ALGAL GROWTH IN TEMPLES OF TAMILNADU A CASE STUDY

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ABSTRACT

The occurrence, frequency and distribution of sub. aerial algal communities on stone monuments are subjected to intensive scrutiny. Samples collected from four different stations such as Srirangam Araôkanātar temple, Rameswaram Rāmanātaswāmy temple, Madurai MÁ¸ākshi cuntarēswarar temple and Thiruchengodu ArtanārÁswarar temple representing different micro climatic Zones of Tamilnadu were examined for algal diversity and distinguishing their specific features. Climate is recognised to play an important role in influencing the activity of microorganisms on stone monuments. The community composition was subjected to minor seasonal changes affecting the population of different communities. In addition, the design, structural components and different kind of stone substrates of temples also influence these communities. Among the algal genera recorded, the genus Scytonema and Oscillatoria were constituted by more number of species followed by some green unicellular algae. Generally, cyanophycean members dominate the temple sites. Moreover, these blue algae are dominant on stone surfaces in tropical region. The temple architecture is unique with numerous components integrated in the buildings. The stone structures themselves give room for the growth of organisms by providing room for stagnation of water in many locations. Generally, disintegration of stone monuments by algae is considered insignificant when compared with chemical and physical weathering. Actually, algae enhance weathering. Algae disfigure and discolour the building facades ultimately marring of the aesthetic appeal by trapping dust or soot particles giving the surfaces a darkened dirty appearance.

Key words: Algae, sub-aerial, taxonomy, ecology, climatic factors, biodiversity, stone monuments, conservation, temple architecture.

Introduction

This paper deals with the occurrence and fluctuations of algal communities dwelling on stone monuments based on the study of the four ancient temples of Tamil Nadu, located in different areas. The algal community composition was found to be affected by seasons, type of stones, design and components. In recent decades, the rate of stone decay has undergone dramatic acceleration owing to the impact of environmental conditions. Monuments with direct exposures are affected not only by physical and chemical weathering, but also by biological activities of stone-dwelling microorganisms, among which algae, fungi and bacteria often prevail. The characterization of these microorganisms and a clear understanding of their role in stone decay process are important steps in the planning for suitable restoration interventions.

I. Investigated Monuments

One of the consequences of microbial development is the formation of pigmented bio-film that covers the sculpture and other structures of temple buildings. Microorganisms are observed in general to grow on the compound wall, roof of *maõÇapas*, pillar bases, sculptures, joints of basement mouldings, *vimā¸a* mouldings and other areas. The samples were collected from different locations of the temples and a detailed study was carried out on some selected samples of Granite, Gneisses, Schist and Basalt structures of *maõÇapas* and sculptures as an investigative model for the bio-deterioration of stone monuments.

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The fluctuations in the process of colonization were studied over a two-year period. The stone structures and sculptures that have not been restored recently or white washed recently or not restored at different times were studied. Usually restoration works, other than white washing or *kāvi* washing, have not been undertaken now in these temples. Sometimes cement and sand mixtures have been used to close the crevices in the stones. In Rameswaram Rāmanātaswāmy and Srirangam Araôkanātar temple, the pillars and other parts of the structures have been replaced by new stone structures or concrete structures.

II. Algal diversity in select Temples

Altogether more than hundred samples from four different temples representing different micro climatic zones of Tamil Nadu were examined for algal diversity. They are the following:

1. Srirangam Araôkanātar Temple
2. Madurai MÁ¸ ākshi cuntarēswarar Temple
3. Rameswaram Rāmanātaswāmy Temple and
4. Thiruchengodu ArtanārÁswarar Temple

In different sites, the algal diversity showed variation.

a) Site-wise Occurrence (Table 1)

In Araôkanātar and MÁ¸ ākshi cuntarēswarar temples, of algal species minimum number of species was recorded. The highest number of species was recorded in the samples collected from Rameswaram temple. In Thiruchengodu temple, only a fair number of species was recorded.

b) Percentage frequency (Table 1)

Frequency occurrence was calculated as below to identify their existence in the stones collected from different substratum of different temples

$$\% \text{ Frequency} = \frac{\text{Number of samples in which the specific organism occurred}}{\text{Total number of samples examined}}$$

Based on the frequency occurrence, algae and fungi were grouped as Rare (0-25% frequency), Occasional (25-50% frequency), Frequent (51-75% frequency) and Common (76-100% frequency) species.

c) Species Composition

Among the algal genera recorded, the genus *Sytonema* and *Oscillatoria* were represented by more number of species followed by some green unicellular algae. Generally, the Cyanophycean members dominate the temple sites. All other genera were represented by one species. Diatoms also occupy a special position with four species. (Plate 1 & 2; Table 2 & 3)

Enumeration of the occurrence and distribution of these microorganisms is based on specific culture media and techniques. They are isolated to determine the nature and composition of microbial communities. Some algae are identified to their generic level and some to species level.

Light and compound microscopy observation showed an abundance of microorganisms in the epilithic microbial communities. Microbial communities form thick biofilms, with intense pigmentation varying from dark-green to dark red that considerably alters the aesthetic appearance of monuments. On recently restored statues and other structures, the development of these biofilms are thin and less extensive. The microbial communities, which are predominant, are cyanobacteria with a few green microalgae. Unicellular cyanobacteria showed various morphotypes, often occurring in cell organelles enclosed by thick, sometimes coloured sheaths. This feature was observed commonly in samples collected during summer months. Filamentous forms showed a dense network with entangled cells of the coccoid form.

Table 1 Occurrence, percentage frequency and frequency class of different algal species in four temple sites.

S.No.	Algal Species	Srirangam	Madurai	Thiruchengodu	Rameswaram	% frequency	Frequency Class
1.	*Gloecocapsa* Sp	-	-	+	+	50%	O
2.	*Lyngbya* Sp	-	-	+	-	25%	R
3.	*Microcoleus* Sp	-	-	-	+	25%	R
4.	*Oscillatoria* Sp	+	+	+	+	100%	C
5.	*Phormidium* Sp	-	-	-	+	25%	R
6.	*Scytonema* Sp	+	+	+	+	100%	C
7.	*Calothrix* Sp	-	-	-	+	25%	R
8.	Blue green alga (BGA species) filamentous	+	+	-	+	75%	F
9.	Blue green alga (Colony)	+	+	+	-	75%	F
10.	Blue green alga (unicellular)	+	+	-	-	50%	O
11.	Green alga (filamentous)	-	-	+	+	50%	O
12.	Green alga (unicellular)	+	+	-	+	75%	F
13.	*Oedogonium*	-	-	+	-	25%	R
14.	*Pithophora*	-	-	-	+	25%	R
15.	*Spirogyra*	-	-	+	-	25%	R
16.	*Gomphonema* (Diatom)	-	-	-	+	25%	R
17.	*Nitzchia Obtusa* (Diatom)	-	-	-	+	25%	R
18.	*Diplonies subovalis* (Diatom)	-	-	-	+	25%	R
19.	*Scolproides* (Diatom)	-	-	-	+	25%	R

(+) denotes presence of species; C – Common; O – Occasional
(-) denotes absence of species; F – Frequent; R – Rare

Stones in the shrine wetted by running water show a rich epilithic community including diatoms, in addition to chlorophytes. On the unrestored statues and structures, both filamentous and unicellular cyanobacteria and some genera of green microalgae are found. Similarly, they are also found in the decayed parts of the sculptures and structures. However, they were absent on the very recently restored structures. The composition of the communities on the unrestored structures shows successive growth of organisms. Seasonal changes also affect the composition of communities in these parts of the temple.

Samples taken from more recently restored sculptures or structures indicate that the algae require several months, about six months after white washing, for reestablishing in the same area. In any case, the first phototrophic colonizer was the blue-green microalgae *Scytonema* species, which showed a marked increase during winter and rainy season.

Table 2 Algal species identified in the study sites.

S.NO	DIVISION	CLASS	ORDER	FAMILY	GENUS /SPECIES
1.	Cyanophyceae	Cyanophyceae	Chroococcales	Chroococcaceae	*Chroococcus* sps
2.	Cyanophyceae	Cyanophyceae	Chroococcales	Chroococcaceae	*Gloeococapsa* sps
3.	Cyanophyceae	Cyanophyceae	Chroococcales	Chroococcaceae	*Gamphospheria* sps
4.	Cyanophyceae	Cyanophyceae	Chroococcales	Chroococcaceae	*Entophysalis* sps
5.	Cyanophyceae	Cyanophyceae	Oscillatoriales	Oscillatoriaceae	*Oscillatoria* sps
6.	Cyanophyceae	Cyanophyceae	Oscillatoriales	Oscillatoriaceae	*Lyngbya* sps
7.	Cyanophyceae	Cyanophyceae	Oscillatoriales	Oscillatoriaceae	*Phormidium* sps
8..	Cyanophyceae	Cyanophyceae	Oscillatoriales	Oscillatoriaceae	*Microcoleus* sps
9.	Cyanophyceae	Cyanophyceae	Scytonematales	Scytonemataceae	*Scytonema* sps
10.	Cyanophyceae	Cyanophyceae	Rivulariales	Rivulariaceae	*Calothrix* sps
11.	Chlorophyta	Chlorophyceae	Chlorococcales	Chlorellaceae	*Chlorococcum* sps
12.	Chlorophyta	Chlorophyceae	Chlorococcales	Chlorellaceae	*Spherocystis* sps
13.	Chlorophyta	Chlorophyceae	Oedogoniales	Oedogoniaceae	*Oedgogonium* sps
14.	Chlorophyta	Chlorophyceae	Clacdophorales	Cladophoraceae	*Pithophora* sps
15.	Chlorophyta	Chlorophyceae	Zygnemales	Zygnemaceae	*Spirogyra* sps
16.	Bascillariophyta	Bacillariophyceae	Pennales	Bacillariophyceae	*Nitzschia Obtusa* (*scolproides* variety)
17.	Bascillariophyta	Bacillariophyceae	Pennales	Bacillariophyceae	*Diplones subovlis*
18.	Bascillariophyta	Bacillariophyceae	Pennales	Bacillariophyceae	*Gomphonema parvulum*
19.	Bascillariophyta	Bacillariophyceae	Pennales	Bacillariophyceae	*Fragillaria* sps

The number of algae increased slightly from late pre-monsoon to monsoon. In summer, dried biomass could be seen on the surface in between mouldings of the temples where they grow. They always remain in unrestored structures as dried patches mingling with dust. Almost in all the four study sites, in different locations of the temples, dried biomass could be noticed. During rainy seasons, they again become abundant. If removed systematically before monsoon suitably during summer the growth of these organisms could be arrested.

III. Temple design, substrate features and Environmental Condition and growth of Algae

The data showed that the majority of Cyanobacteria preferred calcareous substrate, the different stone surfaces and structures in these four temples.

High stone porosity and rough surface played a significant role than mineral composition in promoting microbial establishment. The surfaces of these stone monuments are always porous, since they are age-old monuments. Nearly all stone structures have weathered and exfoliation is observed on many outdoor structures. Weathering is predominantly seen in Madurai and Srirangam temples' outer compound walls and *gōpura* walls. Likewise, due to saline wind, all the stone structures and sculptures of Rāmanātaswāmy temple at Rameswaram are weathered and have become porous and rough. Dense cluster or patches of algae, fungi and bryophytes could be seen in Rameswaram temple. Pillars and *maõÇapas* exposed to sunlight have become porous and a slight touch or rub or scratch by hand is sufficient to remove exfoliation of stones.

Microbial colonization of calcareous stone surfaces was found to depend primarily on physical stone parameters and on water availability. Adequate temperature, solar irradiance, and of atmospheric deposition are additional factors.

The effect of environmental factors on the monument depends upon the design, structures and position of the building. Only certain areas or surfaces of the monuments are often affected based on the design of the building where space for shade and stagnation of water is made available.

Solar irradiance influences the predominance of the photosynthetic microorganisms and its qualitative composition. Generally, on the underside of roof and shaded locations, Cyanophycean members are predominantly seen. Chlorophycean members are found in locations where large amount of light is available.

Growth of sub-aerial algae in large measure dependent on water obtained directly from the atmosphere as the substratum on which they grow normally furnishes them with little moisture. They are most in abundance over wet periods, when they are actively growing and reproducing. During dry seasons, some blackened and appear as scale-like growths or crusts on the surface (especially blue-greens). It is known that some are able to absorb water directly from the atmosphere (Fritsch and Haines, 1923). Indeed, the algae disfiguring or obscuring carvings, inscriptions and frescoes within buildings appear to be very reliant on atmospheric moisture. The possession by blue green algae of a muscilaginous sheath or envelope, probably, protects the cells by retaining water for a long period. Some terrestrial green algae also have such sheaths or envelopes (eg. *Gleocapsa*) whereas others (eg. *Apatococcus lobatus, Trentepholia* sp) are reported to overcome dry periods by passing into a resting phase (Peterson *et. al.*, 1988). It seems that one of the most important features of all truly subaerial algae is the ability of their protoplasm to withstand extremes of temperature, high light intensity and water loss.

i) Substratum

It is evident that only a limited number of algal taxa are adapted to survive in above ground habitat. This is due to the harshness of the environment in terms of not only high temperature and insolubility, the general effect of climate and wind, but to the physio-chemical properties of the surface available for colonization and subsequent growth.

a. Walls

Many of the algae and other plants growing on natural exposures of base rock and in rock crevices also occur on walls. The principal difference between a wall and natural exposure is the presence of mortar. The mortar is present in between the stone blocks as binding material. The high pH of the mortar normally enhances the growth of algae.

Table 3 Algal species found in each monument

Sample	Araôkanātar temple	MÁ¸ ākshi cuntarēswarar Temple	ArtanārÁswarar Temple	Rāmanātaswāmy Temple
1	×	Scytonema	Oscillatoria, BGA colony, Sytonema	Gloeocapsa
2	Scytonema sp	×	Spirogyra	Pithophora, Phormidium,Entophysalis
3	Scytonema sp	Oscillatoria	Spirogyra	Gloeocapsa, Scytonema, Gomphospheria
4	Scytonema sp	Scytonema	Spirogyra, Gomphonema (Diatom)	×
5	Moss	×	Scytonema	BGA filament, Green algae filament
6	BGA	Scytonema	Scytonema, Gloeocapsa	Green algae filament, Oscillatoria, Chlorococcum Microcoleus
7	BGA	Scytonema + fauna	Oedogonium, Calothrix, Lyngbya	Chlorococcum Sphaerocystis
8	Oscillatoria	×	Scytonema	×
9	Scytonema, BGA	Scytonema	Oscillatoria	×
10	Chrococcus	BGA	Gomphonema (Diatom)	Gamphospaeria Sphaerocystis
11	Scytonema	Unicellular Green alga, BGA, Chlorococcum	Gloeocapsa, Green alga, Scytonema	Nitzschia obtusa (Diatom), Scolproides (Diatom), Calothrix, Oscillatoria, Diplonies subovalis (Diatom)
12	Scytonema	×	×	Oscillatoria
13	Scytonema	×	Oscillatoria, Scytonema	Oscillatoria
14	×	×	BGA colony	-
15	×	×	Oscillatoria	-
16	×	Chlorococcum, BGA, Scytonema	-	-
17	×	-	-	Scytonema
18	×	-	-	Scytonema
19	Scytonema	-	-	Scytonema
20	Green alga, BGA, Scytonema	-	-	Scytonema
21	-	-	-	x
22	-	-	-	x

1 To 22– Samples collected from different locations of the temple
(x) indicates absence of organisms
(-) indicates no sample collection at the location

On all the walls of the four temples, algal presence is seen in many places (Plate 4; Fig. *e* & *f*) (Plate 5; Fig. *d* & *f*) (Plate 10; Fig. *a*). The walls are porous and rough, which accelerate the growth of the algae. Various environmental factors including rainfall, influence the change in pH and thereby the colonization of algae. The duration of the wet period is more crucial than frequency, so anywhere if a building is damp for any length of time, it is prone to algal development as seen in Araȏkanātar temple (Plate 8; Fig. *f*) (Plate 9; Fig. *a* to *f*). Algal growth will therefore be more evident on shaded surfaces, which are slow to dry out, and horizontal surfaces, where drainage is hampered. Leakage of water from a fractured gutter, faulty overflow of tap all encourages algal growth. Heavy growth is commonly found on walls close to ground level, which is subject to splash back during rainfall. No doubt at this level soil alga is more likely to become associated with the more typical subaerial forms.

b. Roofs

The roofs of buildings are flat or sloping and made of stones. Roof surfaces, probably, present harsher substratum for algae than walls, due to their generally greater exposure and rapid water drainage. Algal growth on the lower surfaces of the roofs of *maõÇapas* in Rāmanātaswāmy temple (Plate 3; Fig. *a,b* & *c*) indicates the specific requirement of the algae, i.e. moisture, low temperature or low light intensity. Likewise, algal growth could be seen in ArtanārÁswarar temple (Plate 12; Fig. *a* to *h*) under roof surfaces. Similarly in Araȏkanātar temple (Plate 10; Fig. *c* to *h*), under weathered wall of *maõÇapa,* one could notice the growth of alga in dense clusters. The discoloration of paint surfaces is due to the presence of algae. The early colonizers of the stone surfaces were dominated by green algae. Later the surfaces were dominated by blue-greens, especially the species of *Gloeocapsa.* Algal spread appears to be most rapid on north and west facing roofs. Scytonema and other blue green algae are responsible for the discoloration of stones in these temples. Types of stone, surface properties, length of period of wetting, and amount of exposure to rain and sunshine are mentioned as factors governing the degree of discolouration of the stones.

Scytonema of one the common blue-green algae on stone surfaces is easily mistaken for a fungus, as it forms soot-like specks, dark brown to black in colour (Skinner, 1972). A number of other algae have also grown over basement in between mouldings on shaded places. Such algal assemblages must represent the result of the selective influence of an environment in which the temperature is low, humidity high, and levels of light usually low.

In Araȏkanātar temple, algae are found in the walls, joints of mouldings and walls below basement segments, crevices of stones of various structures (Plate 8; Fig. *a* to *f*). Especially, the algae could be noticed in the maõÇapa roof on the lower side at the joints of pillars and water leakage areas. At the base of pillars, in joints of segments, Oscillatoria and other filamentous green algae are present. Unicellular forms are present in the stagnant water around sculptural parts in the pedestals of pillars. On the walls, algae grow in between the broken or weathered stones, in the gap of weathered rocks exfoliated. In addition to climatic conditions, growth of dense cluster of algae adds to the weathering of stone sculptures.

In MÁ¸ākshi cuntarēswarar temple algae are found on the walls, joints of mouldings, and structures on which water stagnation is observed. They are abundant in stone crevices and in between the space of weathering rocks (Plate 6; Fig. *a* to *h*).

In Rāmanātaswāmy temple algae could be seen on almost all the walls adjacent to the twenty-three wells or *thÁrtas*. They were also observed around the maõÇapa pillar base, pillar surfaces, joints of structures in walls and in between mouldings of structures, especially in the basement of shrines. In the superstructure of *vimā¸ as* many locations are shaded. The spaces in between components are numerous and provide shade and shelter to organisms. Water stagnation is also observed in many locations of the superstructures.

In Rāmanātaswāmy temple, in all the seasons the temple structures are wet due to the presence of *thÁrtas* and the bathing of the pilgrims. In ArtanārÁswarar temple, algae were observed on the walls of buildings, pillar basement and joints between structures in pillars, basement of *maõÇapas*, basement of shrines and other places.

The temple architecture is unique with numerous components integrated in the buildings. The stone structures themselves give room for the growth of organisms by providing room for stagnation of water in many locations. The pedestal mouldings, basement components (Plate 13; Fig. *g*), wall segments and superstructure components are placed in such a way to help in stagnation of water or shadow or dust and promote growth of microorganisms.

ii. Distribution of algae

Little mention is made in most studies on difference in the micro-distribution of subaerial algae. It is evident that algal distribution is seldom uniform and often changed dramatically over very small distances. Sometimes the substratum is heterogeneous and so the reason for the change is evident, for example, the change in distribution of algae between the brick or stone and the mortar on the wall. Factors other than the physical or chemical nature of the material forming the wall are also probably important. Of these the most significant is likely to be microclimate (eg. moisture, light) which varies depending on inclination aspect, proximity to other surfaces, and height above the ground in addition to thickness of wall or internal properties of the wall (eg. Influence of foundation, damp course). Darlington (1981) recognized four zones developing in response to a gradient of diminishing moisture conditions. The wettest zone was characterized by filamentous algae followed by the so-called 'proto-pleurococcus' community and then lichens. It is also observed in the present study that Oscillatoria species are found in locations where high moisture condition is present. Scytonema is present in some locations of temples where moisture and sufficient amount of light are present.

Fritsch (1907) considered the nature of the surface as irrelevant in his study of the sub aerial algae of Sri Lanka that the character and distribution of the communities were dependent mainly on temperature, moisture and degree of shading rather on the nature of the surface. This contradicts with some reports from temperate regions where the substratum is reported to influence algal distribution. Schlichting (1975) reported sub aerial alga *Chlorella* on bricks and the blue-greens *Chrococcus* and *Schizothrix* were confined to the mortar between them. He also noted that algae may grow in abundance on limestone or gravel blocks and may be entirely lacking on adjacent sandstone of the same age. This is confirmed by Sokoll (Strezetczyk, 1981) who reported algae on stone monuments and plasters. She found 15 taxa - seven blue-green algae on limestone surfaces, and of the four reported on sandstone, none was blue-green. Algae are sensitive to pH, with blue-greens commonly inhabiting alkaline rocks (limestone, marble) rather than acid siliceous rocks (granite, gneisses). The samples collected in the present study are mainly from the surfaces of granite and gneisses. However, it is found that the blue-greens are dominant on stone surfaces in tropical regions. Diatoms are generally infrequent in sub aerial situations though are known to occur in abundance on natural exposure of sandstone. Virtually nothing is known of the properties of surfaces responsible for differences in algal floras.

iii) Deterioration of Stone by Algae

Algae are known to liberate small amounts of extra cellular products of assimilation as well as various organic acids including lactic, oxalic, succinic, acetic, glycoleic and pyruvic acids. These acids either directly dissolve rock and stone components or increase their solubility. Algae may thus alter the diameter of the capillaries in stone, the size of minute fissures, the chemical characteristics of the water in the capillaries and fissures, the co-efficient of thermal expansion, and other features, which increase the sensitivity of the surface to weathering (Strzetczyk, 1981).

Besides organic acids they produce chelating agents, which may contribute to the dissolution of phosphate rocks. Sugars, growth promoting substances and antibiotics released by algae, stimulate the growth of other organisms including bacteria and these bacteria, principally sulphur and nitrifying bacteria, play an important role in the decay of stone.

Disintegration of stone material by algae and other plants is considered insignificant when compared with chemical and physical weathering. Darlington (1981) suggests that heavy growth of algae and other plants reduce weathering by smoothing out wide fluctuations in temperature and water content of a surface. On the other hand water entrapment and the retardation of drying by these plants might well exacerbate water-induced damage to the underlying substratum.

Algae disfigure and discolor the building facades ultimately marring of the aesthetic appeal by trapping dust or soot particles giving the surface a darkened, dirty appearance. Algae will develop on porous stone provided dampness, warmth and light are present (Richardson, 1973). Numerous reports on disfigurement and damage to stone buildings, monuments and works of art are found in literature (Keen, 1971; Paleni and Curri, 1972; Faville, et. al., 1981; Lee and Wee, 1982).

Evidence on the contribution of algae to the decay process has been conflicting. Pictrini *et. al*. (1985) have shown that discoloration of marble was due to the growth of algae; but no deterioration was reported. Staining of sculptures by algae without surface changes like these attributed to lichens has also been described (Giaccone *et al.* 1976). Krumbein and Lange (1978) reported some damage caused to plaster and stone building by algae associated with bacteria and fungi, but were unable to attribute the decay to algae alone. Krumbiins' view seems to be correct when analyzing the present study sources. Almost all samples were collected from the same location for algae and fungi. The samples were divided into two segments. One segment is used for algal culture and another one is used for fungal culture. Many samples show the presence of algae and fungi along with bacteria. In the present study, almost in all locations, it is possible to see algae, fungi, bacteria and other organisms together. Thus, an ecological holistic approach is important to study the deterioration of monuments.

References

Darlington, A. 1981. *Ecology of Walls*. London:Heinemann Educational Books.

Favilli, F., Pelosi, E., Torzillo, G. and Giovannett. L. 1981. Nuovi parametric microbioogici dell inquinamento del suolo da erbicidi, problemi relative – all inquinamento da erbicidi con particolare riguardo all Atrazina. *CNR. AQ* 4 (1–11): 117–153.

Fritsch, F.E. 1907. A general consideration of the subaerial and fresh-water algal flora of Ceylon. A contribution of the study of tropical algal ecology. Part I. Subaerial algae and algae of the inland fresh-water. *Proceedings of the Royal Society* B79:197-254.

Fritsch, F.E. and Haines, F.M . 1923. The moisture relations of terrestrial algae, II. *Annals of Botany*, 37:683-728.

Giaccone, G., Velocci, A., Rinaldi, M.L., and Giacobiai, C. 1976) Forme biologiche delle algae esistenti sulle sculture all aperto. In Rossi Moneresi R. (ed). *Conservation of stones.* Bologna, Italy:Centro Perla conservations delle sclture all Aparto:245-256.

Keen, R. 1971. Controlling algae and other growths on concretes. In *Advisory note of the Cement and Concrete Association.* London:45-120.

Krumbein, W.E. and Lange, C. 1978. Decay of plaster paintings and wall material of the interior of buildings via microbial activity. In *Environmental Biogeochemistry and Geomicrobiology*. Vol. 2: The Terrestrial Environment. Krumbein. W. (ed.), Ann Arbor, Michigan, USA:Ann Arbor Science Publishers:687-697.

Lee, K.B. and Wee, Y.C. 1982. Algae growing on wall around Singapore. *Malayan Nature Journal* 35: 125-132.

Paleni, A., and Curri, S.B. 1972. Biological aggression of works of art in Venice. In Walters A.H. Hueck. Van der Plas E.H. (eds.) *Biodeterioration of Materials Vol. 2.*, New York:John Wiley and Sons:288-291.

Peterson, K., Kuroczkin,J., Strzelczyk, A.B., and Krumbein, W.E. 1988. Distribution and effects of fungi on and in Sandstones. In Houghton, D.R., Smith,R.V. (eds), *Biodeterioration.* New York:Elsevier:123-128.

Pictrini, A.M., Ricci, S., Bartolini, M., Giuliani, M.R. 1985. A reddish colour alteration caused by algae on stoneworks. Preliminary studies. In Proceedings of the 5th International Congress on Deterioration and Conservation of Stone, Vol. 2, Felix,G. (ed)., Loussana, Switzerland:Presses Polytechniques Romandes:653-658.

Richardson, B.A. 1973. Control of biological growth. *Stone Industries* 8:2-6.

Schlichting, H.E. Jr. 1975. Some subaerial algae from Ireland. *British Phycological Bulletin* 10:257-261.

Skinner, C.E. 1972. The role of algae in the deterioation of decorative and marine paints. In *Proceedings of the XI Congress of* FATIPEC:6.

Strezetczyk, A.H. 1981. Stone. In Rose,A.K. (ed.). *Microbial Biodetorioration, Vol.6.* London: Academic Press:62-80.

Plate 1

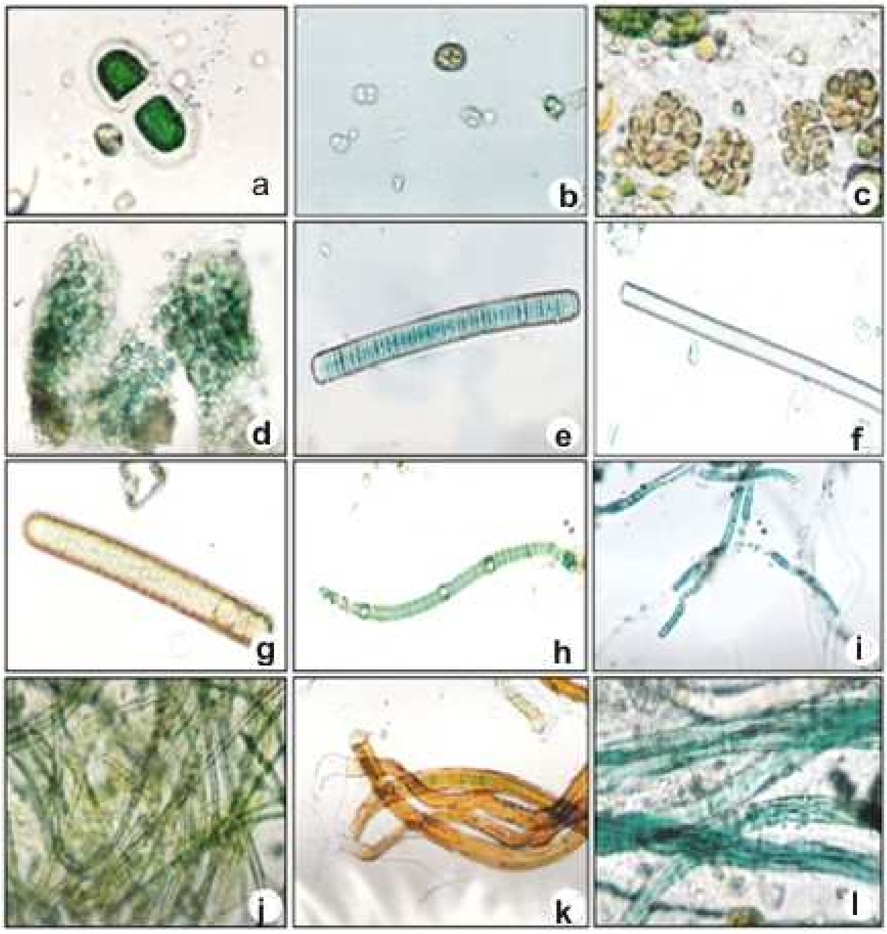

Plate 1 Identified algal species in the stone monuments

a. *Chroococcus sp;* **b.** *Gloeocapsa sp;* **c.** *Gomphosphaeria sp;* **d.** *Entophysalis sp;* **e-h.** *Oscillatoria sp;* **i.** *Lyngbya sp ;* **j.** *Phormidium sp* ***k.*** *Scytonema sp;* **l.** *Microcoleus sp*

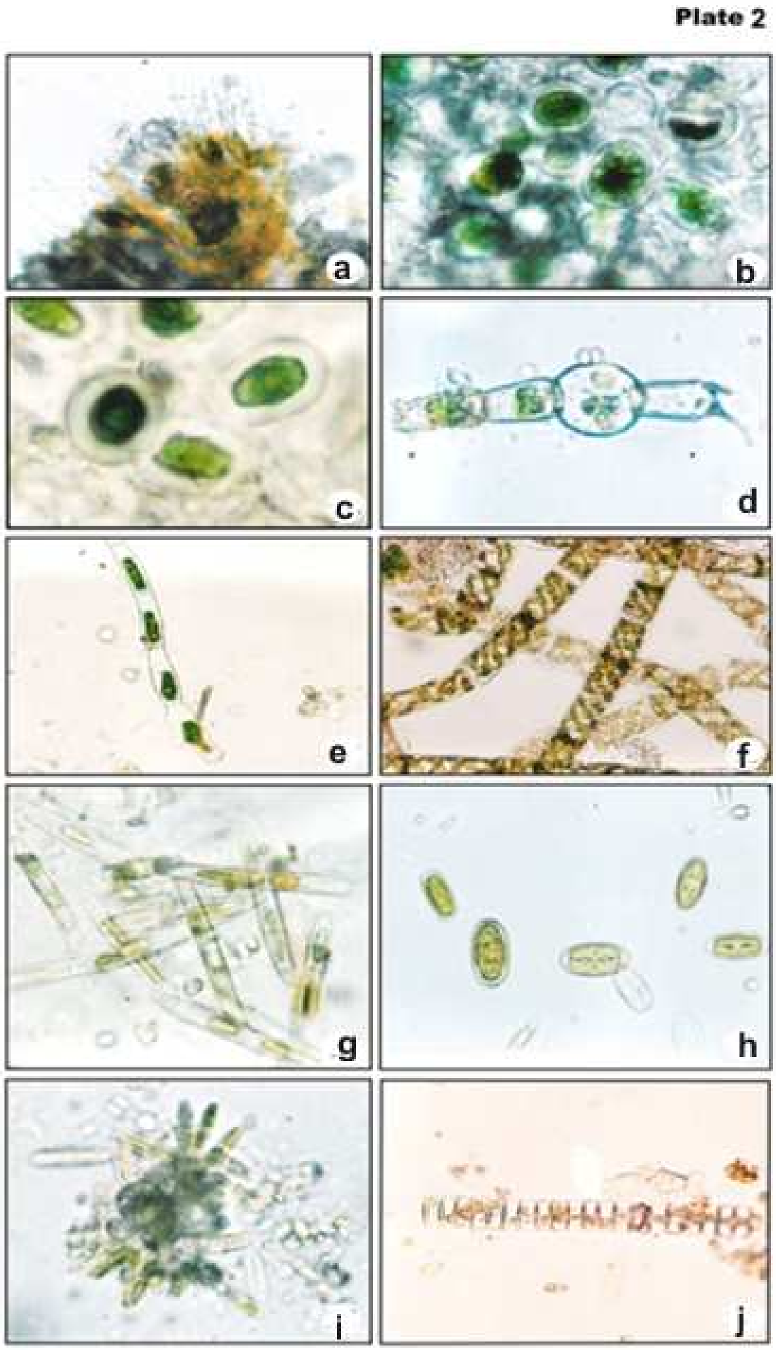

Plate 2 Identified algal species in the stone monuments

a. *Calothrix sp;* **b**. *Chlorococcum sp;* **c**. *Sphaerocystis sp;* **d**. *Oedogoium sp;* **e**. *Pithophora sp;* **f.***Spirogyra sp* **G**. *Nitzschia obtuse;* **h**. *Diplonies subovalis* **i**. *Gomphonema parvulum;* **j**.*Fragilaria brevistriata*

Plate 3

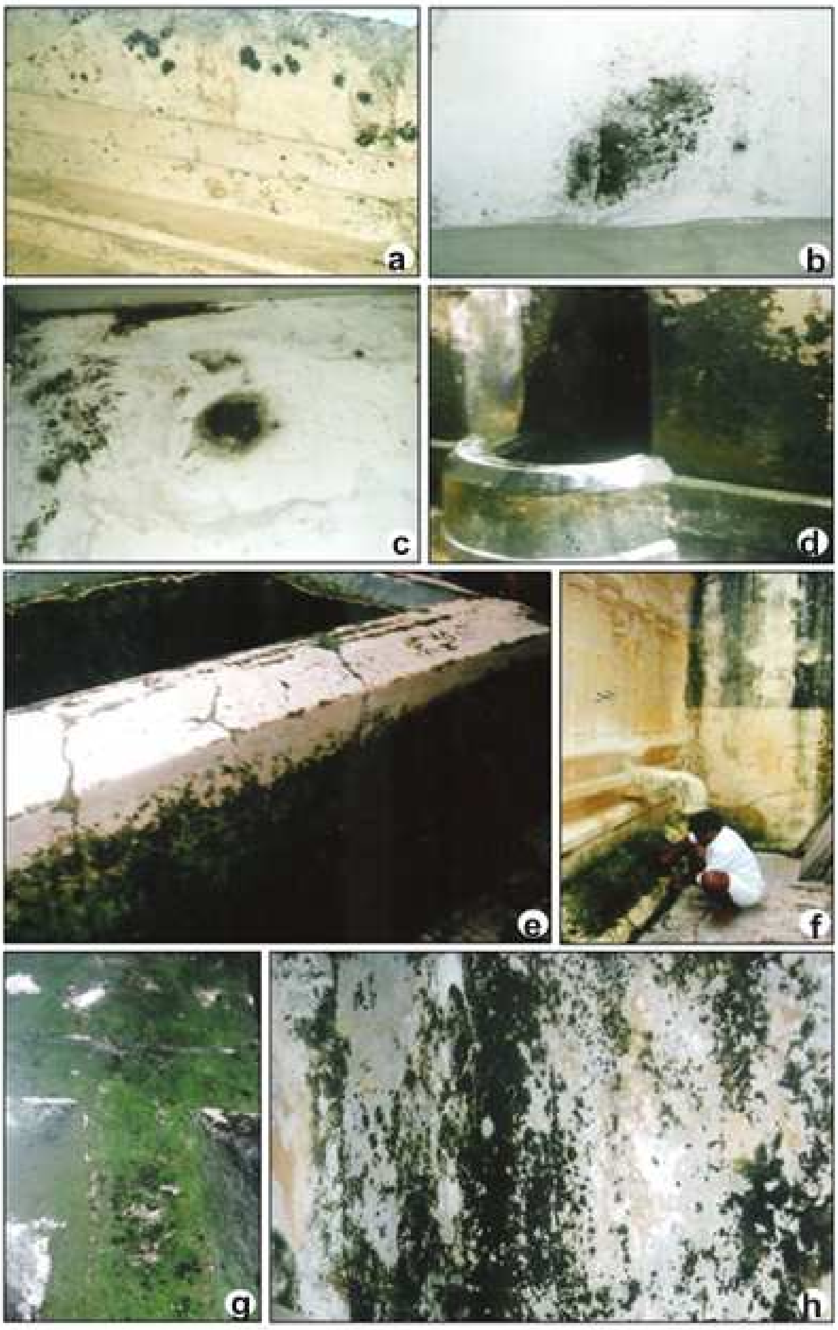

Plate 3 Rāmanātaswāmy temple, Rameswaram

a,b & c. Organisms under roof; **d**. A well and adjacent wall; **e**. A well wall; **f**. Sample collection at a shrine basement; **g**. Organisms in a Pillar; **h**. Floor near a well

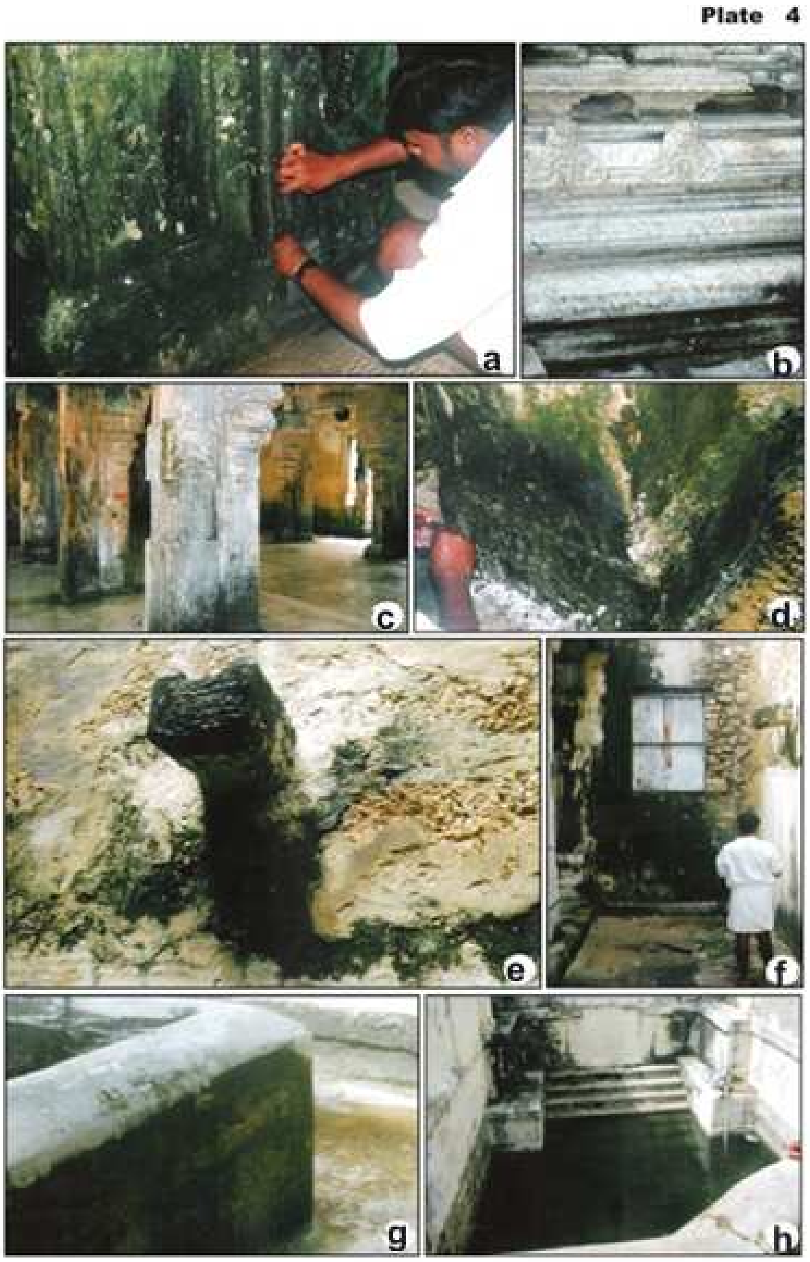

Plate 4 Rāmanātaswāmy temple, Rameswaram

a. A pillar near well – Collecting samples; **b**. A shrine basement with organisms; **c**. A maõÇapa pillars adjacent to wells; **d**. A pillar base with organisms; **e**. Compound wall weathered; **f**. Compound wall with organisms; **g** & **h** A well - ThÁrta

Plate 5

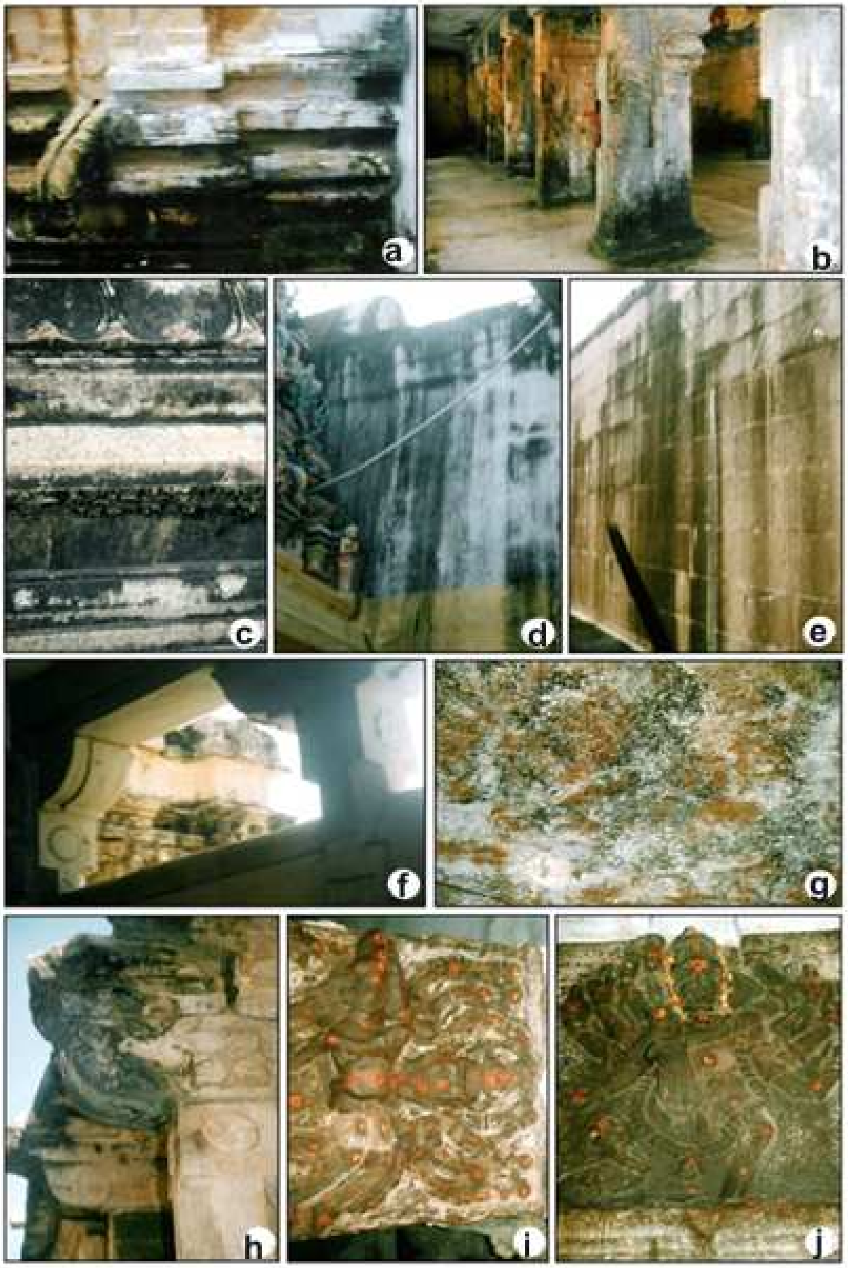

Plate 5 Rāmanātaswāmy temple, Rameswaram

a. Basement of a shrine with organisms; **b**. A maõÇapa pillars adjacent to wells; **c**. A shrine basement with organisms; **d**. A compound wall with organisms; **e**. A compound wall; **f**. A shrine superstructure; **g**. Succession of plant growths; **h**. Entablature of a maõÇapa with successional growth of organisms; **i&j** .Kumkum and oil application on bas-relief sculptures

Plate 6

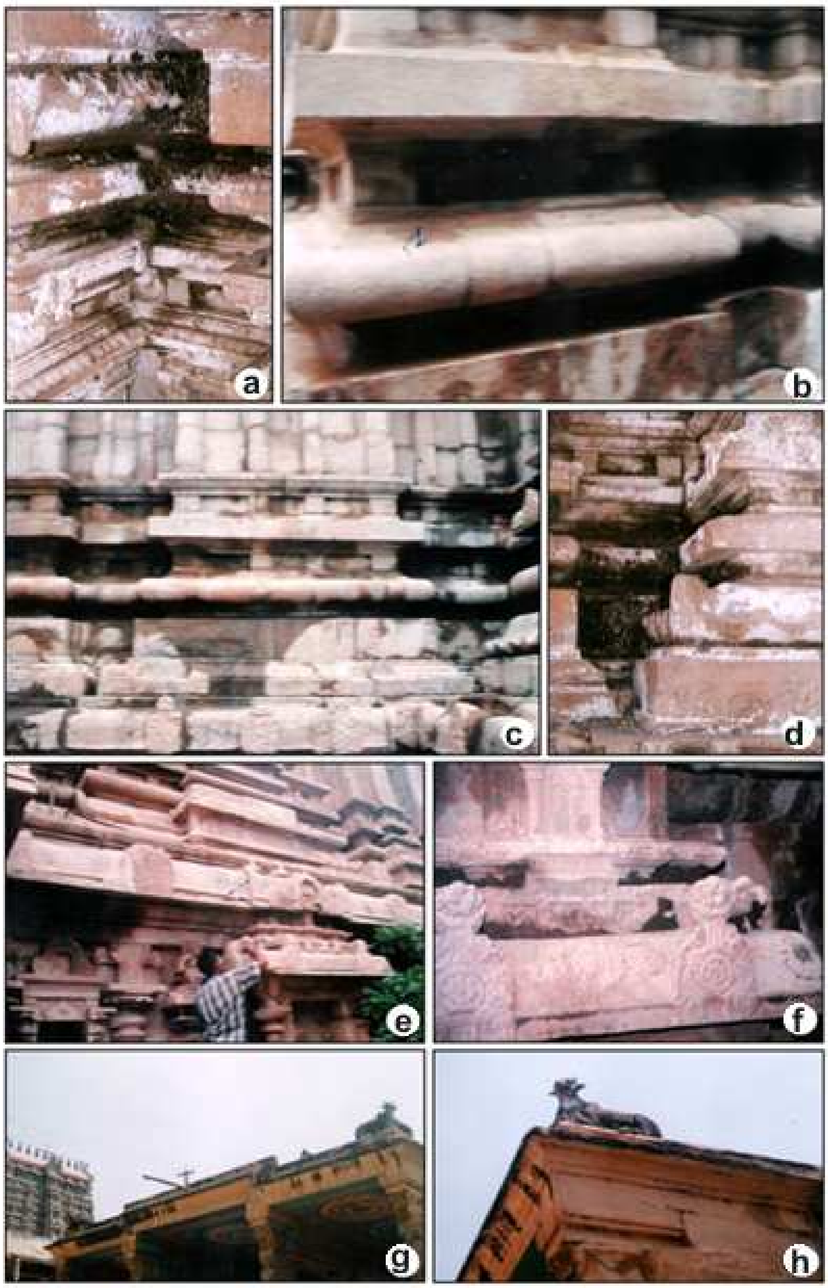

Plate 6 MÁ¸ ākshi cuntarēswarar temple, Madurai

a&**b** Basement of a gopura; **c**. Basement and wall of a gopura; **d**. Basement of a gopura; **e**&**f** Pedestal and wall segments of gopura; **g**&**h** A maõÇapa entablature

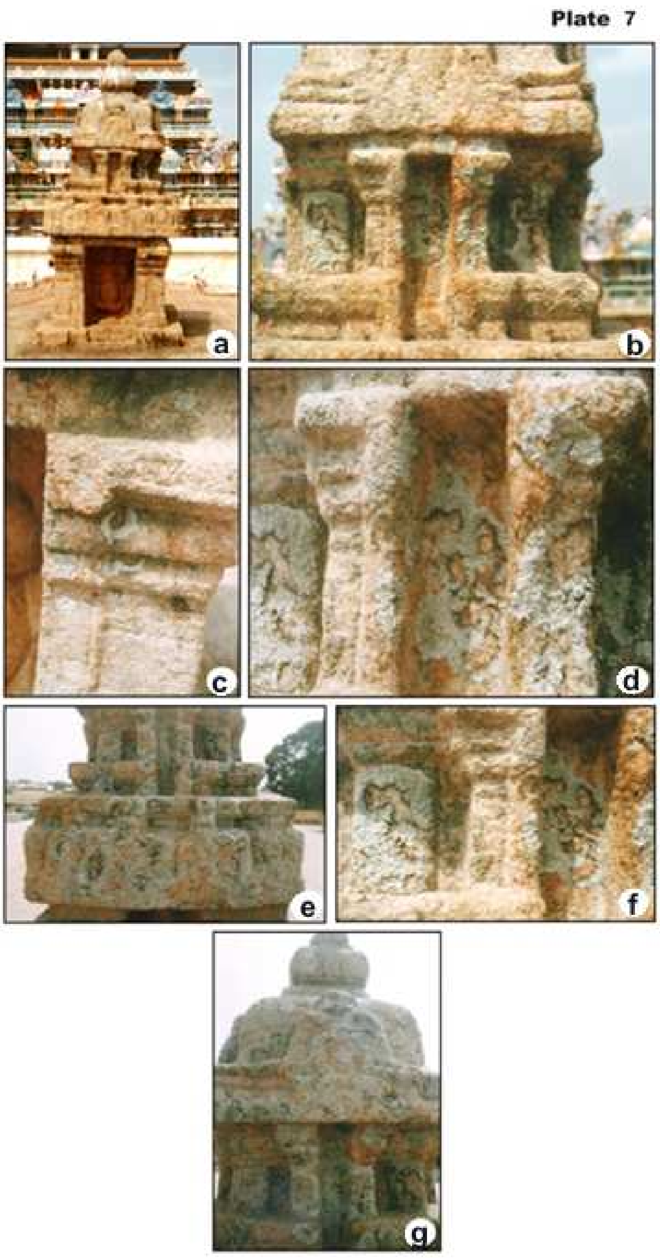

Plate 7 Araôkanātar temple, Srirangam

a – g. A pillar top segment infected by lichens

Plate 8

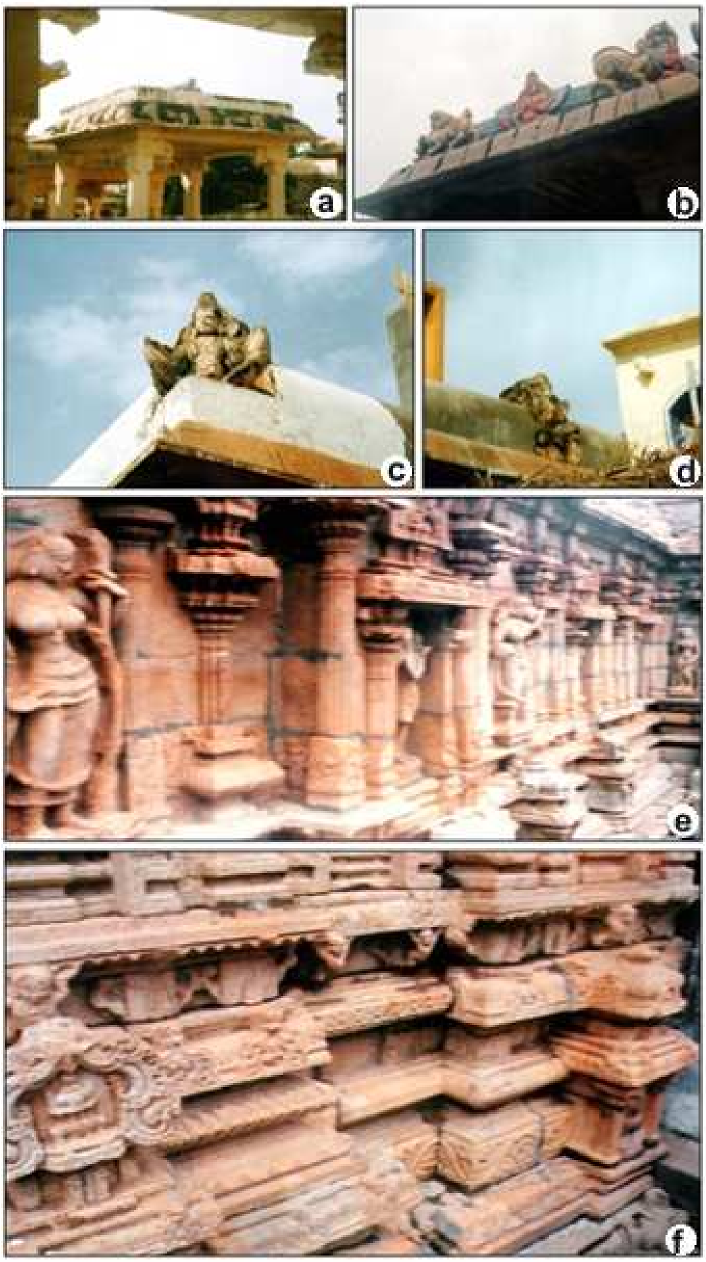

Plate 8 AraÔkanātar temple, Srirangam

a. A four pillared maõÇapa – entablature with organisms; **b**. Entablature of a maõÇapa with organisms; **c** & **d** A stucco sculpture infected by organisms; **e**. Venugopalan shrine basement and wall components; **f**. Venugopalan shrine basement segments

Plate 9

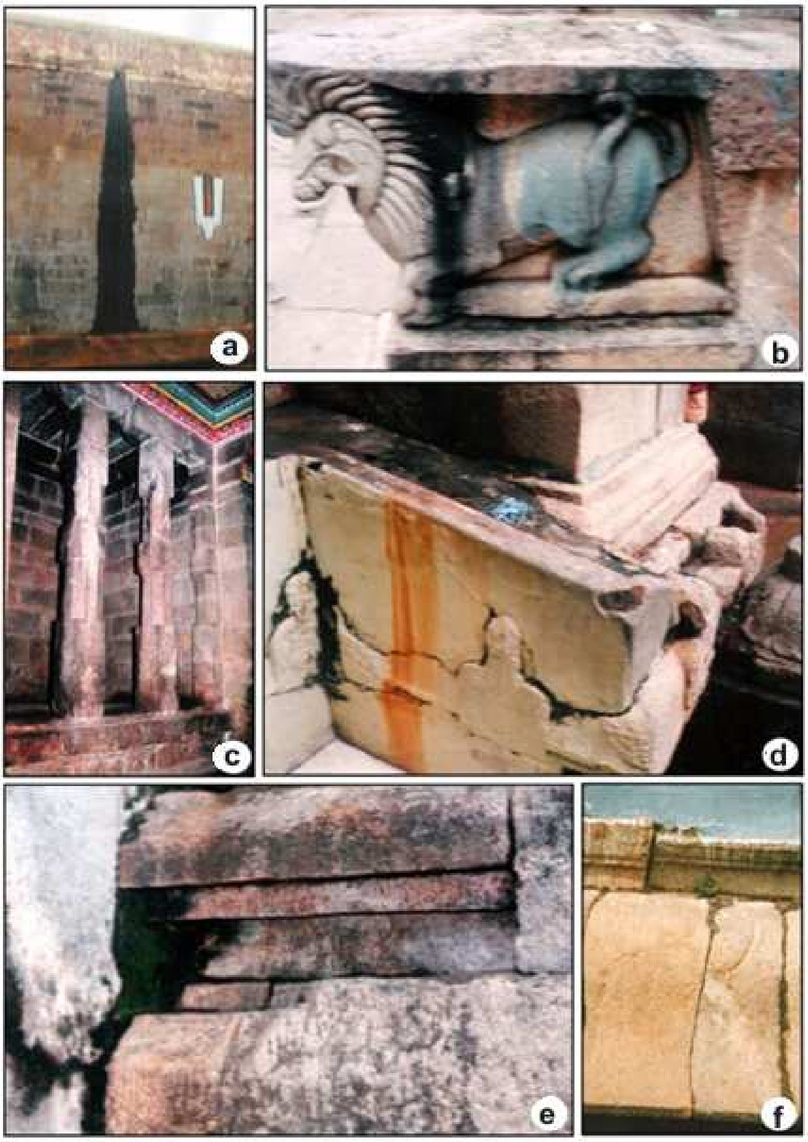

Plate 9 Araôkanātar temple, Srirangam

a. Leaking water on the compound wall; **b**. A blackened animal sculpture; **c**. Vestibule of a gopura – bat's resting place; **d**. Crevices in the pillar base; **e**. A basement mouldings with organisms; **f**. Entablature joints

Plate 10

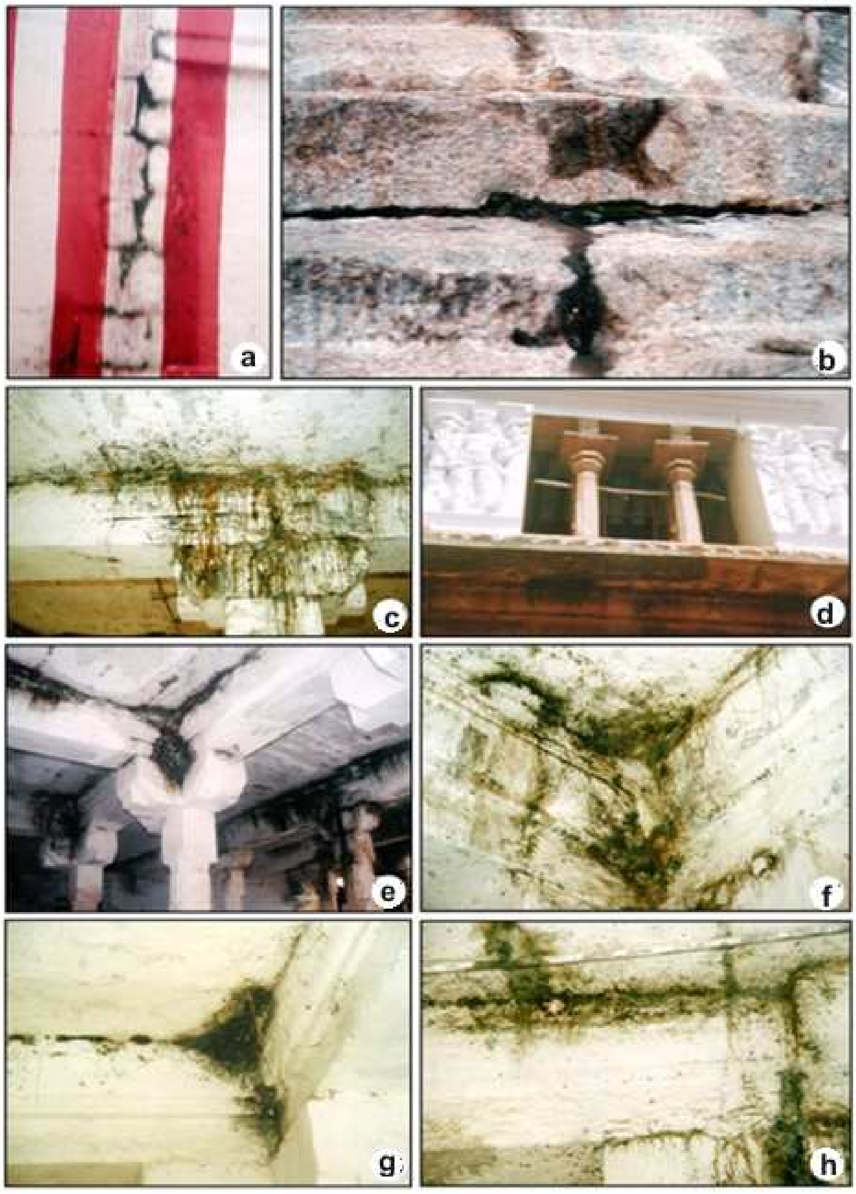

Plate 10 Araôkanātar temple, Srirangam

a. A compound wall crevices; **b**. Crevis between basement mouldings; **c**. A maõÇapa roof infected with organisms; **d**. A gopura entablature; **e – h**. A MaõÇapa roof with organisms

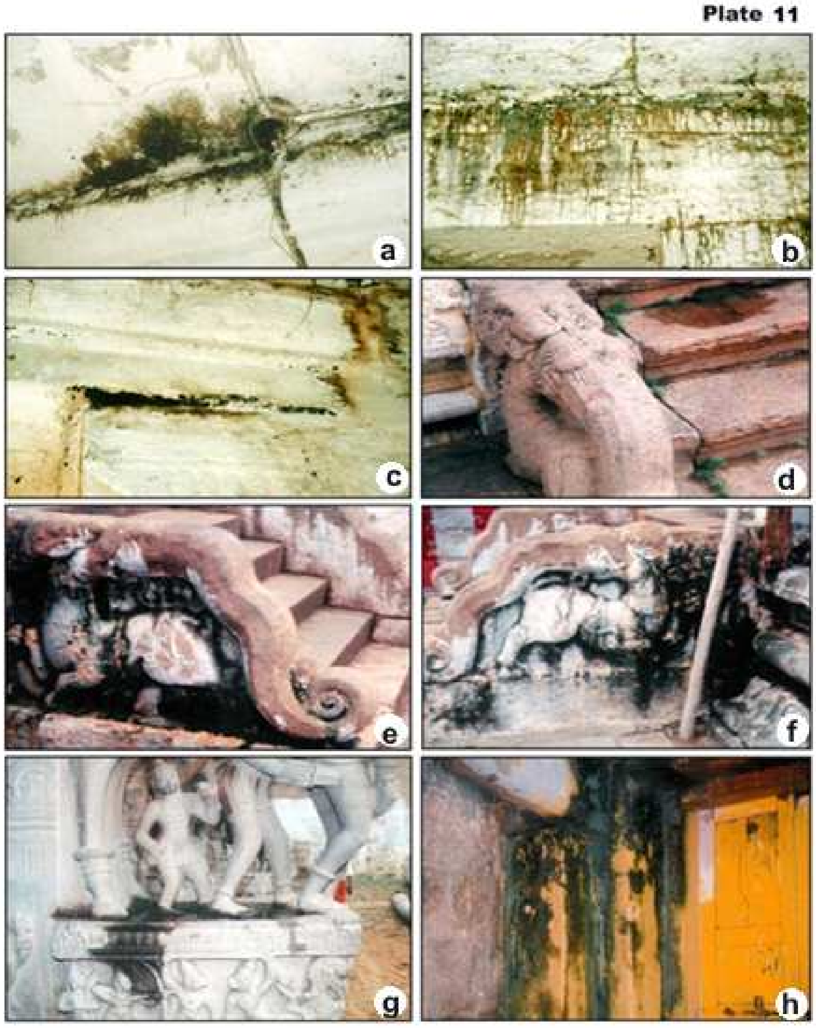

Plate 11 Araôkanātar temple, Srirangam

a – **c**. A MaõÇapa roof with organisms; **d** – f. A shrine yali staircase; **g**. A pillar sculptures after the rain; **h**. A shrine wall with organisms

Plate 12 ArtanārÁswarar temple, Thiruchengodu

a – h. Roof and pillars of a maõÇapa affected by organisms

Plate 13

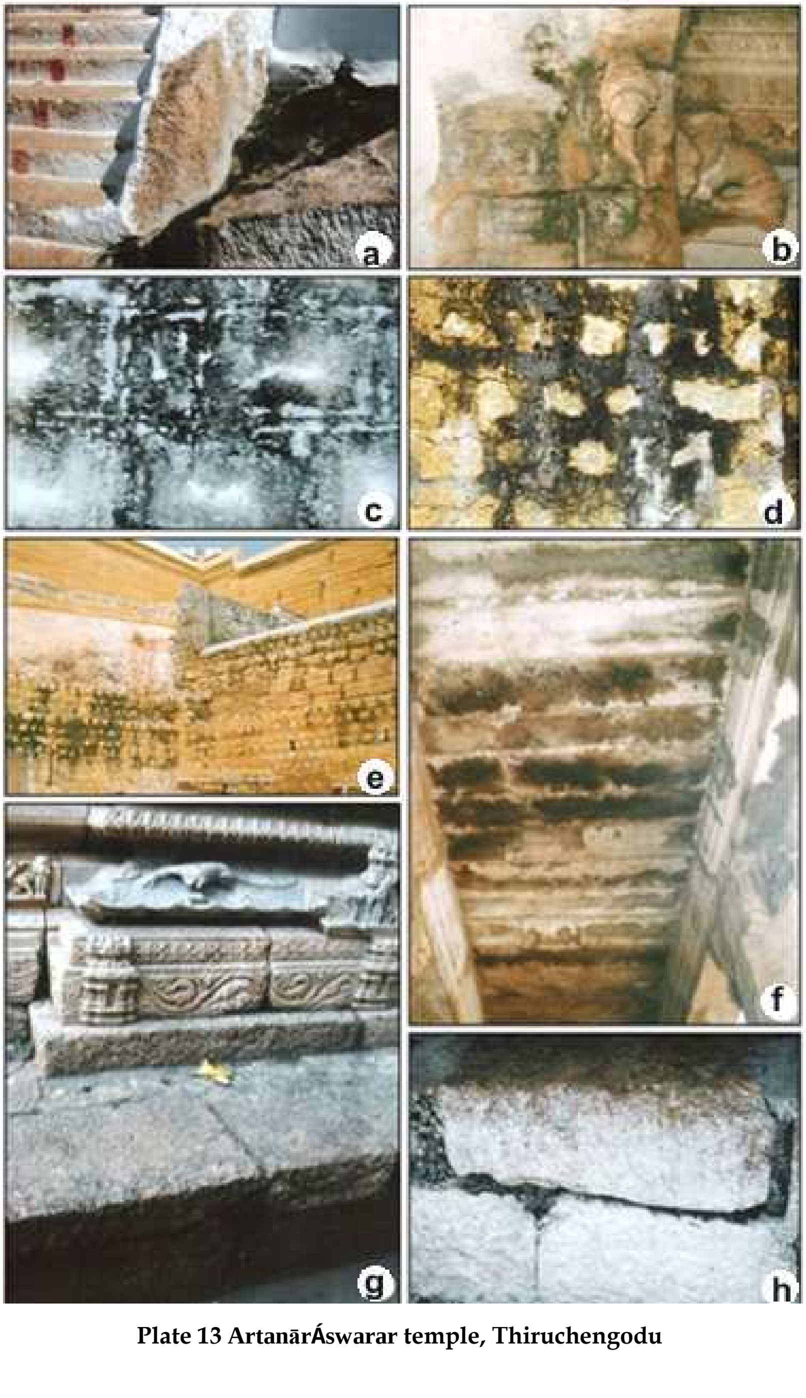

Plate 13 ArtanārÁswarar temple, Thiruchengodu

a. Running water near a staircase; **b**. A pillar carbel base; **c**. A white washed shrine wall with organisms; **d** & **e**. Compound wall with organisms; **f**. Roof of a corridor; **g**. A shrine basement; **h**. A pedestal crevice