Lesson 2:

Resistance Management Considerations in the Realm of Available Herbicides, Aquatic Plant Growth Patterns, and Current Control Strategies

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Some weed scientists infer that one resistant individual is present in a population and repeated applications of the same herbicide allow the resistant plants to expand.

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Resistance Management Considerations in the Realm of Available Herbicides, Aquatic Plant Growth Patterns, and Current Control Strategies

Aquatic plants are found in many combinations with other plant and animal species. They are also found growing under many different ecological and climatological conditions in waters with uses and functions that may vary throughout the year.

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Resistance Management Considerations in the Realm of Available Herbicides, Aquatic Plant Growth Patterns, and Current Control Strategies

Different strategies are employed to cope with each situation; therefore, there is no one strategy to address resistance management in aquatic plant control.

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Lesson 2:

By the end of this lesson you will:

Be familiar with the relatively short list of herbicides available for aquatic plant management in natural areas

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    - Understand key differences between production crop management and aquatic plant control using herbicides

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  - Learn common scenarios that aquatic plant managers face when considering herbicide stewardship programs
    - Understand key differences between production crop management and aquatic plant control using herbicides
      - See herbicide resistance strategies that aquatic plant managers currently implement

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The Universe of Effective Herbicide Options

Aquatic plant control using herbicides represents a relatively small market compared to production crop management.

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The Universe of Effective Herbicide Options

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With low economic return, significant registration costs, and a relatively short patent life after registration, few new compounds were registered prior to 2002 and companies allowed many existing off-patent registrations to expire.

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The Universe of Effective Herbicide Options

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Consequently, in 2001, there were only six herbicide compounds registered for use in natural area aquatic systems.

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Aquatic Use Herbicides Registered Before 2002

Herbicide	Application Site	Year Registered	Mode of Action
Copper	Submersed	1950s	Undefined
2,4-D	Sub., Emergent, Floating	1959	Auxin mimic
Endothall	Submersed	1960	Serine/threonine phosphatase inhibitor
Diquat	Sub., Emergent, Floating	1962	Photosystem I inhibitor
Glyphosate	Emergent	1977	Enzyme inhibitor - EPSP
Fluridone	Submersed	1986	Enzyme inhibitor - PDS

Consequently, in 2001, there were only six herbicide compounds registered for use in natural area aquatic systems.

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Considerations Toward Registering Aquatic Herbicides

A Matter of Scale

About 175 million acres of corn and soybeans are planted in the U.S. and herbicides are applied to vast acreages 2-3 times per year with management costs estimated in billions of dollars.

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Considerations Toward Registering Aquatic Herbicides

A Matter of Scale

Compare this to Florida, where aquatic plant control in natural areas far exceeds all other states:

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Considerations Toward Registering Aquatic Herbicides

A Matter of Scale

Compare this to Florida, where aquatic plant control in natural areas far exceeds all other states:

An average 70,000 acres of aquatic plants are controlled each year in Florida public lakes and rivers - mostly in small scale or spot applications that are applied once per year with total annual management costs of about 20 million dollars.

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Considerations Toward Registering Aquatic Herbicides

Seeking EPA Registration for use in Water

Chemical compounds must pass a lengthy and rigorous process to be registered by EPA for use in natural area aquatic sites.

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- more than 140 health and environmental tests

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- more than 140 health and environmental tests
- average 8-10 years for full EPA registration
- $40-60 million to register for aquatic site use

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The Universe of Effective Herbicide Options

After fluridone resistance was confirmed in hydrilla in 2000, several compounds that had been registered for weed control in rice were evaluated for aquatic plant control and registered for use in water.

Eight of the ten herbicide active ingredients registered for aquatic use since 2002 are single site enzyme inhibitors, classes of compounds in which resistance has been documented in terrestrial applications.

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Aquatic Use Herbicides Registered Since 2002

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Triclopyr	Submersed, Emergent	2002	Auxin mimic
Imazapyr	Emergent	2003	Enzyme inhibitor - ALS
Carfentrazone	Sub., Emergent, Floating	2004	Enzyme inhibitor - PPO
Penoxsulam	Submersed, Floating	2007	Enzyme inhibitor - ALS
Imazamox	Sub., Emergent, Floating	2008	Enzyme inhibitor - ALS
Flumioxazin	Sub., Emergent, Floating	2011	Enzyme inhibitor - PPO
Bispyribac	Submersed, Floating	2012	Enzyme inhibitor - ALS
Topramezone	Submersed	2013	Enzyme inhibitor - HPPD
Sethoxydim	Emergent - grass specific	2017	Enzyme inhibitor - ACCase
Flurpyrauxifen-benzyl	Sub., Emergent, Floating	2018	Auxin mimic

Comparing Commodity Based Control vs. Aquatic Weed Control in Natural Areas

Commodities	Natural Areas Aquatics

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Business operation - private lands	Resource management - public lands

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Many herbicide options and mixtures	Limited options subject to substantial regulation
Minimal other issues	Regulatory, permitting, non-target, public perception issues
Hybrid weeds rare	Hybrid weeds and invasive polyploids prevalent

Resistance Considerations in the Realm of Aquatic Plant Management

The following scenarios face aquatic plant managers on a regular basis, especially when controlling invasive weeds in natural areas where conserving off-target plants and animals is as or more important than controlling the invasive weed.

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Resistance Considerations in the Realm of Aquatic Plant Management

The following scenarios face aquatic plant managers on a regular basis, especially when controlling invasive weeds in natural areas where conserving off-target plants and animals is as or more important than controlling the invasive weed.

Singly, these scenarios present difficulties for aquatic plant managers to incorporate traditional resistance stewardship strategies. Adding to the complexity, most of the following issues occur collectively within each water body – each influencing management plans and anticipated outcomes.

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Resistance Considerations in the Realm of Aquatic Plant Management

Large-scale vs. spot applications

Large-scale applications expose a greater number of plants to a herbicide, intuitively increasing the potential for resistance. Managers often increase surveillance and control smaller populations before they become widespread. However, controlling small submersed plant populations usually ensures that sub-lethal doses of herbicides will dissipate and expose plants outside the target area, presenting an additional pathway toward resistance.

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Resistance Considerations in the Realm of Aquatic Plant Management

Large lakes or reservoirs vs. small ponds

Small water bodies usually have fewer uses and functions and fewer non-target species; therefore, there is usually a larger array of herbicides to incorporate into resistance management strategies on smaller systems, and herbicides may be applied economically to the entire system.

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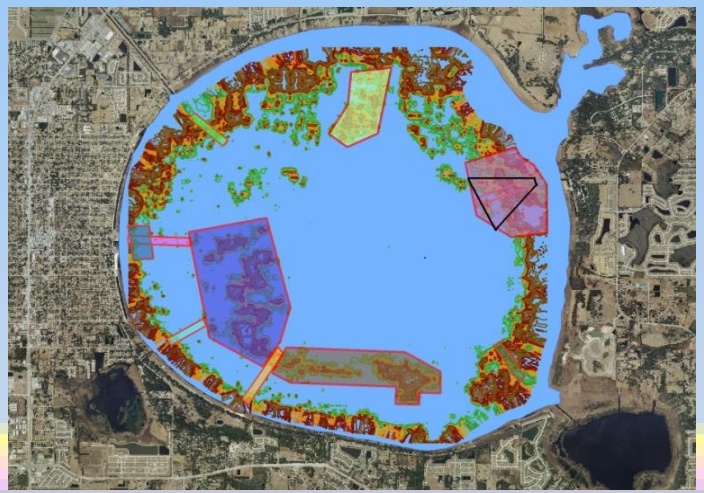
Resistance Considerations in the Realm of Aquatic Plant Management

Large lakes or reservoirs vs. small ponds

System-wide applications are rarely applied to large lakes or reservoirs. Conversely, there may be many small herbicide applications in a year's time with fewer available options, all of which are subject to dissipation and sub-lethal doses outside the control area, providing opportunities for resistance development.



Polygons represent small-scale plots to apply herbicides as needed to control about 2,000 acres of submersed plants in 12,000-acre East Lake Toho, Florida.

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Resistance Considerations in the Realm of Aquatic Plant Management

Large lakes or reservoirs vs. small ponds

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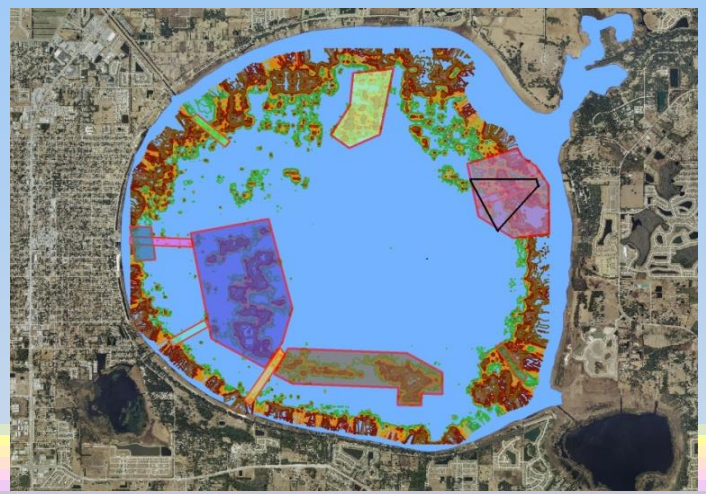
Conversely, there may
with
opportunities for resistance

It is important to note that despite multiple thousands of herbicide applications to small ponds over a period of decades, there are no documented cases of herbicide resistance emanating from these venues.



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Resistance Considerations in the Realm of Aquatic Plant Management

Plant populations with many individuals

It may seem intuitive that some plant species may be more susceptible to developing resistance based on the number of plant individuals or growing apices in the population. This scenario may get some support in the case of fluridone-resistant hydrilla strains that developed in Florida where applications exposed millions of growing tips.

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Resistance Considerations in the Realm of Aquatic Plant Management

Plant populations with many individuals

However, no resistance issues have been documented after decades of applying fluridone to control watermeal that can reach densities approaching 5-10 billion plants per acre, or applying copper to control planktonic algae that can reach cell counts approaching 20 million cells per milliliter of water.

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Resistance Considerations in the Realm of Aquatic Plant Management

Invasive vs. native plant control

Invasive plants like hydrilla, water hyacinth and Eurasian watermilfoil have much faster growth rates than most native plants; therefore, requiring more frequent management. Additionally, invasive plants usually interfere with the uses and functions of water bodies more than native plants and are more often targeted for control.

water hyacinth

water chestnut

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Resistance Considerations in the Realm of Aquatic Plant Management

Sub-lethal herbicide doses

A frequently recommended herbicide resistance management strategy is to apply full label rates to control target plants. This may be logical in commercial crop management where lowest effective rates are often close to maximum label rates. In aquatics, the maximum label rate may be many times higher than the lowest effective rate. Higher rates may be more damaging to non-target species and are more costly, an important consideration when applying limited public (tax) funds.

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Resistance Considerations in the Realm of Aquatic Plant Management

Sub-lethal herbicide doses

A frequently recommended [illegible] apply full [illegible]

Herbicide applications to control submersed plants are immediately subject to dissipation via herbicide solubility and water exchange. Managers often try to control small areas of invasive plants before they become widespread disruptive populations. Unless the entire water body is treated at a high rate, plants outside the target area will likely be exposed to a sub-lethal rate. Paradoxically, treating at maximum rates for spot applications may enhance lake wide exposure to sub-lethal rates via dissipation.

[illegible] important [illegible] (tax) funds.

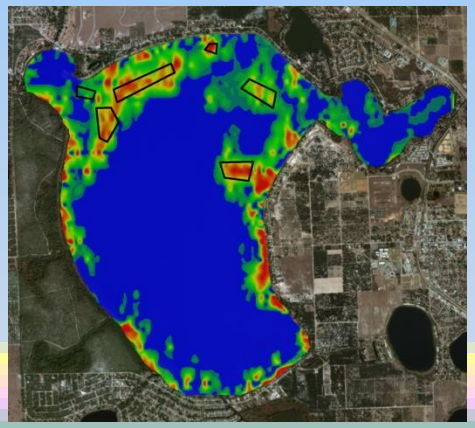

Image of 3,500-acre Lake June, Florida showing partial-lake herbicide application plots. Color intensities represent submersed plant densities in the water column.

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Resistance Considerations in the Realm of Aquatic Plant Management

Herbicide modes of action

Since the early 1980s, ALS herbicides have shown the greatest propensity for resistance development in crop management applications. Eight of the 16 herbicides registered by the EPA for aquatic use act on a single gene site. While aquatic plant managers should be aware of which herbicide modes of action have the greatest number of resistant weed species, resistant issues have almost exclusively arisen in terrestrial venues that are far different in magnitude and exposure processes.

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Resistance Considerations in the Realm of Aquatic Plant Management

Herbicide modes of action

Since the early 1980s, ALS

There is considerable difference in scale between the volume of herbicides applied in crop production vs. aquatic plant management. An estimated 175 million acres of corn and soybeans planted in the U.S. may receive 2-3 herbicide applications per year. In Florida, where far more aquatic plants are managed in natural areas than any other state, about 70,000 acres are controlled annually; about 0.04% of the nationwide crop estimate.

different in

Herbicide Resistance Management Strategies Employed in Aquatic Sites

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Herbicide Resistance Management Strategies Employed in Aquatic Sites

Eliminate pioneer invasive plant populations where possible

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Eliminate pioneer invasive plant populations where possible

Manage invasive plants at low levels to avoid large scale applications

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Herbicide Resistance Management Strategies Employed in Aquatic Sites

Eliminate pioneer invasive plant populations where possible

Manage invasive plants at low levels to avoid large scale applications

Apply when success is most likely - to reduce follow up control events

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Herbicide Resistance Management Strategies Employed in Aquatic Sites

Eliminate pioneer invasive plant populations where possible

Manage invasive plants at low levels to avoid large scale applications

Apply when success is most likely - to reduce follow up control events

Rotate active ingredients where feasible

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Herbicide Resistance Management Strategies Employed in Aquatic Sites

Eliminate pioneer invasive plant populations where possible

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Combine active ingredients if cost-effective

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Combine active ingredients if cost-effective

Follow up large applications to control survivors with different method

Integrate bio, mechanical, physical control methods where feasible

Control target plants before they produce seeds or tubers

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Limitations to Herbicide Resistance Management Strategies in Aquatic Sites

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Limitations to Herbicide Resistance Management Strategies in Aquatic Sites

Cost - especially for public (tax) funded plant control

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Limitations to Herbicide Resistance Management Strategies in Aquatic Sites

Cost - especially for public (tax) funded plant control

Reduced non-target plant selectivity - especially at higher rates

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Limitations to Herbicide Resistance Management Strategies in Aquatic Sites

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Constant water exchange reducing optimum herbicide rate

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Stakeholder objection

Long-term data development to justify use in some sensitive areas -
(difficult to alter strategy without similar long-term data development)

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Summary for Lesson 2:

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- Only 16 herbicides are registered for use in natural area aquatic sites. Efficacy, selectivity, and current conditions further reduce the number of cost-effective herbicide strategies for each application.

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- Only 16 herbicides are registered for use in natural area aquatic sites. Efficacy, selectivity, and current conditions further reduce the number of cost-effective herbicide strategies for each application.

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Summary for Lesson 2:

- Only 16 herbicides are registered for use in natural area aquatic sites. Efficacy, selectivity, and current conditions further reduce the number of cost-effective herbicide strategies for each application.
- Consider stewardship strategies that incorporate herbicide mixtures, application timing, and rotation where feasible with biological, mechanical, and cultural control methods.
- Aquatic plant managers face considerable variability in plant groupings and environmental conditions for each application that substantially affect herbicide control strategies and efficacy.

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