

TOPIC: Integrated Water Resources and Coastal Areas Management
TITLE: Preliminary Analysis of the Nutritional Content of Duckweed and the Quality of Water that Supports its Growth in Guyana.

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BACKGROUND INFORMATION

Introduction

Duckweed has been identified as a tiny aquatic plant with enormous potential for agriculture and the environment (FAO, 1999). In recent years this commonly occurring aquatic plant, "duckweed" *Lemna sp.*, has become prominent, because of its ability to concentrate minerals on heavily polluted water such as that arising from sewage treatment facilities, intensive animal or crop processing or production industries. However, it has also attracted the attention of scientists because of its apparent high potential as a feed resource for aquaculture and livestock (Skillicorn et al., 1993; Leng, et al., 1994). Duckweed grows on water with relatively high levels of N, P and K and concentrates the minerals and synthesizes protein and therefore, duckweed can clearly supply the protein needs of aquaculture. Also the nutrients mentioned above are often critically deficient in traditional fodders and feeds given to ruminants and to pigs and poultry particularly where the former depend on agro-industrial by-products and crop residues.

The impacts of climate change will threaten valuable resources; as a result, water availability is likely to limit terrestrial crop production particularly of cereals in the coming years (World Watch 1997). Water purification and re-use particularly that water arising from sewage works, industrial processing and run-off from irrigation appears to be mandatory in the future, both to reduce pollution of existing water bodies and to provide reusable water for many purposes including that required by humans in some places as drinking water.

Therefore, duckweed seems to be the opportunity crop since it can grow on polluted water and also be used as an alternative food source for aquaculture and other animals. This seems as a positive response mechanism at a time when oceans and seas and land masses are being threatened by climate change.

Duckweed is no new term to the wider cross section of Guyana, however it's potentials as a feed source is inadequate. Within recent times studies relating to duckweed technology have been initiated worldwide with quite successful results especially in the Asian continent. In response to agricultural diversification the National Aquaculture Association of Guyana (NAAG) in its strategic plan identifies the research priorities for the production of duckweed as fish food. (Stabroek News, March 2008). Complimenting such ideas is the IADB funded project (GY-M 1010) aimed at "increasing the productivity of small farmers by integrating duckweed production with fish farming". This project is being executed by the Institute of Private Enterprise Development (IPED), to the tune of USD \$125, 672.00, through an Integrated Farming System.

Anatomy and Morphology of Duckweed

Duckweed is the common name given to the simplest and smallest flowering plant that grows ubiquitously on fresh or polluted water throughout the world. Duckweeds are diminutive, fragile, free floating aquatic monocotyledon perennial plants. Its size of approximately 1-15 mm, often occurs as a solid cover on the surface. Duckweeds belong to four genera; *Lemna*, *Spirodela*, *Wolffia* and *Wolffiella*. About 40 species are known worldwide. All of the species have flattened minute, leaf like oval to round "fronds" from about 1mm to less than 1cm

across. Its leaves and stems merged in common structure typically called a frond or thallus, though neither term is correct by strict botanical definition. The frond itself consists of one to several layers of conspicuous air spaces and one to several veins. The frond is a flattened, suborbicular to elliptic-obovate in outline; generally symmetrical, with smooth upper surface. Fronds are usually solitary or in connected clonal clusters of 2 to 5. Some species develop root-like structures, usually one root connecting on the underside of the frond in open water which either stabilize the plant or assist it to obtain nutrients where these are in dilute concentrations. However, at times they grow on mud or water that is only millimeters deep to water depths of 3 meters. Their vegetative reproduction can be rapid when nutrient densities are optimum. They grow slowly where nutrient deficiencies occur or major imbalances in nutrients are apparent. They are opportunistic in using flushes of nutrients and can put on growth spurts during such periods. When conditions are ideal, in terms of water temperature, pH, incident light and nutrient concentrations they compete in terms of biomass production with the most vigorous photosynthetic terrestrial plants doubling their biomass in between 16 hours and 2 days, depending on conditions. Duckweed reproduces at twice the rate as other vascular plants, hence the fronds and ultimately the biomass doubles every 1-2 days (Rook, E, 2002). In natural or farming conditions, however, the growth rate is altered by crowding, nutrient supply, light incidence and both air and water temperature in addition to harvesting by natural predators (fish, ducks, crustaceans and humans).

Because duckweed is largely made up of metabolically active cells with very little structural fiber, the tissue contains twice the protein, fat, nitrogen, and phosphorus of other vascular plants. Each frond absorbs nutrients through the whole plant and not through a central root system, directly assimilating organic molecules such as simple carbohydrates and various amino acids. With the entire body of the duckweed composed of non-structural, metabolically active tissue, most photosynthesis is devoted to the production of protein and nucleic acids, making them very high in nutritional value.

Duckweed has been found to be a quite usable ecological species since it serves as an essential link in the aquatic food chain. It is also useful since a cover of duckweed fronds shades the water below and reduces the growth of algae. Floating duckweed plants are relatively easy to remove by skimming or are eaten by herbivorous fish. These traits make duckweeds useful in nutrient removal and bioremediation schemes. Duckweeds have potential in wastewater treatment, absorbing excess nutrients from surface waters, including phosphorus and ammonias, reducing suspended solids, and reducing biochemical oxygen demand. They are also useful as a water crop as they can acclimatize themselves to almost all growing conditions, with some thriving in manure-rich or eutrophic waters. They reproduce quickly, extending over large surface areas, and are easily harvested. Their high fat and protein content makes them a source of food for animals and poultry.

Requirements & Conditions for Duckweed Growth

Like all photosynthetic organisms, duckweeds grow with only requirements for minerals, utilizing solar energy to synthesize biomass. They have; however, the capacity to utilize preformed organic materials particularly sugars and can grow without sunlight when provided with such energy substrates. Most research on nutrient requirements have centred on the need for nitrogen, phosphorus and potassium (NPK). However, like all plants, duckweeds need an array of trace elements and have well developed mechanisms for concentrating these from dilute sources. However, considerable interest has been shown by scientists in the capacities of duckweed to concentrate, in particular, copper, cobalt and cadmium from water resources where these have economic significance. Mineral nutrients

appear to be absorbed through all surfaces of the duckweed frond; however, absorption of trace elements is often centred on specific sites in the frond. Duckweeds grow at water temperatures between 6 and 33° C. Growth rate increase with water temperature, but there is an upper limit of water temperature around 30° C when growth slows and at higher temperature ceases. Duckweed survives at pH's between 5 and 9 but grows best over the range of 6.5-7.5. Efficient management would tend to maintain pH between 6.5 and 7. In this pH range ammonia is present largely as the ammonium ion which is the most readily absorbed N form. On the other hand a high pH results in ammonia in solution which can be toxic and can also be lost by volatilization. Depth of water required to grow duckweed under warm conditions is minimal but there is a major problem with shallow ponds in both cold and hot climates where the temperature can quickly move below or above optimum growth needs. However, to obtain a sufficiently high concentration of nutrients and to maintain low temperatures for prolonged optimal growth rate a balance must be established between volume and surface area. Depth of water is also critical for management, anything greater than about 0.5 meters poses problems for harvesting duckweeds. Incident sunlight and environmental temperatures are significant in determining the depth of water as undoubtedly duckweed is stressed by temperatures in excess of 30° C and below about 20° C growth rate is reduced.

Duckweeds appear to be able to concentrate many macro and micro minerals several hundred folds from water, on the other hand high mineral levels can depress growth or eliminate duckweeds which grow best on fairly dilute mineral media. There is a mass of data on the uptake by duckweed of micro-elements which can be accumulated to toxic levels (for animal feed). However, their ability to concentrate trace elements from very dilute medium can be a major asset where duckweed is to be used as an animal feed supplement. Duckweeds need many nutrients and minerals to support growth. Generally slowly decaying plant materials release sufficient trace minerals to provide for growth which is often more effected by the concentrations of ammonia, phosphorous, potassium and sodium levels. There is by far the greatest literature on the requirements of duckweed for NPK and the ability of the plant to concentrate the requirements of micro nutrients from the aquatic medium is usually considered not to be a limitation. Duckweeds evolved to take advantage of the minerals released by decaying organic materials in water, and also to use flushes of minerals in water as they occurred when wet lands flood.

Nutritive Value of Duckweed

Duckweeds now appear to have the potential to be harnessed as a commercial crop for a number of purposes. Although farmers, particularly in South East Asia and probably elsewhere had developed the use of duckweeds as a source of nutrients for livestock, there are, however, a number of reports in the literature on the use of duckweeds as feed supplements for fish and livestock. Duckweeds are highly variable in their composition. They grow slowly on low nutrient waters and are high in fiber, ash and carbohydrates but contain low crude protein. In contrast when grown on waters high in ammonia and minerals they grow rapidly and have a high protein content associated with a high ash and are often lower in fiber. Duckweeds have been largely researched as a total feed for fish, including carp and tilapia production, as a protein supplement for pigs and poultry (including ducks) and as fermentable N and mineral supplement for ruminants.

Much reliable analytic data is available to support the usefulness of the duckweeds as valuable food sources (Landolt and Kandeler, 1987-FAO 1999). Most species have protein contents in the range of 15-45%, depending on the nitrogen supply, and the amino acid balance is favorable, with only TRP and MET generally limiting (Landolt and Kandeler, 1987, pp 375-377. The yearly protein yield/ha is up to tenfold higher with Lemna than with

soybeans, and nearly as much better than for alfalfa (Said et al. 1979). Recent work with *Lemna paucicostata* in Nigeria (Mibagwu, and Adeniji, 1988) indicates an especially high nutritional value. Their analyses of plants from three locations in the Kainji lake area showed a crude protein ranging from 26.3-45.5% of dry weight: "The amino acid content compared favourably with that of blood, soybean and cottonseed meals and considerably exceeded that of groundnut meal. The levels of the essential amino acids surpassed the FAO, 1999 reference pattern, except for methionine which met 61.4% of the recommended value. The levels of minerals were high but should not pose any toxicity problems if incorporated into animal feeds. The levels of nitrogen in the plant are comparable to those in commercial fertilizers. The plant could be a good dietary supplement and nutrient source for humans, livestock and fish...." "With an average standing crop of 309 kg dry mass/ha and doubling time of 1.2 d, 129 kg DM/ha of dry duckweed are obtainable daily in the Kainji Lake area, which could ensure a daily supply of 59 kg of high-quality protein for poultry and fish feed formulation...." Duckweed is proving a valuable replacement for soybeans in these "more intensive" production practices. The truly important issue here is that the research confirms the potential of duckweed as a high quality mineral source with protein equivalent to soybean protein but which is readily produced locally on farm. An analysis of duckweed used in all experiments (i.e. in lab and on farm) indicates the ability to supply major mineral elements and trace minerals. (FAO 1999)

Heavy Metal Accumulation by Duckweed

All members of the duckweed family concentrate heavy metals in particular cadmium, chromium and lead which may at times reach levels in the plant which are detrimental to both the health and growth of the plant in addition to creating problems where the plant is used in any part of a food chain eventually leading to human consumption. The accumulation of heavy metals by duckweed is not normally a problem for those wishing to use duckweeds from natural water resources or effluent from human or intensive animal housing as these metals are normally at extremely low concentrations. Duckweeds, however, are contaminated by such heavy metals from industries such as tanning (chromium) leachates from mining (e.g. cadmium) and great care is needed where water is contaminated to be sure that heavy metals do not get into the human food chain. On the other hand, duckweeds may find use in stripping heavy metals from industrial water. Also their content of heavy metals can be used to indicate potential pollution levels of waters; and therefore be used as indicator species.

Other Environmental Benefits of Duckweed

Within recent times a major benefit of duckweed is emerging, and there is accumulating evidence that duckweed release compounds that have insecticidal properties particular to the larval stages of mosquito. Thus the development of duckweed aquaculture in wet tropics may have implications for mosquito control in areas where malaria is becoming a growing problem even as a result of climate change. Also other studies have suggested that duckweed growth have been able to suppress algal growth in many waterways.

METHODOLOGY

Samples of duckweed tissue and water used in the research were collected from various local sources. The sources include natural environment and experimental conditions. However, the samples of duckweed that were used in environmental conditions were initially sourced from natural environments. Laboratory analysis were conducted on duckweed tissue and water quality.

Duckweed tissue collected were analysed with their respective repeats and controls for the basic plant mineral nutrients and other metals namely nitrogen, phosphorus, potassium,

calcium, magnesium, sodium, aluminium, iron, manganese, lead and zinc. These were done on the dry weight of the tissue samples of duckweed. While the water samples collected from the same sources were analysed for the various parameters including; nitrogen, phosphorus, potassium, calcium, magnesium, sodium, aluminium, iron, manganese, lead and zinc. The procedures for testing the samples are summarized as follows:

Duckweed Tissue¹

Table 1 Method of Analysis for Duckweed Tissue

Parameter	Method	Detection	Reference*
N	Kjeldahl Digestion	Spectro/Nesslerer	978.04
P	Kjeldahl Digestion	Spectro/Phosphomolybdenum Complex	978.04
K	Kjeldahl Digestion	Flame Emission	978.04
Ca Mg	Acid Digestion (H ₂ SO ₄ /HNO ₃)	Atomic Absorption	
Na	Acid Digestion (H ₂ SO ₄ /HNO ₃)	Flame Emission	

Water Quality²

Table 2 Method of Analysis for Water Quality

Parameter	Method	Detection	Reference*
pH	Electrometric	pH meter	4500-H ⁺ B
EC	Electrometric	EC meter	2510
TSS	Filtration	Microfiber Filter	2540 D
COD	Dichromate reflux	Titration	5220 B
TKN, P	Kjeldahl Digestion	Spectro	4500 N
Metals	Acid digest	Atomic Absorption	3030 e

RESULTS AND DATA ANALYSIS

Duckweed as an aquatic species contains a high percentage of water and varies from 86- 97 % (Landolt and Kandler, 1987), while the fresh duckweed contains 92-94% water (Leng, R.A. et.al, 1995). The assessment of the moisture content of the samples collected yielded an average water content of 97.5% and dry weight at 2.49%.

¹ * = Patricia A. Conniff, (ed.), Official Methods of Analysis of AOAC International, 18th ed.

² = L.S. Clesceri et al (Editors), Standard Methods for the Examination of Water and Wastewater, 20th Ed. 1998. APHA AWWA WEF. United Book Press, USA

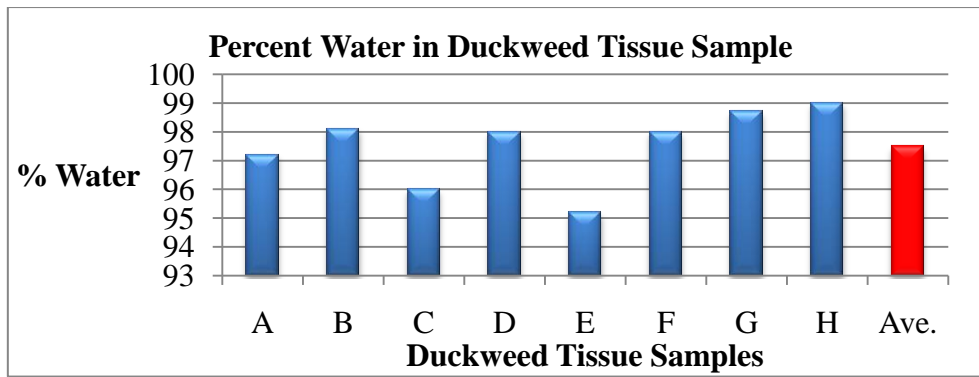


Figure 1 Percent Water (Moisture) in Duckweed Samples

Duckweed survives in conditions that range in pH from 5 to 9, but grows best over the pH range 6.5-7.5 (Leng, R.A. et al, 1995). The pH analysis conducted on the water quality that supports locally grown species indicated that the average pH that supported growth was calculated at 7.58.

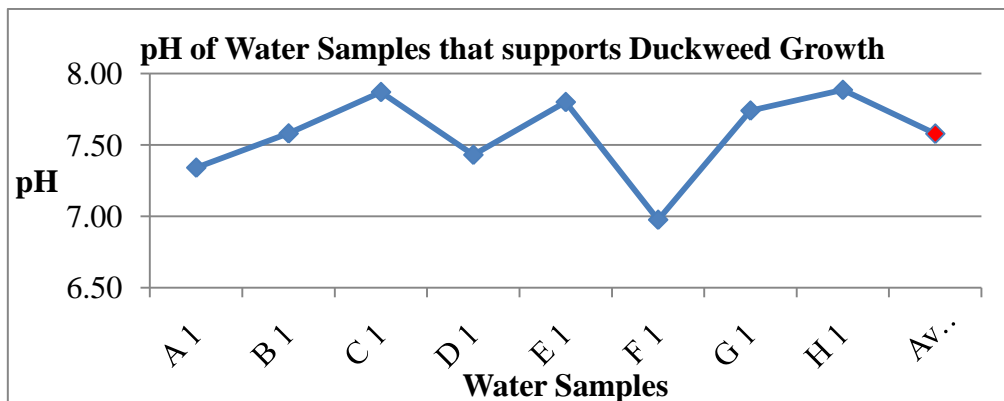


Figure 2 Graph of pH of Water Samples supporting Duckweed Growth

Generally the results obtained for basic plant nutrients were very favourable and occurred within the range established by referenced data.

Table 3 Distribution of Mineral Nutrients in Duckweed Tissue Samples

Duckweed Tissue Samples	Minerals				
	N	P	K	Ca	Mg
A	2.47	0.55	2.20	5.73	0.62
B	3.88	0.95	0.90	11.50	0.35
C	3.60	0.96	4.88	5.05	0.28
D	4.57	1.14	4.70	7.14	0.39
E	4.33	0.88	4.39	12.21	0.29
F	3.30	0.97	6.95	0.47	0.96
G	3.70	0.68	7.28	0.47	0.95
H	4.77	0.92	7.70	0.41	0.86
Average	3.83	0.88	4.87	5.37	0.59
Range (Landolt & Kandler, 1987)	0.8-7.8	0.03-2.8	0.03-7	0.18-4.5	0.04-2.8
Range (Men et.al, 1995, 1996)	Nil	0.60	4.30	0.70	Nil

In consideration of both primary and secondary macromolecules investigated for duckweed tissue; namely N, P, K and Ca, Mg respectively, the overall average value obtained compared well with referenced data of Landolt and Kandler, 1987.

Table 4 Distribution of Primary & Secondary Macro Nutrients in comparison to referenced data

Primary	Average %	Average %
Macro Nutrients	(Landolt & Kandler, 1987)	(Ramjeet-Samad, 2009)
Nitrogen (N)	0.8---7.8	3.8
Phosphorus (P)	0.03---2.8	0.88
Potassium (K)	0.03---7.0	4.88

Secondary	Average %	Average%
Macro Nutrients	(Landolt & Kandler, 1987)	(Ramjeet-Samad, 2009)
Calcium (Ca)	0.18---4.5	5.38
Magnesium (Mg)	0.04---2.8	0.58

From the above data collected it suggests that Ca is the only mineral nutrient that has exceeded the range referred to in the referenced data. The accountability for this implies that the calcium content of the water supporting duckweed growth was richly supplied in Ca. However, calcium usually occurs as calcium oxalate crystals in duckweed and varies between species; however, this research did not investigate the occurrence of these crystals. A point to note is that calcium oxalate is not a nutrient nor a beneficial source of calcium, hence minimizing these crystals makes duckweed more nutritious and digestible. (Landolt & Kandler, 1987)

Water quality supporting duckweed growth influences the chemical composition of the duckweed tissue and also the kind of species found in a particular location. (Landolt & Kandler, 1987) In review of the local situation it is often observed that different species of duckweed or related species may be found growing in the same pond. However, in most instances, one species usually dominates the location.

The results of the water quality analysis indicate the following distribution of nutrient mineral in the water samples.

Table 5 Distribution of Mineral Nutrients in Water Samples supporting Duckweed Growth

Water Quality	Mineral Nutrients (mg/L)				
	N	P	K	Ca	Mg
A ₁	19.76	52.55	113.00	129.00	107.00
B ₂	19.52	0.61	31.00	124.00	6.00
C ₃	79.52	3.45	49.70	13.90	38.40
D ₄	17.81	0.19	2.00	4.00	7.00
E ₅	37.80	1.66	20.50	24.63	9.49
F ₆	8.40	1.40	12.45	27.70	9.52

Water Quality (cont'd)	Mineral Nutrients (mg/L)				
Sample Description	N	P	K	Ca	Mg
G ₇	3.39	0.19	21.55	7.15	3.53
H ₈	8.85	1.35	34.80	40.00	13.75
Average	24.38	7.67	35.63	46.30	24.34
Range (Landolt & Kandler, 1987)	0.02-10	0.03-2	1.0-30	1.0-80	0.5-50

The average mineral nutrients concentrations calculated from the study surpassed the referenced data for all the primary macronutrients, suggesting that the water was more nutrient rich than required for optimum duckweed growth. In the case of Mg and Ca the results occurred within the specified range, however, the calcium concentration level in plant tissue was very high and suggested that the water quality would be the contributing factor, but the results of above do not advocate same.

The assessment of the electrical conductivity measure in water samples corresponds to the salinity content of the growth medium. Duckweeds are known to tolerate some degree of salinity, and like other plants can tolerate some amount of salt, but not grown in salt marshes. Evaluation of the extensive work by Landolt, 1986, indicates that the absolute range of electrical conductivity for Lemnaceae is 0.01-10.9 mS/cm, whilst the range for 95% of the samples of is 0.05-2.0 mS/cm. According to the data analysis of this research the average calculated value is 1.23 mS/cm.

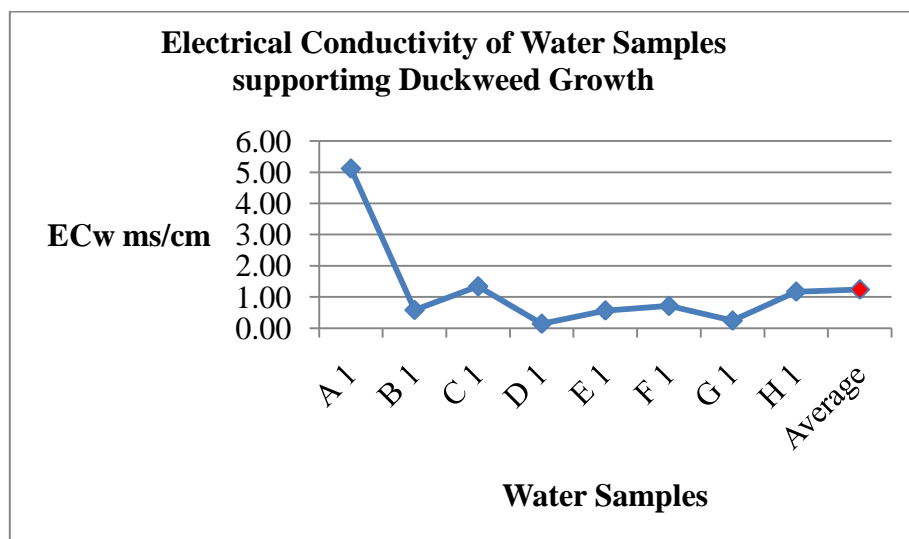


Figure 3 Line graph showing the electrical conductivity of duckweed tissue

All members of the duckweed family have the ability to concentrate heavy metals, in particular cadmium, chromium and lead and at times reach levels in the plant which can be both detrimental to both the health and growth of the plant, in addition to creating problems in the food chain, due to human consumption. The accumulation of heavy metals is usually at extremely low concentrations, unless the aquatic environment for growth is an industrialized area where the heavy metal concentration may be very high.

Many reports indicate that duckweed will uptake and concentrate Cd, N, Cr, Zn, Sr, Co, Fe, Mn, Cu and Pb, and as these levels of minerals rise, health and growth is inhibited. But at low level accumulation the plant become a very useful source of trace minerals for livestock and fish.

Table 6 Table showing the distribution of the other mineral elements investigated

Elements	%	%
	(Landolt & Kandler, 1987)	(Ramjeet-Samad, 2009)
Aluminium (Al)	0.000---11.4	0.2
Copper (Cu)	0.2×10^{-3} ---3.2	0.18
Iron (Fe)	0.007---3.2	0.57
Manganese (Mn)	0.003---6.4	0.39
Sodium (Na)	0.03---1.3	0.2
Lead (Pb)	0.2×10^{-4}---0.02	0.07
Zinc (Zn)	0.004---0.14	0.03

The above results indicates that the concentration for the other minerals are occurring in low concentrations and within a referenced range, with the exception of lead in which the concentration is above the acceptable range and hence can lead to problems for the growth and health of the plant and even higher up the food chain.

CONCLUSION

Duckweed ecology is of importance because of the very promising physiological characteristics of this species. On the basis of the research conducted and the results analyzed, there is quite enough evidence that supports the fact that data on local duckweed corresponds well with the referenced data for both duckweed tissue and water quality. The conditions for growth are ideal and also the results obtained were very similar to other locations where duckweed growth is commercialized. Also that duckweed has the ability to tolerate some degree of salinity.

The analysis of duckweed's nutritive content shows that both primary and secondary macronutrients are present in the duckweed's tissue and the results are quite promising when assessed on the dry weight mass. This suggests that duckweed can provide the basic nutrient requirements, hence can be promoted as an alternative feed source.

Duckweed tissue also have the ability to accumulate heavy metals, which in low concentrations can provide trace elements in feed source, while in heavier concentrations can be fatal to the plant itself and even in the food chain. However, the study accumulated data that showed low heavy metal concentration among species studied. However, if this plant species is to become commercialized as a feed source, then careful monitoring must be done to its habitat, thus growing should be limited in industrialized areas.

RECOMMENDATIONS

The results of this preliminary investigation indicate that the growth conditions for duckweed are ideal and that duckweed has the requisite nutritive composition to be put to further use. This research therefore recommends further validation research to compliment existing referenced data and even to provide further baseline information.

At a time when climate change is affecting the productivity of seas and oceans, aquaculture activities should be promoted, hence duckweed can be investigated as an opportunity crop or alternative feed source for use as an animal and fish feed.

Other major benefits of duckweed have been emerging including some evidence suggesting that duckweed release compounds that have insecticidal properties particular to the larval

stages of mosquito. Thus the development of duckweed aquaculture in wet tropics may have implications for mosquito control in areas where malaria is becoming a growing problem even as a result of climate change. Also other studies have suggested that duckweed growth have been able to suppress algal growth in many waterways. These therefore should be further investigated at the local levels since the benefits seem appropriate.

REFERENCES

- Leng, R. A. 1999. Duckweed: A tiny aquatic plant with enormous potential for agriculture and environment.
- FAO (viewed May 15, 2009) <http://www.fao.org/ag/AGAinfo/resources/documents/DW/Dw2.htm>
- Leng R.A. et.al 1995 Duckweed - a potential high-protein feed resource for domestic animals and fish. (viewed June 10, 2009) <http://www.lrrd.org/lrrd7/1/3.htm> updated April 1995.
- Rook, Earl J.S. 2002. Lemna minor Lesser Duckweed. (viewed June 05, 2009) <http://www.rook.org/earl/bwca/nature/aquatics/lemna.html> updated February 2004
- IADB 2009 GY-M1010 : Demonstration of an Integrated Farming Model for Poor Farmers (viewed May 15, 2009) <http://www.iadb.org/Projects/project.cfm?id=GY-M1010&lang=en>
- Duckweed Nutritional Composition (viewed February 24, 2009) <http://www.mobot.org/jwccross/duckweed/nutritional-composition.htm> updated April, 2003
- Synthetic Media for Growing Duckweed (viewed February 24, 2009) <http://www.mobot.org/jwccross/duckweed/media.htm#nature> updated August, 2001
- IADB-GOG 2005 Fast Tract Sector Development, Commercial Aquaculture, Action Plan. http://www.aquaculture.org.gy/publications/ETG_Guyana_Action_Plan_Aquaculture__11Dec05_.pdf (viewed August 28, 2009)
- Ullah, S. 2009 Bio-digester to power down costs to growers. Stabroek News, July 02, 2009