forward with one step back towards restoration.

So, what do we do?

Despite the amazing accomplishments in nutrient management, which we should all celebrate, we need to acknowledge that it is not yet "Mission Accomplished" and this unforeseen challenge is interfering with our best plan. Moving forward we must adapt to these rapidly changing conditions, improvise our solutions and overcome the gauntlet that is hydrilla. Extreme caution should be used against extreme responses. Based on history, the extreme position to eradicate hydrilla from Lake Apopka has a low feasibility to succeed due to economic constraints, risk of environmental impact and hydrilla's tenacity. On the other extreme, accepting hydrilla as the keystone species in this successional restoration plan inherently increases the uncertainty in the ecosystem services, usability and environmental fate of Lake Apopka. Thus, we're left with meeting somewhere in the middle: harnessing the best virtues that hydrilla can immediately provide, coincided with a diligent and strategically-placed intervention schedule averting the risks that come with cultivating an invasive species.

In closing, some have argued that we cannot afford another Lake Toho where a hundred-thousands of dollars are spent on hydrilla management every year. Unfortunately, Lake Apopka has become the next Lake Toho which will require a commitment to a sophisticated, long-term strategy if we are to realize what Lake Apopka deserves to be.

The views expressed here are the opinions of the author and may not be the positions taken by others including the agencies mentioned in this article.

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2022 Calendar of Events

July 18-22, 2022
62nd Annual Meeting of the Aquatic Plant Management Society & Joint Meeting with SCAPMS
Greenville, SC
https://apms.org/2022-annual-meeting/

August 22-25, 2022
UF/IFAS Aquatic Weed Control Short Course
DoubleTree by Hilton Orlando at SeaWorld
Orlando, FL
https://go.ufl.edu/awcsc

October 3-6, 2022
46th Annual Florida Aquatic Plant Management Society Training Conference
Hilton Daytona Beach Oceanfront Resort
Daytona Beach, FL
https://fapms.org/conference/2022-conference/

October 24-26, 2022
41st MidSouth Aquatic Plant Management Society Conference
Battle House Renaissance Mobile Hotel & Spa
Mobile, AL
http://www.msapms.org/conferences/2022/

November 7-9, 2022
Texas Aquatic Plant Management Society Annual Conference
Embassy Suites by Hilton San Marcos Hotel Conference Center and Spa
San Marcos, TX
https://www.tapms.org/2022-annual-meeting/

Fueling and Fire Safety

Working on the water provides us with beautiful scenery, access to wild places, and the privilege of interacting with our environment and exploring the backcountry. Operating a vessel, though, requires attention to detail and commitment to safety to keep ourselves, our crew, the environment, and our equipment safe.

In a previous issue of Aquatics, the importance of the float plan was discussed. I spend a lot of my free time scuba diving, and I borrowed a phrase from the diving world—"Plan your dive, and dive your plan"—that is also applicable to boating safety—always "plan your float, and float your plan" for that article. A similar analog can be made between diving and boating for gas use and reserves. Before heading out on the water, make sure to have plenty of fuel for the planned objectives and distance to be traveled. Ideally, it is recommended that 1/3 of the fuel be used in transit to the project site, 1/3 to get back to the launch site, and 1/3 should be reserved for emergencies. Redundancy and gas consumption planning in diving are necessary for the safety of the diver and dive buddy to safely make it back to the surface, and the same is true for boating.

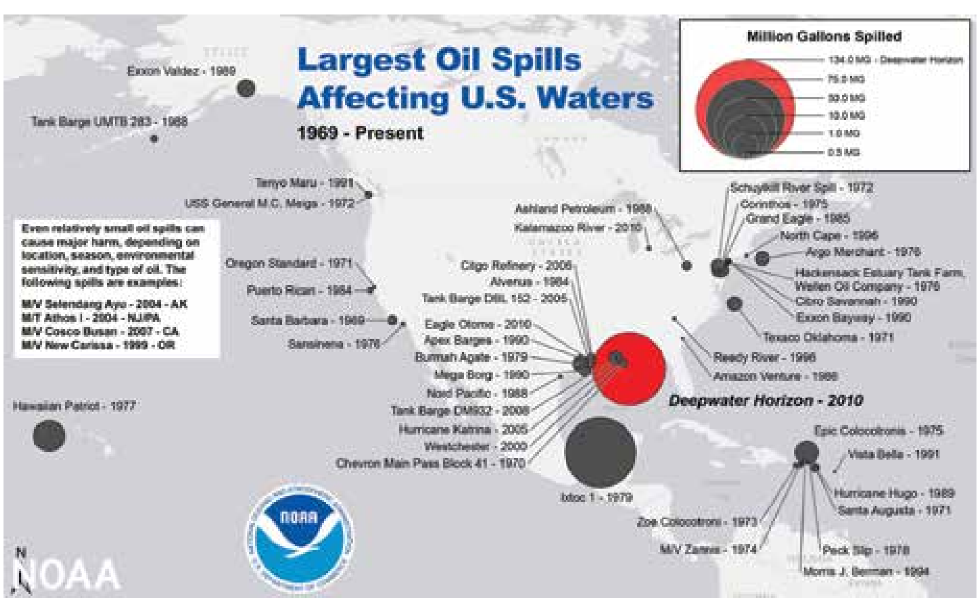
Boating accidents can happen while preparing the vessel, launching, recovering, or enjoying a day on the water. Fueling the vessel before heading out or while out on the water can be a risky activity when specific safety procedures are ignored or compromised. Accidents can result in a fuel spill, explosion, or injury to others.

Before heading to the ramp/gas station:

- Know where the fire extinguisher is and how to use it.
- Make sure a proper spill kit is on board to address any fuel or oil leaks.
- The nuances of aquatic plant management often necessitate that applicators operate a fleet of different vessels, and before heading out on a new boat, familiarize yourself with the location and condition of the fire extinguisher and the spill kit.
- Make sure the fire extinguisher on board has been inspected recently and is in good working condition. It should be free of any damage, rust, corrosion, cracks to the tubing, etc., and it should have a proper charge. Inspect the handle, nozzle, valve, gauge for debris.
- For most extinguishers, the red and green on the charge gauge indicate the pressure. Green means the extinguisher is "ready", and red means "no go." This gauge will usually have a pressure indicator for when the extinguisher needs to be recharged or is overcharged as well.
- Older models that still utilize the pin can be tested by pressing and releasing the pin. Proper pressurization will result in the pin being popped back out immediately.
- There are several different kinds and models of fire extinguishers present and in use on boats today. Fire extinguishers typically have a working life of up to 12 years depending on manufacturer, design, storage conditions, etc….and this lifespan is only reliable if routine inspections occur monthly to check for damage to the cylinder and to verify the cylinder has an acceptable pressure charge. Annual inspections should be conducted by a certified fire safety specialist. Log all maintenance and service records for the fire extinguisher and use a permanent marker to note on the cylinder the date of purchase.
- Always check to see that the inspection sticker is present and legible.
- Any discharge at all —even if minor or accidental —warrants a professional service to evaluate if the cylinder needs to be replaced or refilled. Discharging reduces pressure inside the cylinder and that can cause the extinguisher to not work when you need it most.
- The United States Coast Guard requirements dictate how many and what class of fire extinguisher you need to have on board. You may be surprised to learn that there are exemptions for some types of recreational outboard motorized vessels less than 26' in length, but it is always better to be safe than sorry when on the water. You can learn more here: https://uscgboating.org/recreational-boaters/fire-extinguisher-faq.php

Before fueling:

- Know the capacity of your fuel tanks and containers and don't overfill. There are various devices on the market to prevent overfilling tanks.
- Avoid the use of cell phones, e-cigarettes, lighters, matches, etc. around the fueling station or dock. Ensure that no one around you is smoking.
- Ask all passengers to leave the vessel and remain on the dock or on the ground until fueling is complete.
- Close all hatches, windows, and doors to



prevent fumes from entering any open compartments.

- Carefully inspect fuel lines and connections for damage, debris, obstructions, etc.
- Verify that air vents to the fuel tank are open.
- Turn off all electrical systems to avoid generating a spark. This includes the engine, navigation lights, bilge pumps, etc.
- To reduce the chance of creating a spark, always maintain contact between the fuel nozzle and the fuel line. This grounding prevents the buildup of a static charge which could result in a spark.
- Portable gas tanks carried on board should be removed from the vessel and filled on the ground or dock.

While filling up:

- Make sure all valves and air vents for the gas tank are open.
- Never fill the tank more than 90% full. As fuel heats, it expands and can overflow from the fuel tank into the bilge, creating an unsafe condition for you and your crew. Gasoline and gasoline fumes are explosive — particularly when the fumes accumulate in the bilge.
- After fueling, replace the gas cap tightly and evenly.
- Smell for fumes and watch for any leaks.
- Wipe up any fuel that has leaked or spilled.

After fueling:

- For boats with inboard engines, run the blower for at least five minutes before starting the engine to clear residual fumes that may have accumulated in the bilge area.
- Clean up any spills on the vessel or on the ground using the materials in the spill kit or those provided at the fueling station.
- Open hatches, windows, and doors to allow air to circulate throughout the boat.

What to do when a fuel spill occurs:

- The Oil Pollution Act and the Clean Water Act mandate that any oil or fuel spill —even accidental - that leaves a sheen on the water must be reported to the United States Coast Guard National Response Center at 1-800-424-8802. Be prepared to report the location of the spill, cause or source of spill, type and amount of fuel spilled, level of threat, and weather conditions at the spill site.
- By law, any spills in Florida must also be reported to the State Warning Point of the Florida Department of Environmental Protection at 1-800-320-0519.
- The use of detergents, emulsifying agents, soaps, and other chemicals to disperse a spill is strictly prohibited as these products have permanent impacts to wildlife, sediment, and biochemical properties of the water and substrate.
- Absorbent pads, socks, pillows, etc. can be used to mop-up and minimize damage until professional help arrives.
- Spill kits can be purchased online and come in convenient easy-to-transport buckets/containers to assist with any spills or leaks on board. Invest in these, train your crews, and make sure disposal of used items is done properly.

We learn a lot in our industry about taking the proper steps to minimize herbicide spills and accidents but mitigating risks from fuel and oil is equally important. According to the United States Environmental Protection Agency, just one pint (two cups) of oil spilled into the water spreads into an oil slick one acre in size. And the National Academy of Sciences reports that 64% of the petroleum that enters North American waters each year originates from land-based runoff and recreational boating. There are thousands of spills that occur each year, and even small spills threaten wildlife, habitat, water quality, and ecosystem health. The severity of impacts depends largely on spill location, local hydrology, environmental sensitivity, type of fuel/oil, weather conditions, season, wildlife present, water chemistry, response time of environmental personnel, etc. Oil and fuel spills can happen anywhere and at any time. It is up to each of us to reduce the likelihood of accidents like these, and in the event they do occur, know how to appropriately respond.

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