AZOLLA

A Comprehensive Guide To:

I.D., Treatment and Prevention

Brittany Pondeljak ©

Authored by Brittany Pondeljak

Aquatic Technologies, 2021

AQUATIC TECHNOLOGIES

The Water Treatment Experts!

TABLE OF CONTENTS

INTRODUCTION

Azolla is a free floating aquatic fern.

There are two species in Australia: Azolla filiculoides and Azolla pinnata.

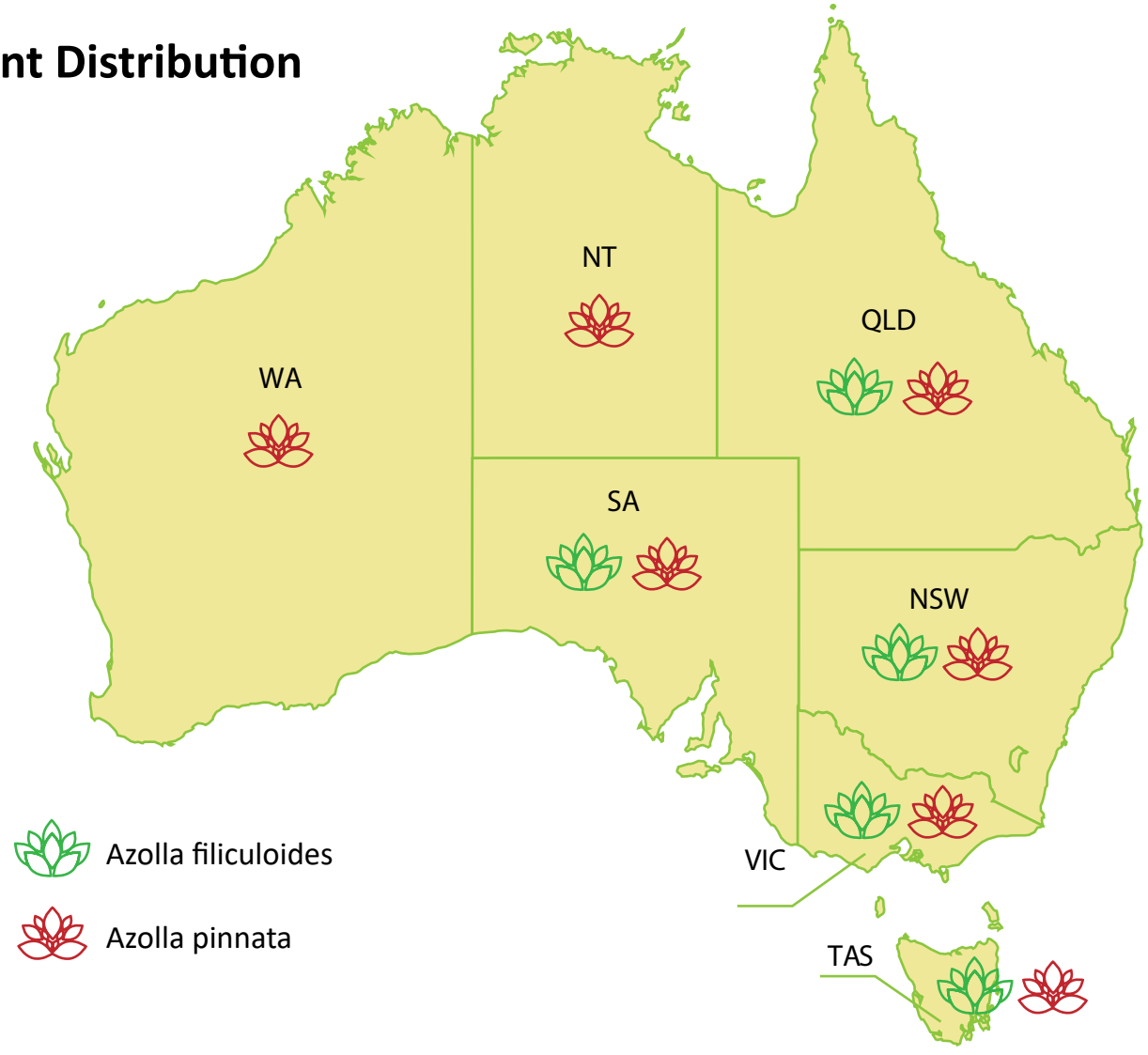
Both are native and can form dense mats that cover the entire water surface in freshwater systems.

ABOUT THIS GUIDE

The information presented here provides a detailed guide on how to identify, manage and treat Azolla in varying freshwater situations.

It is designed to enable the user to make an informed decision on what management approach is best suited to their unique situation.

Current Distribution



HOW TO IDENTIFY AZOLLA

Scientific name:	*Azolla filiculoides*
Common name:	Red Water Fern, Water Fern
Description:	Azolla filiculoides is a small, free floating freshwater fern, green to reddish-brown or purplish orange or red at the edges, branching freely, and breaking into smaller sections as it grows. The adult plant is approximately 25-35mm long, with the length of the individual frond ("leaves") being approximately 1-1.5mm. Plants can change colour from green to brown and red as a result of changes in sunlight intensity (and shade) as well as ambient temperature.
Habitat:	Stationary and slow-moving water bodies, especially where nutrients are high. E.g. ornamental ponds, fish ponds, dams, irrigation dams.
Distribution:	NSW, QLD, SA, TAS, VIC
Reproduction:	It reproduces vegetatively (plant fragments) or by spores. Azolla filiculoides is able to undergo rapid vegetative reproduction throughout the year by the elongation and fragmentation of the small fronds. Under ideal conditions an infestation can double in area every 4-5 days.
Dispersal:	It can be dispersed by attaching to animals such as water birds, turtles or livestock, human activity, floods or wind dispersal (spores).

Scientific name:	*Azolla pinnata*
Common name:	Mosquitofern, Feathered Mosquitofern, Water Velvet
Description:	Azolla pinnata is a small free floating fern with a triangular frond measuring up to 2.5cm. The frond is made up of many rounded or angular overlapping leaves each 1 or 2mm long. They are green, blue-green, or dark red in colour and coated in tiny hairs, giving them a velvety appearance. The hairs make the top surface of the leaf water-repellent, keeping the plant afloat even after being pushed under. Roots have fine lateral rootlets, appearing feathery.
Habitat:	Stationary and slow-moving water bodies, especially where nutrients are high. E.g. ornamental ponds, fish ponds, dams, irrigation dams.
Distribution:	NSW, NT, QLD, SA, TAS, VIC, WA
Reproduction:	It reproduces vegetatively (plant fragments) or by spores. Azolla pinnata is able to undergo rapid vegetative reproduction throughout the year by branches breaking off the main axis. Under ideal conditions an infestation can double in area every 2 days.
Dispersal:	It can be dispersed by attaching to animals such as water birds, turtles or livestock, human activity, floods or wind dispersal (spores).

WHY TOO MUCH AZOLLA IS BAD

Although Azolla is native to Australia, it is a known weed under the right conditions due to its ability to double in biomass in just 2 to 10 days [1] [12-14] [17].

In some areas Azolla is recognised as an invasive plant [18] and its ability to reproduce via fragmentation is the most likely cause of its explosive spread [14] [19] [20].

Azolla can establish quickly and form dense monospecific mats that cause a great alteration of the physical and chemical water features [1] [21]. Once established, these floating mats can negatively impact the water by shading out submerged plants and algae [22] [23], inhibiting their photosynthesis and stopping oxygen diffusion [1].

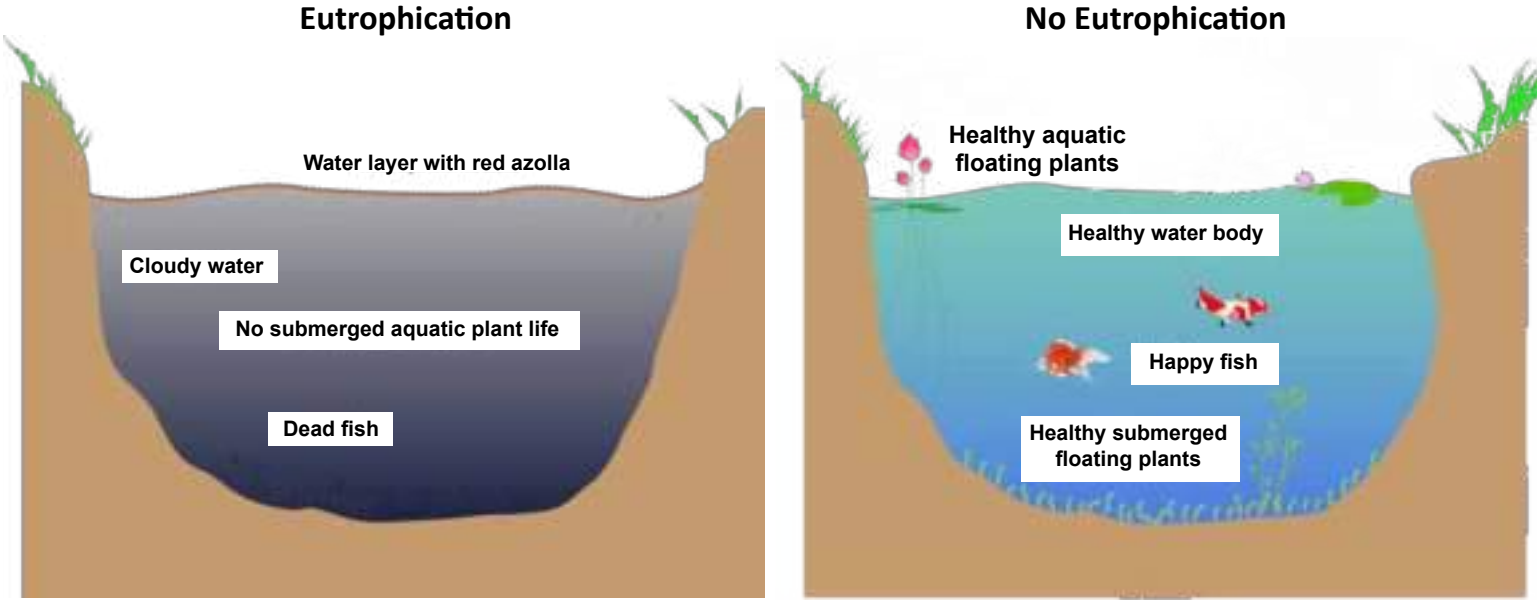
Aquatic fauna are also impacted in the water beneath the mats, deteriorating the food web of the aquatic ecosystem [1] [24] [21].

The dense mats which Azolla can form directly impacts water quality. Commonly correlated are a decrease in pH and oxygen concentration, and increase in nitrogen and phosphorus compounds in the water [23-20].

Succession of the aquatic plants has also been accelerated due to the shading effect on other plants and increase of organic matter upon the death and eventual sinking of the plant biomass [22].

Decomposition of the weed requires large amounts of oxygen which leads to a drop in levels of oxygen in areas infested by the weed, reducing survival of aquatic organisms especially fish. The decomposed material also leads to pollution of the water making it unfit for any use [22].

HOW AZOLLA CAN GROW OUT OF CONTROL



FUN FACT: AZOLLA GROWS FAST!

Asexual reproduction is the more common form of reproduction [12]. Under ideal growth conditions, Azolla can reproduce (asexually) extremely fast, often able to double its biomass in 2 to 10 days [1] [12-14].

This is achieved simply by multiplication of fragmented fronds (fern leaves) [12] [14]. These fragments break off from the parent plant and form entirely new plants. Azolla species grow best between 15-20°C water temperature and in strong sunlight [15] [16] [4].

Fact: Azolla is Unique!

Azolla is an Australian native aquatic fern and is the only species of fern known to have a symbiotic relationship with anabaena cyanobacteria (blue-green algae) [1]. Because of this relationship, Azolla is beneficial for agricultural use in rice fields as it is able to utilise atmospheric nitrogen gas thanks to the cyanobacteria (blue green algae) living in cavities in the Azolla fronds [3] [5-9].

Through its symbiotic relationship with Anabaena azollae, the aquatic fern is able to grow in nitrogen-deficient waters [1]. Australian surface waters are inherently low in nitrogen (n) and phosphorus (p) [10]. The level of phosphorous present in a water body has a direct correlation to the growth habits of the species [11]. One study found Azolla is able to double its biomass in one week in a nitrogen-free nutrient solution growing in a phosphorus-rich environment, entirely relying on the symbiosis with anabaena cyanobacteria for its nitrogen supply [17].

What is phosphorus?

Azolla can become a dominant feature of a water body when there is an abundance of the nutrient Phosphorus [17].

Phosphorus is an essential plant nutrient needed for DNA, RNA and energy transfer [25] and most often controls aquatic plant and algae growth in freshwater [26].

Phosphorus is found in:

- fertilizers
- human and animal wastes
- decaying organic matter
- naturally in rocks and other mineral deposits

There are few natural sources of phosphorus and it is often a limiting nutrient in aquatic systems [26].

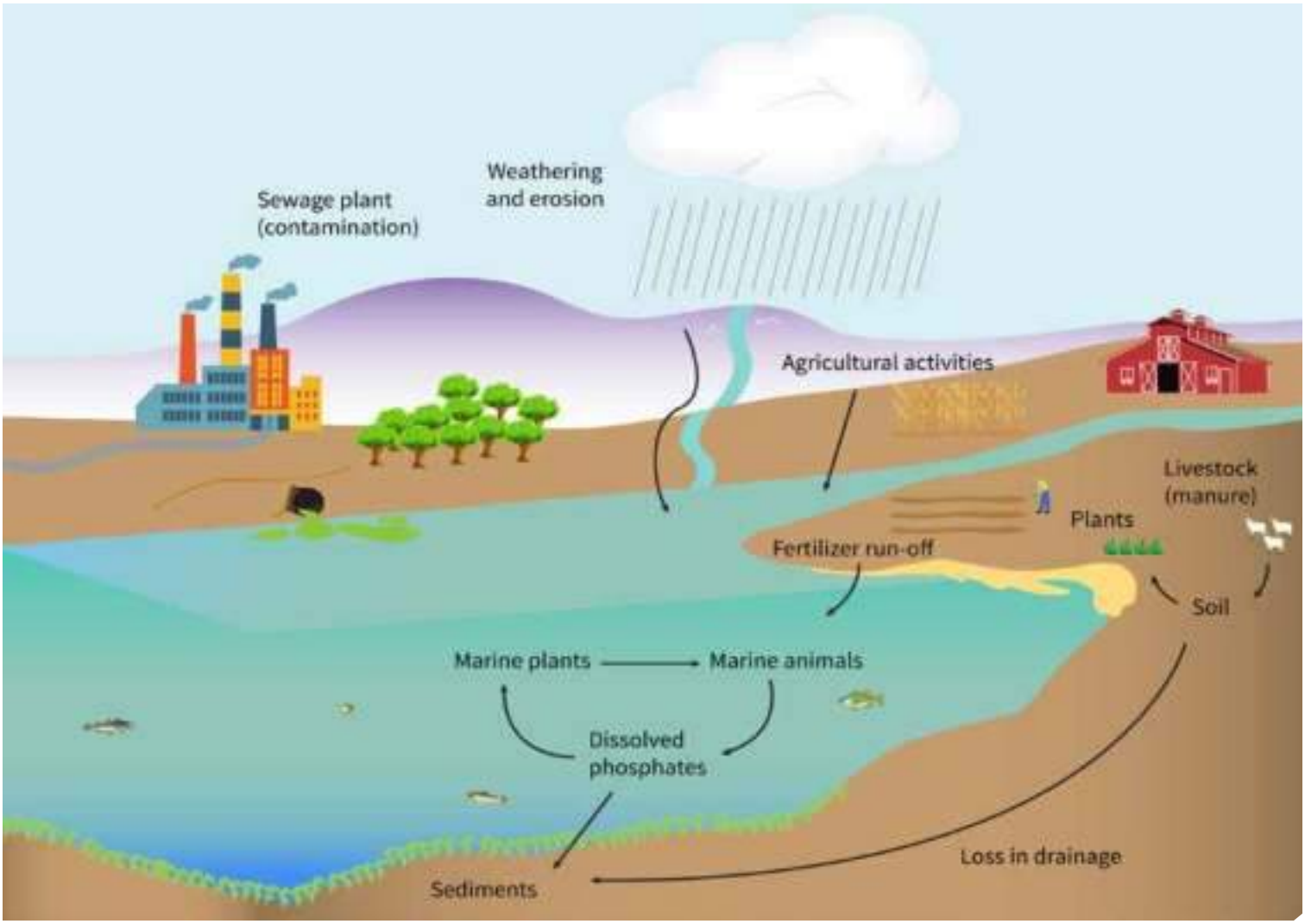
How does phosphorus get into the water?

- Fertilizers
- Run-off (after a storm or heavy rain)
- Erosion of topsoil into the water
- Sewage
- Decomposing organic matter
- Natural weathering of rocks
- Bushfires

Phosphorus levels in water bodies have significantly increased worldwide because of fertilizer use, as well as from municipal and industrial wastewater [25].

Australian soils and surface waters are naturally low in phosphorus [10] and our native plants have adapted to these low levels whereas introduced pastures and crops have not. Therefore, we synthetically apply phosphorus through agricultural fertilizers, manure and organic wastes to keep these non-native crops healthy. This activity is primarily where excess phosphorus can enter our water ways.

Because our native plants are highly efficient at utilising the small amounts of available phosphorus, when there is an excess it enables plants like Azolla to grow extensively to the point where they can become problematic.



HOW TO IDENTIFY THE RIGHT AZOLLA TREATMENT FOR YOUR SITUATION

Treatments currently avaliable

Currently there are 2 main types of treatment available. These are:
- Aquatic herbicides (chemical & natural based)
- Physical removal (manual & machine)

To determine which treatment will suit your situation best, you must first categorise the severity of your Azolla bloom.

How Severe is your Azolla Bloom?

Primary Growth Stage

0-30% of the water body is covered in Azolla
Primary growth occurs in the early stages of an infestation, when plants are not crowded.
The water surface is clearly visible between plants and the plant is lying flat on the surface of the water [27].

Secondary Growth Stage

30-60% of the water body is covered in Azolla
Secondary growth occurs when the water surface is barely visible but the azolla is still only a single layer [27].

Tertiary Growth Stage

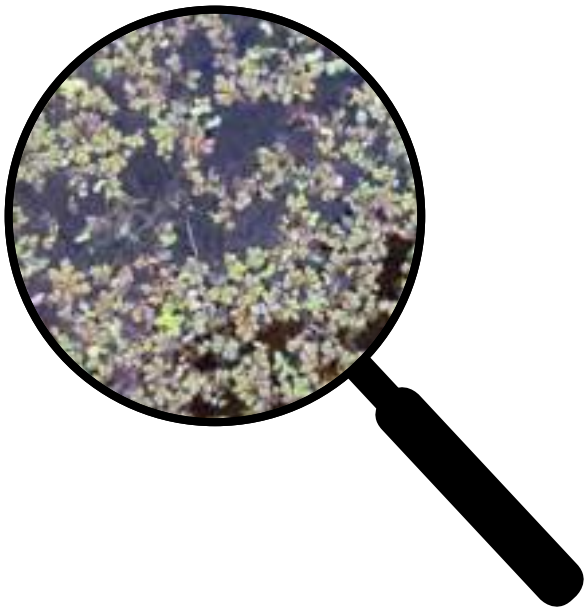
60-100% of the water body is covered in Azolla
Tertiary growth occurs when the plants become crowded and mature in infestation. The water surface is no longer visible preventing light from entering the water [27].

Multilayered Growth Stage

100%+ of the water boy is covered in Azolla
Tertiary weed mats can become multilayered, displaying ridge-like thickenings as layers build up affecting the water beneath by eliminating submerged plants and algae, preventing photosynthesis and blocking oxygen diffusion from the air resulting in an anaerobic environment [28] [29].

Primary Growth Stage

Example of Azolla in its primary growth stage. Notice how much free water is present and how spread out the individual plants are!



Secondary Growth Stage

Example of what Azolla can look like in its secondary growth stage. Azolla can appear as red or green or a combination of both colours. Notice how the water is barely visible.

Tertiary Growth Stage

Example of what Azolla can look like in its tertiary growth stage. Azolla can appear as red or green or a combination of both colours. Notice how the water is no longer visible.

Multilayered Growth Stage

Examples of what Azolla can look like in its multilayered growth stage.

Azolla can appear as red or green or a combination of both colours. Notice how dense the Azolla has become and there is no visible water at all.

Once you have categorised your Azolla bloom, you can then choose your treatment. Use the table below to help you:

	Treatment Options			
Growth Stage	Herbicide: chemical-based	Herbicide: natural-based	Physical removal: manual	Physical removal: machine
Primary	✓	✓	✓	
Secondary	✓	✓	✓	✓
Tertiary	✓		✓	✓
Multilayered	✓			✓

What you use your water body for will also play a role in the type of treatment most suitable for you. For example if you are unable to withhold using the water for 10-days, then a traditional herbicide may not be suitable.

There are different treatment methods available to suit most types of water bodies. Continue reading to find out which treatment is most suitable for your waterbody.

Types of Aquatic Herbicides

All approved aquatic herbicides can be used on all species of Azolla but not all aquatic herbicides are effective against all growth stages.

The following Aquatic Herbicides are successful on primary and secondary growth stages:

- AQ200
- Calcium dodecyl benzene sulfonate
- Glyphosate
- Orange Oil

The following Aquatic Herbicides are successful on tertiary stages of growth:

- AQ200
- Glyphosate

The following Aquatic Herbicides are successful on multilayered stages of growth:

- AQ200

Benefits of chemical control:

Typically only one full application with follow up spot treatments advised.
Kills azolla fast (within 1-7 days).

Disadvantages of chemical control:

Treated plants remaining in the water can cause deoxygenation within the system, affecting water quality [30]. However, if left untreated water quality will continue to decline. Treating with aquatic herbicides may see a short term decline in water quality, however once cleared a rapid recovery takes place.

Possibility of spray drift onto non-target vegetation [30].

There is a withholding period is once the herbicide has been applied meaning the water cannot be used for either irrigation or watering stock until the breakdown of the herbicide (excludes orange oil) [30].

Table 1. Summarises the effectiveness of various herbicides on the growth stages of free-floating aquatic weeds, as outlined by the NSW DPI [27].

Herbicide	Primary Stage 0-30%	Secondary Stage 30-60%	Tertiary Stage 60-100%	Multilayered 100%+
Orange oil (Natural-based)	✓	✓	×	×
AQ200	✓	✓	✓	✓
Glyphosate	✓	✓	✓	×
Calcium dodecyl benzene sulfonate	✓	✓	×	×

Primary: early stages of infestation, crowded plants, water surface visible
Secondary: moderate infestation, water surface barely visible
Tertiary: mature infestation, water surface is not visible
Multilayered: display ridge-like thickening as layers build up

	AQ200	Glyphosate	Calcium dodecyl benzene sulfonate	Orange Oil
Mode of action	• Contact herbicide that causes rapid plant injury in exposed tissue through disruption of photosynthesis [27] [31].	• Disrupts the shikimic acid pathway through inhibition of the enzyme 5-enolpyruvyl-3-shiki-mate phosphate (EPSP) synthase. The resulting deficiency in EPSP production leads to reductions in aromatic amino acids that are vital for protein synthesis and plant growth [32] [33].	• Reduces buoyancy causing plant to sink [34].	• Disrupts cuticle, breaking down or dissolving the waxy coating on plant cell walls. Contributes to the desiccation or burndown of young tissues [35] resulting in the plant losing its ability to retain water [36]. The damaged leaf cells leak water and the plants die of dehydration [37].
Timing of application	• Throughout the entire growing season; Control of early growth is recommended [34].	• When plant is actively growing [40].	• During primary and secondary growth stages only to floating plants only [34].	• Throughout the entire growing season [38] [39].
Waiting period	• Plants absorb AQ200 rapidly; plant decline is usually within less than 7 days post treatment [34].	• Following treatment, plants will gradually wilt, appear yellow/brown, and will die in approximately 2 to 7 days [40].	• Needs at least three applications and anything from a week to three weeks between applications [34].	• Plants will begin to sink within the hour after application. Full results may take up to 7 days [34].
Use restrictions/ Precautions	• Do not use herbicide in muddy water or on vegetation coated with mud or algae [34].	• Does not work on solid plant mats or where no water surface is visible [34]. • Do not treat weeds under poor growing or dormant conditions [34]. • Is not effective on submerged aquatic plants [40]. • Do not treat in water with high turbidity [34].	• Free water must be visible for application [34]. • Only works on floating ferns [34].	• Avoid a single heavy application; instead apply several light applications over a 1-3 week period [34]. • Apply when weed infestation is small, rather than advanced. Do not spray dense solid mats with no visible water surface. Water bodies with an average depth of less than 1 metre should not be treated [34].
Breakdown in water	• AQ200 is rarely found longer than 10 days after application and is often at levels below detection 3 days after application [31] [41]. • Binds tightly to clay particles in the water and the bottom sediments, where it becomes biologically unavailable [31] [41].	• The concentration of glyphosate is reduced through dispersal by water movement, binding to the sediments, and break-down by microorganisms [40]. • Glyphosate's half-life is between 3 days and 19 weeks depending on water conditions [40].	• Calcium dodecyl benzene sulfonate takes between 24 hours and 7 days to vaporise, depending on weather conditions (it takes longer on overcast days) [34].	• Non-persistent which means it decomposes rapidly, preventing the accumulation of compounds in soil and its subsequent influence on non-target organisms [42].

TREATMENTS AQUATIC TECHNOLOGIES OFFER

AQ200 Aquatic Herbicide + Wetting Agent Treatement

Preparing AQ200 + Wetting Agent Solution:	Applying AQ200 + Wetting Agent Solution:	Spot Treatment:
Step 1) Combine 400mL of AQ200 with the 150mL of Wetting Agent and dilute in 100L town/tank water (please note it is important to use town/tank water for this application). *Always put 80 per cent of the required water into your clean sprayer before adding the chemicals, then slowly add the other 20 per cent of the water. This avoids frothing of the spray mix.*	Step 2) Spray diluted mixture directly onto Azolla using a shower spray (not a mist spray). Ensure all Azolla is covered. *If Azolla is at 100% coverage, it is advised to physically remove some prior to spraying OR ensure a heavy wetting application is applied.*	Step 3) Spot treat any remaining plants 1-2 weeks after a full application. Continue to spot treat until Azolla is no longer visible. *Check beneath rocks, lily pads and reeds etc. for any hidden azolla plants.*

1L of AQ200 + 500mL Wetting Agent will treat between 250m² – 500m² of surface area depending on how dense the azolla coverage is.

Tips for eradicating:

• If Azolla is layered or at 100% coverage, physically remove some Azolla to thin it out before commencing herbicide treatment OR ensure a heavy drenching is applied.

• It is best to treat on a day with no rain and minimal wind

• Spot treat any remaining plants

• Check beneath rocks, lily pads and reeds etc. for any hidden azolla plants.

Notes:

• Use PPE when handling AQ200 including; gloves, goggles, mask, overalls/protective clothing

• DO NOT use treated water for human consumption, livestock watering or irrigation purposes for 10 days after application

• AQ200 is best applied with a spray unit

• Use a shower spray (do not mist)

• Limit overspray as this can affect non-target terrestrial and aquatic plants.

Orange Oils: Natural Treatments

Preparing Orange Oil Solution:	Applying Orange Oil Solution:	Spot Treatment:
Step 1) Dilute 1L of Orange Oil per 100L of water.	Step 2) Spray diluted Orange Oil directly onto Azolla using a light shower spray (not a mist spray). Ensure that the full surface area of the water is treated (even where no Azolla is present). Spray onto Azolla enough to change their normal colour (plants darken and show an oily sheen). Spray a light coverage over any free water present.	Step 3) Spot treat any remaining plants 1-2 weeks after a full application. Continue to spot treat until Azolla is no longer visible.
Always put 80 per cent of the required water into your clean sprayer before adding orange oil, then slowly add the other 20 per cent of the water. This avoids frothing of the spray mix.	*If Azolla is at 100% coverage, you must physically remove some until the Azolla is single layered and there is free water present prior to spraying.*	*Check beneath rocks, lily pads and reeds etc. for any hidden azolla plants.*

1L of Orange Oil will treat between 250^2 - 500m^2 of surface area depending on the azolla coverage.

Tips for eradicating:

• For large infestations covering up to 90% of the water's surface – partially remove sections of the infestation to create space for the treated matter to sink. In such instances, we recommend applying an extra 20% of the product to ensure saturation.

• This product works best when surface matter is small and manageable. It's advised to do several light applications, instead of a single heavy dose.

Aquatic Technologies have found best results when Orange Oil is applied on day 1, day 2 and day 4.

• It is best to treat on a day with no rain and minimal wind.

• Spot treat any remaining plants until no longer visible.

Notes:

• Use PPE when handling Orange Oil including; gloves, goggles, overalls/protective clothing.

• Orange Oil is best applied with a spray unit.

• Use a shower spray (do not mist).

• Ensure your shower spray is not too powerful, you want to lightly coat the Azolla not blast at it as this may cause the product to wash off.

Physical Removal: Azolla Skimmers

Physical removal can be a labour-intensive method, but has the advantage of being ecologically benign [30]. Small infestations of Azolla in accessible areas can be removed with rakes and fine-mesh nets, and used as either fodder or compost [30].
The disadvantage of this method is that under optimal conditions, Azolla can double its population in 2 to 10 days [1] [12-14] [30].

Advantages of physical removal:

• Removes extra nutrients caused by the breakdown of Azolla thereby reducing the likelihood of future blooms.

• A dense coverage consumes a lot of oxygen leaving little left for fish and other aquatic organisms. Avoids fish kills by ensuring adequate oxygen levels remain.

• Removes habitat for breeding mosquitoes.

Aquatic Surface Skimmers

can be used on all species of Azolla and primary, secondary and tertiary growth stages. This method is best used in conjunction with spray treatments or when partial removal is desired.

Physically removing Azolla from the water's surface will reduce the likelihood of future blooms by decreasing the amount of nutrients in your water. Nutrient-rich water lets aquatic vegetation thrive, meaning you might experience more infestations of unwanted Azolla.

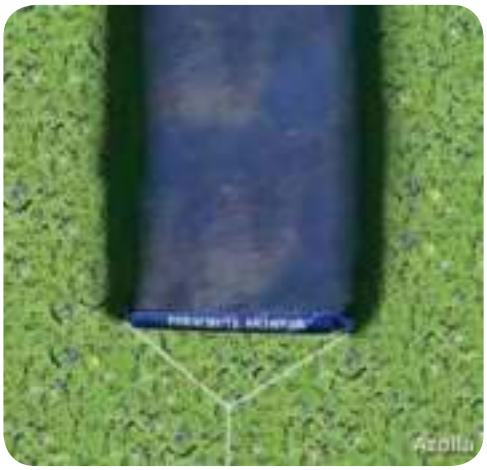
Easily remove Azolla from your water body in 4 steps:

1. Toss the skimmer in the water
2. Slowly pull it back in using the string attached
3. Dump the Azolla out onto the bank or into a container for easy transport
4. Repeat

Tips:

• Keep collected Azolla away from water's edge to avoid re-contamination

• Use the collected Azolla on your garden! Azolla is a great fertilizer.



Aquatic Harvesting

Amphibious Aquatic Harvesting machines can be used on all species of Azolla and is better suited to larger infestations where chemical treatment is not desirable or practical.

Aquatic harvesters can remove the bulk of an infestation in accessible areas, and other control methods are then required for the remnant Azolla left close to edges, or in shallow or inaccessible areas.

Brittany Pondeljak ©

HOW TO PREVENT AZOLLA BLOOMS

The best practice to minimise Azolla blooms is to maintain a healthy water body. As described previously, one of the main contributing factors to excessive. Azolla growth is phosphorus.

Phosphorus can be controlled by:

- Limiting run-off
- Reduce fertiliser use
- Prevent top soil erosion
- Manure handling management
- Soil conservation practices
- Restoring wetlands and riparian buffers

Phosphorus Removal

Phoslock - Removes excess phosphorus

Developed by the Australian CSIRO, Phoslock is a highly effective product that removes excess phosphates from any body of water.

Phoslock is a unique modified bentonite clay granule that effectively locks phosphorus into its own particles, which then sink to the bottom of the water body. These particles then become part of the natural sediment – so there's no need to remove them after application.Phoslock will continue to absorb phosphorus released from the sediment and new phosphorus inputs until it is saturated, giving long-lasting results.

Preparing Phoslock Solution:	Applying Phoslock Solution:
Step 1) Mix Phoslock in batches into an aqueous slurry You can spread the granules straight from the container across the water's surface if an aqueous slurry is too difficult (for small applications only).	Step 2) Apply evenly across the water's surface using a spray unit or by pouring the phoslock slurry from a container.

25kg of Phoslock is applied for every 100m² of water surface area.

Tips for application:

- Ensure there is visible water when applying Phoslock
- Mix phoslock into water using a paint mixer
- Add phoslock slowly to ensure even mixing

Notes:

- Use PPE when handling Phoslock including; gloves, mask, goggles, overalls/protective clothing
- Phoslock is best applied with a modified spray unit
- An Aerated water body will enhance and prolong the Phoslock treatment

Maintaining a healthy water body

A healthy water body consists of native plant and animal populations interacting in balance with one another as well as nonliving things.
In a healthy ecosystem there will be:

- An energy source (primarily the sun)
- Living organisms (primary producers, consumers, decomposers)
- Non-living things (water, soil, rocks etc.)
- Dead/decaying matter

Freshwater ecosystems differ greatly from one another depending on type, location, and climate, but they nevertheless share important features [42]. By knowing what's normal for your water body will help you maintain a healthy ecosystem.

Water Features:
1. Flow pattern – defines where the water comes from. Knowing the source of your water can be indicative of factors that may influence water body health.

2. Sediment and organic matter – raw materials that create physical habitat structure as well as supply energy sources to sustain aquatic plants and animals. Knowing what inputs are going into your water body will help you manage its overall health.

3. Temperature and light – regulate metabolic processes, activity levels, and productivity of aquatic organisms. These factors change seasonally and aquatic plants and animals have adapted tothese changes. Knowing what is regular for your water body will help you monitor any unusual changes.

4. Nutrient and other chemical conditions – regulate pH, water quality and plant and animal productivity. An imbalance will likely be displayed by algal blooms, excessive aquatic plant growth, foul odours or changes in animal behaviour.

5. Plants and animals – influences ecosystem function and community structure. A diverse range of aquatic plants and animals indicate a healthy ecosystem. When one species becomes dominant, it is indicative of an imbalance within the water body.

By monitoring the status of these five features, you can more easily distinguish where an imbalance might be and rectify the issue.

Signs that your water body is unhealthy:

- Odours (foul, sulphur, rotten-egg)
- Water clarity (turbid water can be indicative of health concerns)
- Algal blooms
- Excessive aquatic plant growth
- Dead animals
- Fish consistently swimming near the water's surface

An essential feature for water body health not listed above is oxygen, known as dissolved oxygen in the context of water.Dissolved oxygen is an essential requirement for living aquatic organisms.

Most of the organisms that inhabit fresh water constantly consume dissolved oxygen (DO).
In order for life to be sustained this oxygen must be replenished, and in many waters this can be accomplished by a process called re-aeration (surface water taking up oxygen from the overlying air) [43].

However, re-aeration is only effective if the water is moving and mixing rapidly enough for the DO to reach deeper water before oxygen reserves become depleted [43].

In rivers and streams, the constant flow of water is the likely source of re-aeration and mixing in freshwater systems [43], however the same cannot be said for slow moving water bodies such as dams and lakes.

In northern parts of Australia, a substantial amount of habitats are highly productive and very warm, therefore oxygen consumption rates are very high [43].

As a consequence the re-aeration rates required in order to maintain oxygenation are often highest at the sites that are most poorly re-aerated [43].

Some large exposed waterbodies such as lakes can be partially re-aerated by winds, but some freshwater habitats are too small and/or sheltered to allow wind mixing to fully replenish oxygen reserves [43].

Waterbodies that cannot rely on re-aeration will primarily rely on submerged photosynthetic organisms (plants and algae) to produce enough DO during daylight hours to meet the needs of the entire ecosystem during the night [43].

Biological oxygenation of this kind can be surprisingly effective; nevertheless it is still very common to find that DO concentrations have fallen to potentially life-threatening levels by the time the sun rises each day [43].

Changes to this type of ecosystem can greatly influence DO levels and collapse it entirely e.g.

- water clarity
- depth
- amount and type of submerged plants
- nutrient availability

Nowadays, DO can be maintained artificially via aquatic aerators. This is a reliable way to ensure the basic health needs are met of all aquatic life in managed waterbodies.

AERATION

Water aeration is the process of increasing or maintaining sufficient oxygen levels of water in both natural and artificial environments.

Aeration is a common tool used in pond, dam, lake, and reservoir management to maintain healthy waterbodies by addressing low oxygen levels or controlling algal blooms.

Artificial aeration can help reduce algal and noxious aquatic plant blooms by encouraging the growth of beneficial aerobic bacteria.

These bacteria consume excess nutrients that is otherwise available to aquatic plants and algae.

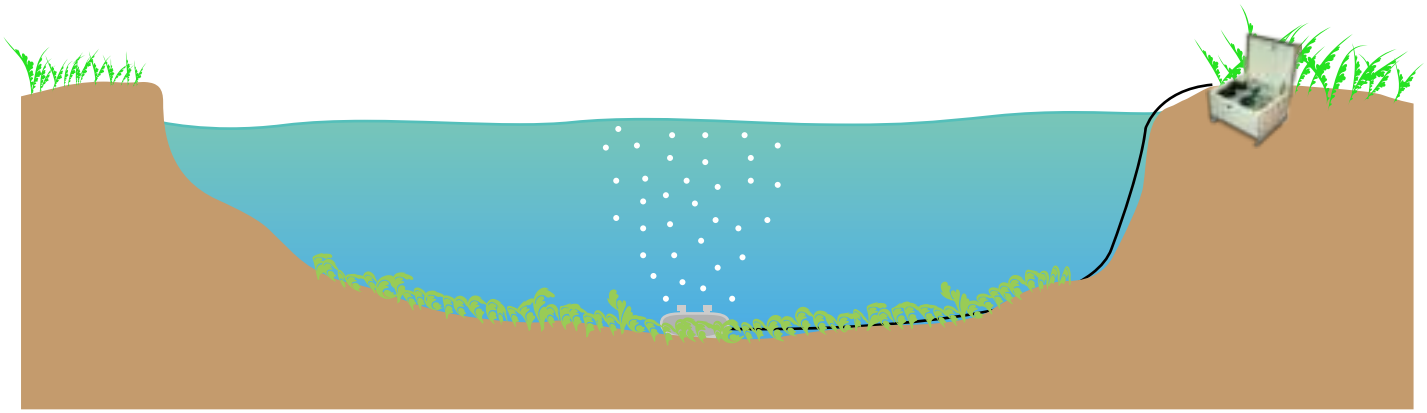
Not only do these bacteria reduce the amount of nutrient availability, they help prevent a build-up of “muck” at the bottom of the water body. This muck can house noxious gases that can lead to foul odours and muddy water.

An aerated water body will have reduced algal blooms, normalised aquatic plant growth, adequate oxygen availability, no foul odours, improved water clarity and a reduction in muck accumulation.

Subsurface aeration:

Subsurface aeration is designed to release bubbles from the bottom of the water body and allow them to rise by the force of buoyancy. Diffused aeration systems utilize bubbles to aerate as well as mix the water to prevent stratification (water stratification is when water masses with different properties - salinity, oxygenation, density, temperature - form layers that act as barriers to one another preventing mixing). Water displacement from the expulsion of bubbles will cause a mixing action to occur, and the contact between the water and the bubble will result in an oxygen transfer.

Subsurface aeration is better suited to deeper waterbodies where stratification is more likely to occur.

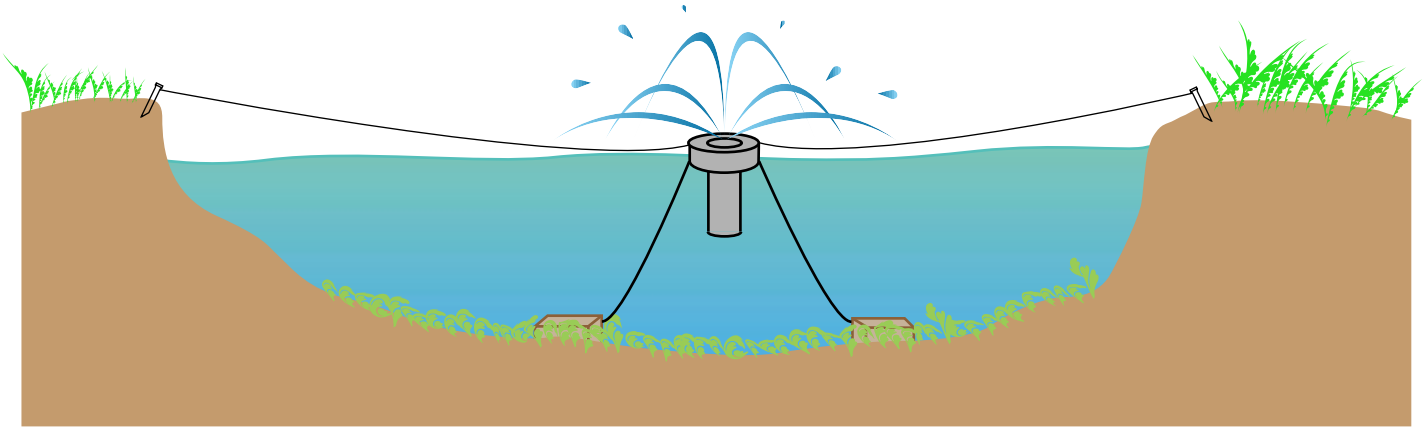


Surface aeration:

Surface aeration is designed to mimic re-aeration (surface water taking up oxygen from the overlying air). The surface aerator disrupts the surface of the water body allowing adequate air-water contact for successful oxygen diffusion.

In a fountain surface aerator, the water droplets created have a large surface area through which oxygen can be transferred and as they fall back into the water body, the droplets mix with the rest of the water and transfer the oxygen.

Surface aeration is better suited to smaller, shallower waterbodies.



References

[1] Hussner, A. (2010): NOBANIS – Invasive Alien Species Fact Sheet – Azolla filiculoides. – From: Online Database of the European Network on Invasive Alien Species – NOBANIS www.nobanis.org, Date of access 24/03/2021.

[2] McConnachie AJ, Hill MP, Byrne MJ. Field assessment of a frond-feeding weevil, a successful biological control agent of red water fern, Azolla filiculoides, in southern Africa. Biological Control 2004;29:326-331.

[3] Moore AW. Azolla: biology and agronomic significance. Botanical Review 1969:35:17-35.

[4] Janes R. Growth and survival of Azolla filiculoides in Britain. 1. Sexual Reproduction. New PhytologistI 1998;138:367-376.

[5] Mandal B, Vlek PLG, Mandal LN. Beneficial effects of blue-green algae and Azolla, excluding supplying nitrogen, on wetland rice fields: A review. Biology and Fertility of Soils 1999;28(4):329-342.

[6] Choudhury ATMA, Kennedy IR. Prospects and potentials for systems of biological nitrogen fixation in sustainable rice production. Biology and Fertility of Soils 2004;39:219-227.

[7] De Macale MAR, Vlek PLG. The role of Azolla cover in improving the nitrogen use efficiency of lowland rice. Plant and Soil 2004;263:311-321.

[8] Nayak S, Prasanna R, Pabby A, Dominic TK, Singh PK. Effect of urea, blue green algae and Azolla on nitrogen fixation and chlorophyll accumulation in soil under rice. Biology and Fertility of Soils 2004;40:67-72.

[9] Kimura M. Populations, community composition and biomass of aquatic organism in the floodwater of rice fields and effects of field management. Soil Science and Plant Nutrition 2005;51:159-181.

[10] Cary PR, Weerts PGJ. Growth and nutrient composition of Azolla pinnata R. Brown and Azolla filiculoides Lamarck as affected by water temperature, nitrogen and phosphorus supply, light intesity and pH. Aquatic Botany 1992;43:163-180.

[11] Kitoh A. The growth and nitrogen fixation of Azolla filiculoides Lam. in polluted water. Aquatic Botanyl 1993;46:129-139.

[12] Qiu YL, Yu J. Azolla – A Model Organism for Plant Genomic Studies. Genomics, Proteomics & Bioinformatics 2003;1(1):12-25.

[13] Hasan MR, Chakrabarti R. Use of algae and aquatic macrophytes as feed in small-scale aquaculture: a review. FAO Fisheries and Aquaculture Technical Paper, No. 531. FAO. 2009. Rome, Italy.

[14] G. M. Wagner, "Azolla: a review of its biology and utilization," The Botanical Review, vol. 63, pp 1-26, 1997.

[15] H. F. Tung, I. Watanabe, "Differential response of Azolla-Anabaena associations to high temperatures and minus phosphorus treatments," New Phytologist, vol. 93, pp. 423-431, 1983.

[16] I. Watanabe, N.S. Berja, "The growth of four species of Azolla as affected by temperature," Aquatic Botany, vol. 15, pp. 175-185, 1983.

[17] R. J. M. Temmink, S. F. Harpenslager, A. J. P. Smolders, G. van Dijk, R. C. J. H. Peters, L. P. M. Lamers, M. M. L. van Kepmen, "Azolla along a phosphorus gradient: biphasic growth response linked to diazotroph traits and phosphorus-induced iron chlorosis," Scientific Reports, vol. 8, 4451, 2018.

[18] A. W. Sheppard, R. H. Shaw, R. Sforza, "Top 20 environmental weeds for classical biological control in Europe: a review of opportunities, regulations and other barriers to adoption," Weed Research, vol. 46 (2), pp. 93-117, 2006.

[19] R. Fernandez-Zamudio, S. Cirujano, S. Sanchez-Carrillo, A. Meco, P. Garcia-Murillo, "Clonal reproduction of Azolla filiculoides Lam.: implications for invasiveness," Limnetica, vol. 32 (2), pp. 245-252, 2013.

[20] D. Sculthorpe, "The biology of aquatic vascular plants," Edward Amold Ltd., London. UK.

[21] M. J. Pinero-Rodriguez, R. Fernandez-Zamudio, R. Arribas, I. Gomez-Nestre, C. Diaz-Paniagua, "The invasive aquatic fern Azolla filiculoides negatively impacts water quality, aquatic vegetation and amphibian larvae in Mediterranean environments," Biological Investigations, vol. 23, pp. 755-769, 2021.

[22] R. Janes, J. W. Eaton, K. Hardwick, "The effects of floating mats of Azolla filiculoides Lam. and Lemna minuta Kunth. on the growth of submerged macrophytes," Hydrobiologia, vol. 340, pp. 23-26, 1996.

[23] P. Aloo, W. Ojwang, R. Omondi, J. M. Njiru, D. Oyugi, "A review of the impacts of invasiveaquatic weeds on the biodiversity of some tropical water bodies with special reference to Lake Victoria (Kenya)," Biodiversity Journal, vol. 4 (4), pp. 471-482, 2013.

[24] B. Gratwicke, B.E. Marshall, "The impact of Azolla filiculoides Lam. on animal biodiversity in streams in Zimbabwe," African Journal of Ecology, vol. 39 (2), pp. 216-218, 2001.

[25] Conley DJ, Pearl HW, Howarth RW, Boesch DF, Seitzinger SP, Havens KE, et al. Controlling Eutropication: Nitrogen and Phosphorus. Science 2009;232:1014-1015.

[26] Gorde SP, Jadhav MV. Assessment of Water Quality Parameters: A Review. Journal of Engineering Research and Applications 2013;3(6):2029-2035.

[27] NSW DPI, Salvinia Control Manual, Orange, NSW: NSW Department of Primary Industries, 2006.

[28] Gratwicke B, Marshall BE. The impact of Azolla filiculoides Lam. on animal biodiversity in streams in Zimbabwe. Department of Biological Sciences, University of Zimbabwe, Notes and Records, 2001.

[29] Gopal B. Water Hyacinth. Aquatic Plant Studies 1, Elsevier, Amsterdam.

[30] Hill MP, McConnachie AJ. The Biological Control of Azolla filiculoides Lamarck (red water fern). Department of Zoology and Entomology, Rhodes University and Weed Research Division, Plant Protection Research Institute, Agricultural Research Council, South Africa, 2000.

[31] Skogerboe JG, Getsinger KD, Glomski LAM. Efficacy of diquat on submersed plants treated under simulated flowing water conditions. Journal of Aquatic Plant Management 2006;44:122-125.

[32] Tomlin CDS. The Pesticide Manual: A World Compendium. 14th ed.; British Crop Protection Council: Hampshire, UK, pp. 545- 548, 2006.

[33] Vencill WK. Herbicide Handbook," 8th ed.; Weed Science Society of America: Lawrence, KS, pp. 231-234, 2002.

[34] Westerdahl HE, Getsinger KD. Aquatic plant identification and herbicide use guide. vol 2, ed. Mississippi: Mississippi: US Army Corps of Engineers, Waterways Experiment Station, 1988.

[35] Soltys D, Krasuska U, Bogatek R, Gniazdowska A. Allelochemicals as Bioherbicides — Present and Perspectives. In Herbicides - Current Research and Case Studies in Use, IntechOpen, 2013.

[36] Messerschmidt O, Jankauskas J, Smith F. Limonene-containing herbicide compositions, herbicide concentrate formulations and methods for making and using same. United States of America Patent US 8,273,687 B2, 25 September 2012.

[37] Koperek E. Organic Herbicides. World Agriculture Solutions, Pennsylvania, 2015.

[38] NSW Government, Salvinia - Smothers Dams and Waterways, New South Wales DPI, 2015.

[39] Environmental Sustainability Office of Estate and Commercial, Weed Management Plan, Sydney: Western Sydney University, 2020.

[40] Wisconsin Department of Natural Resources, "Glyphosate Chemical Fact Sheet" [Fact sheet]. https://dnr.wi.gov/lakes/plants/factsheets/GlyphosateFactsheet.pdf

[41] Siemering GS, Hayworth JD, Greenfield BK. Assessment of Potential Aquatic Herbicide Impacts to California Aquatic Ecosystems. Archives of Environmental Contamination and Toxicology 2008;55(3):415-431.

[42] Ribeiro R, Lima M. Allelopathic effects of orange (Citrus sinensis L.) peel essential oil. Acta Botancia Brasilica 2012;26(1):256-259.

[43] Baron JS, Poff NL. Sustaining Healthy Freshwater Ecosystems. Water Resources Update 2004;127:52-58.

[44] Butler B, Burrows DW. Dissolved Oxygen Guidelines for Freshwater Habitats of Northern Australia. Australian Centre for Tropical Freshwater Research: Prepared for Department of Environment and Heritage Canberra, Townsville, QLD, Australia, 2007.