THE AZOLLA COOKING AND CULTIVATION PROJECT

Cover photo: *Azolla* soup and *Azolla* veggie balls with rice noodles cooked at Färgfabriken in Stockholm 2010.

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INTRODUCTION

In “The Azolla Cooking and Cultivation Project”, I experiment with cooking and cultivating the water fern *Azolla* together with artists, farmers, gardeners, chefs and scientists. This book summarizes my work with the project during 2010 and 2011 and has been updated in 2024 with new information regarding *Azolla* cultivation and the nutritional content and healthiness of *Azolla*. The book is intended as a base for future research on *Azolla* food and *Azolla* cultivation as well as a general introduction to *Azolla*’s biology and its many uses.

Before engaging in the cultivation of Azolla, it is important to note that Azolla is classified as an invasive species and weed in many regions, and should not be introduced into the wild. Whether it makes sense to use *Azolla* as a food stuff for humans ultimately depends on how healthy *Azolla* is to eat, and that is still unclear. However, it is possible to cook tasty food using *Azolla* as a cooking ingredient. Since *Azolla* is one of the world’s fastest growing plants and a rich source of protein and other nutrients this calls for more research on the healthiness of *Azolla* and on *Azolla* cooking and cultivation.

Erik Sjödin, 2012 / 2024

ACKNOWLEDGEMENTS

The Azolla Cooking and Cultivation Project is an independent research project. Any errors or omissions in this publication are my own. I would like to thank: John Larsson at The Department of Botany at Stockholm University (SE) who introduced me to *Azolla*; Masamichi Yamashita at Japan Aerospace Exploration Agency (JP), whose research on *Azolla* as a component of a space diet inspired this project; Kultivator who gave me the opportunity to work with the project at their experimental cooperation of organic farming and art practice on the island of Öland and at Kalmar konstmuseum in Kalmar (SE); Färgfabriken, an experimental platform for art and architecture in Stockholm (SE) and their café, for letting me grow *Azolla* in their backyard and experiment with *Azolla* in their kitchen; Oloph Fritzén and Jenny Olofsson at Hästa gård in Stockholm (SE) for helping me grow *Azolla* and evaluating it as animal fodder; RIXC for giving me the opportunity to grow *Azolla* at KIM? Contemporary Art Center in Riga (LV); Rogaland Kunstsenter, Øyvind Erland and Ullandhaug økologiske gård, and the Norwegian Gastronomical Institute in Stavanger (NO) for their help with growing *Azolla* and evaluating its taste; Halikonlahti Green Art and gardener Tiia Paju for their help with growing and cooking *Azolla* in Salo and at Salo Art Museum (FI); Grizedale Arts for inviting me over to Grizedale Arts and Wysing Arts Centre to experiment with dried *Azolla* in bread; Regine Debatty for giving me permission to include an interview from We Make Money Not Art; Everyone who has been involved in the reviewing of the initial version of this booklet, including John Larson, Masamichi Yamashita and many of the above, but also botanist Ernest Small, paleontologist Jonathan Bujak and biologist Francisco Carrapiço.

INTERVIEW BY WE MAKE MONEY NOT ART

RÉGINE DEBATTY I am interested in the way you try to engage the public into your research about *Azolla*. You have already exhibited this project in several art spaces. How does the *Azolla* project take shape? Do you change strategy each time you exhibit it? Cooking at Färgfabriken for example and doing something else in Riga?

ERIK SJÖDIN What I end up doing is shaped a lot by circumstances. At Färgfabriken in Stockholm I exhibited in the summer and they had a courtyard so it was possible to grow *Azolla* outside. RIXC's exhibition at KIM? Contemporary Art Center in Riga was too early in the spring for it to be possible to grow *Azolla* outside, and the room I exhibited in didn't have any windows so I had to grow the *Azolla* under artificial lights. I also try to find people to collaborate with around the exhibitions. At Färgfabriken I got the chef at Färgfabriken's café to experiment with *Azolla* cooking with me.

Azolla cultivation at Rogaland Kunstcenter in Stavanger, Norway 2011

I exhibit “The Azolla Cooking and Cultivation Project” as a work in progress because I think that an ongoing process can be more interesting and engaging than the conclusion. The project has always been more about the process than the result, but it is not that I don’t care about the result. I am hoping to arrive at something, but the result is the outcome of the process and in that sense the process is everything. Finding new ways of working, or living if you want, is very much what the project is about for me.

RD You are going to exhibit “The Azolla Cooking and Cultivation Project” again in end of May / June at Rogaland Kunstsenter in Stavanger. What will the work look like in Stavanger? Will you be cooking, growing *Azolla*?

ES I will make an installation inside the gallery where I will grow *Azolla*. There will also be a reading corner where a draft of the *Azolla* cookbook and cultivation manual that I am working on will be available along with some literature that relates to the project. Two texts that I will include are *Tomorrow is Our Permanent Address* by John Todd from New Alchemy Institute and the sociologist and philosopher Bruno Latour’s text *An attempt at a “Compositionist Manifesto”*. New Alchemy Institute was a research center that did pioneering research into agriculture, aquaculture and architecture in the 70’s and 80’s. In 1976 they experimented with *Azolla* as a mulch for lettuce. The results of these experiments were published in the 1977 issue of their journal, the same issue in which *Tomorrow is Our Permanent Address* was published. Already in the 70’s New Alchemy Institute were doing and thinking about much of what is being talked about as novelties today. In Tomorrow is Our Permanent Address, John Todd talks about exploring a “new synthesis”; how “biological consciousness would fundamentally alter our sense of what human communities could be” and how “in the adaptive model of nature lie design ideas that will enable humans to create societies and cultures as beautiful and as significant as any that have thus far existed”.

Bruno Latour takes interest in the so called nature / culture dichotomy and argues that it has become untenable. In *An attempt at a “Compositionist Manifesto”* (published in 2010) he talks about how “everything happens as if the human race were on the move again, expelled from one utopia, that of economics, and in search for another, that of ecology” and that perhaps it is time to “innovate as ever before, but with precaution” if we are to build a livable and breathable “home”.

This is what I know will happen in Stavanger. I am also trying to involve the Norwegian Gastronomic Institute in Stavanger in the project. I am hoping that we can make a larger outdoor *Azolla* cultivation somewhere and experiment with *Azolla* cooking together but nothing is set yet.

Throughout the summer I will also be working with Oloph Fritzén and Jenny Olofsson, farmers at Hästa gård, a 180 hectare urban farm in Stockholm. We will try to make some kind of *Azolla* installation on the farm and grow *Azolla* to use as mulch and as fodder for the farms animals.

In September I will exhibit "The Azolla Cooking and Cultivation Project" at the Halikonlahti Green Art Trilogy in Finland. For that exhibition I am collaborating with Tiia Paju, a gardener who will be growing *Azolla* in Salo during the summer. During the opening weekend of the exhibition I will be facilitating an *Azolla* kitchen where people can drop in and experiment with *Azolla* cooking.

RD *Azolla* has been used for biological fertilizer and as animal fodder. At some point in the booklet, you call it 'not super tasty' and you even add further on "To sum up you eat *Azolla* on your own risk. It might be healthy and it might not." That was quite a warning! So what is your aim with "The Azolla Cooking and Cultivation Project"? To convince people that it is a valuable food resource? Or rather to enter in a broader discussion about the future of food and food production for example?

ES I am trying to find out if there is any real potential in *Azolla* as a food for humans but I haven't reached any conclusions yet and I want that to be clear. As far as I know no studies have been carried out on the effects on humans of *Azolla* consumption so no one really knows weather it is healthy or not. But I will rewrite that sentence before the booklet is published. I don't want to overemphasize the risks either. Apart from potentially being a new foodstuff *Azolla* has many applications, as fertilizer, animal fodder and for biofuels for example. I want to disseminate this information so that people can find appropriate uses for *Azolla* but I don't want to "sell" *Azolla* or give any illusions that it is a panacea.

I am interested in how we produce our food today and could be producing it in the future and I try to get some insight into this by looking at how *Azolla* can be used in agriculture. When I started to work with "The Azolla Cooking and Cultivation Project" I knew very little about agriculture. Now I know enough to be convinced that the industrial agriculture we have to day is a dead end and that we ought to move towards an agriculture based on a diversity of species working together in stead of ever larger monocultures dependent on fossil fuel driven machines, synthetic fertilizers and pesticides. The way I see it this is not a matter of going back to a pre-modern agriculture but of putting together both old and new knowledge of how the world functions and creating something that we have never had before.

Azolla has been used as an organic fertilizer in rice paddies for thousands of years in parts of China, but it is not until recently that this practice has started to spread to other parts of the world.

Azolla cultivations at Färgfabriken in Stockholm 2010

Azolla soup and *Azolla* veggie balls with rice noodles at Färgfabriken in Stockholm 2010

Experiments with *Azolla* in rice cultivation has for example just started in Italy where rice producers have problems with pollution and depleting soils. Using *Azolla* as an organic fertilizer in rice paddies is great, but when it becomes really interesting is when even more species are introduced in the paddy. A farmer in Japan, where *Azolla* commonly is regarded as a rice paddy weed, has recently shown that if rice is co-cultured with *Azolla*, fish and ducks in the same paddy you can get greater rice yields than with conventional rice farming while at the same time getting fish, duck meat and eggs. I think that systems like these are really promising and that what we need to do is to develop an agriculture with both a a great diversity of systems and great diversity within the systems themselves.

RD How does the public react to your project?

ES Most people I have met are really curious and enthusiastic about the

project. It is fun to look at, touch and eat a plant you haven't heard of before. Especially one as odd as *Azolla*, a floating fern that lives in symbiosis with a cyanobacteria and grows like crazy. I also think that a lot of people are inspired by the project because it is an amateur pursuit and because it is an attempt to look at how we can improve things. The only negative reaction I have received was when I presented the project at a permaculture course. I mentioned that scientific studies have shown that cow's milk productions can be increased and that chickens gain weight if they are given *Azolla* as a supplemental fodder. This prompted some strong negative reactions from a participant who associated this with pushing animals too far and treating them as biological production units rather than conscious beings. There was also a discussion around the appropriateness of introducing *Azolla* in agriculture in Sweden where it isn't an indigenous species. If *Azolla* would be introduced in the wrong environment it could become a problem. There are already examples of this having happened in Iran for example. However, I have found a Swedish garden enthusiast who has been growing *Azolla* in a pond in Stockholm for the past ten years without it ever surviving the winter so I don't think we need to worry about it spreading uncontrollably at these latitudes. These are relevant concerns though.

I am interested in our notions of what is "natural", how these notions are connected to language and aesthetics and how they are tied to how we relate to the past, the present and the future. I think we need to look beyond appearances at how things actually function and consider both new and old practices.

RD The nickname of *Azolla* is "super plant". How come I read all those health magazines full of "super food" articles and I have never heard about *Azolla*? Could it become the new Tofu one day?

ES I don't know why the health food industry hasn't picked up on *Azolla* yet. My guess is that they just haven't heard of it, though it seems strange. I don't think it would be difficult to market *Azolla* as a health supplement, like spirulina, and make a profit from it. I have been contacted by people who have been interested in growing *Azolla* as health food and I have been asked if I have intentions of doing this myself, which I don't.

Tofu and in particular Quorn are interesting foodstuffs. Many people don't know what they are made of or how they are made but they still eat them.

Quorn is also interesting because it is a newly invented foodstuff. In the 60's it was predicted that by the 80's there would be a global famine and shortage of protein-rich foods. Quorn is the result of research that was done in response to this. The fungus that Quorn is made from was discovered in 1967. After it had been evaluated for ten years the company that makes Quorn got permission to sell it for human consumption in the 80's. The global famine never happened but Quorn ended up being a great vegetarian substitute to meat. I don't find it unlikely that *Azolla* could be turned into a foodstuff like Quorn or Tofu with the right processing, but a lot more research has to be done.

RD In the introduction of your booklet you thank Masamichi Yamashita at Japan Aerospace Exploration Agency (JAXA) because his work, you write, has inspired this project. What did JAXA make with *Azolla*? Did they manage to successfully include it in a diet? What was in it in JAXA research exactly that triggered your idea to work on a project about *Azolla*?

ES I was impressed that by designing systems similar to the rice-duck-fish-*Azolla* system I mentioned earlier, and including *Azolla* in a human diet, it would theoretically be possible to grow all the food a human needs in an area of 200 square meters. That is less than a hundredth of the area the average Americans food production occupies today. This made me curious of what *Azolla* tasted like and since I couldn't find any *Azolla* recipes or satisfying accounts of what *Azolla* tasted like anywhere I decided to try to grow it and cook it myself. For many people space and the future are synonymous so I thought it would be interesting to look into how we produce our food today and could be producing it in the future using space agriculture research as a starting point. I think a lot of valuable knowledge can come out from research on space colonization but at the same time I find our fascination with it kind of peculiar. I recently watched Werner Herzog's The Wild Blue Yonder where a researcher talks enthusiastically about how in the future we will be living and working on asteroids and going to Earth on vacation. Why would we want to do that? Living on an asteroid and eating *Azolla* doesn't sound that appealing to me. I would rather see that we try to find ways of co-existing with the diversity of species that we still have left here on Earth so we can continue to have varied food.

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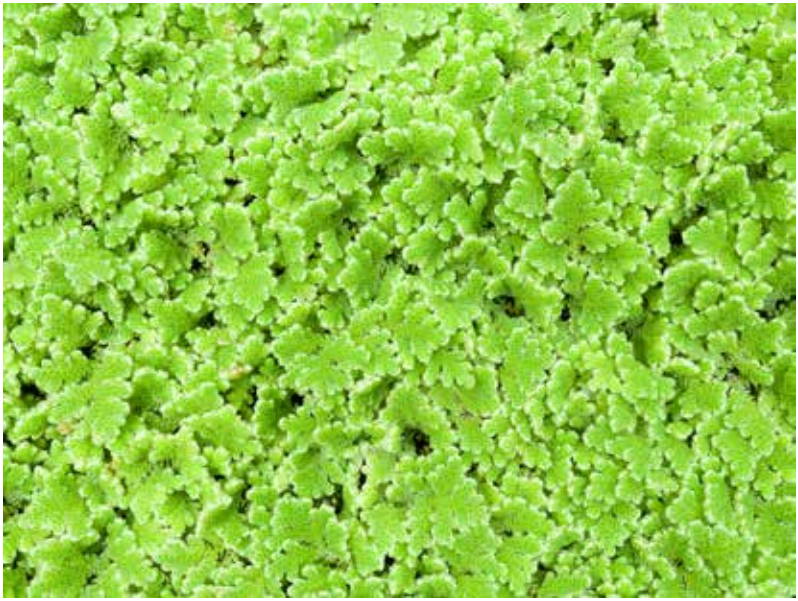
Installation at Halikonlahti Green Art at Salo Art Museum in Salo, Finland 2011

THE SUPER PLANT



Close up of *Azolla*

Azolla, also known as mosquito fern, duckweed fern, fairy moss and water fern, is a genus of freshwater ferns that grows floating on water surfaces in temperate and subtropical regions throughout the world [1, 2].* It can reproduce by forming spores but it mainly reproduces vegetatively by breaking off side branches, and it does this at an enormous rate. Under ideal conditions it grows exponentially, doubling its biomass every two days [1]. If it has enough room to grow, such as in a large rice paddy, it can increase thousandfold in a month [3].

This extremely rapid growth is enabled by the ferns symbiosis with a cyanobacterium (sometimes referred to as a blue-green alga) that lives in cavities in the ferns leafs. The cyanobacterium fixes nitrogen, an essential plant nutrient, from the air and makes it available to the fern. In turn the fern provides the cyanobacterium with carbon fixed through photosynthesis and a favorable environment to grow in [4]. *Azolla* is also capable of photosynthesizing

at rates higher than most plants since the light-harvesting pigments in the fern and cyanobacterium are complementary and can capture a wide range of wavelengths of light [5].

This combination of capability to fix atmospheric nitrogen and effective photosynthesis has enabled *Azolla* to become one of the fastest growing plants on Earth and earned it the title “super plant”. However, there are more reasons to call *Azolla* a super plant.

Azolla is the only known plant where a nitrogen fixing cyanobacterium lives in cavities inside the plants photosynthesizing leaves [1].* *Azolla* also appears to be the only known plant where bacteria are transferred with the plant as it reproduces. In fact, the nitrogen fixing cyanobacterium in *Azolla* has co-evolved with the fern to the degree that it no longer can survive outside of it [4]. Other plants that form symbiosis with bacteria have to be reinoculated with the bacteria between each generation.

Beside the nitrogen fixing cyanobacterium a number of other bacteria are found in the leaf cavities of *Azolla* [4]. Little is known about the individual roles of these bacteria, but the complex community of bacteria and cyanobacteria cooperate with the fern to maintain the whole. This has led scientists to suggest that *Azolla* should be considered a “superorganism”; an organism made up of many organisms [6, 7].

Recently *Azolla* has also entered into a discussion around how to define symbiosis. Symbiosis is commonly understood as a system of exchange where two or more partners benefit from cooperating. However, scientist have now begun to argue that the common denominator of symbiosis is not mutual benefit, but novel capabilities – that through cooperation capabilities are acquired that extend beyond the capabilities of the individuals. An idea that they claim could be a new paradigm in science that rests almost unexplored [7, 8]. *Azolla* is an excellent example of a symbiosis of this kind.

* Legumes such as clover, peas and beans are other examples of plants that lives in symbiosis with nitrogen fixing bacteria. However, *Azolla* is the only known plant where the bacteria lives inside the plant.

A GREEN GOLD MINE

In “The Azolla Cooking and Cultivation Project” the focus is on exploring *Azolla* as an ingredient in food for humans, but *Azolla* has so many uses that it has been nicknamed “a green gold mine” [5]. The most common uses of *Azolla* are as organic fertilizer and as an animal fodder rich in nutrients and protein.

Azolla can be used as fertilizer and soil improver for many plants [9, 6, 10, 11]. However, it is best known for its use as a fertilizer for rice, especially in China where it has been grown in rice paddies for centuries. Already in 540 A.D. the use of *Azolla* as a fertilizer in rice paddies is described in a Chinese book on agriculture with the title “The Art of Feeding the People” [1].

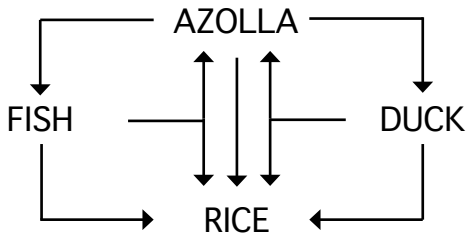
Other uses for *Azolla* are for wastewater treatment, as a water quality indicator, for controlling algal blooms and mosquitoes and for production of biofuels such as biogas and bioethanol [5,12, 13].** *Azolla* has also been reported to be used effectively as a traditional cough medicine in Tanzania, though there are no mentions of how it is used [5].

Azolla is also effective at capturing and fixating carbon dioxide and is believed to have played a significant role in reversing a greenhouse effect that had caused the region around the Arctic Ocean to turn into a hot, tropical environment around 49 million years ago [14]. However, drawing down atmospheric carbon and reversing the earth’s climate is not done over night. This climate changing process is believed to have lasted for 800,000 years during which time an area of up to 4,000,000 km² was covered with *Azolla* [15].

AZOLLA IN POLYCULTURES

"The Azolla Cooking and Cultivation Project" was inspired by a scientific paper with the title "Azolla as a Component of The Space Diet During Habitation on Mars" published in 2008. In this paper Japanese space agriculture researchers show that if *Azolla* is co-farmed with rice, fish and some other carefully selected crops and animals, such as soybean, sweet potato and silkworms, it is theoretically possible to produce all the food a human needs in an area less than 200 square meters [16, 17]. Today, the average Americans food footprint is more than a hundred times that area [18].

In Japan, and many other industrial countries, *Azolla* has mainly been considered as a weed and hardly any attempt to make positive use of it is known [12]. However, by approaching *Azolla* as a resource and not as a weed the Japanese farmer Takao Furuno has come up with an agricultural system know as "integrated rice, duck, fish and *Azolla* farming" [3].



In integrated rice, duck, fish and *Azolla* farming, *Azolla* is grown in polycultures together with rice, ducks and fish. The *Azolla* provides nitrogen to the rice and protein to the ducks and fish, it limits the growth of weeds, algae and mosquitos and it reduces water evaporation and possibly also reduces methane emissions. The ducks and fish eat weeds, insects and other pests, their droppings provide phosphor and other nutrients to the rice and *Azolla*, and their swimming activity spreads the *Azolla* and aerates the water which stimulates rice and *Azolla* growth. The only thing that is added from the outside of this system is a little leftover rice that is used as duck feed [3].

According to Furuno using this system it is possible to grow organic rice with larger yields than traditional monoculture rice farming that uses pesticides and synthetic fertilizers and heavily relies on fossil fuel based mechanical aids, and at the same time produce organic fish, duck meat and duck eggs [19].

However, whether integrated rice, duck, fish and *Azolla* farming makes sense or not depends on local circumstances. As Furuno puts it in his book "The Power of Duck", today's agriculture is based on technology and resources "which is not produced on the farm, it is a passive, highly controlled and "do according to the manual" type technology in which the farmer has no creative involvement." Integrated rice, duck, fish and *Azolla* farming in contrast is a creative combination of things found "in or around the farm, so that they work together under the natural, economic and social conditions of the locality".

Clover and other legumes such as peas and beans also live in symbiosis with nitrogen fixing bacteria. Like *Azolla* clover can be grown as a ground cover in between grains such as wheat, rye and barley and in this way work both as a fertilizer and as a weed protection. This method can also be applied to rice cultivation which the Japanese farmer and philosopher Masanobu Fukuoka has demonstrated [20]. What both Furuno's and Fukuoka's systems have in common is that, just like *Azolla*, they are constituted of communities of organisms that cooperate in support of the whole.

In China, twelve thousand square kilometers of rice paddies are already co-cultivated with *Azolla* [13].However, rice paddies worldwide have been estimated to cover an area of over 1.3 million square kilometer. The thought that all of these rice paddies could be converted from monocultures dependent on non-renewable fossil fuels, synthetic fertilizers and pesticides to productive self-supportive polycultures is staggering. Not to mention the idea that this kind of polyculture thinking could be applied to agriculture in general.

COOKING AND EATING AZOLLA

Until now no *Azolla* recipes seem to have been published. However, several mentions of *Azolla*-food can be found in scientific papers. Researchers in China suggest that after sterilization by steam *Azolla* can be used in salad or as stuffing in Chinese spring rolls and dumplings [21]. Gregory M. Wagner at the University of Dar es Salaam notes that researchers have experimented with *Azolla* in soup and *Azolla* "meat balls" [5], researchers In the Philippines have experimented with *Azolla* omelets and burgers and researchers at The Space Agriculture Task Force in Japan writes that *Azolla* can be cooked in many different ways, for example fried, sautéed, baked or added to soup or salad [16]. Students of Usuda High School in Nagano, Japan have also experimented with *Azolla* cooking together with The Space Agriculture Task Force and have come up with cookies and crepe that are "very delicious". There are also accounts of Indians who have made Tambulli on *Azolla*. Tambulli is a dish made using the leaves of various plants blended with curds, salt and spices. Apparently Tambulli made on *Azolla* is "pretty tasty". Food scientists at Pennsylvania State University have noticed that fermented *Azolla* has a sweet and aromatic scent which is considered appetizing to some, and consider *Azolla* a good candidate for using during times of food insecurity, such as after natural disasters [29].

Chefs at the Norwegian Gastronomical Institute, whom I introduced to *Azolla*, describe fresh *Azolla* as crisp and juicy, without much flavor but tasting somewhat of earth, metal, minerals, mushrooms, moss and grass. They describe cooked *Azolla* as similar to fresh *Azolla* but with less taste. Dried *Azolla* they describe as having more taste. It is sweet, has much tannin taste and is reminiscent of green tea, buttercup and kelp. They conclude that they see no particular value in using *Azolla* in cooking for its taste. However, if it is nutritious and healthy it could make sense as a nutritive supplement or blended and mixed into soups and stews with other vegetables.

I find *Azolla* edible, but not particularly tasty, there are also fibers in it that makes it difficult to chew. On its own *Azolla* fails to evoke cravings for more. However, cooked and chopped *Azolla* can be used similar to chopped spinach in many dishes and pulverized dried *Azolla* can work well mixed into bread and biscuits.

The recipes included here are the first dishes I attempted to make with *Azolla*. They are deliberately made simple and are better seen as fragments of

recipes than complete recipes. I wanted to use few ingredients beside *Azolla* so that the *Azolla*'s taste and texture would come through. Asides from *Azolla*, I have primarily used ingredients that can be harvested from a rice, duck, fish and *Azolla* system and ingredients suggested for space agriculture.

Cooking *Azolla* veggie balls at Färgfabriken in Stockholm 2010

AZOLLA SOUP

Azolla soup cooked at Färgfabriken in Stockholm 2010

250g fresh or frozen *Azolla*
1 deciliter soy cream
4 deciliter water
1 vegetable bouillon cube
Salt and pepper

1. Rinse and chop the *Azolla*.
2. Let the *Azolla* cook in the bouillon for about 10 minutes.
3. Stir in the soy cream.
4. Season with white pepper and salt.

AZOLLA VEGGIE BALLS AND BURGERS

Azolla veggie balls with rice noodles cooked at Färgfabriken in Stockholm 2010

100 grams fresh or frozen *Azolla*
Breadcrumbs
Salt, pepper
Oil

1. Rinse the *Azolla* and fry it in a pan.
2. Chop the fried *Azolla* and mix it with the spices.
3. Add breadcrumbs until it is possible to form balls or burgers of the mince.
4. Fry the Azolla veggie balls or burgers in vegetable oil.

The Azolla veggie balls or burgers are preferably served with rice noodles or rice. Fresh herbs and spices can be used to improve the taste.

AZOLLA PANCAKES

Azolla pancakes cooked at Halikonlahti Green Art at Salo Art Museum in Finland 2011

100 grams fresh or frozen *Azolla*
1 egg
4 deciliter milk
2 deciliter wheat flour
1/2 teaspon salt
Oil

1. Mix the pancake batter and let it swell for a while.
2. Rinse and fry the *Azolla*, chop it up and stir it into the batter.
3. Bake thin pancakes in a frying pan.

AZOLLA BREAD AND HARDTACK

Azolla bread baked at Wysing Arts Center in England 2011

2 deciliter wheat flour
1 deciliter dried *Azolla*
4 deciliter water
1/2 tablespoon salt

1. Run the dried *Azolla* in a blender until it is a fine powder.
2. Mix *Azolla*, flour, and salt into a stiff dough, adding water little by little.
3. Roll the dough flat and thin on a baking sheet.
4. Bake the dough in an oven for thirty minutes at 200°C.
5. Take the dough out of the oven and use a knife to cut it into small squares.
6. Turn the hardtack over and bake for another 30 minutes.
7. Turn the oven off, leaving the hardtack in the oven until the oven is cool.

Dried and powdered *Azolla* can also be mixed in flour used to bake other breads, such as loafs and flatbreads.

THE HEALTHINESS OF AZOLLA

Azolla has a nutritional value similar to that of Alfalfa sprouts and Spirulina (a dietary supplement made from the cyanobacteria Arthrospira) [16, 22]. It is a rich source of minerals (10-15% of dry weight), essential amino acids (7-10% of dry weight), vitamins and carotenoids. 19 - 33% of *Azolla*'s dry weight is protein, which is a lot for a vegetable [21, 29]. The quality of the protein in *Azolla* is good, although there are some deficiencies of the amino acids methionine, histidine and lysine [22, 13]. Two to five percent of *Azolla*'s dry weight is nitrogen.

The water content of Azolla is around 97%, however it's fast grow rate still allows its dry mass yeild to be close to, or exceed that of most commercially grown crops, such as potatoes, maize and soybeans [29]. Research suggest that 335g of dried, raw Azolla is enough to provide an adult person's daily protein requirement of 50g a day [29].

100 grams of fresh *Azolla* plant body contains 7kcal energy, 1.1g protein, 0.1g Lipid (vegetable oil), 0.4g sugar and 1.6g dietary fiber [16]. The table below shows the nutritional value of *Azolla* per 100 grams of dried Azolla [29]. The exact nutritional value depends on the species and strain as well as the conditions during which the *Azolla* was grown [24, 29].

19g	Protein
0.964g	P
5.179g	K
0.434g	Ca
0.258g	Mg
0.65g	S
10.9mg	Mn
18.9mg	Fe
1.6mg	Cu
2.3mg	B
2.2mg	Al
15mg	Zn
19.3mg	Na

Judging from these figures *Azolla* appears to be nutritious and healthy, but the figures do not show how well humans can digest *Azolla* and make use of its nutrients.

Azolla is high in so called neutral detergent fiber, which are indigestible by humans, but digestible by ruminants such as cows [22]. This does not mean that *Azolla* is not nutritious for humans, but it does imply that *Azolla* is more nutritious for ruminants than for humans and other non-ruminant animals.

When *Azolla* is subjected to stress, such as bright sunlight, it produces large amounts of deoxyanthocyanins and turns red. Deoxyanthocyanins are known to have antioxidative functions, and are generally considered healthy [16]. However, the increase in deoxyanthocyanins leads to a reduction of polyunsaturated fatty acids in the *Azolla*, which lowers its nutritive value and palatability [23].

The use of *Azolla* as food is thought to be limited by its high polyphenolic content. At lower concentrations polyphenols are beneficial because of their antioxidative functions, but at higher concentrations polyphenols can limit nutrient absorbtion. The total phenolic content of *Azolla* is five to ten times higher in *Azolla* than in most other fruits and vegetables [29].

Cooking methods, including boiling, pressure cooking, fermenting and sautéing have been shown to decrease polyhenol content by up to 92% and increase polyphenol digestibility [29]. It is not well researched how cooking affect the overall nutrition of *Azolla* but it seems likely that in larger qualities *Azolla* is best served cooked.

There are also some reasons to be concerned about the healthiness of *Azolla*. Some cyanobacteria produce toxins, such as BMAA and microcystins, which can be harmful to animals and humans. Some ferns are also known to contain carcinogens. The presence of small amounts of the neurotoxin BMAA in Azolla has been indicated in a study [30]. However, the study found that BMAA was produced by the fern and not the cyanobacteria in *Azolla*. Since no other plants have been found to produce BMAA this seems questionable. The study that showed BMAA being present in *Azolla* can also be questioned since new analysis methods show that earlier methods may have mistaken the common, non-toxic, isomers DAB and AEG for BMAA.

However, further research is necessary to with certainty rule out BMAA and other toxins and carcinogens in Azolla.

Perhaps of more concern is that *Azolla* is able to absorb and concentrate heavy metals such as lead and mercury if it is grown in polluted water [21]. Contamination with dangerous bacteria such as Salmonella and EHEC is another risk that should be taken seriously, especially if *Azolla* is grown in warm, standing water.

Azolla is much more explored as an animal fodder than as food for humans. In India, it is common to cultivate *Azolla* as a supplemental fodder for cows and poultry, other animals that have been shown to eat *Azolla* are earthworms, snails, shrimp, fish, geese, rabbits, goats, sheep, pigs and horses. In some areas of Africa, wild *Azolla* is harvested from lakes and ponds and used as animal fodder [25, 21, 13]. Dried *Azolla* has been found less palatable for animals than fresh *Azolla*, and different strains of fresh *Azolla* vary in palatability [26].

For most animals it seems that *Azolla* is best used as a dietary supplement and not as the sole fodder. Trials on dairy animals have shown that animals whose diets have been supplemented with *Azolla* have an increase in milk yield that is higher than that expected based on the nutritional content of *Azolla* alone. It is therefore assumed that it is not only the nutrients, but also components like carotenoids, biopolymers, and probiotics that contribute to the increased milk production [25]. Feeding *Azolla* to poultry has also been shown to improve the weight of broiler chickens and increases the egg production of layers [25]. The effects that *Azolla* has on these animals makes you wonder what the effects of eating *Azolla* is on humans.

Taking all of this into account, *Azolla* should probably not be considered as a staple food until further research have been carried out. Care should be taken that *Azolla* that is to be used as food or fodder is grown in unpolluted environments and to be on the safe side it is best to cook *Azolla* before eating it. As with all foods that have not been consumed before, it is advisable to be cautious when first tasting *Azolla* and make sure that no allergic reaction is experienced.

CULTIVATING AZOLLA

Azolla can be found in the wild or in some garden and aquatic stores. In several countries *Azolla* is considered an aquatic weed and its import, possession and distribution is prohibited or discouraged. In other countries *Azolla* has disappeared due to indiscriminate use of pesticides and needs to be nurtured as an endangered species [9].

Azolla can grow rapidly and outperform other species. For this reason, care should be taken when cultivating *Azolla*. It should not be introduced in regions where it is not an indigenous or already established species without carefully considering the potential consequences of its introduction.

Azolla prefers a placid water surface and temperatures around 20-30°C [27]. It will die if it is subjected to prolonged freezing but it can survive short periods of freezing [3]. However, in practice I have found that Azolla grown in a pond in Sweden somehow have survived relatively harsh winters with prolonged freezing for several years in a row.

Azolla's growth rate is greatly reduced above 35°C and it dies at temperatures above 45°C [5]. It thrives in plenty of light (though not in direct sunlight) and in water that is rich in all essential plant nutrients [2, 21]. *Azolla* can grow in a nitrogen-free solution, but the nitrogen concentration level in water does affect growth and nitrogen-fixation rates. It is especially responsive to phosphorus and requires a continuous supply of this nutrient to maintain rapid growth [2].

Azolla that is exposed to intense sunlight or heat turns red and grows more slowly. A good location for a *Azolla* cultivation is in the shadow of a north facing wall or under a tree canopy. If no shadow is available, then shade cloth or mesh can be used to decrease the amount of light falling on the *Azolla*. Shade cloth can also be used to prevent animals, such as birds, from eating *Azolla* and polluting the cultivation.

Azolla can grow in layers and form mats that are several centimeter thick [13]. However, *Azolla* grows best when there are gaps between the plants [3]. It is therefore advisable to harvest *Azolla* regularly so that plants do not crowd or overlap, and to gently stir the water occasionally so that fronds break and the *Azolla* multiplies. After an *Azolla* cultivation has been seeded it takes some time for the growth to stabilize. Once stabilized, the doubling time of *Azolla* is three to five days if the conditions are good [21, 3]. In a two square meter culti-

vation about 250 grams of *Azolla* can be harvested daily [25]. In a 100 square meter cultivation it is possible to harvest about 10 kg of *Azolla* daily [25]. The table below shows the ideal conditions for most species of *Azolla*.

Temperature	20°C - 30°C
Light	25 - 50% of full sunlight for 20h / day (3000 - 6000 lux) [21]
Relative Humidity	85 - 90%
Water Depth	3 - 5 cm
pH	5 - 7
Salinity	0.3% - 2.5% depending on species
Nutrients	All essential plant macro- and micro-nutrients except Nitrogen

There are three basic methods for growing *Azolla*; In hydroponic systems using liquid nutrients and no soil, in systems with soil and water, and in aquaponic systems such as integrated rice, duck, fish and *Azolla* farming. Each of these three methods has its advantages and disadvantages.

Among small farmers in India a common method of growing *Azolla* seems to be to use a one to two square meter pond by placing a tarp over a frame of bricks or over a shallow pit. The pond is then filled with water and about two kilos of cow dung. A half to one kilo of cow dung is periodically added to keep the cultivation going. Some also add a couple of liters of “Jeevamrutha”. Jevamrutha is a microorganism-rich mixture made of water (20-25 L), cow dung (1-1.5kg), cow urine (0.3-0.4 L), palm sugar (0.1-0.2kg) and soil (less than a handful taken from under a tree or from other undisturbed land) that is mixed together and kept in the shade for three to four days.

Using soil and water is a cheap, reliable and easy way of growing *Azolla* [11]. I have been growing *Azolla* indoors and on my balcony in trays with an approximately 5 cm deep soil layer and about 5 cm of water on top. I use soil that comes from a garden that I know is doing well and is unpolluted. Store-bought top soil generally does not work well as it contains peat which floats to the surface.

In regions where *Azolla* cannot survive outside throughout the whole year you need to keep an off-season stock growing indoors until you can plant the *Azolla* outside. Indoors I use daylight fluorescents kept on for eighteen

hours per day. I have had some problems with mold and the *Azolla* grows considerably slower under these conditions than it does outdoors if the conditions are good, but it survives. Transfer to fresh soil is required only every three months or so [11].

Besides growing *Azolla* on my balcony and in my basement workshop I have been growing *Azolla* outdoors in ponds and soil-based cultivations at several locations in Sweden, Norway and Finland.

At Hästa gård in Stockholm, the *Azolla* grew rapidly when it was planted in a mud pond inside a pig pen. We also planted some *Azolla* in a small cultivation in a greenhouse, where it grew rapidly and eventually formed a dense blanket that was about 10 cm thick. In a pond at Kultivator on Öland, which was approximately 50 square meters and very rich in nutrients (since the nearby farm land is extensively fertilized), was completely covered with *Azolla* in just a few weeks, and the *Azolla* grew so quickly that Kultivator had difficulties keeping up with the harvesting. The results were similar in ponds at Under Tallarna in Järna. The quick growth surprised the farmers on both Öland and in Stockholm and evoked their interest in using *Azolla* as animal fodder, fertilizer and soil improver and as a pond cover to prevent evaporation.

In Stavanger, in Norway where the climate is colder the *Azolla* survived outdoors but it didn't grow nearly as fast as in Sweden. At Rogaland Kunstcenter in Stavanger, where the *Azolla* was placed in a south facing window, the *Azolla* survived, but it didn't grow well. Indoors at Kalmar konstmusem in Kalmar it didn't grow well at all, most likely because the cow dung we used as fertilizer, as we later discovered, might have been polluted with diesel. At KIM? Contemporary Art Center in Riga and at Salo Art Museum in Salo, Finland the *Azolla* grew ok indoors under a strong daylight fluorescent light.

Azolla cultivation in a pond at Kultivator on the island of Öland, Sweden 2010

TROUBLESHOOTING AZOLLA CULTIVATIONS

Thriving *Azolla* is green and doubles in biomass in three to five days [21]. This guide may help you troubleshoot an *Azolla* cultivation.

Intense Sunlight
A brick red color of the *Azolla* indicates high light intensity. *Azolla* grows best in the shade, away from direct sunlight.

High Temperature and Humidity
Too much heat will cause *Azolla* to grow slower and turn brown to reddish pink [3]. *Azolla*'s susceptibility to fungi- and insect attacks as well as algae that competes for nutrients also increase with high temperature and humidity [2, 5].

Phosphorous Deficiency
Azolla suffering from phosphor deficiency becomes smaller, pink to red and less vigorous. Under severe stress the plants become highly compact and develop long curled roots [2]. *Azolla* that is free floating cannot absorb phosphorous from the soil. Supplying enough phosphates in the water is one of the biggest challenges in *Azolla* cultivation [3].

Potassium Deficiency
In potassium-deficient plants fronds become yellowish brown, roots become dark brown and their growth is stunted [5].

Iron Deficiency
Iron-deficient *Azolla* become yellow due to depletion of chlorophyll, and roots become thin and whitish. The availability of iron is decreased by neutral to alkaline conditions [5].

Calcium Deficiency
In calcium-deficient *Azolla* there is intense reddening of the dorsal lobes and fronds become fragmented while roots become short, thin, and light in color [5].

KNOWN AZOLLA SPECIES

There are at least six species of *Azolla* worldwide; *Azolla caroliniana*, *Azolla circinata*, *Azolla filiculoides*, *Azolla japonica*, *Azolla mexicana*, *Azolla microphylla*, *Azolla nilotica*, *Azolla pinnata* and *Azolla rubra*. However, some *Azolla* species can be very difficult to identify and there is uncertainty whether *Azolla carolinae*, *Azolla japonica* and *Azolla rubra* might be the same species as *Azolla filiculoides*, which is the species that I have been working with. The nitrogen fixing cyanobactrium in *Azolla* is commonly referred to as *Anabaena azollae*, but is also known as *Nostoc azollae* and *Trichormus azollae*.

The various *Azolla* species vary in size, temperature tolerance and growth rate [27]. The smallest *Azolla* species is the North- and South American *Azolla caroliniana*, whose fronds are 0.5 to 1.5 cm, and the largest is the African *Azolla nilotica* whose fronds can become up to 40 cm long [1]. A study on six different species of *Azolla* found *Azolla microphyla* and *Azolla caroliniana* to have the greatest biomass production rate [28]. *Azolla filiculoides* is the most salt tolerant species and *Azolla caroliniana* the most cold tolerant one [13]. The nutrition value and palatability also varies between species and strains [26]. For example, given a choice, Tilapia fish and snails prefer eating *Azolla filiculoides* to *Azolla pinnata* [23]. As far as I know no attempts have been made to breed varieties of *Azolla* that are better suited for human consumption. However, researchers have found that *Azolla filiculoides* has a significantly lower concentration of polyphenols than *Azolla pinnata*, which might make *Azolla filiculoides* better suited for human consumption.

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