
WEED MANAGEMENT – LESSONS FROM THE USA

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John is a Research Biologist with the US Department of Agriculture, Agricultural Research Service, Exotic and Invasive Weed Research Unit in Davis, California. He has been involved in research on the ecology and management of invasive aquatic plants around the country for over 25 years. John has a Bachelor of Science degree from Wheaton College, Wheaton, Illinois, and Master of Science and Doctor of Philosophy degrees in Botany from the University of Wisconsin-Madison. Before joining ARS in California in April 2014, he was an Associate Professor of Research and Extension in the Geosystems Research Institute and the Department of Plant and Soil Sciences, Mississippi State University. Prior to that, he was an Assistant Professor of Biology at Minnesota State University-Mankato from 2000-2003, and a Research Biologist with the US Army Engineer Research and Development Centre from 1991 to 2000.

He has served as an Associate Editor of the Journal of Aquatic Plant Management (1996-1997, 2011-current), Editor of the Journal of Aquatic Plant Management and Board Member (1997-2002), and a Director and Board Member (2010-2013). He has also served as the Chair of the Student Affairs Committee (1996-1997), the Legislative Affairs Committee (2010-2013), and the Membership Committee (2010-2013). He is currently the Vice President of the Aquatic Plant Management Society, a chapter of the Weed Science Society of America. He has been a Member of the Board of Directors for both the Texas Aquatic Plant Management Society (1993-1994) and the Mid-South Aquatic Plant Management Society (MSAPMS, 2005-2007). He has served as Chair of the Scholarship Committee for both TAPMS (1993-1996) and MSAPMS (2005-2014). He was also President-Elect (2007-2008), President (2008-2009), and Immediate Past President (2009-2010) of the MSAPMS.

He has also served as an Associate Editor for the journals Invasive Plant Science and Management, and Wetlands. He was Secretary of the Weed Science Society (2012-2014), Board of Director Member of the Council for Agricultural Science and Technology (CAST, 2011-2014), APMS Representative to CAST (2008-2011), and a Board of Director's Member for the Texas River and Reservoir Management Society (1994-1996).

ABSTRACT

Aquatic weed management has a more than 100 year history in the United States, with the first efforts by the US Army Corps of Engineers to remove water hyacinth from southeastern United States waters in 1899. Through these efforts, several important lessons have been learned. First, plant management requires a plan of action that considers the level of infestation, makes site-specific management recommendations, and considers all potential techniques for use both spatially and temporally.

A good plan also includes public involvement and education. Integrated Plant Management has become the model for aquatic plant management. It includes developing an understanding of factors that exacerbate plant growth, and methods to mitigate plant

growth and enhance management success, including an understanding of target plant biology and phenology. In addition, most natural water bodies will require selective management, targeting the weed and minimizing the impact on desirable native plant species.

Steady funding to invest in plant management is a necessity. Disruptions to funding will result in larger problems in the future. An important part of the investment is a consistent investment in applied research, with the target of improved plant control. In the United States, an attempt is made to consider biological, chemical, mechanical, and physical techniques for management of aquatic weeds. The use of these techniques is restricted by economic, environmental, and regulatory thresholds.

While biological control may appear to be the preferred approach, many weeds do not have an effective biological control agent. Even effective biological control agents do not provide uniform control across the ecological range of a weed. Chemical control is still the most widely used technique in the United States. Chemical control is effective and relatively inexpensive, but increased regulatory restriction has impacted the use of herbicides in some areas.

Mechanical techniques use machines to remove plant growth. In particular, harvesting is widely used as an immediate control to plant growth. However, harvesting is relatively slow and expensive, and may have a significant fish and aquatic animal bycatch. Physical control involves altering the environment to reduce plant growth. In the United States, this includes the use of benthic barriers, shading materials, and drawdown. Each of these techniques can be considered tools in our plant management toolbox, and all have their place and utility.

TRANSCRIPT

My talk today gives an overview of aquatic plant management and aquatic weed problems in the United States. I will talk about developing integrated management plans and what that means. I want to emphasise the importance of research as a part of ongoing aquatic plant management programmes and look at some of the commonly used management techniques, both their positive and negative aspects.

I must make a few caveats to begin with. The first is to point out that the United States government and my parents spent a small fortune to teach me to speak and write English, so I would appreciate your tolerance of that. I have heard many people helpfully try and correct my poor use of English but it is hopeless; so, I will forewarn you.

Please do not construe anything I say as a specific recommendation of what you should do; that would be very arrogant of me to fly in and tell you what you need to do. Rather, I will tell you what I have found in the United States, and not everybody there might agree with what I say either. Any comments I make are my own observations and opinions and not the official policy of the United States government. No one has ever called from the higher echelons to ask me what I think and I doubt that is going to change in the near future. Lastly, any mention of a product name is certainly not an endorsement by the United States government or the United States Department of Agriculture.

There are two publications that are readily available that I would highly recommend:

Benefits of Controlling Nuisance Aquatic Plants and Algae in the United States.
2014. Council for Agricultural Science and Technology. www.cast-science.org

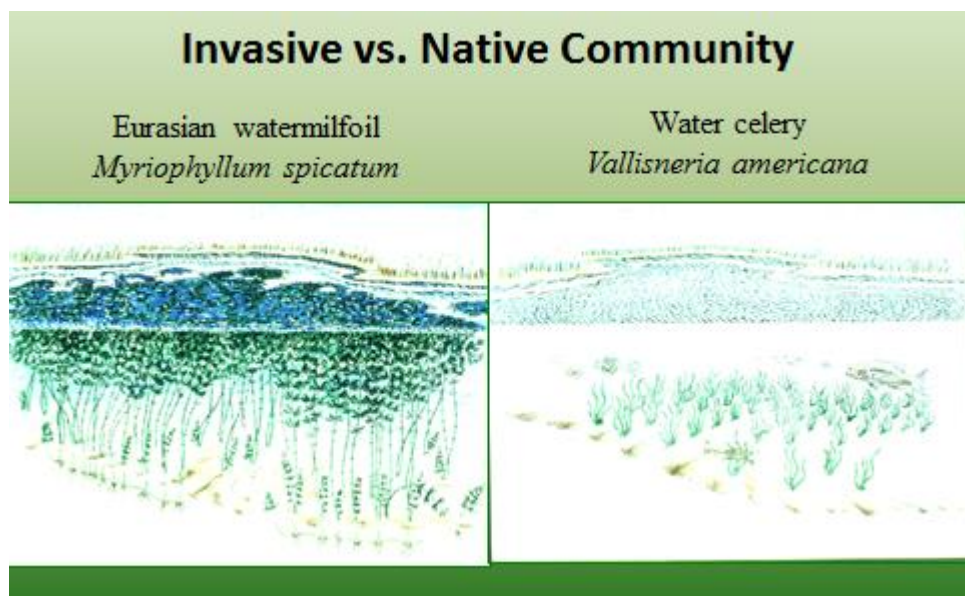
The first is an article written by the Council for Agricultural Science and Technology. I was the liaison between the Council for Agricultural Science and Technology and the authors on the production of this publication. It is about the benefits of controlling nuisance aquatic plants and algae in the United States, showing that we do, in fact, derive many benefits, both economic and ecological, from managing invasive and nuisance species.

The second is a Best Management Practices handbook and is a multi-author publication on different species as well as different management techniques. It is written by experts in the field: the biological control section is written by entomologists, the herbicide section is written by weed scientists, and so on.

Benefits of Aquatic plants

- Stabilize lakes sediments, reducing re-suspension, keep the nutrient content in the water lower
- Increase sedimentation, reducing turbidity, thus improving transparency
- Provide habitat for insects, forage fish, fish spawning and YOY fish
- Provide food for waterfowl and other animals

We are talking about controlling invasive aquatic plants, but I want to point out that there are many benefits of aquatic plants. Our goal is not to kill all the vascular plants in the lake, but rather to preserve the native plant community that typically is well behaved. They are a great place for aquatic organisms to hang out. We want to preserve the native plant community, and we are not seeking to overdo the management of plants in general, but rather are targeting the invasive aquatic plants, plants that are from somewhere else.



Slide 1

For instance, in the United States (**Slide 1**) Eurasian watermilfoil will form a very dense surface canopy in contrast to our native water celery. Water celery is a very desirable plant in the United States both for fish habitat as well as for waterfowl food and very rarely causes a nuisance. It is important to stress that invasive aquatic plants are not a direct result of nitrification. Nuisance problems are a direct result of an invasion of a novel species. In the United States we find invasive species in very oligotrophic lakes as well as very eutrophic lakes, across the entire span of water quality. The assumption is often made that the plants are there because there are too many nutrients in the water. Most of these species derive their nutrients from the sediment rather than the water so they are not a result of increased nutrients in the water.

Economic Impacts of Invasive Plants

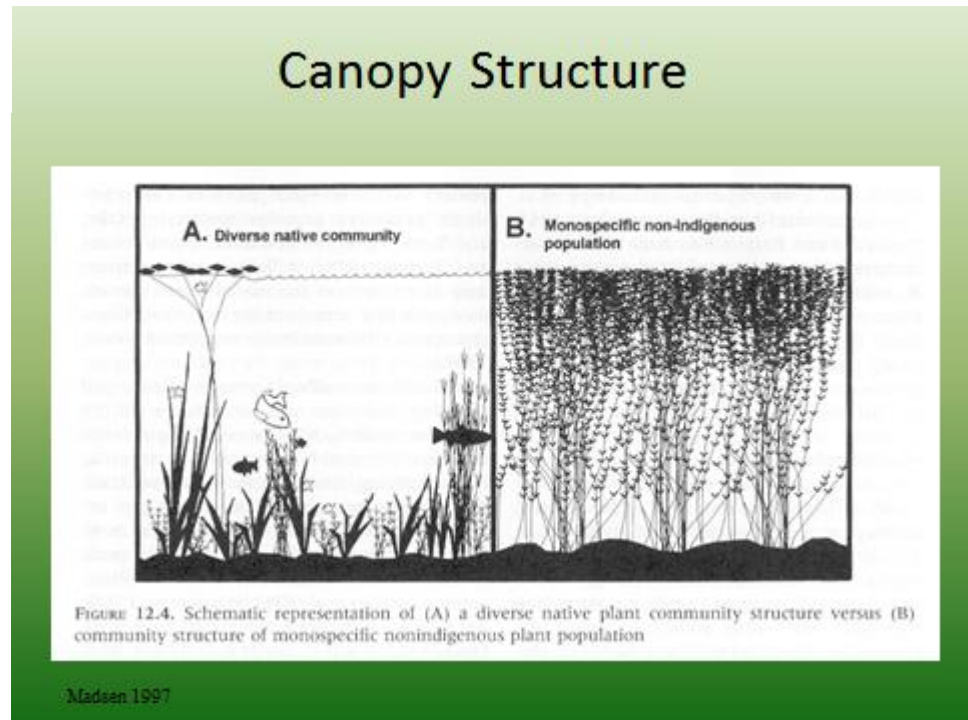
- Obstructing commercial and recreational navigation
- Interfering with hydropower generation
- Disrupting the flow of irrigation
- Disrupting the flow and quality of drinking water
- Exasperating the problems of controlling floods
- Encouraging the spread of insect-borne diseases
- Impairing recreational use
- Decreasing property value
- Affecting human health

Ecological Effects of Invasive Plants

- Degrades water quality
- Reduces species diversity of plant and animal
- Suppresses native plant species
- Potentially impacts endangered species
- Alters animal communities
- Alters ecosystem services

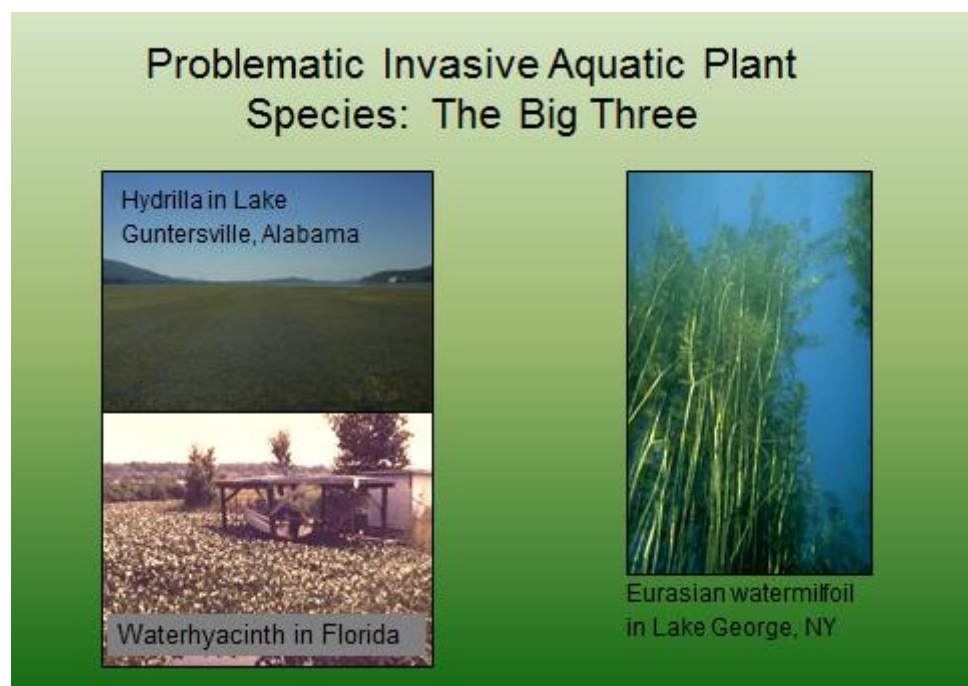
Both the economic and ecological effects stem from the growth form of the invasive species. (**Slide 2**) The invasive species, which is captioned under B, forms a very dense surface canopy and tends to exclude other species, as opposed to the diverse native community under A which has a variety of open and vegetated spaces that provide a more optimal habitat for organisms. So both the nuisance and ecological problems are derived from the formation of these dense mono specific surface canopies.

Slide 2



In the United States we have what I call the Big 3. **(Slide 3)** The total acreage of nuisance problems is largely dominated by these 3 species, although there are certainly many others. The big three are hydrilla, water hyacinth and Eurasian watermilfoil. Water hyacinth is the number one aquatic weed worldwide, particularly in tropical and sub-tropical regions. The doubling time, that is the length of time it takes to get twice as much biomass, or twice the number of hectares covered, is 7 to 8 days. You may come and look at the problem and then come back the next week and there will be twice as much of the same problem.

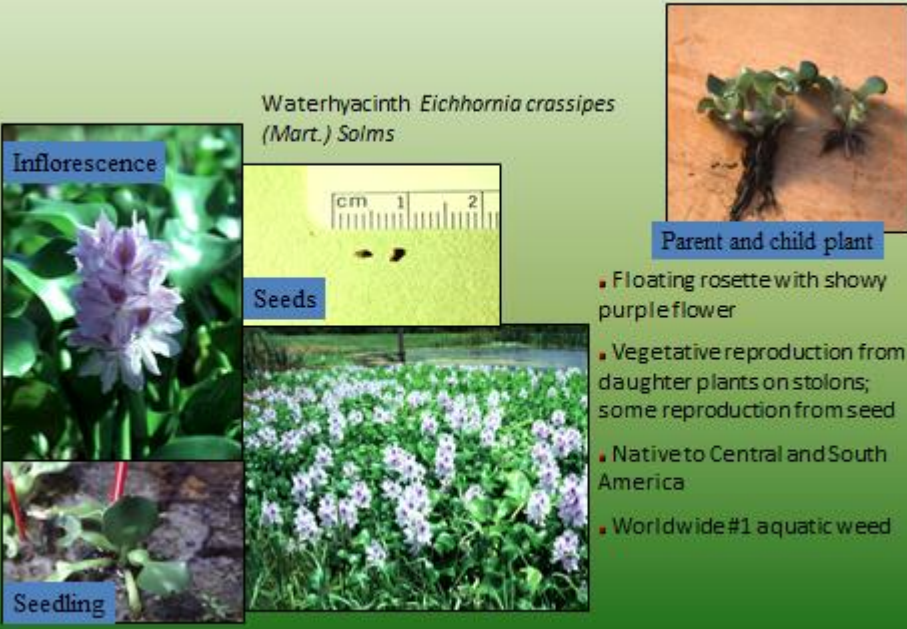
Slide 3



Slide 4 explains in part why water hyacinth is such a tremendous weed. The reproduction is almost entirely vegetative. It was originally from the Amazonian basin in South America.

Slide 4

Waterhyacinth *Eichhornia crassipes*
(Mart.) Solms



Inflorescence

Seeds

Seedling

Parent and child plant

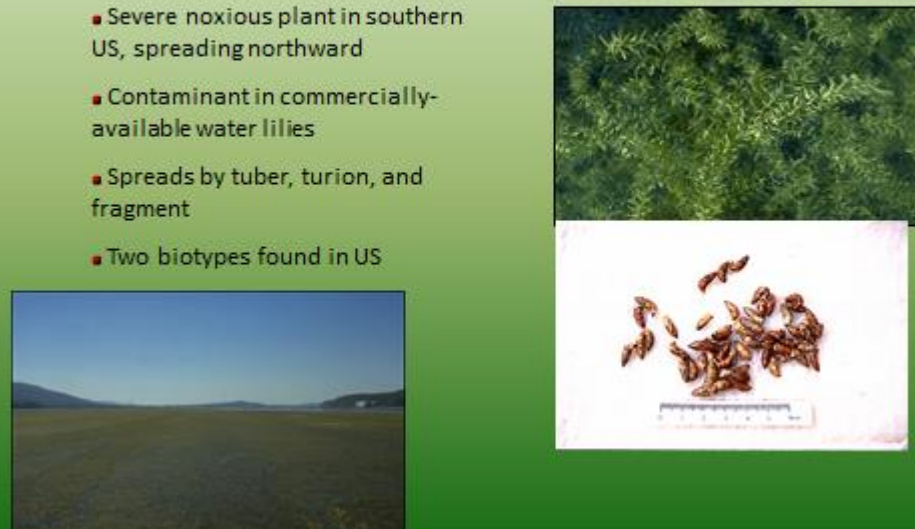
- Floating rosette with showy purple flower
- Vegetative reproduction from daughter plants on stolons; some reproduction from seed
- Native to Central and South America
- Worldwide #1 aquatic weed

Hydrilla (**Slide 5**) is a submersed plant found in the United States and has two biotypes, monoecious and dioecious, two different varieties, and each a severe nuisance. It was thought for many years that hydrilla was a weed of the southern United States but it is now expanding well into the northern states.

Slide 5

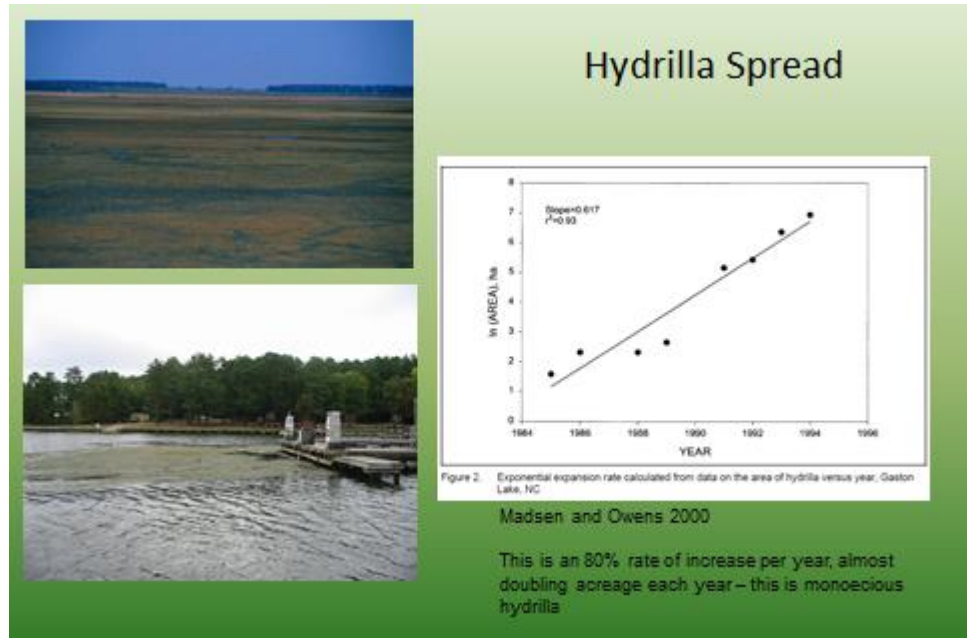
Hydrilla

- Hydrilla (*Hydrilla verticillata* (L.f.) Mich.)
- Severe noxious plant in southern US, spreading northward
- Contaminant in commercially-available water lilies
- Spreads by tuber, turion, and fragment
- Two biotypes found in US



The picture on the upper left hand side of **Slide 6** is a lake in Florida. The Florida lakes tend to be fairly shallow averaging 3 metres in depth, and there will be a surface canopy of hydrilla for much of the year across 80% of the lake. Likewise at the bottom, the monoecious hydrilla forms dense surface canopies though typically not quite as extensive. It can spread very vigorously as well.

Slide 6



The third is Eurasian watermilfoil. Those of you who know my background will understand why I have a slight affection for this plant even though it is a vigorous weed. I have been studying this plant now for 25 years and while some people might call it a weed I call it my bread and butter. **(Slide 7)** It is a submerged evergreen perennial, spreading by vegetative means. It forms stem fragments by creating an abscission zone, much like the process by which leaves fall off trees in the fall. These are purposeful propagules and the canopy will shatter into thousands of fragments that drift off and form new colonies.

Slide 7

Eurasian Watermilfoil (*Myriophyllum spicatum* L.)

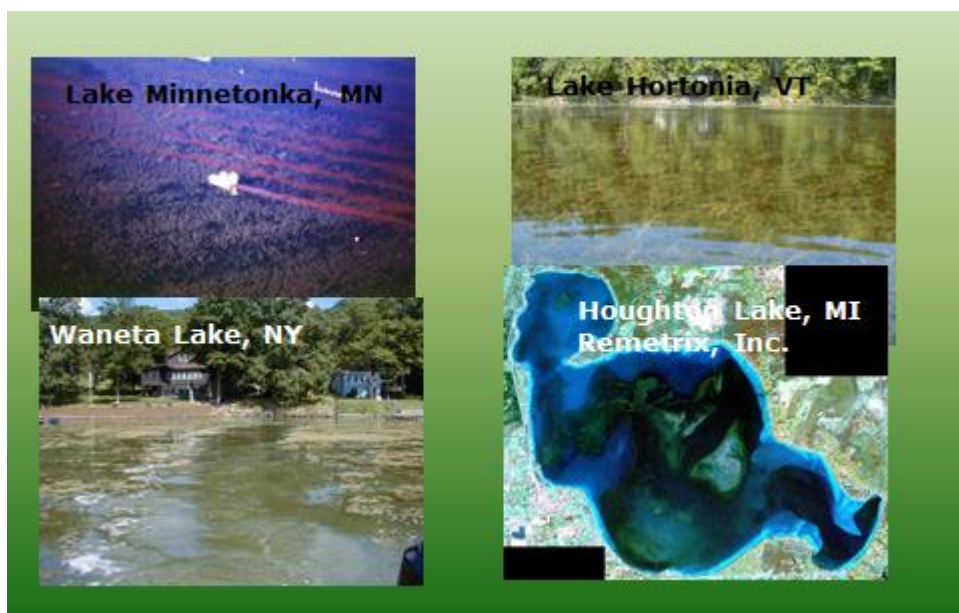
- Eurasian watermilfoil (*Myriophyllum spicatum* L.)
- Submersed evergreen perennial
- Spreads by root crown, runner, and fragment
- Nonnative from Eurasia

Slide 8



What impresses me about Eurasian watermilfoil is the vast diversity of habitats into which it will thrive. **(Slide 8)** From cold water oligotrophic rivers like the Fall River in California to some of the river reservoirs like the Pend Oreille River in Washington, shallow pot hole lakes in the prairies of Illinois to brackish water estuaries like Mobile Bay in Alabama.

Slide 9



Slide 9 at the top left shows the very large kettle lakes of Lake Minnetonka in Minnesota and the ongoing treatment using a fluorescent dye to help track where the herbicide goes. It is in front of the home of a professional football player and a very high value property.

Below that is Waneta Lake, one of the Finger Lakes in New York which are very deep with steep sides. In Vermont those lakes are on a granite rock layer with very poor nutrients. The last one is Houghton Lake in Michigan which is about 8,000 hectares and the 4,000 hectares of Eurasian watermilfoil can be seen in the satellite image of that lake.

We have dozens of other invasive aquatic plants including emergent, riparian, floating, free-floating and submerged plants that span the range from aquatic algae through flowering plants to the planktonic algae (**Slide 10**).

Slide 10

And many other species...

- Dozens of invasive aquatic plant species in the United States and Canada
- Span the range from emergent, floating, free-floating, and submersed
- Span the range from macroalgae to liverworts, ferns, fern allies, gymnosperms, monocots, and dicots



Alligatorweed (*Alternanthera philoxeroides*)

Curlyleaf pondweed (*Potamogeton crispus* L.)

The paradigm in the United States for developing pest management plans is integrated pest management. This is a definition I took off the US Department of Agriculture web page and the more I read it the more confused I become. Basically the idea is to use multiple tactics to optimise the control between the different pests that are on a crop plant in an ecologically and environmentally sound manner.

Integrated Pest Management (IPM)

'A decision-based process involving coordinated use of multiple tactics for optimizing the control of all classes of pests (insects, pathogens, weeds, vertebrates) in an ecologically and economically sound manner.'

US Department of Agriculture

IPM was designed for cropping and agro ecosystems and for wildland weeds or aquatic weeds. The question is what is relevant in aquatic plant management from this paradigm? The two things of most relevance are to understand the invasion process of these invasive plants, and secondly, to understand how we can use the life history of these plants to improve management.

Main Points of Integrated Pest Management

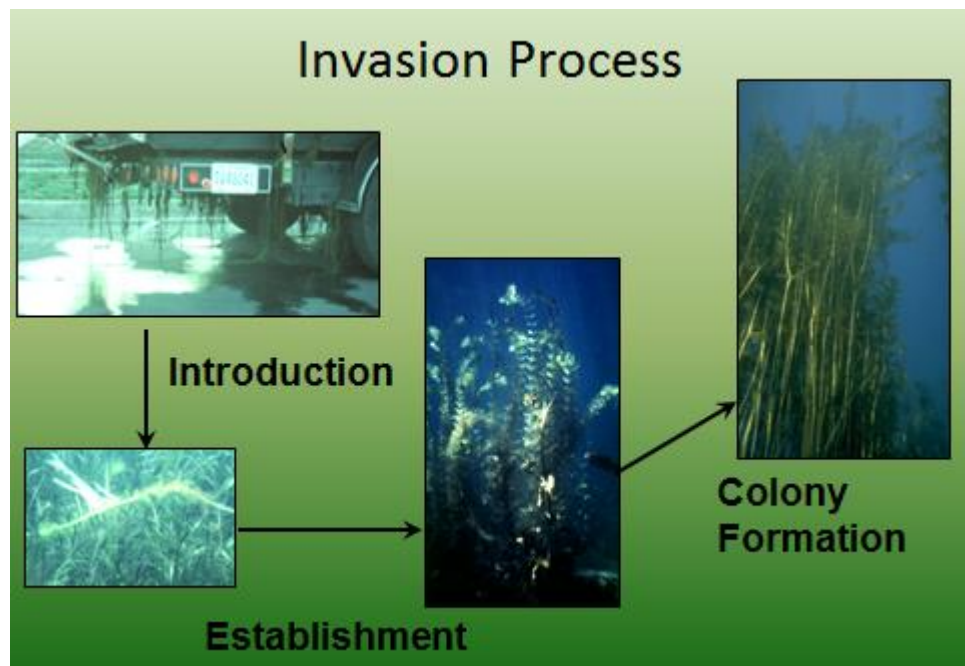
- Simultaneous management of multiple pests
- Regular monitoring of pests, and their natural enemies and antagonists as well
- Use of economic, ecological, or treatment thresholds when applying pesticides
- Integrated use of multiple, suppressive tactics to control pests

IPM for Aquatic Plants

- IPM is largely designed for cropping systems and agroecosystems
- What does this mean for aquatic plant management?
 - Ecological understanding of invasion process
 - Ecological life history and management

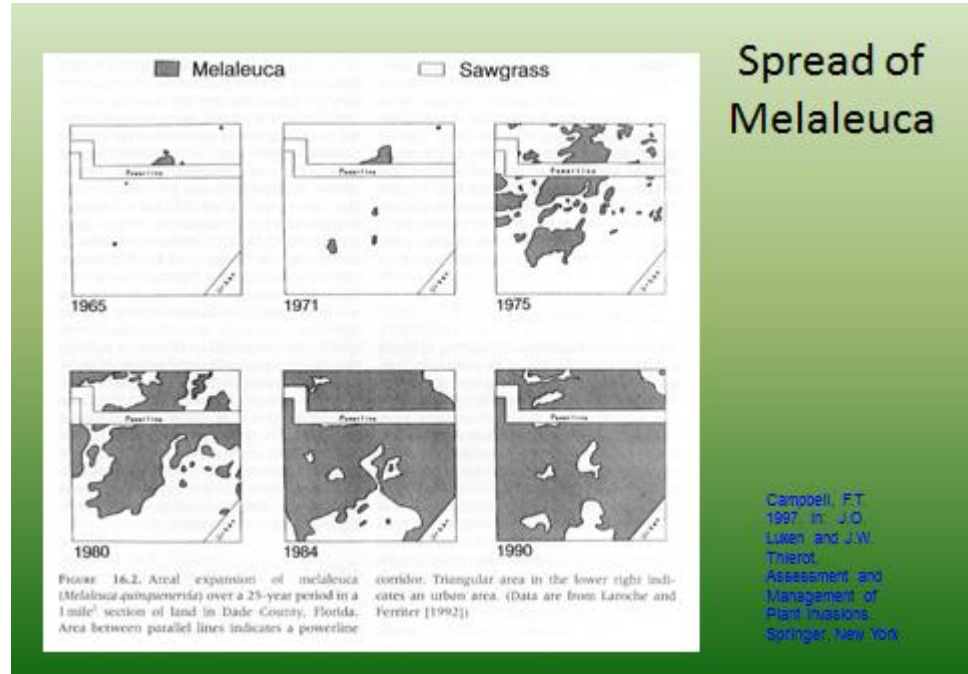
Slide 11 shows the invasion process where a plant is introduced to a lake and that plant propagule establishes and grows into larger and larger colonies. The predominant way of moving plants around is on boats and boat trailers. The licence plate on that trailer says, 'US Government'. In the words of the great philosopher Pogo, 'We have met the enemy and he is us'.

Slide 11



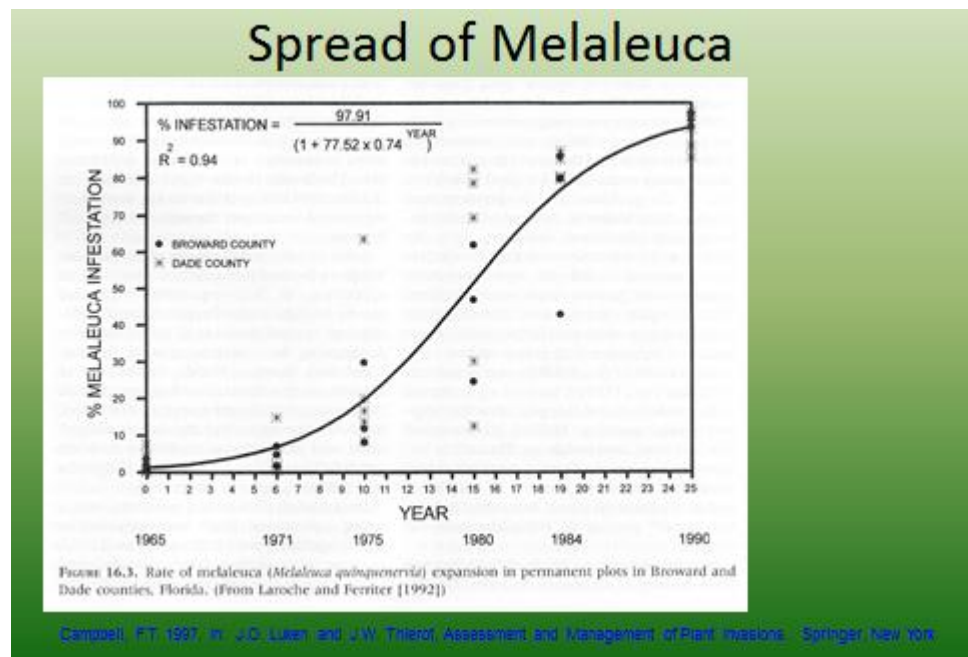
Slide 12 is about the spread of melaleuca. It can grow as a wetland tree and in this case in the Everglades of Florida. The authors of this paper studied the appearance of colonies in a large section of the Everglades and how an individual colony will spread and new colonies form and coalesce over time until eventually the entire area is dominated by this plant.

Slide 12



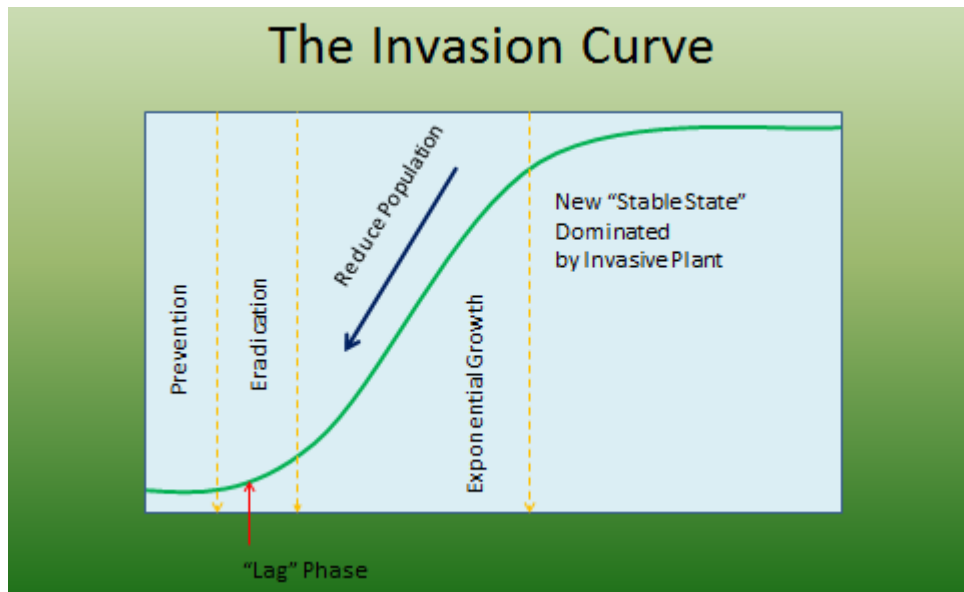
This process may look similar to what you might experience with invasive plants in your lakes. **Slide 13** details how much of the area is covered and put it on a timeline. Those who have taken biology will say, 'I've seen that before'. It is the Sigmoid growth curve where plants start out in a lag phase not spreading particularly rapidly. Then they grow at an exponential rate, faster and faster until they cover the entire available habitat and can no longer spread.

Slide 13



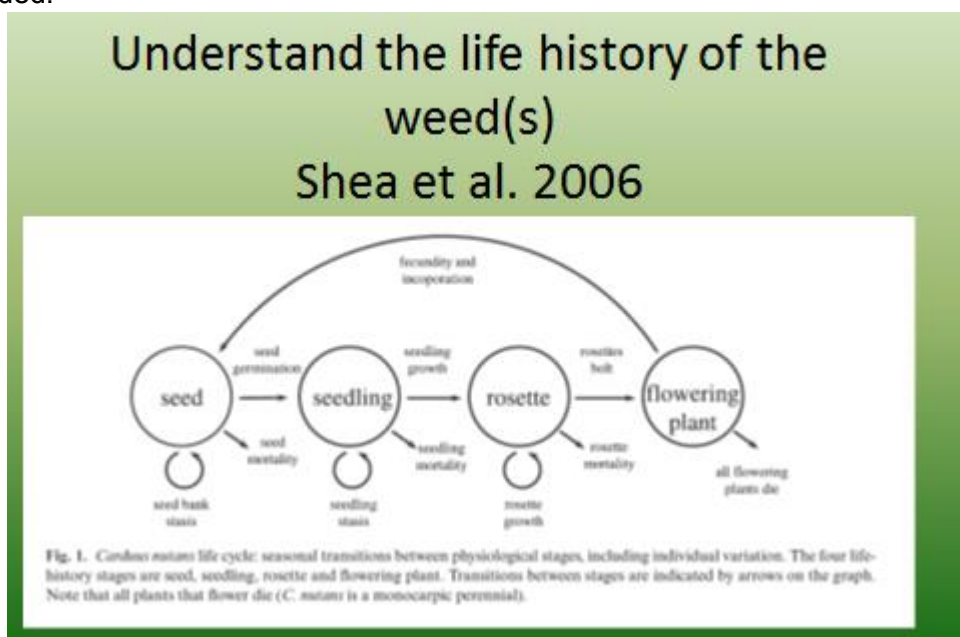
Slide 14 is a restatement of this invasion curve which show a few features of interest. The first is that the best time to control a plant is before we have it, namely, prevention. Second, when a species first appears in the lake is the next best time to manage that plant. Do not wait to see whether or not that plant is going to be a nuisance, it needs to be managed right away. As the exponential growth continues the management should try to reduce the population down to a level that can be sustainably managed. Ultimately if nothing is done a new stable state is reached, one dominated by the invasive plant. The larger the infestation gets the more expensive and difficult it is to manage that population: either eradicate or maintain at a lower level.

Slide 14




The second thing from IPM that we can incorporate into aquatic plant management is to develop an understanding of the life history of the pest (**Slide 15**) and target stages where it is more susceptible to manage and affect long term management to reduce the population. This is difficult particularly for plants like lagarosiphon and egeria which do not have a vegetative propagule. It is hard to know how we could apply this and more research is needed.

Slide 15



There are many instances in which we can identify the critical propagule, the critical life stage. **Slide 16** is an example from the Minnesota Lakes in the United States managing curlyleaf pondweed. This is an herbaceous perennial, which rather than over-wintering, it over-summer as a dormant turion. In its life history the turion sprout in the fall growing slowly to a low level over winter. Then they grow rapidly to the surface in early spring, flower, form the turion and then die back.

Slide 16

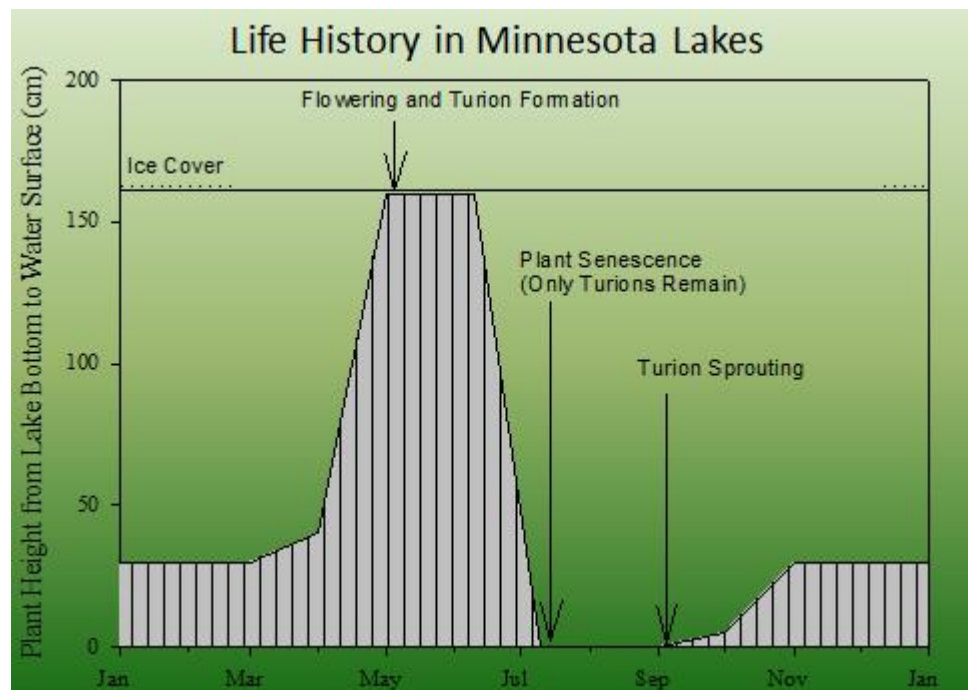


Potamogeton crispus L.
Curlyleaf pondweed

- Family Potamogetonaceae
- Monocot
- Herbaceous perennial, from axillary turion; "oversummering" instead of overwintering
- Native to east Asia
- Exotic to northern United States and Canada
- Rooted submersed plant in 0.3 to 5 m depth
- Nuisance forming species, impacts native plant communities and summer "internal loading"

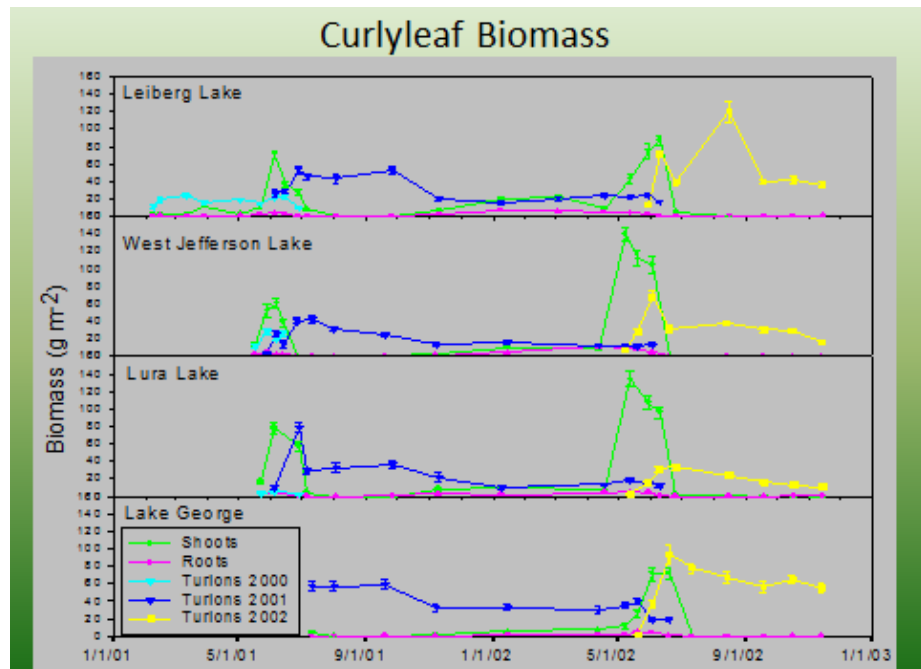
Fig. 381. *Potamogeton crispus*: a, b, upper portion of plant; c, young inflorescence; d, inflorescence; e, leaf. f, section of stem with leaf bases and stipules; g, winter turion; h, stem, cross-section; i, j, fruit (Marsch).

Slide 17



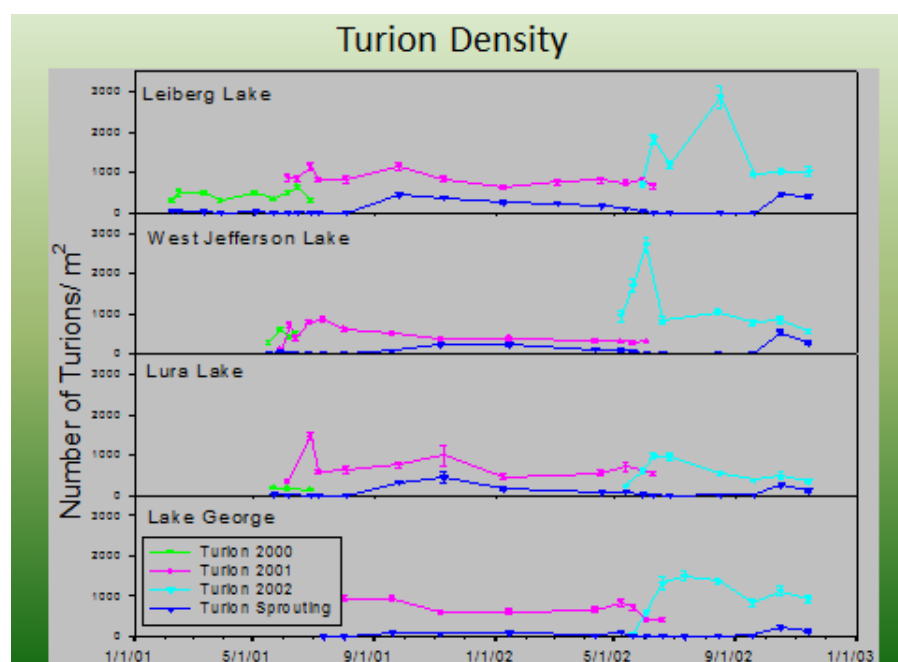
Traditionally in Minnesota and elsewhere in the northern states folks appear at their lake cabins around the end of May and see a mass of curlyleaf pondweed. They pick up the phone, call the company that manages aquatic plants and say, 'Hey I've got a nuisance problem'. The authorities come by mid-June and apply the herbicide and the plants die. Another great job done! Well I have news for them; the plants were going to die anyway. They could have sprayed water and achieved the same effect. I was with the US Army Corps of Engineers at the time and we suggested a change in the way to manage this weed to effect long term control of curlyleaf pondweed (**Slide 17**).

Slide 18



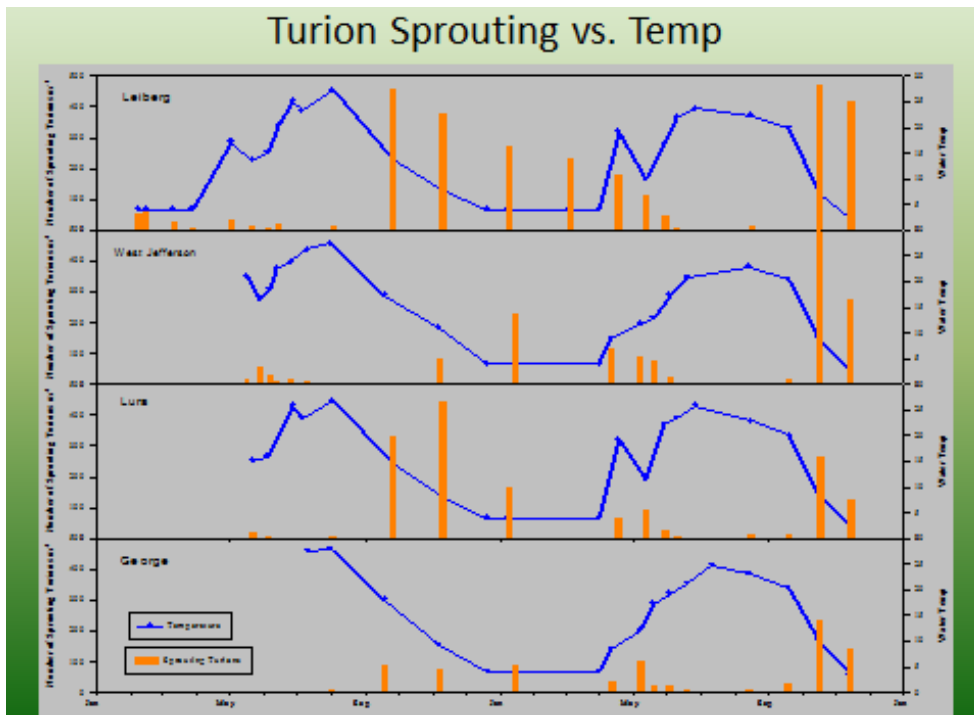
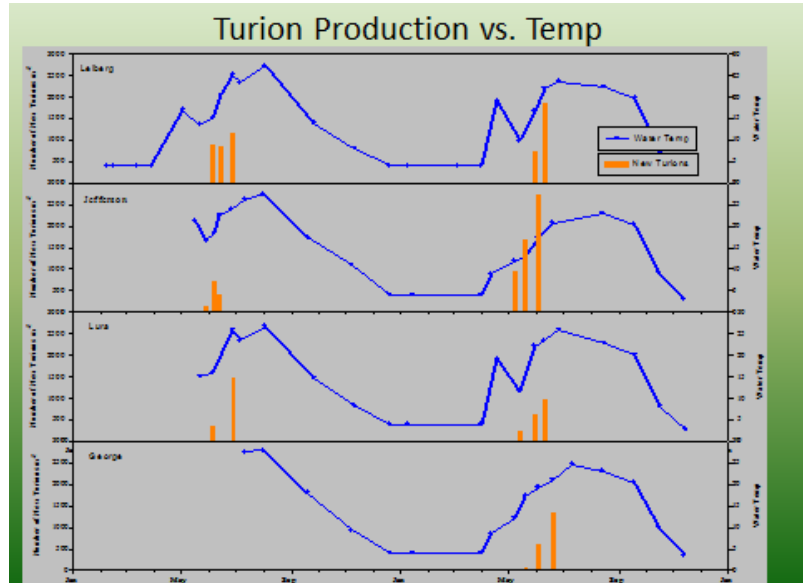
Slide 18 is a study I did when at Minnesota State University. The bright green line is the biomass of the shoots which have very short periods of time growing up into the water column. The other long lines are the very high biomass of turion, the vegetative propagule. There will be thousands per square metre of the turion from this plant. (**Slide 19**)

Slide 19



Slide 20

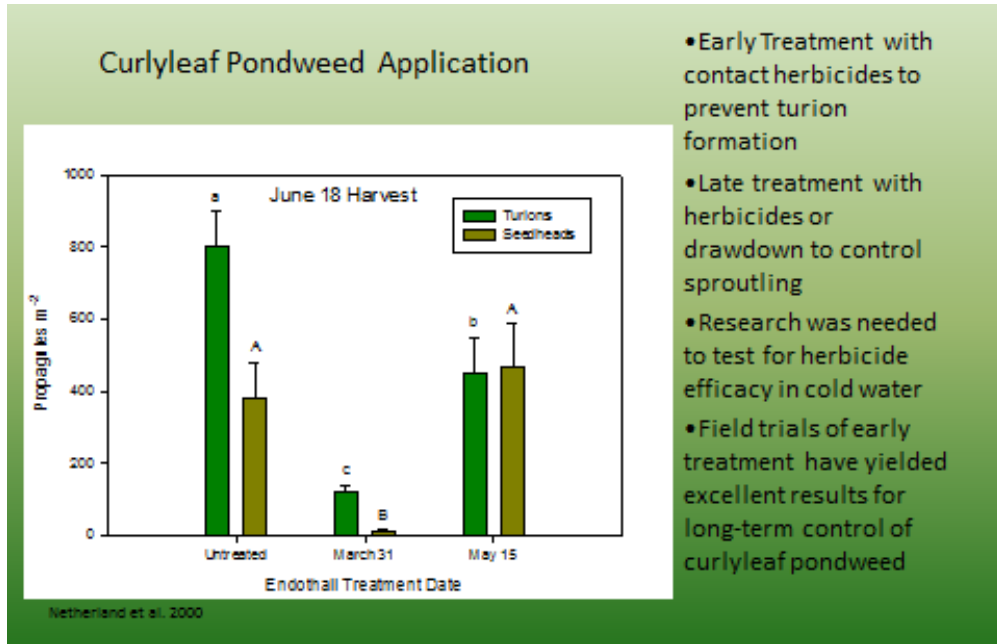
Turions are very sensitive to increasing water temperature in the spring and form in a very synchronised time, over about a 4 to 6 week period. **(Slide 20)** If we use some management strategy before that time we can prevent turion production and affect long term management



Slide 21

The next best time is when the turions sprout, which is the rational time, for instance, for weed prevention in lawns. We apply a herbicide that kills the seedlings as they sprout. With curlyleaf pondweed this would not be effective because the sprouting occurs over a very long period of time. **(Slide 21)**

The herbicide labels for both diquat and endothall say not to apply if water temperatures are less than 65 degrees Fahrenheit (18 degrees Celsius). We did some research to show that the herbicide would be effective at much lower temperatures, even at 10 degrees Fahrenheit. The company went back and revised their labels so that we could use this tool to control curlyleaf pondweed in long term effective management.



- Early Treatment with contact herbicides to prevent turion formation
- Late treatment with herbicides or drawdown to control sprouting
- Research was needed to test for herbicide efficacy in cold water
- Field trials of early treatment have yielded excellent results for long-term control of curlyleaf pondweed

We then did trials to prevent turion formation, applying endothall and diquat. **(Slide 22)** This was the policy for a number of states in the cold northern temperate states where they recommended treatment of curlyleaf pondweed before turion formation. The State of Minnesota then contracted the University of Minnesota to monitor 6 of the lakes receiving whole-lake treatments with endothall and compare them to 3 lakes not treated. They found that in every single treated lake the formation of turions was prevented and this reduced the population of curlyleaf pondweed over the long term. **(Slide 23)** It was a very effective application of research combined with companies that provided the tools used to manage the aquatic plants and with states that developed the regulations to change the way that aquatic plants are managed.

Production of turions in treated and untreated lakes (Johnson 2010)

Table 2. Production of new curlyleaf pondweed turions (N produced/m²) in June within the littoral area (≤4.6 m depth) of herbicide-treated lakes and untreated reference lakes 2006 to 2008; presented as littoral mean (\bar{X}) with standard errors (SE) in parentheses.

	HERBICIDE-TREATED LAKES						UNTREATED REFERENCE		
	Crookneck	Fish ^a	Julis	L. Mission	Rush	Weaver ^a	Coal	Estebas	Vails
2006 \bar{X}	<1	3	0	0	0	0	96	1871	360
(SE)	(-1)	(2)	-	-	-	-	(47)	(589)	(144)
2007	<1	<1	0	<1	0	0	312	778	509
	(-1)	(-1)	-	(-1)	-	-	(93)	(210)	(124)
2008	2	<1	0	0	0	0	87	313	379
	(2)	(-1)	-	-	-	-	(44)	(93)	(124)

^a Fish and Weaver were treated for four consecutive years (2005 to 2008)

Research is important to develop new management patterns (whether herbicidal, biological or mechanical) by identifying key points in these weeds' life cycles and understanding more about both our target weeds and our native plants so we can selectively manage the target weed.

In the last few years the changes in our herbicide regulations have required that everyone develop an integrated pest management plan for their lakes when treating larger areas. We have had to retrain people to develop these plans and incorporate integrated pest management into their programmes. Management plan elements include prevention, assessing the problem, tracking the resources to manage the weeds, ongoing monitoring, doing education and outreach, setting very specific goals, doing site-specific management and then evaluating management activity.

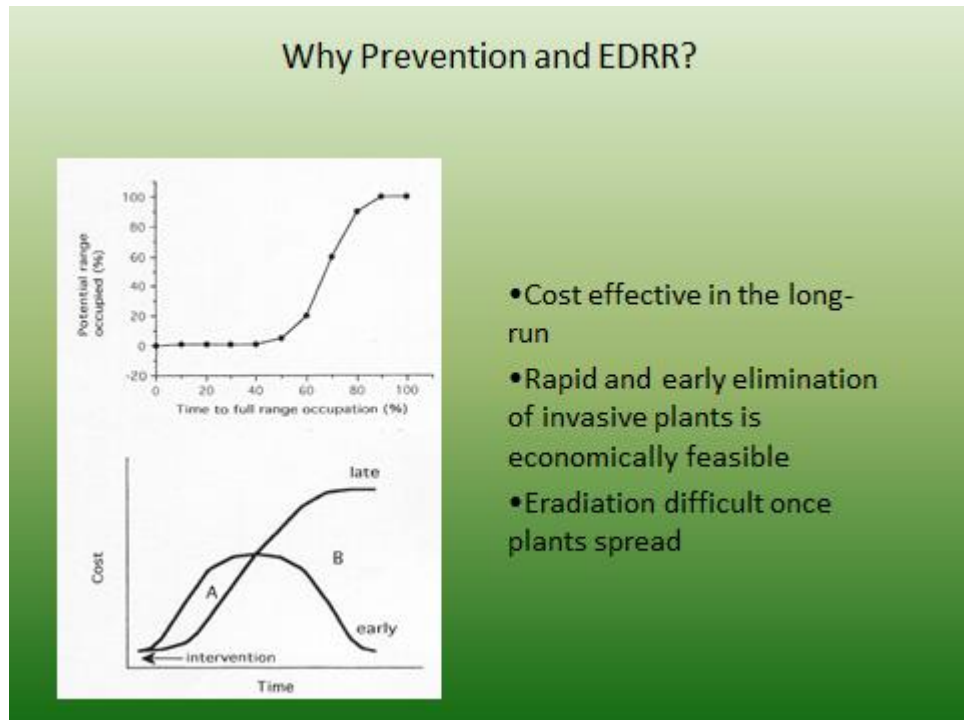
We need to educate everyone using the water bodies so that we do not spread invasive weeds from one lake to another. In the United States a number of states have enacted very tough legislation and regulations which they enforce. In the State of Minnesota if one is seen driving down the road with weeds on their trailer a highway patrolman will ticket that person and that has been very effective. In many of the western states it is necessary when towing a boat to pull over at inspection stations to have the boat inspected for plants.

Boats are the No. 1 mode of invasive species spread in North America. The most important focus for prevention is at boat launches and on the transportation of weeds on boats.

The next most important thing is early detection. It is important to search a lake regularly to find invasive species and look for new species. In many of the states in the United States they utilise volunteers, to either search for plants or monitor boats and trailers at boat launches. In this case there needs to be one contact person in an area or a state to receive the reported sightings and verify the identification of that species. In my experience many volunteers, while enthusiastic, are not terribly knowledgeable and it is important to follow up on those sightings.

Having a rapid response plan is the essential follow-up to verified sightings. I was working with the State of Montana for a number of years when they found Eurasian watermilfoil in a new reservoir. The State required an environmental assessment before they could do any management. It took two years. Do you think the Eurasian watermilfoil was polite and waited for the State to finish their plan before starting to grow up again? It certainly did not. We need to be ready to jump on problem plants with both feet which will be cheaper in the long run. **(Slide 24)**

Control plants early rather than wait and see.



Education and outreach should be a very important programme. In the United States we have a built-in system called Cooperative Extension where a specialist will compile information and send it to the county-level agents that deal with people on a day to day basis. It is also important to reach the various people who may have a concern about the water body in question. Giving information and addressing concerns from the onset can help answer an objection that could otherwise stop a programme. Lastly it is important to be transparent. Prepare information and let people know what you are doing and why.

Complying with permits may require monitoring and assessments of the success of the management activities.

There are also a number of things that volunteers can do, or what we call in the States, Citizen Scientists. Train volunteers to identify plants and reporting the occurrence of invasive plant species via the web.

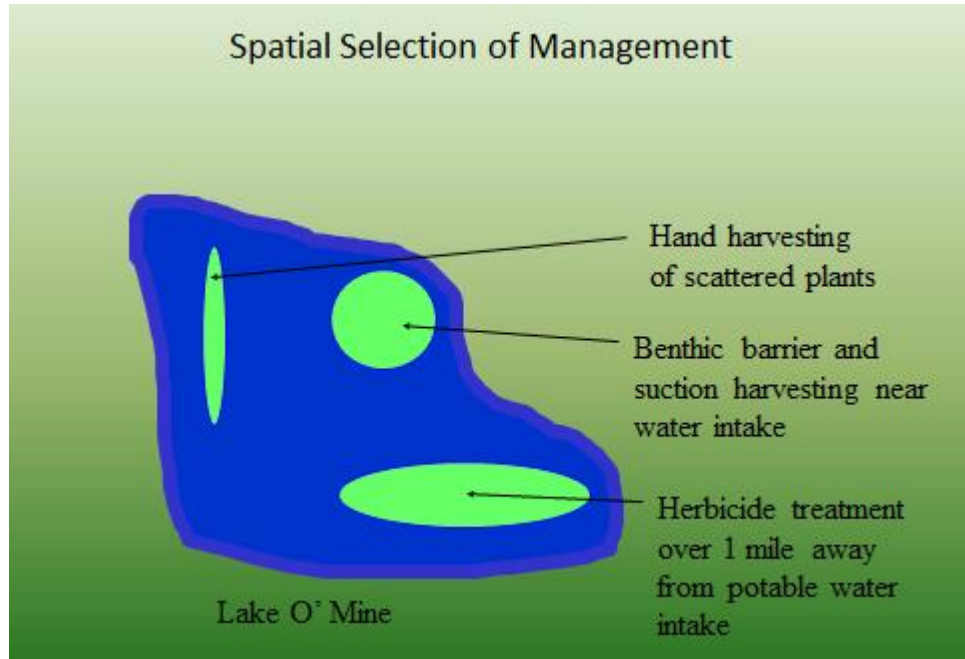
Develop very specific management goals based on a statement of the problem. In a hypothetical example we may find that 90% of the potential habitat of our weed is topped out with the weed which we do not want and our goal is to reduce that to 15%. That is a concrete goal and can be assessed using an objective monitoring technique. This eliminates unnecessary discussion on whether the outcome was successful. Have a goal, either meet it or not, and then it can be revised and move on.

It is essential to implement goals in ways that are acceptable to environmental and economic standards, to the stakeholders and to regulatory agencies. It will take a long time to pursue treatment plans that are outside of the law. People are very reluctant to agree to those!

Vary techniques both spatially and temporally. What do I mean by that? Look at each weed site and develop a site specific management strategy, whether the site is a lake or a discreet portion of the lake. Consider all the available techniques and evaluate them

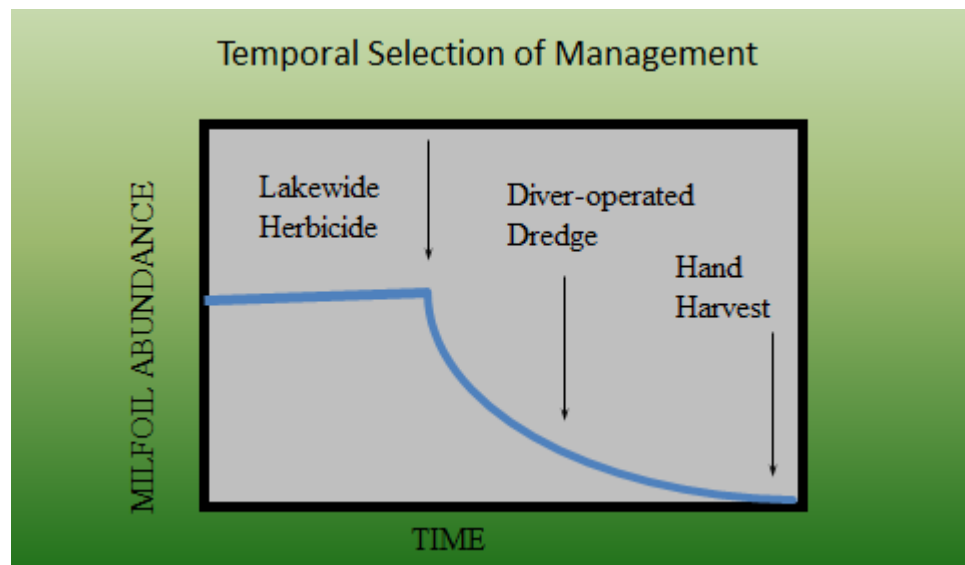
based on their merit, not just how you feel but how effective are they really. Techniques will vary both spatially and temporally. For instance there may be areas conducive to hand pulling in a particular lake if there are only scattered plants. It would be just as easy to remove them by hand as it would be to do any other technique. There may be a particularly sensitive spot environmentally, for instance, near a drinking water intake suitable for a benthic barrier treatment or diver-operated suction harvesting. But an area with very dense plants remote from that sensitive zone it would be suitable to use a herbicide to bring the population down more quickly. **(Slide 25)**

Slide 25



Over time techniques will change and **Slide 26** is based on a lake where 70% of the littoral zone (the area that can be colonized by rooted plants) was dominated by Eurasian watermilfoil. The first approach was a whole lake treatment with fluridone which achieved 98% control. Then there was a combination of diver-operated dredging and benthic barriers to control the remaining 2%. In subsequent years there were fragments of Eurasian watermilfoil which were removed by hand. Monitoring has continued for the past 20 years and it has been a very successful programme for this lake.

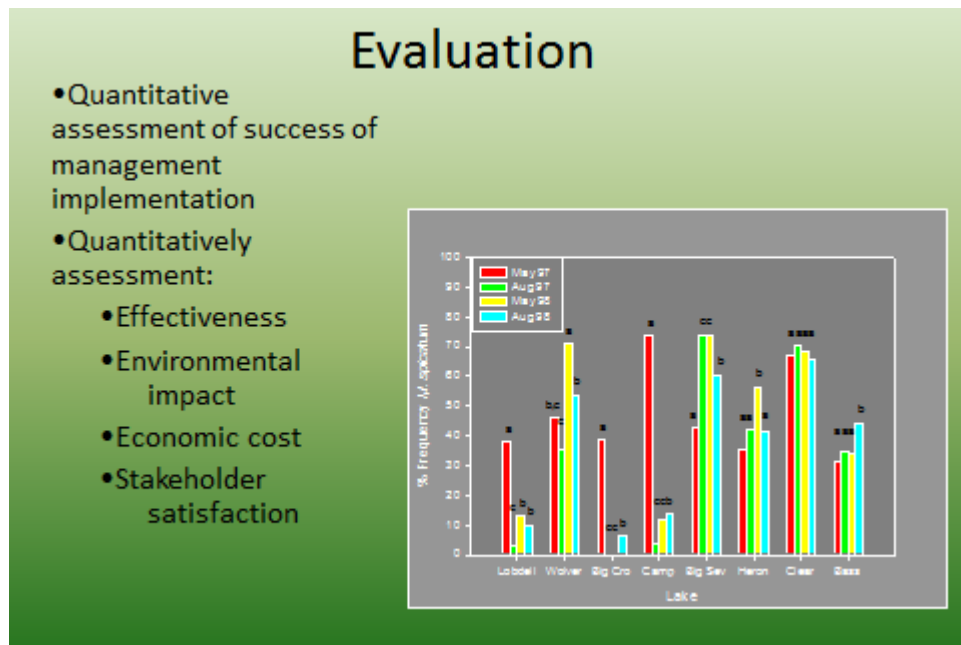
Slide 26



There are several aquatic plant management techniques we use in the United States:

- biological control
- chemical control
- mechanical control
- physical control
- institutional control

Slide 27



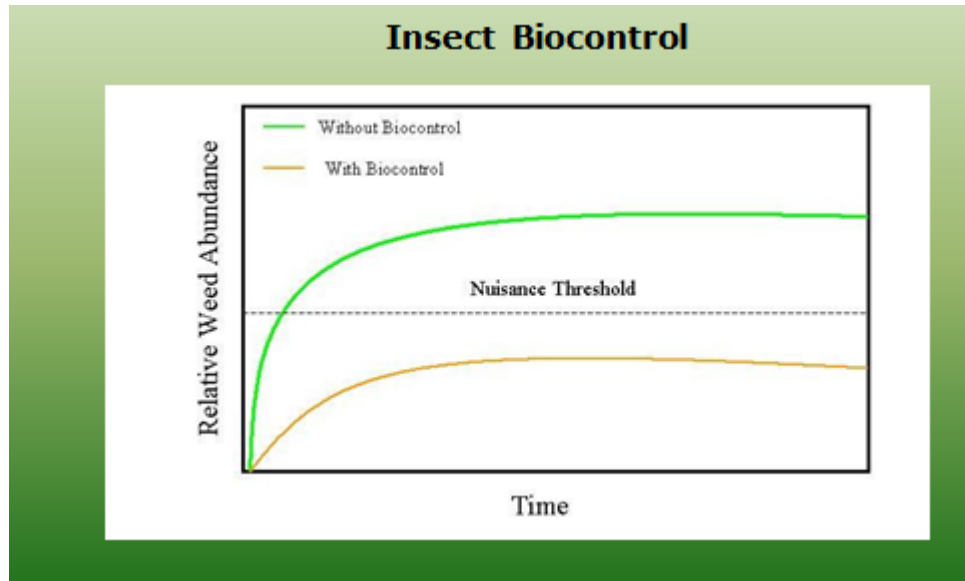
Find the ones that are most suitable for a particular lake and evaluate those techniques. Has this been successful or not? Based on that objective evaluation using quantitative data, decide on some improvements or continue with the current practice. Because management of aquatic plants is an iterative process, learn from your mistakes, learn from your partial successes and then move on. **(Slide 27)**

The two most common biological control techniques are the classical insect approach using insects that feed on the target weed or grass carp. There are also pathogens (classical or naturalized).

There have been four significant bio-control agents released on aquatic plants in the United States targeting alligator weed, water hyacinth, hydrilla and giant salvinia. Alligator weed was the first programme and it was hugely successful. Within 2 years of releasing the insects, plants growing in the water were gone. Along the Gulf Coast in the southernmost states water insects respond very quickly to alligator weed growing in the water. However they do not attack alligator weed growing in moist soil. The level of success in the United States with other species has been substantially less. But the whole purpose with insect biological control is to reduce the biomass of the plant below the nuisance threshold not eliminate it. **(Slide 28)**

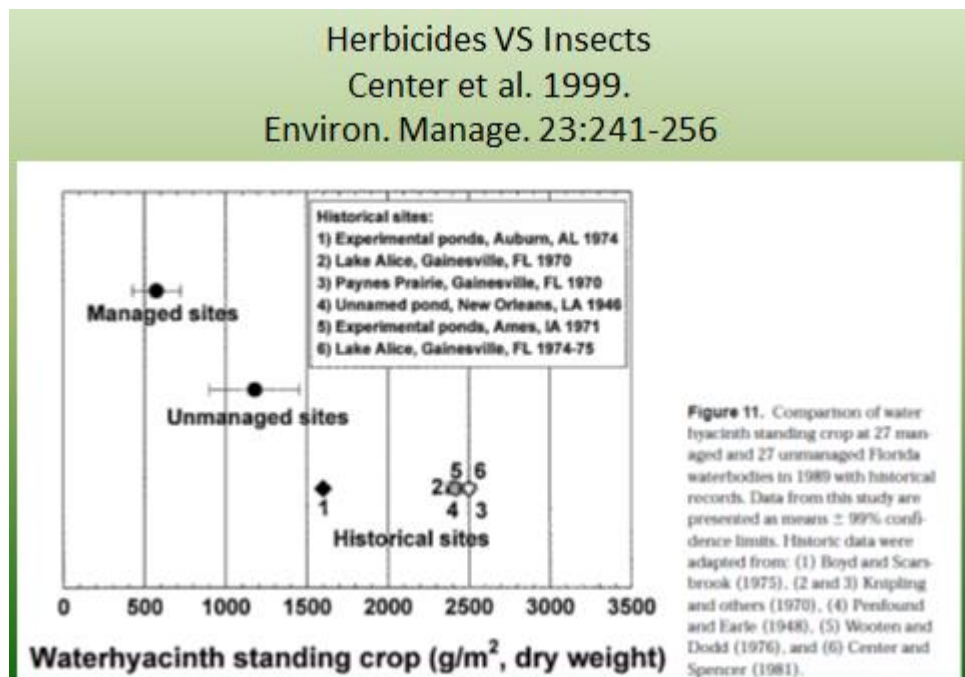
The biological control researchers will set the threshold to have a self-sustaining population of insects. A successful biological control programme is when insects are established and can survive on their own. Sometimes no nuisance threshold has been set. Comments like mine are sometimes interpreted as saying biological control does not work but it is not what I am saying. **Slide 29** is research in Florida by Ted Center, an

Slide 28



eminent bio-control researcher. If we look at the historical data, the growth of the water hyacinth was 2,500 grams per square metre. Looking at the sites that are not managed with herbicides but have a sustaining population of insects, the biomass is 1,200 grams per square metre. The biomass is cut in half. In some ways it is a success, but if 1,200 grams per square metre of biomass is completely covering a waterway that is not a success in terms of suppressing the nuisance of the plant.

Slide 29



The typical biomass of sites being actively managed with herbicides was about 500 grams per square metre. At these sites the waterways stayed open to navigation. If there is no common goal clearly stated, there is no nuisance threshold stated, some people will say that the programme is a success, others will say it is a failure. That is why it is important to have clearly stated goals in a management programme.

Environmental Effects of Grass Carp

Abstract.—We investigated effects of triploid grass carp *Ctenopharyngodon idella* on aquatic macrophyte communities, water quality, and public satisfaction for 98 lakes and ponds in Washington State stocked with grass carp between 1990 and 1995.

Grass carp had few noticeable effects on macrophyte communities until 19 months following stocking. After 19 months, submersed macrophytes were either completely eradicated (39% of the lakes) or not controlled (42% of the lakes) in most lakes.

Intermediate control of submersed macrophytes occurred in 18% of lakes at a median stocking rate of 24 fish per vegetated surface acre. Most of the landowners interviewed (83%) were satisfied with the results of introducing grass carp.

For sites where all submersed macrophytes were eradicated, average turbidity was higher (11 nephelometric turbidity units, NTU) than at sites where macrophytes were controlled to intermediate levels (4 NTU) or unaffected by grass carp grazing (5 NTU).

Bonar, S.A., B. Boldin, and M. Divens. 2002. *Effects of triploid grass carp on aquatic plants, water quality, and public satisfaction in Washington State*. N. Am. J. Fish. Manage. 22:96-105.

The grass carp can be effective on some species. They have a natural feeding preference and there tends to be an 'all or nothing' effect. A paper by Bonar, Boldin and Divens in Washington State clearly defines both the benefits and the drawbacks of using grass carp. The first thing to note is that no successful management was observed until at least 19 months after stocking. The effects are seen a year and a half later which is pretty typical. About 39% of the lakes had complete elimination of all submerged aquatic plants. If the goal is to completely remove all plants grass carp is perfect, there just has to be enough stock. But in another 42% of the lakes no control of any plant species was observed, so that might be termed a failure. In all the cases with complete elimination of aquatic plants the turbidity more than doubled which is another drawback of grass carp.

In the US we currently have 14 active ingredients that are labelled for use in aquatic sites. Most of these have been labelled since 2000. One of the drivers was the populations of hydrilla that were resistant to the active ingredient in Floridone. Hydrilla is a \$A30 million per year market in Florida alone, so there was a lot of interest in a suitable product. We clearly have a lot more tools than New Zealand in terms of herbicides, but there are some things that we would still like to see labelled for aquatic use. For an emergent or floating leaf plant we put the product into a tank and add surfactants to help penetrate the waxy cuticle. The products above do not come with a surfactant, in part because many states require additional registration. These are applied directly to the foliage and absorbed by the plant through that mode very much like a terrestrial plant application. Instead of a tractor a boat is used.


EPA-Approved Aquatic Herbicides (see www.aquatics.org)

- 2,4-D (AquaKleen, DMA-IV, Navigate, others)
- Bispyribac sodium (Tradewind)
- Carfentrazone (Stingray)
- Complexed and chelated copper (A veritable host)
- Diquat (Reward, Weedtrine)
- Endothall (Aquathol K, Aquathol Super K, Hydrothol 191)
- Flumioxazin (Clipper)
- Fluridone (Sonar)
- Glyphosate (Aquapro, Rodeo, others)
- Imazamox (Clearcast)
- Imazapyr (Habitat, others)
- Penoxsulam (Galleon SC)
- Peroxidases (Greenclean, Pac-27)
- Topramezone (Oasis)
- Triclopyr (Renovate 3, others)

For submerged plants, herbicides are applied to the water either through hoses that are trailing in the water or through injecting a liquid or dropping a granular herbicide into the water. **(Slide 30)** It is very important to understand both the residence time in the water - how quickly the product will dissipate, and the concentration of the product in the water which will determine whether the herbicide is effective in controlling the plant. Adjusting the concentration and exposure time will determine selective control. Selectivity is controlling the target plant with minimal or no damage to the native plant which is the goal of most management programmes in the United States. There is a common misconception that when a herbicide is applied to the water it kills all the plants, but that is

Slide 30

Submersed Plant Herbicide Applications



The diagram, titled "SUBMERSED TREATMENT", illustrates the process of herbicide application to submerged plants. It shows a cross-section of a body of water with a sandy bottom and submerged vegetation. On the left, a diver is shown applying herbicide. Two methods are depicted: "LIQUID" being poured from a container and "GRANULES" being dropped from a bucket. An orange arrow labeled "UPTAKE" points from the water column towards the plants. Above the water surface, "WATER EXCHANGE" is noted, with factors listed as "FLOW", "TIDES", "WIND", and "TEMP". At the bottom of the diagram, another "UPTAKE" label is shown near the plant roots. The background is a green gradient.

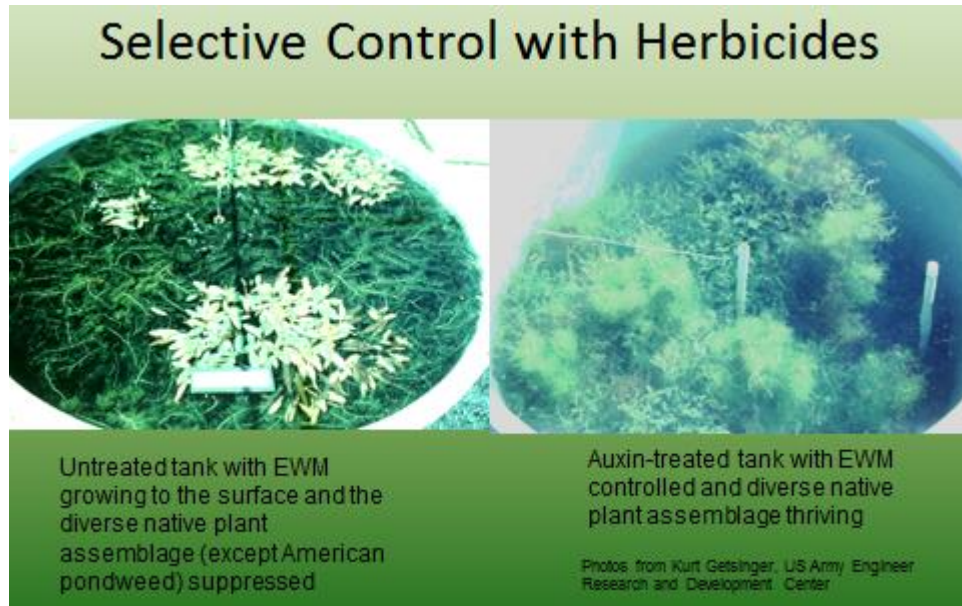
- Herbicides are applied to water, and plants take up herbicide from water
- Water movement, residence time, and concentration are critical for effective treatment
- Generally, no need for surfactants or adjuvants

K. Getsinger, USAERDC

simply not true.

Slide 31 shows an untreated tank with Eurasian watermilfoil planted with a half dozen other native species in comparison with a tank planted in the same way and treated with triclopyr and auxin herbicide showing that the Eurasian watermilfoil was completely controlled, leaving a diverse assemblage of native plants.

Slide 31



Quite often we harm the native plant species but typically there are some species that are tolerant to the herbicide. In fact we select the active ingredient, the concentration and the anticipated exposure time to ensure that we have some level of selectivity. Different products have different levels of effectiveness on different target species as well as on the native plants. **(Slide 32)**

Slide 32

Herbicide Selection

Table. Efficacy of U.S. EPA-Approved herbicides on common invasive aquatic weeds. E, excellent; G, good; F, fair; P, poor; NA, not applicable.

Chemical	Alligatorweed	Eurasian watermilfoil	Giant salvinia	Hydrilla	Waterhyacinth
2,4-D	E	E	P	P	E
Copper	P	P	P	E	P
Diquat	G	G	G	G	G
Endothall	NA	G	NA	G	NA
Glyphosate	E	NA	G	NA	E
Imazapyr	E	NA	P	NA	E
Fluridone	NA	E	NA	E	NA
Triclopyr	E	E	P	P	E

A mechanical control technique is one that involves either using manual labour or a tool to remove plant growth. A physical control technique changes the environment to prevent or reduce the growth of aquatic plants. Some of the mechanical control techniques include hand pulling, cutting, harvesting, diver-operated suction harvesting and rotovating. Hand harvesting is the most widely used control technique in the world. In many areas of the

world labour is inexpensive and hand pulling the weeds or using a simple tool to pull them from the water is still a very viable technique. But it should be targeted at species that are scattered, where more time is spent looking for the plant than doing a control technique. This technique is most effective if labour is inexpensive or there are volunteers who know the right plant.

We once had a dive club volunteer to help control Eurasian watermilfoil on Lake George. We left for a while and later returned to find a big pile of native plants in the bin. When we asked, 'What's going on here?' The answer was, 'It was too turbid to hand pull the milfoil here so we decided to hand pull it over there where the visibility was better.'

It can be a useful technique, particularly in areas sensitive to other control techniques. Hand harvesting is also best used in smaller areas or in areas where there are scattered plants.

Cutting is where an implement severs the stem from the root but there is no effort to remove the plant matter. There are a number of places that use cutting, though in most lakes people find the floating mats of plants somewhat obnoxious.

Harvesting, in contrast, is where the cutting machine also removes the biomass from the water and disposes of it onshore. There has been a lot of discussion in the United States about using harvesting as a nutrient reduction technique. This is a paper from 1974 by Spencer Peterson researching a very eutrophic lake. He determined that harvesting was inefficient for nutrient removal because of the very high loading rates of nitrogen and phosphorus to that lake. If there is a very discreet and reasonable nutrient reduction goal, then harvesting may make some sense. Trying to change the trophic state of the lake based on harvesting alone is unlikely to work.

Harvesting as Nutrient Reduction

Peterson et al. 1974. J. Wat. Pollut Control Fed. 46:697-707

Perhaps the most significant conclusion to be derived from this study is that continuous harvest of aquatic plants from Lake Sallie during the growing season could not offset the high loading of phosphorus and nitrogen.

The wet-weight harvest of 944,000 lb (428,576 kg) of plants was successful in removing only 1.37 percent of the total phosphorus input to the lake, or 1.03 percent of the phosphorus contained in the water volume of the lake during the fall circulation period.

Harvesting is also the only aquatic plant management control technique which, when used according to the manufacturer's specifications, kills fish. It is ironic that when I talk to groups and mention herbicides everybody assumes that I will kill fish. The herbicides that are labelled for aquatic use in the United States, when used according to the label, will not kill fish, but harvesting will. There is nothing to prevent it killing fish; it is a giant mechanical predator.

In **Slide 33** Mikoil found that by harvesting the entire littoral zone of the lake he removed about 5% of the standing crop of fish. Now most of the fish are young of the year fish that

are seeking to escape predation in the dense weed mats. Fish produce many more young in a year than are likely to survive and harvesting is not likely to cause the collapse of a year class of fish. Nevertheless, if killing fish is not an option, then harvesting should not be an option.

Slide 33

Total Fish Impact: Largemouth Bass			
Mikol, G.F. 1985. Journal of Aquatic Plant Management 23:59-63.			
TABLE 4. SUMMARY OF DIRET EFFECTS OF 1982 MECHANICAL HARVESTING ON JUVENILE LARGEMOUTH BASS (<i>Micropterus salmoides</i>).			
	COLLECTION DATE		
	8/13/82 ¹		
	Site #1	Site #2	Combined
Total # fish removed	11	7	18
# fish removed/ha	220	56	103
Fish standing crop estimate (#/ha)	1,894	1,894	1,894
% standing crop removed	11.6	3.0	5.4

¹Site #1 was previously harvested in June 1982. Site #2 was previously unharvested.

Diver-operated suction harvesting is a technique gaining interest in the United States. One or two divers are attached by surplus air supply to a machine that uses a venturi pump to create suction to remove material. These are widely used for gold dredging and underwater archaeology. In **Slide 34** they suck up the plants, (either like a vacuum or the diver hand pulls a plant to feed into the machine) and deposit them on shore. It makes hand removal more systematic and efficient. It is used where there are small infestations that are not dense.

Slide 34

Diver-Operated Suction Harvesting

- Surface-supplied
Divers use a gold dredge or archeological dredge to remove rooted plants with very little sediment
- Plants separated and disposed

Our 4 inch suction dredge machine featuring 13hp dredge pump, high pressure agitator, and commercial diver air compressor



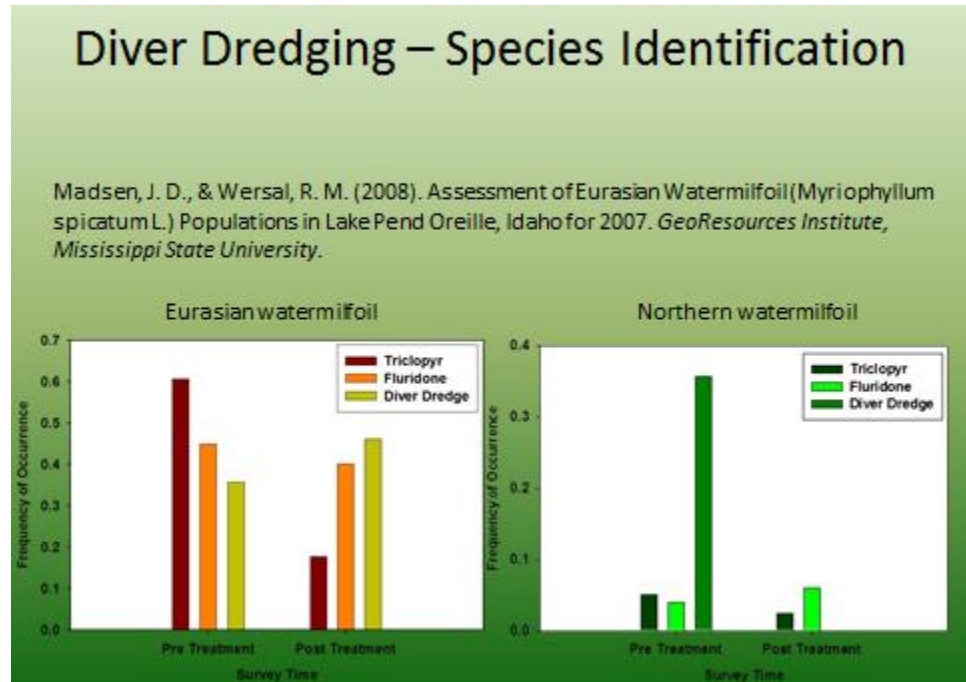



Figure 5: Power sludge/suction dredge combination

Most importantly the operators must identify their target plant. That sounds common sense but we did a study in Idaho on the effectiveness of triclopyr, fluridone and a diver dredge at a number of sites. **(Slide 35)** We found that the Eurasian watermilfoil was increasing in the diver dredge areas. We analysed all our data and found that Northern watermilfoil was eradicated at the diver dredge sites. Instead of controlling Eurasian watermilfoil the desirable native plant was being controlled. It is important to train the operators in the identification of the target plant species.

Slide 35



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