Plant Management in Florida Waters : An Integrated Approach

Details About the Aquatic Herbicides Used in Florida

There are fourteen active ingredients (chemical compounds) approved for use in Florida waters as of 2011. These active ingredients may be formulated and sold under various **trade names** such as Aquathol, Rodeo and Sonar. They are applied directly to the target plant or dispersed within the water for the purpose of treating invasive weeds. These formulations are purchased and used by state, federal and local government agencies responsible for environmental management and weed abatement. They are also used by environmental contractors, farmers and, in some cases, homeowners. Permission in the form of a state **permit** may be legally required prior to herbicide application depending on type of water body, ownership, aquatic species present, proximity and hydrologic connection to other water bodies, amount of herbicides to be used, and other variables. Contact your **regional Florida Fish and Wildlife Conservation Commission (FWC) office** prior to herbicide application to ensure compliance with regulations and to gain helpful advice for your treatment.

According to the plant species being treated, the location, time of year, weather, water-oxygen levels, and a host of other variables, aquatic herbicides may be applied directly to the plant, directly to the water, or to the plant and water at the same time. On some occasions, environmental conditions may dictate that certain herbicides are not permissible. It is up to the user to follow the herbicide use label that accompanies the herbicide container and to follow it exactly. The herbicide's label is a legal document that provides important information about the specific herbicide product that you are using. The label explains in detail:

- which type of site may be legally treated with the herbicide (ex: lakes, flowing waters, canals, reservoirs);
- how to use the herbicide;
- which rates to use for specific plants and environmental situations;
- precautionary statements relative to the herbicide's possible hazards;
- specific first aid.

A separate document, the herbicide's Material Safety Data Sheet (MSDS), presents specific technical information that is useful in the event of a spill or mistake. It includes hazardous ingredients, spill or leak procedures, data on physical components, fire and explosion, reactivity, health hazards, and special precautions.

Applying a time-release granular herbicide

Useful Terminology for Herbicide Use and Invasive Plant Management

The following terminology is often used to describe herbicides, their proper use and expected outcomes. This information can be obtained by reading the herbicide label, the MSDS and technical fact sheets and supplements provided by the herbicide manufacturer.

- The lethal plant dose is the amount of active ingredient required to kill a plant, often measured in parts per million (ppm) or parts per billion (ppb).

- A contact herbicide causes injury to plant tissue where contact occurs; contact herbicides control plants relatively quickly.
- A systemic or translocated herbicide is absorbed into the plant through the leaves, stems or roots and translocated throughout the plant to kill it from the inside. Systemic herbicides control plants less quickly than contact herbicides.
- Selectivity refers to the ability of a herbicide to kill certain types of plants without causing significant injury to others. Herbicides can be selective (narrow-spectrum) or non-selective (broad spectrum), based on the range of plants affected. Selectivity is also influenced by factors including application rate, time, method of application, environmental conditions and stage of plant growth.
- Liquid formulations contain active ingredients that are suspended in liquid. Liquid formulations may be best for certain species of plants or certain management situations, such as areas where water movement is slow, or where there are deep sediments.
- Dry formulations contain active ingredients that are mixed into dry, slow-dissolving pellets or granules. Dry formulations make it easier to "time-release" herbicide into the water or soil at the lethal dose rate. This is important especially in areas where water movement might dilute liquid formulations.
- “Mode of action” describes the specific mechanism that causes plant death. Although there are several modes of action, there are four associated with aquatic herbicides registered in Florida: synthetic auxins, photosynthesis inhibitors, enzyme inhibitors and cell membrane disruptors.
- An algaecide is a substance used for the control of planktonic algae. It is essential to the management of aquatic environments and there are several EPA-registered algaecides approved for use in Florida waters.
- Half-life is the time it takes for the concentration of a compound such as a herbicide to be reduced by half because of breakdown or deactivation of the molecule.
- Breakdown is the chemical transformation of a herbicide active ingredient into non-toxic compounds. This can happen through hydrolysis (breakdown due to contact with water), microbial breakdown (degradation from the action of microbes) and photolysis (breakdown from the absorbtion of energy from sunlight).

Carfentrazone

Carfentrazone is a contact herbicide that is used on a limited basis in Florida's aquatic plant management programs. It is occasionally applied via foliar applications to control water lettuce and sometimes water hyacinth. It is a contact herbicide and has very low toxicity to fish and waterfowl. The mode of action is as an enzyme inhibitor that is absorbed through the leaves and interferes with photosynthesis. Carfentrazone is fairly slow acting, causing symptoms in 2-5 days and plant necrosis in about 3-4 weeks. It is also selective in that it will not control comingled non-target plants like pickerelweed or grasses that may be mixed with water lettuce. Carfentrazone breaks down both through microbial action in soil and through hydrolysis with a half-life of 3-5 days in water.

Copper

Copper is a fast-acting, broad-spectrum, contact herbicide that kills a wide range of aquatic plants and algae. Although copper is a micro-nutrient required by living plants and animals in small amounts, too much copper kills plants by interfering with plant enzymes, enzyme co-factors, and plant metabolism in general.

Copper has long been used in natural and industrial waters for algae control, often applied directly to water as blue copper sulfate crystals. Today in Florida however, "chelated copper" is most often used for aquatic plant and algae management. "chelate" is a chemistry term meaning combining a metal ion, in this case, copper, with an organic molecule, triethanolamine or ethylenediamine. Chelated liquid copper products reportedly remain in solution longer than copper salts (when applied to hard water). Copper that is in solution (suspended in the water) for a longer time has greater effect on the aquatic plants and algae. Several different brands of copper are available for aquatic plant and algae control in Florida; however, the chemistry and mode of action of each is similar.

Because copper is an element, it will accumulate in the sediments regardless of its bioavailability. The FWC only permits the use of copper herbicides in waters when no alternative management options are available. Most notably, FWC

authorizes the use of copper herbicides to control aquatic plants near potable water intakes where use of other herbicide compounds may be restricted. There are no drinking water restrictions for copper herbicides when applied at label rates. Copper is toxic to non-target organisms, particularly in soft waters. Copper is considered highly toxic to mollusks and fish at relatively low doses. Levels of 1-5 ppm are toxic to fish, so copper is usually applied at concentrations 1 ppm or less. Copper chelates are broken down by hydrolysis and rapidly decline to ambient concentrations with a half-life reported from 2-8 days depending on conditions.

Diquat

Diquat, first formulated in the mid-1950s, is a fast-acting contact herbicide that is mainly used to control floating plants such as water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*) in Florida. Diquat is also used as a foliar spray for the control of some emergent plants. On the emersed portions of plants, diquat acts as a systemic herbicide; it enters the plant and diffuses within its aerial parts. Diquat interferes with photosynthesis by forming highly reactive and toxic free-radicals, such as peroxide and super oxide, in plant cells.

Time release granular herbicide

Diquat kills the aerial portions of plants in 24-36 hours. It is water soluble and diffuses rapidly through the water, quickly adsorbing into plant tissue. However, diquat is also strongly cationic and has a positive charge, so it quickly adsorbs to and is tightly held by the negative charges of clay and peat. For this reason, diquat is ineffective in muddy waters where it will bind to the suspended particles. Diquat becomes inactivated in the water, and breaks down slowly in sediments. Half-life in water is 1-7 days.

Time release granular herbicide

Diquat can also be used in a tank mix to control certain submersed plants. Diquat is relatively ineffective when used alone to control hydrilla (*Hydrilla verticillata*), but it can be used in combination with chelated copper for quick, albeit temporary control. A synergism has been reported between these two compounds such that hydrilla takes up more diquat and copper when they are applied together than when equal concentrations are applied separately. This is a good option for quick control to eradicate or contain small pioneer populations around boat ramps. Diquat and copper are not often considered for large scale hydrilla control because repetitive treatments increase the amount of copper in the system. Diquat is used in combination with potassium endothall and flumioxazin herbicides for hydrilla control. In each case, the addition of diquat provides more rapid and perhaps more thorough hydrilla control while introducing a second mode of action for herbicide resistance management.

Endothall

Endothall acid, first available as an aquatic herbicide in the 1960s, was originally used in agriculture as a plant desiccant. The active ingredient is relatively fast-acting and is formulated into two compounds for aquatic use: a potassium salt (potassium endothall) and an alkylamine salt (amine endothall). Products that contain potassium endothall are used primarily for control of submersed weeds as well as filamentous algae. Both compounds are available in liquid and granular formulations. Endothall herbicides interfere with plant respiration and photosynthesis by disrupting plant cell membranes. Endothall breaks down in water microbially and the half-life is approximately 4-7 days.

Endothall primarily functions as a contact herbicide, but is also somewhat mobile in plant tissues. Endothall is absorbed by submersed plants in lethal concentrations in 12-36 hours depending on the concentration applied. Usually, two or more applications are required annually to maintain hydrilla control.

Potassium endothall, normally used at rates of 2-3 ppm in water, is not toxic to adult fish, eggs or fry at rates of 100-800 ppm depending on fish species. Amine endothall is 2-3 times more active on plants, but 200-400 times more toxic to fish than the potassium salt. Amine endothall is toxic to fish at 0.5 ppm and carries an EPA label warning to not use it where fish are an important resource. Therefore, amine endothall is not used alone or for large scale hydrilla control in Florida lakes and rivers. It is usually applied at very low rates with potassium endothall to increase efficacy and to introduce a second active ingredient for herbicide resistance management.

Potassium endothall is used extensively in Florida's hydrilla management program since hydrilla's increasing tolerance to fluridone herbicide was confirmed in 2000 after repeated fluridone use. FWC is sponsoring extensive research and operational monitoring to develop new use patterns with potassium endothall alone and in combination with other herbicide active ingredients, especially penoxsulam. Objectives include improving cost-effectiveness, increasing selectivity, and reducing overall herbicide use. These objectives are more achievable when applying potassium endothall to large areas in cooler months (November - April) when hydrilla is actively growing but native submersed plants may be dormant. Cooler water slows microbial degradation of potassium endothall allowing lower rates (1.5 - 2.0 ppm) and providing a more thorough control of the hydrilla standing crop. Killing the stems and root crowns slows hydrilla's ability to recover, forcing regrowth to come from tubers, turions and fragments. Promising results have been achieved for large-scale hydrilla control using potassium endothall in combination with penoxsulam, and for smaller scale control when applied in combination with diquat.

Fluridone

Fluridone is a systemic herbicide, discovered in the mid-1970s. It was first registered for use in agriculture as a herbicide for weed control in cotton. Fluridone was later shown to be effective for the control of submersed plants and was registered by the Environmental Protection Agency for aquatic use in 1986.

As a systemic herbicide, fluridone is absorbed through the roots and shoots of plants and then translocated to shoot tissues. This inhibits the synthesis of light-shielding carotenoid pigments, and allows ultraviolet light to destroy essential chlorophyll pigments. Without chlorophyll, the plant is unable to photosynthesize, shoot tips turn pink or white, and the plant slowly starves and dies.

Fluridone is formulated as both a liquid, and as slow or fast-release pellets. It is used to control various submersed plants and some floating-leaved plants such as duckweed and *Salvinia* species, but it does not control algae. Application rates for plant control are much lower than those for other herbicides - in the parts per billion range compared to parts per million. However, contact time is measured in weeks or months rather than hours or days. Fluridone must be kept at prescribed concentrations for at least 45-80 days for optimum long-term control of hydrilla - even longer exposure is required for more mature plants with high carbohydrate reserves.

Fluridone is a broad spectrum herbicide, and has the ability to control a wide array of aquatic plants. It can be used selectively based on timing of application and application dose. Late winter or early spring fluridone applications provide the best selectivity for hydrilla control, as hydrilla exhibits robust growth while most non-target native plants are still dormant. Fluridone has a half-life in water of approximately 20 to 90 days; much longer but highly variable in sediments. This herbicide does not accumulate in fish or zooplankton and does not affect algae. It has a low toxicity to fish at typical treatment rates in Florida waters between 12 and 15 ppb. Fluridone is approved for use in waters at rates up to 150 ppb.

Two benefits of treating hydrilla with fluridone are the scope and duration of hydrilla control from one application. Large-scale applications can effectively provide several acres of control for each single acre treated, and provide results for as long as two growing seasons. This artifact is suspecterd to be the result of fluridone remaining in the water column at concentrations high enough to control the standing crop as well as subsequent sprouting tubers; thus slowing hydrilla's ability to recover from the control operation. Fluridone disperses readily throughout waterbodies, making spot or partial treatments difficult due to dilution. Because it requires a long contact time for optimum efficacy, fluridone's cost effectiveness decreases in fast-flowing waters where larger amounts are required to compensate for dilution.

Due to the reliance on large-scale fluridone applications for hydrilla control in Florida from the late 1980s through the 1990s, resistance to this herbicide developed. This was the first occurence for a bleaching-type herbicide and the first

for a plant species based solely on somatic mutations. Hydrilla produces only asexually in Florida leaving no avenue for gene recombination. Fluridone attacks only one gene location in hydrilla and several genotypes have been reported in Florida each with different fluridone susceptibilities. Repeated fluridone use effectively removed the more susceptible hydrilla genotypes, leaving the more tolerant plants to expand.

Management strategies using fluridone have evolved due to this unexpected development. Pre-application bioassays are essential to determine each hydrilla population's current level of fluridone tolerance. Applying too little fluridone is wasteful in that it will not control the target plant. Applying too much fluridone is not only wasteful, but it may also injure non-target vegetation in the system. Once applied, fluridone can break down via photylosis or microbial degradation. It can also dissipate from the application zone via wave action or water currents. Periodic monitoring is essential to ensure the proper fluridone concentration is maintained in the hydrilla control zone long enough to kill the hydrilla standing crop.

Glyphosate

Glyphosate is a broad-spectrum herbicide used in both fresh and brackish waters. It is used to control a wide variety of annuals and perennials, broadleaf weeds and grasses, trees and certain floating plants. It does not control plants which are completely submersed or have a majority of their leaves under water as it lacks activity in water. Selective management of plants using glyphosate is achieved only by careful application because, in general, glyphosate damages most plants it contacts.

Glyphosate is a systemic herbicide that moves throughout the plant to cause damage. It is applied to the foliage of floating or emergent plants. It is most effective when applied to actively growing plants which have not recently been mowed, grazed or otherwise disturbed. However, an effective management strategy for torpedograss control is to burn off the standing crop to the soil surface and wait for regrowth to expend the plant's carbohydrate reserves, applying glyphosate alone or in combination with imazapyr where appropriate to the actively growing leaves and stems. Visible effects on most annual weeds occur within 4 to 7 days, or more on most perennial weeds, and 30 days or more on most woody plants and trees. Heavy rainfall or irrigation within 2 hours of application may wash away the herbicide, requiring a repeat treatment; rainfall or irrigation within 6 hours of application may also reduce effectiveness.

Glyphosate is not applied to soil as it binds readily with soil particles, effectively inactivating the chemical activity. Glyphosate works by inhibiting the synthesis of specialized plant amino acids. Without the ability to manufacture these essential components, plant death occurs slowly over a period of 2-3 weeks. Animals do not produce these particular enzymes, explaining the very low toxicity of this herbicide to animals. Glyphosate breaks down in water microbially with no half-life reported.

Hydrogen Peroxide

Sodium carbonate peroxyhydrate is a granular substance made by combining sodium carbonate and hydrogen peroxide. When water is present, the compound breaks down into hydrogen peroxide and sodium carbonate. The hydrogen peroxide oxidizes and thus kills through contact as a cell membrane disruptor. The granular formulation is applied with blowers or spreaders to ensure uniform coverage. When applied according to label directions, no harm is expected to birds or freshwater fish and invertebrates. Hydrogen peroxide immediately breaks down in water via hydrolysis with no half-life .

Products containing sodium carbonate peroxyhydrate are used in aquatic systems for control of planktonic algae, especially blue-green algae. They are also used for controlling problematic algae in domestic water supply sources. Planktonic algae control is not a priority of the FWC; therefore, FWC has not permitted or funded the use of hydrogen peroxide algaecides. Consequently, little is reported in regard to use patterns of this compound in Florida waters.

Imazamox

Imazamox was registered for aquatic use in 2007. Imazamox is a systemic herbicide that is applied to plant foliage to control floating or emersed plants, or to the water for submersed plant control. It works by inhibiting a plant enzyme called acetolactate synthase (ALS) which regulates the production of essential amino acids in plants. When ALS is inhibited, plants die. Animals do not produce these particular enzymes, so imazamox has low toxicity to animals. Enzyme inhibiting herbicides act very slowly. Imazamox is broken down in the water by photolysis and microbial degradation. Its half-life in water is 7-14 days.

Imazamox is generally absorbed rapidly into plant tissues, and growth of susceptible plants is inhibited within a few hours after application. Meristematic areas become chlorotic after 1-2 weeks followed by general chlorosis and death. In Florida aquatic plant management programs, primary uses of imazamox include foliar applications to control Chinese tallow trees (32-64 oz / acre) and wild taro (96-128 oz / acre), as well as submersed applications for hydrilla control. At concentrations of 50-150 ppb, imazamox acts as a growth regulator for hydrilla, persisting for up to several months. At concentrations of 150-250 ppb, imazamox acts with herbicidal activity, killing hydrilla in a few weeks after application.

Imazapyr

Imazapyr was discovered in the 1970s and first sold in 1984. It is a relatively new herbicide for control of aquatic plants in Florida. Imazapyr is used for difficult to control herbaceous aquatic plants such as torpedograss (*Panicum repens*) and woody species growing in water, such as melaleuca (*Melaleuca quinquenervia*). It can also be used for floating-leaf species where it is mixed in low concentrations with a glyphosate-containing product. Imazapyr is not recommended for control of any submersed aquatic species. Cautions on the label regarding damage to non-target vegetation and irrigation restrictions must be carefully followed and limit tryclopyr use to rural settings where irrigation is not a consideration. Injury to plants usually does not appear for at least 1-2 weeks. It breaks down through hydrolysis and has a half-life in water of 2-3 days.

Penoxsulam

Penoxsulam was registered for aquatic uses in 2009. It is currently only sold under the trade name of Galleon™. It is a systemic herbicide that is applied to plant foliage to control floating or emersed plants, or to the water column for submersed plant control. It works by inhibiting a plant enzyme called acetolactate synthase (ALS) which regulates the production of essential amino acids in plants. When ALS is inhibited, plants die. Animals do not produce these particular enzymes, so penoxsulam has low toxicity to animals. Enzyme inhibiting herbicides act very slowly. Control is highly dependent on contact time. For some species and circumstances, split or multiple applications are necessary to keep the herbicide concentration at a sufficient level for 90-120 days for optimum performance. Penoxsulam is broken down in water both microbially and through photolysis and its half-life in water is about 25 days.

Research is underway to apply penoxsulam in combination with potassium endothall for hydrilla control in Florida waters. There are several advantages to this strategy. Resistance to ALS herbicides has been reported in terrestrial plants and a second active ingredient assists in resistance management for both herbicides. Combining with potassium endothall reduces the period of time necessary for penoxsulam to be exposed to hydrilla to about 7-14 days, reducing the effects of degradation and dissipation and the need for additional applications to sustain appropriate penoxsulam concentrations in the water column. Applying these herbicides in combination requires less of each herbicide to control hydrilla and seems to increase selectivity to conserve non-target native plants.

Triclopyr

Triclopyr has been widely used for the control of herbaceous and woody plants in non-cropland sites, forestry and pastures. It is effective for controlling emersed aquatic plants, some floating plants such as water hyacinth (*Eichhornia crassipes*), and some submersed aquatic weeds such as Eurasian watermilfoil (*Myriophyllum spicatum*). It is a systemic herbicide that breaks down in water by photolysis, with a half-life of 6-8 days. Tryclopyr has been used extensively in Florida's upland invasive plant management program for basal and foliar applications to control Brazillian pepper. However, it is only occasionally applied in aquatic situations in Florida due to extensive irrigation restrictions of 120 days for treated waters. It is an organo-auxin growth regulator and causes plant death by causing rapid, uncontrolled growth.

2,4-D

2,4-D, or 2,4-Dichlorophenoxyacetic acid, is the oldest organic herbicide registered in the United States for aquatic use. It is primarily used for weed control in food crops (grains, corn, sorghum, rice, sugarcane), turf, non-crop areas and in certain aquatic environments. The two main formulations currently in use for aquatic sites in Florida are the liquid dimethylamine salt, and the granular butoxyethyl ester. The granular formulations of 2,4-D sink to the bottom and slowly release herbicide into the water; granular 2,4-D is applied for the control of water milfoil species, and for some floating-leaved species. The liquid formulations of 2,4-D are mixed with water and sprayed onto the leaves of water hyacinth and other broadleaf aquatic weeds. It is used especially to control water hyacinth in Florida's aquatic plant control program.

2,4-D is a systemic herbicide. It is absorbed by roots and leaves and then translocates and accumulates mainly in the growing points of shoots and roots. 2,4-D interferes with the plant's ability to maintain proper hormone balance, and plants will undergo uncontrolled growth in some tissues and halted growth in other tissues. The result is injury to the growing regions of the plant and then a gradual death, usually within 3-5 weeks.

2,4-D is sometimes confused with "Agent Orange," the military's name for a defoliant mixture that was created and used during the Vietnam War. During the manufacture of Agent Orange, it became contaminated with a cancer-causing dioxin, tetrachlorodibenzo-*p*-dioxin, known as TCDD. While 2,4-D was one of the components of Agent Orange, it is not Agent Orange, nor does it contain TCDD, nor has it been shown to cause cancer. After numerous lifetime feeding studies in rats and mice, the EPA recently classified 2,4-D as Class D - Not Classifiable as to Human Carcinogenicity. Breakdown of 2,4-D in water occurs microbially and through photolysis and its half-life in water ranges from 7-48 days.

Much of the material for this site was derived from the recently updated "**Aquatic Pest Control – SM 3**" manual by Langeland and Fishel, 2010, available through the University of Florida IFAS bookstore.

A current list of Approved Herbicides for Florida Waters including some of the trade names of approved formulas can be found **here**.

Browse other sections of this site for information relating to the **chemical control** of invasive plants including water use restrictions, herbicide toxicity and the **EPA registration process**.

Reference to products in this publication is not intended to be an endorsement. Persons using such products assume responsibility for their use in accordance with current directions of the manufacturer.

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