Ecology of an Obnoxious Weed, *Salvinia natans* L. in Dal Lake of Kashmir

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ABSTRACT

Salvinia natans is rated among the most obnoxious aquatic weeds, spreading fast and causing severe problems by forming dense mats over a large surface area of varied freshwater bodies of Kashmir. The paper discusses the ecology of the fern at various sampling sites, differing in water depth, vegetation and trophic status, in Dal Lake. The distribution, density, growth and biomass of the species is estimated in relation to the operative influence of the various constituent factors of the environment. The maximum development of the fern species obtained towards the shore areas and in sheltered channels during August-September against a minimum in deeper and open water areas especially in winter are explained on the basis of optimum temperature, rapid propagation by vegetative growth and better trophic conditions; and the small role played by pests in controlling the weed population.

Keywords: Water-fern, weed, eutrophication, Dal Lake, Kashmir

INTRODUCTION

The fern (pteridophyte) genus, *Salvinia*, is a free-floating aquatic plant belonging to family Salviniaceae. Native apparently of Latin America, species of *Salvinia* in the last 50 years have been introduced into a number of tropical countries where they have spread rapidly (Holm *et al.*, 1977). At present water-fern is represented by 12 species all over the world with maximum number of species reported from Africa. In India, it is represented by three species viz. *S. natans* L., *S. molesta* Mitchell and *S. auricullata* Aubl. while *S. natans* is the only species growing in Kashmir valley. It is an annual species while others are perennial (Vashista, 1984). *Salvinia* species are rated among the most obnoxious aquatic weeds in the world for they spread very fast, forming thick mats and covering freshwaters of tropical countries especially in Africa, Asia and Australia (Mitchell, 1970 , 76, 78; Thomas, 1976, 79,81; Edwards and Thomas 1977; Gupta, 1979; Room *et al.*, 1981; Abbasi and Nipaney, 1983, 86; Thomas and Room, 1986). These mats cause serious problems by impeding human use of waterbodies through polluting and depleting the water resources in many ways. According to Varshney and Singh (1976), *Salvinia* species are among the ten most widely distributed aquatic weeds in India.

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In Kashmir *Salvinia natans* grows gregariously, forming thick extensive 'mats' over a large surface of varied types of lentic freshwater bodies like lakes, ponds, wetlands, irrigated crop fields, sewage pools and slow moving side channels, rendering them almost useless for navigation, aquatic sport, game and growth and occurrence of economically important plant and animal species (Fig.1). According to

Figure 1. Thick mat of *Salvinia natans* in Dal Lake.

Zutshi and Vass (1971) and Zutshi (1987), the extensive landuse along the banks of some lakes have resulted in excessive nutrient loading of water, resulting in eutrophication which in turn has affected the constituent vegetation. One of the manifestation of nutrient enrichment is the explosive growth of *Salvinia natans*. In the present study an attempt is made to work out the ecology of one of the world's most aquatic weeds in the famous Dal Lake where it has far reaching biological and economic consequences.

DESCRIPTION OF THE LAKE

Dal Lake is a natural freshwater urban Himalayan lake. It is situated in the northeast of Srinagar at an altitude of 1585 m between $34^0 5'$ - $34^0 6'$ N latitude and $74^0 8'$ - $74^0 9'$ E longitude. The lake is multibasined with the Hazratbal, the Boddal, the Gagribal and the Nagin as its four basins (Fig. 2). The total surface area of the lake is

Figure 2. Map of Dal Lake showing sampling sites.

$11.45 km^2$ and the total volume is estimated at $9.83 \times 10^6 m^3$. A sizable portion of the lake extending from the Hazratbal to Gagribal is covered by floating islands which constitute about 35% of the whole lake (Trisal, 1977). The detailed morphometric description of the lake is published elsewhere (Kaul, 1977).

METHODS OF STUDY

For the present investigation two sites were selected from the Hazratbal basin of the lake (Fig. 2). The sites were located within a channel present in between the floating gardens. The banks of the channel are planted with willow trees and the depth of the channel ranged from 0.4 to 1.0 m. Site I was located in the middle of the channel with a maximum depth of 0.4 – 0.5m whereas site II was located towards the mouth of the channel near the open water with maximum depth of 0.7 – 1.0 m. The study area presented luxuriant growth of duckweed complex (*Lemna*. spp. and *Spirodela polyrhiza*) in the first half of the year and water-fern (*Salvinia natans*) in the second half of the year because such sites are rich in organic matter and other plant nutrients especially N and P.

Quadrats of different sizes were employed for collecting the plant material at random from 20-30 sampling stations varying in water depth, vegetation and other characteristics during June – December 1988. Plants were collected on monthly basis for growth analysis which include the study of following parameters: (i) length of plant, (ii) length of internode, (iii) number of leaves at each node, and (iv) number and length of roots at each node. The dried plant material was used for biomass estimation and elemental analysis, following Jackson (1967) and Misra (1968), was carried out by using Absorption spectrophotometer.

Water samples from fixed sites were collected every month from July 1988 to June 1989, and analysed for physio-chemical characteristics by standard method given by Mackereth (1993) and APHA (1970).

RESULTS AND DISCUSSION

Distribution of *Salvinia natans* in Dal Lake

There is no authentic record of the time of invasion of the pterodophyte genus, *Salvinia*, in Kashmir waters but the first report regarding the presence of the fern in Dal Lake, Srinagar (Kashmir) is by Biswas and Calder (1936) who reported the fruiting of the species during autumn in lakes of Kashmir (c.f. Zutshi and Vass, 1971). There is no fixed time for the germination of *Salvania* spores as the young sporophytes of *Salvinia* were seen in different months of spring by Zutshi and Vass (1971), and these observations were confirmed by the present study as well. In 1988 the young sporophytes were first seen in April whereas in 1989 the young sporophytes were observed during May. Zutshi and Vass (1971), however, reported the young sporophytes in March while according to Kaul and Vass (1972) the sporophytes start appearing with increasing temperatures in May. The plant species showed different distribution patterns in different months of the growing season. The young sporophytes of this plant in Dal Lake were first seen growing in isolation or in association with dense growth of another obnoxious weed, duckweeds (*Lemna minor*, L. *gibba*, L. *trisulca* and *Spirodela polyrhiza*) especially adjacent to the banks of the connecting channels where the movement of water is very little. The decaying weeds, algal blooms and the new vegetation growth served as a substratum for the young sporophytes. As the summer approaches, the plant density increases and during August – September the water channels get completely covered by thick mat of *Salvinia* (Fig.1).

Due to biotic interference like movement of boats etc., the plants are pushed out of the channels and thus invade the open water areas. In the Hazratbal basin the weed has started encroaching upon the lotus (*Nelumbium nucifera*) zone (Fig. 3). It is

Figure 3. *Salvinia natans* spreading fast even in open water areas. The obnoxious weed encroaches upon the lotus (*Nelumbium nucifera*) zone in Hazratbal basin.

often noticed that by September the channels get completely choked by the profuse growth of the weed which further spreads fast in the open water areas adjacent to these channels.

Morphology of *Salvinia natans*

Salvinia natans is an annual aquatic free-floating fern (pteridophyte) belonging to family Salviniaceae. The plant body is a sporophyte which consists of a delicate rhizome about 11- 14 cm long. The rhizome shows differentiation into nodes and internodes. A mature rhizome bears 18-20 pairs of leaves (Fig. 4). The internode is about 0.8 cm long and each node bears a pair of oblong and ovate opposite leaves.

Fig. 4 Sporophyte of *Salvinia natans*

The leaves are 1.5 – 1.6 cm long and 0.8 – 1.0 cm broad. The upper surface of the leaves is provided with minute hairs whereas their lower surfaces are smooth and brownish. Each node bears a tuft of 16 –18 shining leaf roots which are 2.0 – 9.5 cm long. The roots also bear minute hairs.

The sporophytes attain the maximum growth and development during August – September, under optimum temperature conditions (28 –30^{0} C), when they also produce sporocarps in clusters of 4 to 8, a fact well corroborated by the earlier studies of Kaul and Vass (1972). By this time the plant becomes highly gregarious and chokes the side water channels. The sporophytes start decaying with the decreasing temperatures of late November and December, when the frost formation is quite common. By this time the sporocarps get detached and are left in abundant masses, floating on the surface of water to which they impart a characteristic dull red colour. The sporocarps do not usually sink to the bottom. In ephemeral waterbodies which dry up during winter the sporocarps alongwith decaying plants are left over on the drying mud till next March when rains once again lend a new lease of life to these habitats. The plant, therefore, survives the severe winter by means of spores.

Growth Pattern of *Salvinia natans*

Variations in the growth pattern of the plant are set in Table 1. Average length

Table 1. Monthly variations in the average growth of various parts of *Salvinia natans* during the growth period, June – October 1988

Month	Avrage length of plant (cm)	Average length of internode (cm)	LEAVES Average number (pairs)	LEAVES Average length (cm)	LEAVES Average width (cm)	ROOTS Average number at a node	ROOTS Average length (cm)
June 1988	3.7	0.7	10	1.35	0.85	15	3.9
July	7.8	0.8	20	1.6	1.0	18	4.9
August	7.5	0.8	18	1.5	1.0	16	5.9
September	11.4	0.8	15	1.5	1.0	Sporocarps had developed	
October	The plants had stopped growing					The root begins to separate from the plant	

of the plant showed an increasing trend from 3.7 cm to 11.4 cm during June – September 1988 though the average length of internodes depicted slight increase during this period. While average length and width of the leaves showed little variation between months, the number of leaves first showed an abrupt increase during the early growing period but finally declined towards the end of the growing season. The average length of the roots enhanced from 3.9 cm in June to 5.9 cm in August and thereafter they started separating from the plant and were replaced by sporocarps. At the end of growing season the growth got restricted and the plant body started decaying. In November, the sporocarps were mature enough to release spores in water for the next year crop. These studies gain further support from the earlier findings of Clatworthy and Harper (1962) according to whom floating aquatics such as *Salvinia* and *Lemna* showed an exponential increase in dry weight during the first week, followed thereof by a decrease in relative growth rate (g/day) due to frond crowding which resulted in an increase in dry weight during the next six weeks. According to Mitchell (1969, 74,76), the autecology of *Salvinia* can be distinguished into three stages of growth:

(i) The primary invading form with small leaves not exceeding 1.5 cm in width, floating on the water surface.

(ii) The open water colonizing form with long internodes and keeled leaves of about 2 cm width.

(iii) The mat form of the plant with short internodes and of a compressed shape. This form has leaves upto 6 cm in width in case of *S. molesta*, which are folded upwards and have lost direct contact with the water. Sporocarps are present, but sterile.

All the three forms have a submerged leaf at each node. This leaf has a shape of a root and its function is nutrient absorption and stabilization.

Biomass Productivity

Species of *Salvinia* are among the fastest-growing of all the aquatic weeds (Varshney and Rzoska, 1976; Abbasi and Nipaney, 1981, 86) and the growth rate of the weed is even faster than that of water-hyacinth (*Eichhornia crassipes*) which has been recognized as the world's most widespread aquatic weed (Mitchell, 1970, 76, Gupta, 1979). Under favourable conditions *Salvinia* may double its biomass in less than ten days (Blackman, 1960; Abbasi and Nipaney, 1981). In case of *S. molesta* doubling in size is as little as 2.2 days (Farrell, 1979) and thus *Salvinia* can cover freshwater lakes and slow moving streams with thick floating mats which are often colonized by other vegetation to form sudd (Thomas and Room, 1986).

In the present study the highest dry matter production is recorded for the month of September when the atmospheric temperature is high and each plant has numerous sporocarps. During its peak productive stage, *Salvinia natans* recorded a maximum biomass of 260 – 394 g m^{-2} and the rate of production ranged between 2.0 and 2.5 gm^{-2} day^{-1}. From October onwards growth shows decline and finally in late November – early December the sporophytes decay leaving a highly abundant mass of spores floating on the surface of the water. Zutshi and Vass (1971) and Kaul and Vass (1972) attributed maximum biomass of *S. natans* during August – September to high temperature and better light condition. The authors also observed that the plants growing under partial shade had more dry wedight than those growing under deep shady conditions.

Elemental Analysis of *Salvinia natans*

Data on mineral composition of *S. natans* are presented in Table 2. The

Table 2. Mineral content of ($\mu g\ g^{-1}$ dry wt.) of *Salvinia natans in Dal Lake*

Month/Year	P	Ca	Mg	Fe	Zn
August 1988	120	71	52	1.2	0.32
September	113	37	20	0.8	0.23
October	114	64	34	1.6	0.12
November	108	88	62	2.4	0.10
December	110	80	68	1.5	0.22
January 1989	103	96	69	2.2	0.12
x	111.3	72.67	50.83	1.62	0.185
SD (±)	5.28	19.07	18.19	0.55	0.79

studies indicated that phosphorus had the maximum concentration among the investigated elements. Its concentration varied from 103 – 120 $\mu g\ g^{-1}$ with a mean value of 111.3 $\mu g\ g^{-1}$ (± 5.28). The calcium and magnesium contents ranged from 37 to 96 $\mu g\ g^{-1}$ (x= 72.67; SD = ± 19.07) and 20 to 69 $\mu g\ g^{-1}$ (x = 50.83; SD = ± 18.19) respectively. The minimum values for both the elements were recorded in September 1988 and the maximum in January 1989. The levels of iron fluctuated between 0.8 $\mu g\ g^{-1}$ in September and 2.4 $\mu g\ g^{-1}$ in November, the mean value being 1.62 $\mu g\ g^{-1}$ (SD ± 0.55 $\mu g\ g^{-1}$). The increased consumption of P as compared to Ca by the plant species may be attributed to the availabilitv of the ions in the medium which in turn owe their origin to the use of excessive doses of fertilizers (Diammonium phosphate) in the vegetable gardens of Dal Lake in whose water channels the weed manifests profusely. Highest concentration of zinc (0.32 $\mu g\ g^{-1}$), among the micro-nutrients, was recorded in August and the lowest in November (0.10 $\mu g\ g^{-1}$), the mean value being 0.185 $\mu g\ g^{-1}$ (SD = ± 0.79 $\mu g\ g^{-1}$). Cu, Pb, Co, Ni, Hg and Sn were below the detection levels. Pandit (1984), in another study, recorded 1.87% nitrogen in the tissues of *S. natans* collected from Dal Lake . These results are almost similar to the findings of Room and Thomas (1986) who reported the nitrogen content in the range of 0.8 and 1.5 % in plants collected from the field. The authors while estimating nitrogen, phosphorus and potassium content on dry weight basis in *S. molesta* observed that nitrogen content ranged from 0.62 to 4.0%, phosphorus from 0.03 to 1.07 % and potassium from 0.31 to 5.32%. Their studies further revealed that tops sustained more concentration of N and P than roots while K was more concentrated in roots. Furthermore a decrease in N, P and K contents of plant was observed vis-à-vis age with rapid decline at the onset of scenescence. Chapin (1980) also observed similar increase in the calcium contents of *S. molesta* with aging of tissues. In the present study on *S. natans* collected from Dal Lake it has been observed that the calcium content increased as the plant entered the period of scenescence. Similar trend was also observed in case of magnesium. Unlike phosphorus whose concentration decreased with the age of plant, the levels of iron were generally higher towards the later months of the year coinciding with the scenescence period of the plant. Like phosphorus, Zn registered its highest value in August – September when the plant had attained its peak growth. Thenafter, as the plant entered decaying stage, its concentrations showed a declining trend.

Occurrence and Development of *Salvinia natans* in Relation to Abiotic Environment

Two factors seem to have favoured the increased growth of *Salvinia natans* in Dal Lake. The shore areas of the lake are well protected against wind etc., due to extensive plantation of *Salix* and *Populus* species. Likewise, the formation of a myriad of floating garden along the littorals and within the lake have resulted in the formation of network of sheltered channels, under the canopy of trees, which favour its growth. Another plausible reason for the quick and extensive spread of this free-floating macrophyte is the extensive cultivation and construction works which are taking place at an alarming rate, and the consequent enrichment of lake waters with plant nutrients due to the disposal of domestic sewage, night soil and manure besides leaching of agricultural runoff. Mitchell (1969), while exploring the causes of explosive growth of *S. auriculata* in Lake Kariba, Rhodesia, came to a similar conclusion. This assumption gains further support from the studies of Donnelly (1969) according to whom *S.auriculata* tends to accumulate and find anchorage against wind and wave action among the emergent trees and branches in the uncleared areas. The author further observed that on exposed shores the plant is usually confined to comparatively narrow strips along the littoral zone where it gets some anchorage by emergent sedges or is blown out by wind or wave action and heaped along the shores.

Besides the physical environment, the most favourable conditions for profuse distribution of the weed are highly eutrophicated waters as indicated by deficiency of oxygen and heavy mineral loading. The density of plants was high at sites rich in organic carbon (Pandit, 1992,93). Data concerning physico-chemical characteristics of water in lake areas supporting *Salvinia* are given in Tables 3 and 4. A perusal of the data presented indicate that there is no significant variation in the temperature of water for the two sites, the peak values being recorded in August, coinciding with the peak productive stage of the weed, against the low values recorded in January, a view point supported by Zuthsi and Vass (1971). Cary and Weerts (1981, 84) also demonstrated that *Salvinia* produced more biomass when grown at 25°C than at 20

Table 3. Physico-chemical characteristics of water (yearly average with SD) in Dal Lake areas supporing *Salvinia natans*

Parameters	Site I	Site II
Temperature ($^{\circ}$C)	17.6 ± 6.8	17.5 ± 6.98
pH	8.60 ± 0.298	8.62 ± 0.314
Specific conductivity (μ s Cm^{-1} at 25 $^{\circ}$C)	243 ± 66	241 ± 71
Dissolved oxygen (mg l^{-1})	7.3 ± 2.64	7.6 ± 2.03
Cl (mg l^{-1})	16.7 ± 5.32	16.9 ± 6.02
Total alkalinity (mg l^{-1})	107.8 ± 13.16	105.02 ± 14.71
Total hardness (mg l^{-1})	45.7 ± 8.39	48.6 ± 8.12
Fe (mg l^{-1})	6.4 ± 3.71	5.9 ± 4.44
NO_3-N (μg l^{-1})	69.9 ± 51.22	66.8 ± 50.71
NH_4-N (μg l^{-1})	245 ± 174.75	259.5 ± 215.39
Total phosphorus (μg l^{-1})	62.7 ± 55.99	67.5 ± 60.39

Decreasing trend of oxygen concentration from June to December at both the sites coincided with the luxuriant growth of *Salvinia natans*. Minimum values for oxygen concentration were recorded in August (site I) and October (site II) when the plant had attained its peak growth and covered the water surface completely. Oxygen concentration was higher at both the sites from January to May when *Salvinia* mats were absent. However, the differences in the oxygen levels at both the sites were insignificant due to similar environmental set-up. These studies are somewhat similar to those obtained by Tarras – Wahlberg (1986) pointing out that oxygen values below *Salvinia* mats in lake Naivasha (Kenya) were very low which thus strongly influenced the ecology of the lake within the *Salvinia* area because of lack of oxygen.

The death and decomposition of *Salvinia* mats at the end of the growing season resulted in the nutrient enrichment which accounted for the increased specific conductance values from October to April. Vollenweider and Fric (1953) and Berg *et al.*, (1958) related the increase in electrical conductivity to the state of nutrient enrichment. During the active growth period of *Salvinia* the values for specific conductance were low as various ions were being utilized in the mineral uptake of the plants. Similar results were also obtained by Tarras – Wahlberg (1986) in his studies on *Salvinia* infested lake Naivasha (Kenya) having lower values of specific conductivity. Site variations indicated that the specific conductance values at site I fluctuated between 145µS cm^{-1} in July and 247µS cm^{-1} in October with a mean value of 243 µS cm^{-1} (SD = ± 66). At site II the values ranged from 145µS cm^{-1} in August to 409 µS cm^{-1} in October (x =241 ; SD = ± 71).

The waters are alkaline and well buffered without much variation in pH values. The site I recorded a maximum pH of 9.03 in August and minimum of 8.05 in October (x = 8.60; SD = ± 0.298). The site II did not show much variation in pH values from site I and fluctuated between 8.03 (October) and 9.04 (August), the mean values being 8.62 ± 0.314. Our findings are not in consonance with those of Cary and Weerts (1984) according to whom *S. molesta* grew best at pH 6.

The waters supporting *Salvinia* had bicarbonate type of alkalinity as is true for all the Kashmir valley lakes. During the growth period of *Salvinia* (May – September) the waters were less alkaline at both the sites as compared to the rest of the season when the plant species was not growing. Low chloride concentration from July – December, in comparison to the concentrations observed during January – June, coincided with the maximum growth of the plant, a fact also observed by Zutshi and Vass (1971). The values for the total hardness did not depict any seasonal trend but it was evident that the waters were comparatively more hard. The alkalinity values also permit the lake waters to be included within the 'hard water type' of Moyle's (1945) lake typology. The high values for hardness may be related to the leaching of agricultural fertilizers used in the vicinity of the lake. The average values of 45.7 mg l^{-1} for site I and 48.6 mg l^{-1} for site II were almost similar to the values recorded by Zutshi and Vass (1971) in *Salvinia* infested areas.

Phosphorus is considered as the most important nutrient for primary production in an aquatic ecosystem (Hutchinson, 1957; Vollenweider, 1968). In the present investigation, the phosphorus content of the water was comparatively higher at both the sites in absence of the *Salvinia* growth. However, the concentrations of this plant nutrient declined gradually with the onset of new growth indicating the higher phosphorus assimilation of the nutrient during the growing season as is indicated by its tissue concentration also. Cary and Weerts (1984) further believe that *S. molesta* attained maximum biomass in a nutrient solution containing 2 mg of NH_4 -N l^{-1} and 2.01 mg PO_4-P l^{-1} at pH 6 under 25^0 C.

The iron concentration of *Salvinia* infested waters depicted mean values of 6.4mg l^{-1} and 5.9 mg l^{-1} for site I and II respectively. These values are much above the permissible levels of 0.05 mgl^{-1} (Water Resources Centre, Canada, 1968), beyond which the water is unfit for human consumption. The study showed that a higher concentration of iron may be quite favourable for the growth of *Salvinia*.

Ammonical – nitrogen content of water at both the sites did not exhibit any seasonal trend. The values fluctuated between wide ranges (53 µg l^{-1} in July and 614.6 µg l^{-1} in November at site I; 12 µg l^{-1} in September and 677.5 µg l^{-1} in November at site II) at both the sites with 245 µg l^{-1} and 259 µg l^{-1} as the yearly averages for site I and II respectively. Ellis and Wastfall (1946) stated that the amount of ammonia and ammonium compounds in unmodified natural waters is very small (< 0.1 mg l^{-1}) while quantities more than 0.1 mg l^{-1} indicate organic pollution. High concentration of ammonia in the present study indicated organic pollution and thus the waters are favourable for the growth of *Salvinia*. The nitrate – nitrogen content in the present study varied from 9 µg l^{-1} to 142 µg l^{-1} at site I and from 7.5 µg l^{-1} to 146 µg l^{-1} at site II. The two sites depicted almost identical behaviour but no definite seasonal trend was observed. Studies conducted by Cary and Weerts (1981) and Room (1983) demonstrated that abiotic variables like availability of nutrients particularly nitrogen and temperature regulate the growth of *Salvinia*. Room and Gill (1985) further opined that concentrations of N in waters infested by *S.molesta* were below 0.02 mg l^{-1} and nitrogen content in plant tissues was supposedly related to age of plant than to water samples. The authors related growth in *S.molesta* to percent nitrogen dry weight in the plant rather than concentration of nitrogen in water.

Other studies including culture experiments indicated luxury consumption of N and P (Gaudet, 1973) and poor utilization of calcium as compared strontium (Ophel and Fraser, 1970; Gaudet, 1973) by *Salvinia* besides increase in light intensity or in CO_2 increasing its growth rate (Gaudet, 1973). Mehta *et al.* (1987) while studying the effect of Ca deficiency on growth, morphology and anatomy of *S. molesta* observed that the absence of Ca in the nutrient solution reduce growth by more than half, resulting in low fresh and dry weights. A number of anamolies appeared in the morphology and anatomy of the plant.

The colonization of the water-fern (*Salvinia natans*) in Dal Lake is thus attributed to : (i) its gregarious nature, (ii) the water quality, and (iii) the mechanical effects of water such as water level fluctuations and wave actions caused by wind which collectively enable the species to thrive well in highly eutrophic waters especially under the canopy of trees. The absence of natural consumers (parasites) in the environment is perhaps an additional factor contributing towards the wide dispersal of the obnoxious weed.

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