Aquatic Herbicide Resistance Training Modules

Aquatic Plant Management Society
Weed Science Society of America
http://wssa.net/2011/12/wssa-lesson-module-herbicide-resistant-weeds/

Aquatic Plant Management Society

Weed Science Society of America
www.apms.org

Aquatic Plant Management Society
Resistance Stewardship in APM

Whitepaper

Three PowerPoint Lessons

Venues and plants

Considerations / strategies

Practical situations
Lesson 1

Background:

Herbicide Resistance in Aquatics and Description of Aquatic Plant Management Venues and Plant Types
Objectives:

By the end of this lesson you will:

- Recognize key differences between aquatic plant control and crop management that affect herbicide use in water
- Understand how the uses or functions of different types of aquatic systems influence control strategies
- Learn how plant types influence selection of herbicide mode, amount, and application frequency
Uses and Functions of Aquatic Systems:

The uses and functions of aquatic systems greatly influence plant management strategies within these waters. Waters can generally be divided into Man-made systems and Natural or modified natural systems.
Man-made systems:

- include water storage basins, conveyance, flood control, irrigation, and potable water supply.
- any amount of aquatic macrophyte growth may be considered as undesirable.
- are similar to commercial crop herbicide application strategies.
- plants are generally subject to maximum control efforts with low emphasis on selectivity.

Note: Man-made systems also include thousands of water feature ponds in which non-desirable plants and algae are intensively managed. While technically man-made, these systems are managed for aesthetic reasons and often to promote non-target plants and animals.
Natural systems:

- include ponds, lakes, rivers, and reservoirs
- with the exception of invasive plants, most plant and animal species may be considered valuable ecosystem components
- control strategies need to effectively control 1-2 target plants while conserving multiple native or other valuable species
- selectivity considerations may:
  - limit available herbicide active ingredients
  - limit rates and timing of herbicide applications
  - influence cost and amount of control effort
Key differences between crop management and aquatic plant control, especially in natural systems:

In crop management, many weeds are targeted for control, usually among one or two non-target crop species.

In natural areas, one or two plants, usually invasive plants, are targeted among many desirable plant and animal species.

Conserving or enhancing desirable species is equally or more important than control of a target plant.
Plant Types in Aquatic Systems Include:

- Emergent
- Floating
- Submersed
- Algae
Emergent Plants

- include grasses, sedges and rushes and numerous broadleaf species
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- control, especially large-scale control, is similar to commercial crop management
  - vast area monocultures may be targeted
  - herbicides are applied directly to plant foliage
  - herbicides can be precisely applied to a defined area
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  - herbicides can be precisely applied to a defined area
- selectivity concerns may reduce the number of available herbicides
  - i.e., when controlling invasive grasses growing among native grasses or other desirable species
Floating Plants

- include large water hyacinth and water lettuce and minute species like salvinia, duckweeds, and watermeal
Floating Plants

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• herbicides often applied directly to foliage, similar to emergent plant and commercial crop management
  • frequent spot applications for selective control among more desirable plant species
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  • frequent spot applications for selective control among more desirable plant species

• injecting herbicides into water for root uptake is becoming more common
Submersed Plants

- include invasive plants like hydrilla and Eurasian watermilfoil in natural systems
- pondweeds and other species in water conveyance systems
- native submersed plants may be managed in natural areas, especially in late season for access and recreation
Submersed Plant Herbicide Applications

Most strikingly different from commercial crop management

- entire water column is usually treated in submersed plant control vs. foliar applications in row crop maintenance
- herbicide exposures measured in hours in crop management
  - hours / days for aquatic contact herbicides, and
  - weeks / months for aquatic systemic herbicides
- applied in systems where water is constantly moving
- herbicides dissipate immediately upon application to water
- management objectives usually include controlling invasive species while enhancing many comingled non-target species
- pre-emergent strategies are rarely applicable for submersed plant control
Algae

- include filamentous, planktonic, blue-green, and macrophytic algae
- blue-green algae (cyanobacteria) can produce toxins, cause taste and odor problems in drinking water
- copper-based compounds have been the dominant mode of action to control algae for decades
- few realistic alternatives to copper
  - most aquatic herbicides do not have algal activity at label rates
Key Considerations from Lesson 1:

- In crop management, many weeds are targeted for control, usually among one or two non-target crop species.

- In natural aquatic systems, one or two plants, usually invasive plants, are targeted among many desirable plants and animals.

- Submersed plant control is most strikingly different from commercial crop management.

- Conserving or enhancing desirable species is equally or more important than control of a target plant in natural aquatic systems.
Resistance Management Considerations in the Realm of Available Herbicides, Aquatic Plant Growth Patterns, and Current Control Strategies

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.

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

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.

Consequently, in 2001, there were only six herbicide compounds registered for use in natural area aquatic systems.
## Aquatic Use Herbicides Registered Before 2002

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Application Site</th>
<th>Year Registered</th>
<th>Mode of Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>Submersed</td>
<td>1950s</td>
<td>Undefined</td>
</tr>
<tr>
<td>2,4-D</td>
<td>Sub., Emergent, Floating</td>
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<td>Auxin mimic</td>
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<td>Serine/threonine phosphatase inhibitor</td>
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<td>Sub., Emergent, Floating</td>
<td>1962</td>
<td>Photosystem 1 inhibitor</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>Emergent</td>
<td>1977</td>
<td>Enzyme inhibitor - EPSP</td>
</tr>
<tr>
<td>Fluridone</td>
<td>Submersed</td>
<td>1986</td>
<td>Enzyme inhibitor - PDS</td>
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Considerations Toward Registering Aquatic Herbicides

A Matter of Scale

About 175 million acres of corn and soy beans 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.

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.
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.

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

All seven herbicides registered for aquatic use since 2003 are single site enzyme inhibitors, classes of compounds in which resistance has been documented in terrestrial applications.
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</tr>
<tr>
<td>Imazapyr</td>
<td>Emergent</td>
<td>2003</td>
<td>Enzyme inhibitor - ALS</td>
</tr>
<tr>
<td>Carfentrazone</td>
<td>Sub., Emergent, Floating</td>
<td>2004</td>
<td>Enzyme inhibitor - PPO</td>
</tr>
<tr>
<td>Penoxsulam</td>
<td>Submersed, Floating</td>
<td>2007</td>
<td>Enzyme inhibitor - ALS</td>
</tr>
<tr>
<td>Imazamox</td>
<td>Sub., Emergent, Floating</td>
<td>2008</td>
<td>Enzyme inhibitor - ALS</td>
</tr>
<tr>
<td>Flumioxazin</td>
<td>Sub., Emergent, Floating</td>
<td>2011</td>
<td>Enzyme inhibitor - PPO</td>
</tr>
<tr>
<td>Bispyribac</td>
<td>Submersed, Floating</td>
<td>2012</td>
<td>Enzyme inhibitor - ALS</td>
</tr>
<tr>
<td>Topramezone</td>
<td>Submersed</td>
<td>2013</td>
<td>Enzyme inhibitor - HPPD</td>
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## Comparing Commodity Based Control vs. Aquatic Weed Control in Natural Areas

<table>
<thead>
<tr>
<th><strong>Commodities</strong></th>
<th><strong>Natural Areas Aquatics</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Business operation - private lands</td>
<td>Resource management - public lands</td>
</tr>
<tr>
<td>Individual decides management strategy based on fundamental economics</td>
<td>Decisions based on quality of habitat with substantial stakeholder input</td>
</tr>
<tr>
<td>Budget from cash flow - cost increase tolerable</td>
<td>Defined budget - little flexibility</td>
</tr>
<tr>
<td>Annual weeds reproduce sexually - high seed input</td>
<td>Annual / perennial weeds reproduce vegetatively - low seed input</td>
</tr>
<tr>
<td>Herbicides applied to surface area - 2 dimension</td>
<td>Herbicides applied to water volume - 3 dimension</td>
</tr>
<tr>
<td>Can rotate crops</td>
<td>Cannot rotate weeds or algae</td>
</tr>
<tr>
<td>Limited dilution impacts</td>
<td>Rapid dissipation potential</td>
</tr>
<tr>
<td>One desirable species among many weeds</td>
<td>One target weed among many desirable species</td>
</tr>
<tr>
<td>Many herbicide options and mixtures</td>
<td>Limited options subject to substantial regulation</td>
</tr>
<tr>
<td>Minimal other issues</td>
<td>Regulatory, permitting, non-target, public perception issues</td>
</tr>
<tr>
<td>Hybrid weeds rare</td>
<td>Hybrid weeds and invasive polyploids prevalent</td>
</tr>
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</table>
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.
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.
Large lakes or reservoirs vs. small ponds

Small water bodies usually have fewer uses and functions; 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. 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.
Resistance Considerations in the Realm of Aquatic Plant Management

Plant populations with many individuals

However, 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.

However, no resistance issues have been documented after decades of applying fluridone to control watermeal that can reach densities approaching 5,100,000,000 plants per acre, or applying copper to control planktonic algae that can reach cell counts approaching 20,000,000,000 cells per milliliter of water.
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.
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.

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 or 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.

Image of 3,500-acre Lake June, FL showing partial-lake herbicide application plots. Color intensities represent submersed plant densities in the water column.
Since the early 1980s, ALS herbicides have shown the greatest propensity for resistance development in crop management applications. Seven of the 14 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.

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.
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

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
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

Limited effective / selective options

Constant water exchange reducing optimum herbicide rate

Regulatory constraints for some products / uses (i.e. drinking, irrigation)

Stakeholder objection

Long-term data development to justify use in some sensitive areas - (difficult to alter strategy without similar long-term data development)
Aquatic plant managers face considerable variability in plant groupings and environmental conditions for each application that substantially affect herbicide control strategies and efficacy.

Consider stewardship strategies that incorporate herbicide mixtures, application timing, and rotation where feasible with biological, mechanical, and cultural control methods.

Only 14 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.

Aquatic plant managers face considerable variability in plant groupings and environmental conditions for each application that substantially affect herbicide control strategies and efficacy.