A GIS Analysis of Biodeterioration of Historic Resources: A Case Study of St. Louis I Cemetery, New Orleans

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Kyubong Song

1. Introduction

New Orleans' early Creole cemeteries, long appreciated and promoted as

historic sites as well as traditional burial places, are currently experiencing

renewed popularity through heritage tourism. Frank G. Matero, Professor of

Historic Preservation, University

of Pennsylvania, pointed out that

"with this revived interest, has

come commercialization,

overzealous restoration,

environmental deterioration and

opportunistic vandalism in

Figure 1. Aerial Photography of St. Louis I Cemetery

addition to existing neglect and abandonment." A new approach to their care

and management as cultural landscapes is urgently needed to make more

informed decisions regarding their preservation and long-term development.

Saint Louis I cemetery is the oldest of New Orleans' extant early Creole

cemeteries (1789) and among the most intact European-American cultural

landscapes in the region, containing an important collection of family and

society tombs of unique local and national historical and artistic significance.[1]

It is the smallest of the city's early cemeteries in land area and tomb number

(approximately 750), yet it displays all the elements of the early planned

Creole cemetery including tomb types, styles, and materials; walls, paths and

fixtures; and plantings. Its proximity to the French Quarter, coupled with its

historical associations, make it a popular tourist destination.

2. Aims and Objectives

Outdoor cultural resources—such as historic buildings, tombstones,

monuments and sculpture—are under attack by man-made and natural threats.

Biodeterioration of cultural resources is damage due to the growth of

organisms, from microorganisms to higher plants, on the surface of an object.

Biological agents of damage can range from colorful lichens to creeping vines.

Microorganisms may cause damage on an objects. Growth of organisms on

tomb materials can cause two main types of damage: mechanical damage by

the penetration of roots and hyphae, and chemical damage by the secretion of

acids capable of chelating to metal ions found in stone. Biodeterioration of

tomb materials exposed to the environment is a vast topic beyond the scope

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[1] Samuel Wilson, NR., F.A.I.A. and Leonard V. Huber. 2001. *The St. Louis Cemeteries of the New Orleans – Twenty-sixth Edition.* Laborde Printing Co., Inc. pp. 9-19.

of this study, which will focus on exclusively on microorganisms.

It is necessary to recognize the importance of studying the effects of biodeterioration on masonry. New studies on damage caused by microorganisms are crucial to an overall understanding of stone decay and to appropriate preservation management planning. In recent years, deterioration of stone buildings and monuments by biodeterioration is a new research focus. The role that microorganisms play has not been fully understood because many other factors also impact these sites.

In order to suggest methods for reducing the harmful impacts of biodeterioration on tomb materials in the St. Louis I Cemetery, this paper analyzes activities of microorganisms, bio-deterioration mechanisms, and microorganism's nutritional requirements. I have reviewed the literature on microorganisms, conducted microscopy identification, statistical regression modeling, and spatial analysis with geographic information system (GIS). To recommend better preservation management, this paper suggests several recommendations for remedial and preventive treatments. Through discussions on the extent of the problem, available preventive and remedial

treatments, and further the status of current research, this paper aims at

establishing the need for focused scientific investigations on the subject.

3. Data Collection

Data have been collected, in order to understand the environmental conditions

and characteristics of the study site, climate, soil, and air pollution. Building on

an earlier existing survey (the 1981 Condition Survey of St. Louis I cemetery),

an individual tomb and landscape feature assessment has been executed to

document and assess historical and architectural significance and condition.

This will allow the development of a strategic plan for phased conservation

now and in the future. Existing conditions were recorded using site forms and

drawings that will be linked to the Geographic Information System (GIS) data.

All surveys have been entered into a database (Microsoft Access®) for

analysis regarding condition severity, type, and material-age-design

relationships.

Table 1. Data Sources

Data	Contents	Source
Weather	Temperature, humidity, time of wetness, sun radiation, wind, precipitation	Comparative Climatic Data for the U.S., 1999
Pollution	Gaseous SO2, NO2, O3, particulates, polluter's location and emission levels, pH level from the soils	EPA's National Emissions Trends database, Louisiana NET Air Pollution Point Sources from 1983 to 2001
Soil	Physical and chemical contents	Soil Survey of Orleans Parish, USDA, 1989
General Survey	Comprehensive site survey in the Cemetery	Historic Preservation Studio of Graduate School of Fine Art, University of Pennsylvania. March 2001

4. Environmental Geography of the Cemetery

4.1. The City Landscape

The city of New Orleans and Orleans Parish (county) are coextensive,

covering an area of 199 square miles (518 square kilometres). The boundaries

are formed by the Mississippi River and Jefferson Parish to the west and Lake

Pontchartrain to the north. Lake Pontchartrain is connected by the Rigolets

Channel to Lake Borgne on the east, and the southern boundary of New

Orleans is made up of St. Bernard Parish and, again, the Mississippi River.

The city is divided by the Mississippi, with the principal settlement on the east

bank. The west bank, known as Algiers, has grown rapidly. It is connected to

eastern New Orleans by the Greater New Orleans Bridge. The early city was located on the east bank along a sharp bend in the Mississippi, from which its popular name, "Crescent City," is derived. The modern metropolis has spread far beyond this original location. Because its saucer-shaped terrain lies as low as five feet (1.5 metres) below sea level and has an average rainfall of 57 inches (1,425 millimetres), a levee, or embankment, system and proper drainage have always been of prime importance to the city.

4.2. Climate

New Orleans has a moderate climate; the average daily temperature from October through March is 60º F (16º C), and from April through September the daily average is 77º F (25º C). Freezing weather is rare, and the temperature rises above 95º F (35º C) only about six days a year.

Table2. Climate Data of New Orleans[2]

	1	2	3	4	5	6	7	8	9	10	11	12	Ann
Mean Number of Days with Precipitation 0.01 inch or more	10	9	9	7	8	11	14	13	10	6	7	10	114
Mean Number of Days with Maximum Temperature 90 F or more	0	0	0	*	4	16	21	21	9	1	0	0	72
Mean Number of Days with Maximum Temperature 32 F or below	5	3	1	*	0	0	0	0	0	0	1	3	12
Wind Average Speed (MPH)	9.3	9.8	9.9	9.4	8.1	6.8	6.1	5.9	7.3	7.6	8.7	9.0	8.2
Wind Maximum Speed	48	43	38	40	55	49	44	42	69	40	35	46	69
Sunshine – Average Percentage of Possible	46	50	56	62	62	63	58	61	61	64	54	48	57
Snowfall – Average Total in Inches	0	0.1	T	T	T	0	0	0	0	0	T	0.1	0.2
Cloudiness - Mean Number Of Days: Clear	7	8	8	8	9	8	5	7	10	14	10	8	101
Cloudiness - Mean Number Of Days: Partly Cloudy	7	6	8	10	11	13	15	14	11	8	8	7	118
Cloudiness - Mean Number Of Days: Cloudy	17	14	15	12	11	9	12	16	10	9	12	16	146
Average Relative Humidity (%) – Morning	85	84	84	88	89	90	91	91	89	87	86	86	88
Average Relative Humidity (%) - Afternoon	67	64	62	61	61	64	67	67	66	60	63	67	64
Normal Heating Degree Days (Base 65)	0	0	0	30	178	349	450	316	162	28	0	0	1513
Normal Precipitation: Inches	5.05	6.01	4.9	4.5	4.56	5.84	6.12	6.17	5.51	3.05	4.42	5.75	61.88

4.3. Soil of the Cemetery

According to the 1989's *Soil Survey of Orleans Parish,* the study site was

classified as Urban Land. Urban Land consists of areas where more than 85

percent of the surface is covered by asphalt, concrete, buildings, or other

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[2] Congressional Information Service, Inc. 2000. Comparative Climatic Data Report for the U.S.
Through 1999.

impervious surfaces. Examples are parking lots, oil storage tank farms,

industrial parks, and shopping centers. These areas are mainly on the natural

levees along the Mississippi River. The slope is less than 1 percent. Included

in mapping are areas that are mostly miscellaneous, artificial fill material.

Urban land, however, is not assigned to interpretive groups. The soil of the

cemetery has a black clay surface layer about 6 inches thick. This soil

contains plenty of shells, which could be assumed that the land was a swamp.

5. Biodeteriogens

A biodeteriogen is an organism that is capable of causing biodeterioration. A

wide variety of biodeteriogens belonging to both the plant and the animal

kingdoms have been identified on materials (Rakesh and Anuradha, 1996).

These organisms have the potential for causing direct or indirect damage to

many kinds of materials.

Figure 2. Unidentified Microorganisms from Field Samples: Magnifications x 300

The development of specific biological species on a particular material is determined by the nature and properties of material (mineral constituents, pH, the relative percentage of various minerals, salinity, moisture content, texture etc.). It also depends on certain environmental factors (temperature, relative humidity, light conditions, atmospheric pollution levels, wind. rainfall etc.). In other words, "the response of living organisms to a potentially colonizable substrate depends on their ecological and physiological requirements (Caneva & Salvadori, 1988)."

In New Orleans, environmental factors, such as high temperature and high relative humidity levels, are favorable for the sustenance of most organisms. The presence of sunlight is essential for photosynthetic organisms and provides the necessary energy for biosynthesis.

5.1. Bacteria

Bacteria are a group of prokaryotic unicellular or colonial organisms of various shapes (spherical, rod-like or spiral). They may be motile (have cilia or flagella necessary for movent) or immotile (cilia and flagella are absent). They include both autotrophic or heterotrophic species. Due to their simple ecological and

nutritional needs, they develop easily on outdoor stone objects and

monuments, especially where the substrate exhibits a high water content.

Bacteria are so small that their presence on stone is normally recognized

microscopically and by the chemical changes that they bring about in the

material substrates. In general, bacteria prefer alkaline substrates.

5.2. Fungi

Fungi are a group of simple chemoheterotrophic organisms that are

characterized by unicellular or multicellular filamentous hyphae. They lack

chlorophyll and thus the ability to manufacture their own food by using the

energy of sunlight. Hence, they cannot live on stone, even if it is permanently

wet, unless some organic food is present. The waste products of algae and

bacteria or the dead cells of these organisms, decaying leaves, and bird

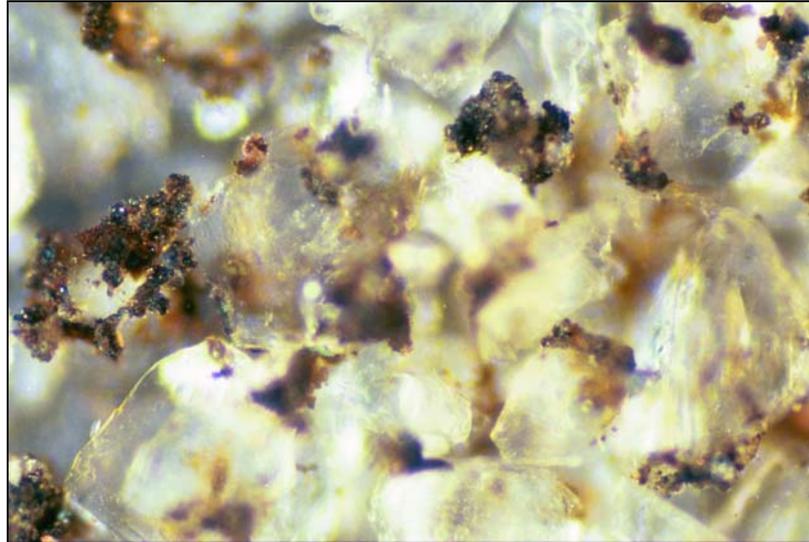droppings can provide such food (Sharma et al., 1985).

5.3. Algae

Figure3. Unidentified Algae and Lichens from Field Samples: Magnifications x 300

Algae are diverse groups of enkaryotic unicellular or multicellular

photoautotrophic organisms of various shapes (filamentous, ribbon like or

plate-like) containing pigments such as chlorophyll carotenoids and

xanthophylls. They are also able to survive heterotrophically when necessary

(Walker, 1989). Out of the eleven classified groups of algae (Bold & Wynee,

1975), the species of two major groups, viz. Chlorophytes, and

Bacillariophytes or Diatoms, have been isolated from stone monuments. The

most important conditions for the establishment of algae on material are the

presence of dampness, warmth, light, and inorganic nutrients particularly

calcium and magnesium. Many algae show a marked sensitivity to the pH of

the substrate preferring acidic substrates but for some, this value is not growth

limiting.

5.4. Lichens

Lichens are a large group
of composite heterotrophic
organisms formed by the
symbiotic association of
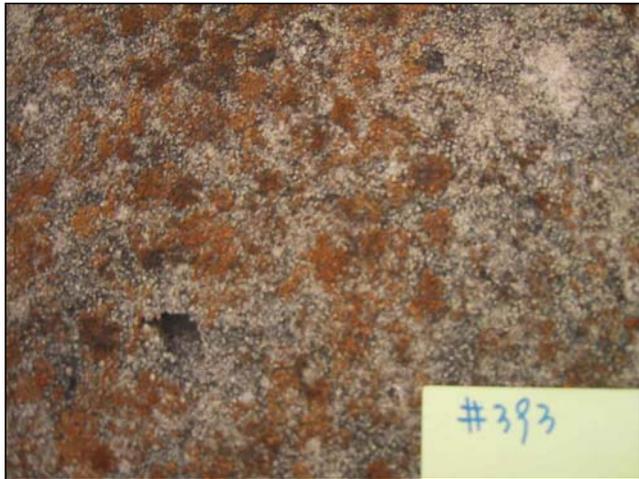cholorphyta or
cyanobacteria and a

Figure 4. Lichens in Tomb Number 393

fungus. Lichens occur in a
wide range of habitats including those normally hostile to other life forms due

to their resistance to dessication and extreme temperature and these

efficiency in accumulating nutrients (Martin, 1985). Together with

cyanobacteria they play an important role as pioneer organisms in colonizing

materials.
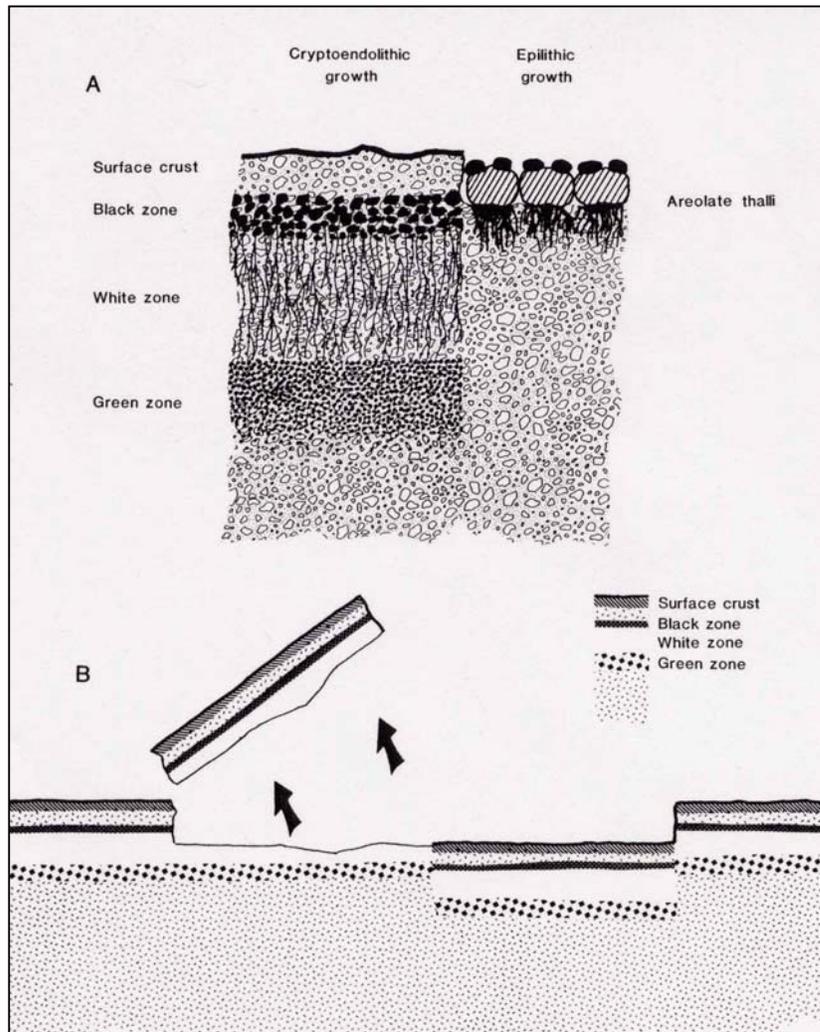
Figure 5. Diagrams of lichen in sandstone. (A) Structure of cryptoendolithic growth and relation to epilithic, areolate growth form. The areolate thalli appear in protected areas after loss of the surface crust by biogenous weathering. (B) Exfoliative rock weathering, showing (from left to right) initial level of lichen growth; exfoliation of surface crust due to biological activity; site of earlier exfoliation with the lichen growing deeper into the rock substrate, and formation of new surface crust; and portion of old surface crust at initial level of lichen growth.[3]

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[3] E. Imre Friedmann. 1982. Endolithic Microorganisms in the Antarctic Cold Desert. Science, Vol. 215, 26 February 1982. p. 1047.
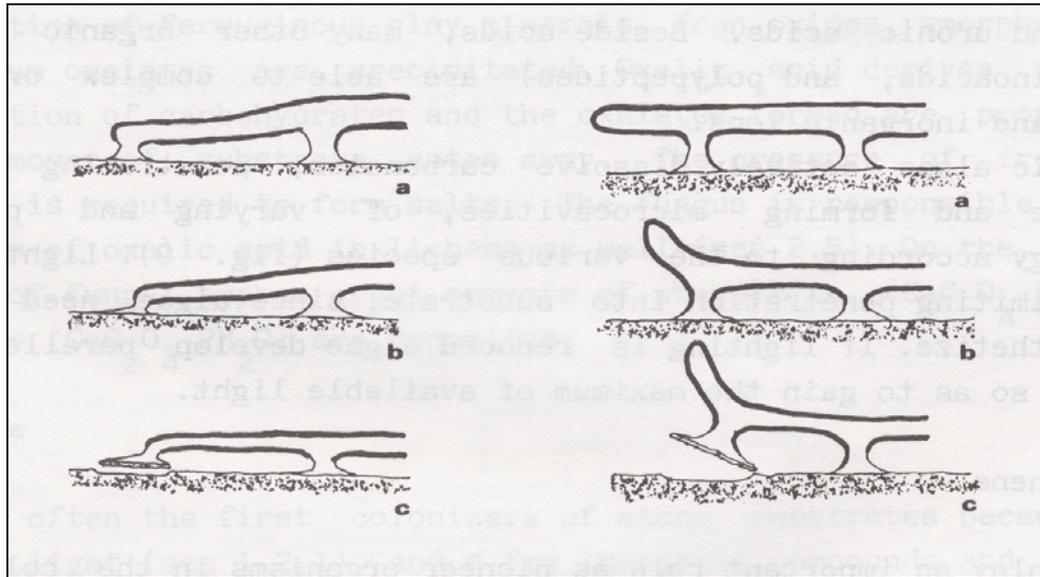
Figure 6. Example of Mechanical Action of a Lichen Thallus: (a) moist conditions, (b) and (c) stages of drying[4]

6. Biodeterioration Mechanisms

The most important factors determining biological growth are:

- Primary energetical input (light)

- Secondary energetical input (nutritive factors)

- Climate

- Environmental pollution.[5]

In a humid temperature environment, almost all tomb materials sustain a

variety of biological growths due to particularly favorable environmental

conditions (high relative humidity, high temperature, and heavy rainfall).

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[4] Lorenzo Lazzarini and Richard Pieper Editors. 1988. *The Deterioration and Conservation of Stone*. p. 198.
[5] Lorenzo Lazzarini. *The Deterioration and Conservation of Stone*. p. 185.

However, much of the primary research in the past on the mechanisms of

biodeterioration, has been conducted outside New Orleans.

The deterioration of tomb materials in the study site may be classified broadly

into three categories: biophysical, biochemical, and aesthetic deterioration

(Dennis, et al., 1986). Depending on the biodeteriogens, the nature of material,

and environmental conditions, these processes may occur separately or
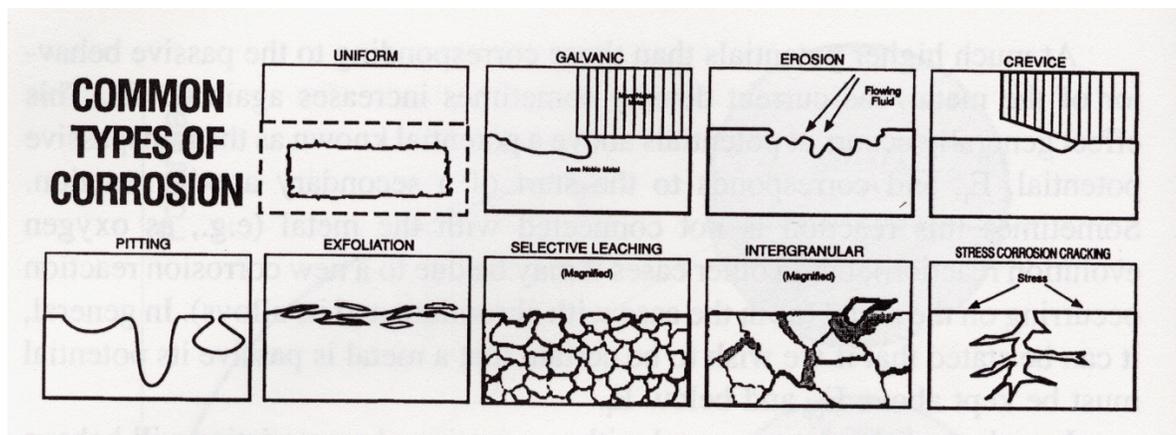
simultaneously.

Figure 7. Scheme of the Different Types of Corrosion[6]

Corrosion manifests itself in several characteristics forms. However, they can

be divided into uniform attack and localized attack. Uniform attack occurs

evenly over the whole material surface, whereas localized corrosion may take

the form of pitting or crevice corrosion, corrosion fatigue, impingement, and

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[6] Hector A. Videla. 1996. *Manual of Biocorrosion*. p. 90.

fretting corrosion. The size of the microorganisms and their wide ubiquity in

nature allows them to grow and act on small areas at the material surface.

Thus, biocorrosion usually occurs as some type of localized attack (mainly

pitting and crevice corrosion), and it is therefore worth considering the various

forms of corrosion in some detail. Microbial biofilms facilitate pitting through

different mechanisms such as the formation of oxygen concentration cells due

to a patchy distribution of the biofilm or by increasing the rate of the cathodic

oxygen reduction reaction.[7]

6.1. Biophysical Deterioration

Biophysical deterioration

of tomb material may

occur due to pressure

exerted on the

surrounding substrate

material during the

Figure8. Biodeterioration in Tomb Number 484

growth or movement of

an organism or its parts. Attachment devices, such as polymeric sheaths of

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[7] Videla. *Manual of Biocorrosion*. p. 89.

prokaryotes and hyphae, rhizines, and extensive root systems of eukaryotes,

penetrate deeply into the material through preexisting cracks or crevices

causing stresses leading to physical damage of surrounding tomb materials.

Fragmentation may also occur due to periodic loosening of attachment

devices due to repeated wet and dry cycles. Once the tomb material is

damaged as a result of biophysical processes, it becomes more susceptible to

other deterioration factors, particularly biochemical actions.

6.2. Biochemical Deterioration

Biochemical deterioration that is result of assimilatory processes, where the

organism uses the substrate as a source of nutrition, is probably more easily

understood than dissimilatory processes, where the organism produces a

variety of metabolites that react chemically with the substrate.

The process of biochemical deterioration of tomb material

Figure 9. Biodeterioration in Tomb Number 2007

due to corrosive metabolites occurs because of the formation of inorganic

acids and organic acids. These acids decompose material minerals through

the production of salts and chelates. Subsequent dissolution and washing

away of these salts and chelates may occur. Insoluble salts and chelates may

concentrate or precipitate on the tomb surface as crusts. An increase in the

volume of soluble salts or chelates may also cause stresses in the pores

resulting in the formation of cracks.

6.3. Aesthetic Deterioration

The aesthetic or visual effects of biodeterioration of tomb material are conceptually subjective but nonetheless important. The growth of biological populations on stone

Figure 10. Biodeterioration in Tomb Number 452

surfaces alters their appearance by causing chromatic alterations and the

development of biological algal and lichen patinas. Today, it is usually

preferable to eliminate biological growth for conservation reasons and to

create an impression that the tombs are well cared of. Microorganisms found growing on an otherwise undamaged tomb surface, utilizing surface dirt and detritus, may not initially cause any noticeable change in the chemical composition of the tomb material.

7. Regression Analysis

This paper's hypothesis for correlation between the growth of microorganisms and independent variables is that micro-growth can be affected by shadow, pavement, distance to the nearest drain, perpetual care, tomb material, and age (sample size – 645 tombs). The dependent variable of the regression is integrated microorganisms' growth based on the general survey checking existing micro-growth in the roof, primary structure, and at the base of each tomb. If there is no micro-growth in a tomb, the record value is 0. If there are micro-growths in three different parts, the record is 3. The result of the regression analysis shows the hypothesis cannot effectively explain the correlation between micro-growth and a range of factors.

Correlation and regression analysis are related in the sense that both deal with relationships among variables. The correlation coefficient is a measure of

linear association between two variables. Values of the correlation coefficient

are always between   -1 and +1.   A correlation coefficient of +1 indicates that

two variables are perfectly related in a positive linear sense, a correlation

coefficient of   -1 indicates that two variables are perfectly related in a

negative linear sense, and a correlation coefficient of 0 indicates that there is

no linear relationship between the two variables.

Neither regression nor correlation analyses can be interpreted as establishing

cause-and-effect relationships. They can indicate only how or to what extent

variables are associated with each other. The correlation coefficient measures

only the degree of linear association between two variables. Any conclusions

about a cause-and-effect relationship must be based on the judgment of the

analyst.

It seems that there is no apparent pattern between micro-growth and

perpetual care, tomb age, tomb heights, distance to drain, total tomb area, and

also between mean values of sunshine. However, the existence of base,

pavement, and invasive vegetation are significant ($p<0.05$).

Call: lm(formula = GROWTH.BIO ~ BASEOX + PERPCARE + PAVEORNOT + Age + HEIGHT2 +
Z.C.DIST + AREA + MEAN, data = yep, na.action = na.exclude)
Residuals:
     Min   1Q   Median   3Q   Max
 -1.981 -1.138 0.02958 1.16 2.34

Coefficients: Value Std. Error t value Pr(>|t|)
        (Intercept)   1.2487   0.2931   4.2607   0.0000
        BASEOX   0.4075   0.1491   2.7323   0.0066
        PERPCARE -0.6651   0.6973   -0.9538   0.3408
 PAVEORNOT -0.4949   0.1245   -3.9764   0.0001
              Age   0.0017   0.0014   1.2550   0.2103
        HEIGHT2 -0.0001   0.0015   -0.0749   0.9403
        Z.C.DIST -0.0040   0.0034   -1.1851   0.2367
             AREA -0.0010   0.0016   -0.6471   0.5179
             MEAN   0.0013   0.0010   1.2204   0.2231

Residual standard error: 1.196 on 374 degrees of freedom
Multiple R-Squared: 0.06948
F-statistic: 3.491 on 8 and 374 degrees of freedom, the p-value is 0.0006667
258 observations deleted due to missing values

Furthermore, there are no special correlations with tomb type and roof type.

However, correlations between micro-growth and invasive vegetation as well

as between surface material finished by stucco and lime-wash show a strongly

negative relation. The implication of the regression allows us to know the basic

direction for subsequent research and management planning. Additionally,

preservation management needs to be prioritized by tombs, which have base,

no pavement, invasive vegetation, and surfaces finished by lime-wash and

stucco.

Call: lm(formula = GROWTH.BIO ~ BASEOX + PAVEORNOT + INVAS.GRAS + INVAS.HERB +
INVAS.SHRU + INVAS.TREE + INVAS.VINE, data = yep, na.action = na.exclude)
Residuals:
     Min   1Q   Median   3Q   Max
 -2.057 -0.6594 -0.05703 0.943 2.341

Coefficients: Value Std. Error t value Pr(>|t|)
(Intercept)   0.5639   0.1095   5.1509   0.0000
       BASEOX   0.3252   0.0953   3.4131   **0.0007**
   PAVEORNOT -0.2297   0.0880   -2.6117   **0.0092**
 INVAS.GRAS   0.4080   0.1055   3.8685   **0.0001**
 INVAS.HERB   0.7599   0.0961   7.9050   **0.0000**
 INVAS.SHRU   0.8830   0.3188   2.7698   **0.0058**
 INVAS.TREE   0.8712   0.6309   1.3809   0.1678
 INVAS.VINE   0.2451   0.2668   0.9187   0.3586

Residual standard error: 1.079 on 633 degrees of freedom
Multiple R-Squared: 0.19
F-statistic: 21.21 on 7 and 633 degrees of freedom, the p-value is 0

Call: lm(formula = GROWTH.BIO ~ BASEOX + PAVEORNOT + SURF.STUCC + SURF.MOD +
SURF.LIME + SURF.CEMEN +
        SURF.OTHER, data = yep, na.action = na.exclude)
Residuals:
    Min   1Q   Median   3Q   Max
 -1.939 -0.8153 0.06146 1.061 2.712

Coefficients:
             Value Std. Error t value Pr(>|t|)
(Intercept)   0.7384   0.1155   6.3907   0.0000
       BASEOX   0.3652   0.0995   3.6703   0.0003
   PAVEORNOT -0.2882   0.0907   -3.1769   0.0016
 SURF.STUCC   0.4496   0.1092   4.1159   **0.0000**
   SURF.MOD -0.0301   0.1105   -0.2727   0.7851
   SURF.LIME   0.3854   0.1039   3.7076   **0.0002**
 SURF.CEMEN -0.1319   0.1588   -0.8307   0.4065
 SURF.OTHER   0.1278   0.2321   0.5505   0.5822

Residual standard error: 1.112 on 633 degrees of freedom
Multiple R-Squared: 0.1407
F-statistic: 14.81 on 7 and 633 degrees of freedom, the p-value is 0

8. Spatial Analysis

The results of many statistical analyses on geographic data may be invalid if

spatial dependence is ignored. Space itself often has important explanatory

value in geographic models. By removing space, we end up with weaker

predictors and risk misspecification if, indeed, space is relevant to our model.

With geographic data we expect to find stronger relationships among nearby

variables than among those that are spatially distant.

The *ArcView 3.2*, a computer software of geographic information systems (GIS), helps discover and better understand spatial relationships in the data from the cemetery, by viewing and querying the data to create an integrated custom application. New types of analysis are possible using the Spatial Analyst because it can be used to model raster data, in addition to the vector data *ArcView 3.2* already supports.

For instance, GIS provides a mean to identify which drain is nearest to each tomb. The user selects an Input theme containing the features of interest, either a single or multiple comparison themes containing features they want to compare. The special extension for ArcView 3.2, *Nearest Features v. 3.4*, then steps through each tomb in the input theme and finds which drain, out of all the comparison themes, is closet to it. The extension then creates a result table containing various user-selected fields such as distance and bearing between each tomb and the nearest drain (Feature 10).
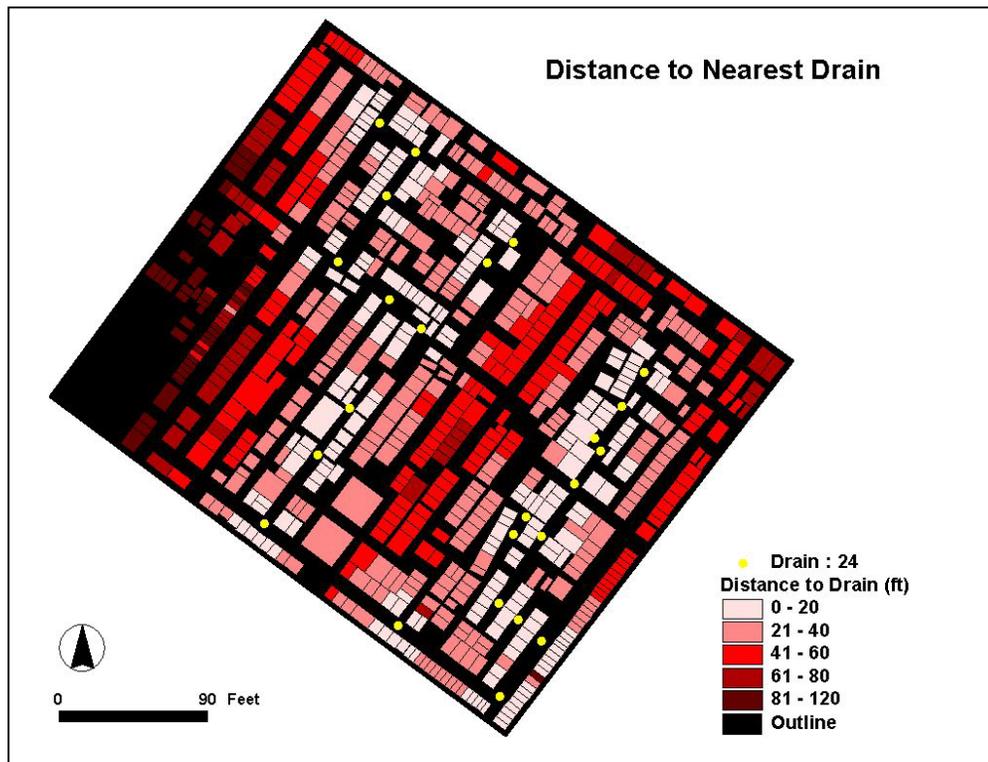
Figure 11. Distance from each Tomb to the Nearest Drain

In the study site, more than sixty-four percent (402 of 645 tombs) of tombs
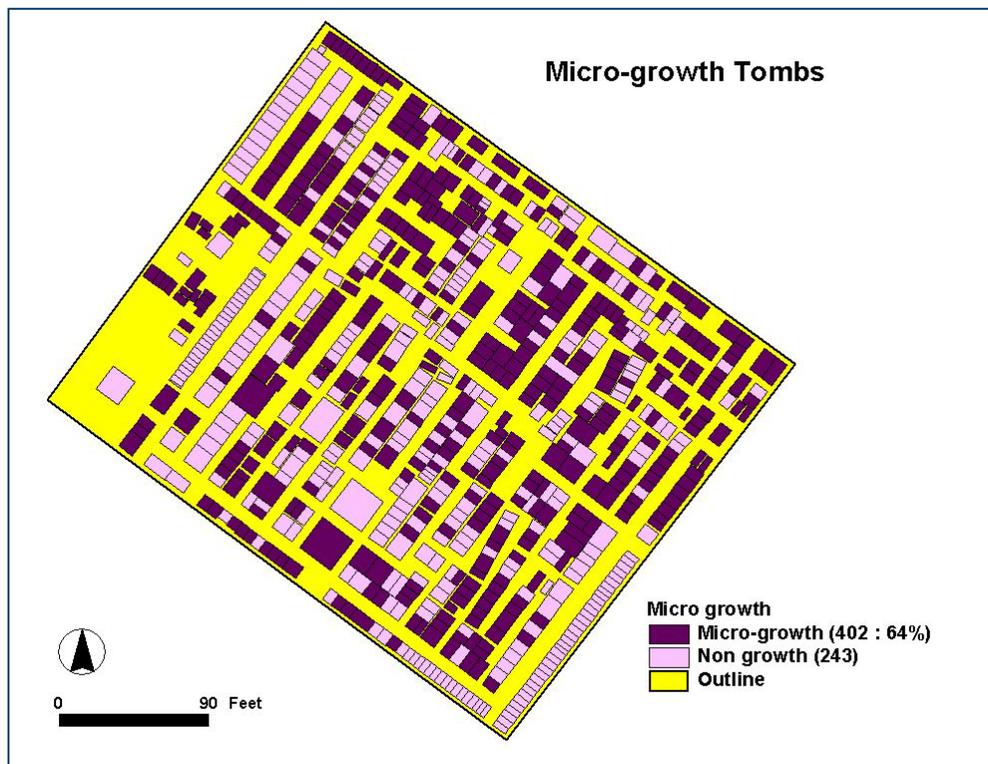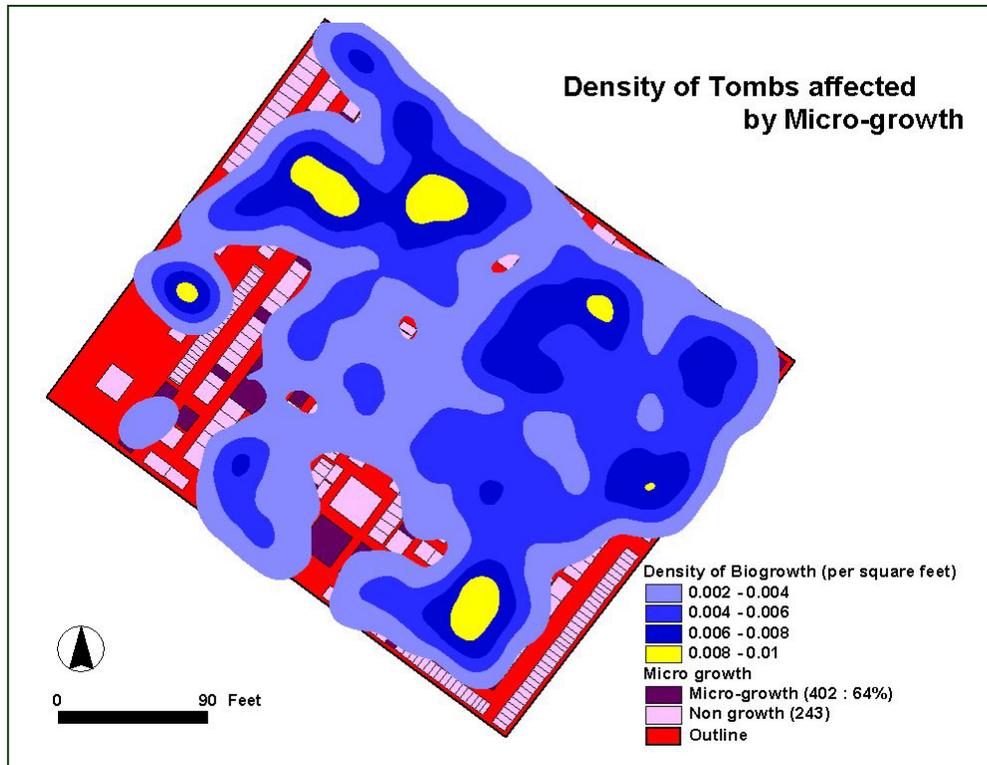
have been affected by microorganisms.

Figure 12. Micro-growth Tombs

Figure 13. Density of Micro-growth Tombs

The density map of tombs affected by micro-growth gives a general concept of

where the problem areas are and where the micro-growth has occurred.

Moreover, spatial analysis points out that brick and marble employed in tomb

materials have a significant relationship with micro-growth in the map below.
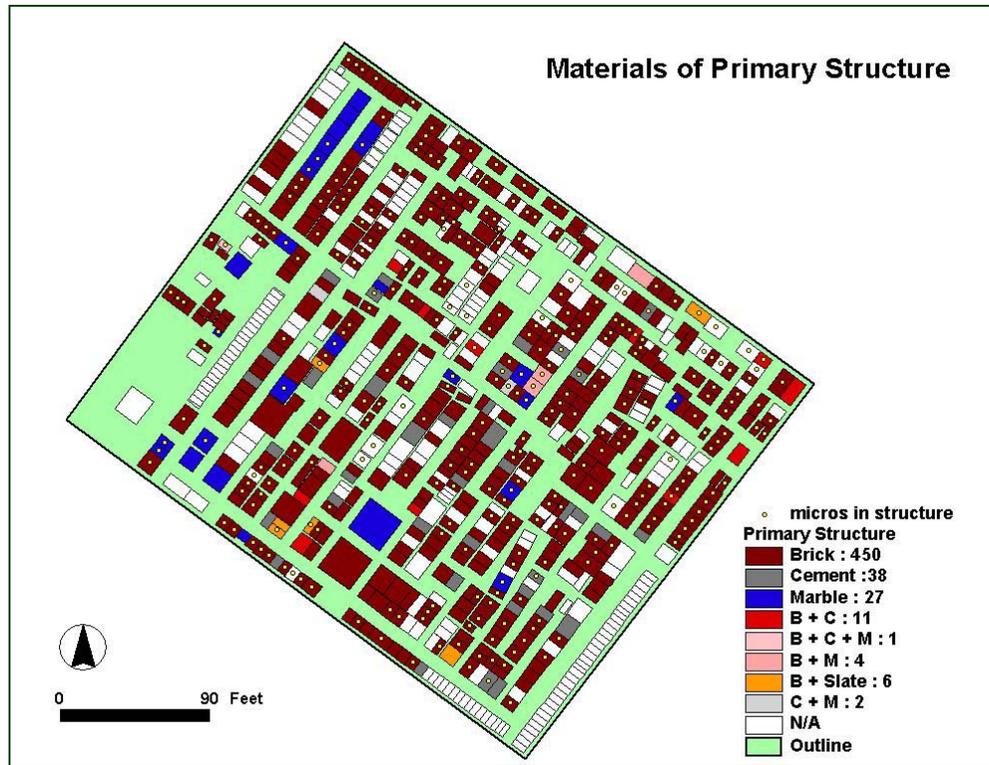
Figure14. Materials of Primary Tomb Structure

In the map above, 276 (61.33%) from 450 tombs built of bricks and 17

(62.96%) from 27 tombs built of marbles have much higher rate of micro-

growth compared to 7 from 38 tombs built of cement (18%). In the two maps

below, tombs, which have a base in their structures, are more sensitive to

microorganisms. The data show that unpaved tombs, which were build on soil,

vegetation, grass, and others are much more vulnerable that tombs paved by

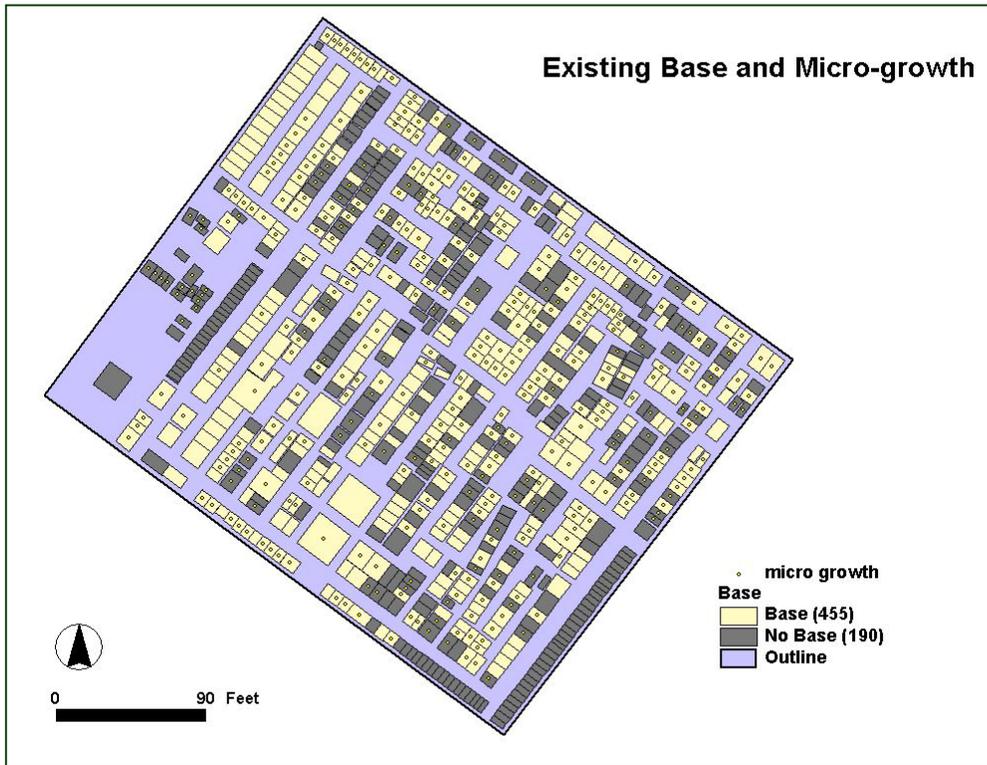shell, stone, brick, asphalt, and concrete.
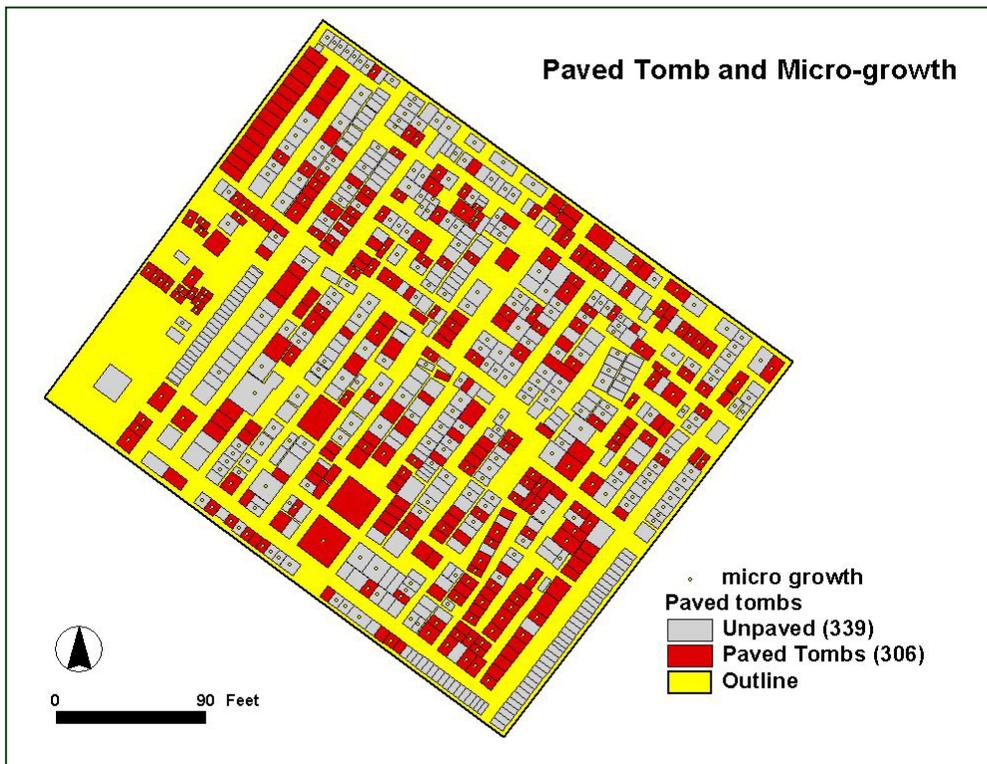
Figure 15. Existing Base and Micro-growth

Figure 16. Paved Tomb and Micro-growth

Based on the regression and spatial analysis, it is necessary to generate a

comprehensive map for an appropriate management plan. The map needs to

contain each value of important variable that affects micro-growth. The strong

correlation variables from the regression and spatial analysis are invasive

vegetation, brick and marble of tomb material, existing base, and pavement.

To do so, the values in correlation maps have to be combined with a spatially

joined map applied by Map Calculator in *ArcView* with the same weight for

each map. After combining every value of significant variables into a new map,

each tomb is assigned the new value indicating sensitivity value to micro-
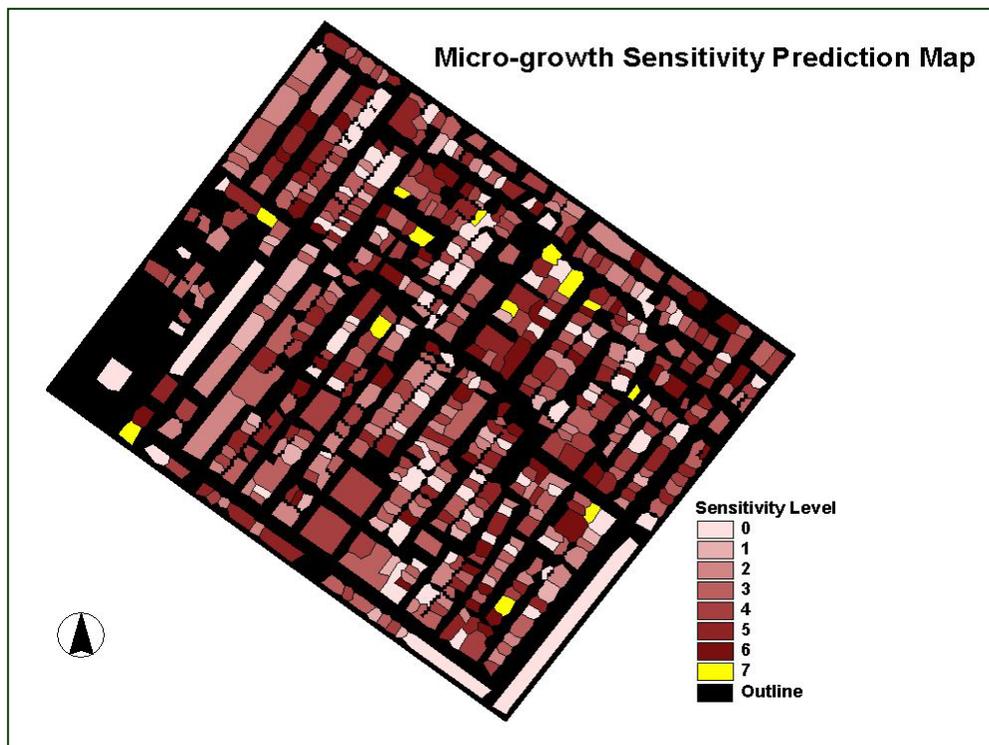
growth.

Figure 17. Micro-growth Sensitivity Prediction Map

This sensitivity map helps better to predict and prioritize future preservation management plan. The yellow spots in the map could be the most vulnerable tombs, which might need to be treated immediately. This map will be tested by future surveys and research in order to make a more accurate prediction map for management.

9. Preventive and Remedial Methods

9.1. Criteria and Considerations

It is extremely important to remember that even the most well-intentioned preservation effort can be very harmful if incorrect techniques and materials are employed. As much irreparable damage has occurred in the name of repair as through years of neglect. There are many practical and philosophical factors that may influence the selection of a treatment for a landscape. These include the relative historic value of the property, the level of historic documentation, existing physical conditions, historic significance and integrity, historic and proposed use (e.g. educational, interpretive, passive, active public, institutional or private), long-and short-term objectives, operational and code requirements (e.g. accessibility, fire, security) and costs for anticipated capital

improvement, staffing and maintenance. Based on these factors, there are

criteria in order to choose the best treatment and management plans including

integrative, sustainable, safe, and cost effective approachs.

Integrative Approach

The treatment and management of a cultural resource should be considered

in concert with the management of the historic property as a whole. For all

treatments, the cemetery's existing conditions and its ability to convey historic

significance should be carefully considered, and its historic integrity should not

altered nor its feature lost. When repairing or replacing a feature, every effort

should be made to achieve visual and physical compatibility. Historic materials

should be matched in design, scale, color and texture.

A Sustainable and Safe Approach

The fundamental goal of historic preservation is to preserve the value of

historic resources as long as possible for the next generation, including the

ambient environment such as wildlife. The significance of these natural

resources may be based on their inherent ecological values. Many natural

resources such as wetlands or rare species fall under local, state, and federal

regulations, which must be considered along with environmental concerns. Moreover, it is necessary to consider the impact that meeting current health and safety codes (e.g., public health, life safety, fire safety, electrical, seismic, structural, and building codes) will have on character-defining features.

The National Park Service favors an integrated pest management program (IPM) approach to pest management. This program maximizes the use of natural controls, when possible, while minimizing chemical treatments. Where chemicals are deemed necessary, it requires that chemicals may be used: (a) only after sufficient monitoring has shown that an injurious level of damage can be expected, if chemicals are not applied and, (b) when the least toxic chemicals are used. (Prior approval for use of chemical preservatives and pesticides may be necessary in organizations that have designated integrated pest management coordinators).

9.2. Preventive Methods

Design Solutions

Considering the ethics of conservation of monuments, it is not possible to alter or change the general design of a monument to avoid water accumulation sties that provide favorably moist environments for biological growth. There are, however, certain preventive measures such as repair and mounting new spillways, damp proofing etc., that help to control microorganism growth on tomb material. A long term inhibiting effect on biological growth on material may be obtained by installing narrow flashing strips of thin-gauge copper.

Dry Cleaning of Dirt and Dust

Sources of nutrition for the organisms such as dust, deposits of various kinds, pigeon droppings, and unsuitable restoration materials, can be removed. Periodic cleaning as part of a routine maintenance is the principal and sometimes only way to prevent biological attack in outdoor environments. It has been found very effective in controlling the initial establishment of mosses, lichens, fungi, algae and higher plants by discouraging the accumulation of spores and seeds of plants and their subsequent germination (Kumar, 1989)

9.3. Remedial Methods

Cleaning of Surfaces

Microorganisms associated with a visual disfigurement of monuments are manually removed by dry or wet scrubbing or brushing and washing with water. In most of the cases, mechanical removal may only slow the deterioration process. A   mixture of quanternary ammonium compounds (Hymine 3500), bromauracil compounds (Hyvar XL) and, a mixture of bicarbonates, carbonxymethylcellulose and EDTA (AC322) at a concentration of 1-2% has been reportedly used for chemical cleaning of Borobudur temple in Indonesia for eradication of biological growth (Sadrin, 1988).

Aqueous ammonia (2-5%) was found to be very effective in cleaning the stone monuments in India covered with mosses, lichens, algae and, fungi, without any side effects (Kumar, 1989). Application of aqueous solutions of benzalkonium chloride (20%), sodium hypochlorite (13%), or formaldehyde (5%), through cotton strips for about 16 hours followed by scrubbing with a brush and water has effectively killed the lichens on stone (Nishiura &

Ebisawa, 1992)

Depending on the types of material used in the cemetery, cleaning may require special techniques, as well as a great deal of skill and patience. For instance, both dry and wet cleaning methods may be too aggressive on soft and friable stone. Periodic cleaning, although effective in controlling the microflora, may be expensive and labor intensive.

Biocidal Treatments

Biocidal refer collectively to fugicides, algaecides and bactericides. They are frequently used to eliminate biological growth on tomb materials. There are numerous studies on the effect of biocides on the activity and growth of microorganisms. Most available biocides are chosen according to their activity, persistence, human risk, and potentially damaging effects on material. Biocides may serve to inhibit metabolic activity while present or cause irreparable damage to the cells of microorganisms, which results in their death.

A good residual biocide that would deposit a long-term reservoir of the appropriate chemical in and on the stone substrate has not been identified.

Research is required to identify such systems within the established criteria of

biocide selection for combating the biodeterioration of stone monuments and

sculpture. No biocide has been found that is uniformly effective on all

organisms and on all stone substrates. Little effort has been made to

investigate the merits of traditional techniques, such as using natural products

for their biocidal properties. In tropical environments this may prove to be a

more viable and cost-effective solution than the use of expensive chemicals

and synthetic products that may be toxic to humans and hazardous to the

environment. (NCPTT Notes, Jan 1998)

Increasing legislative requirements and the necessity for greater

environmental acceptability have contributed to recent restrictions in the use of

some traditional biocides and the development of new compounds or carefully

selected blends of existing chemicals. The classical criteria governing the

selection of an effective biocide have been generally summarized as follows:

- Proven efficacy against a broad spectrum of microorganisms

- Ability to penetrate and disperse microbial slime

- Chemical and physical compatibility with products (e.g., corrosion

    inhibitors) and environment (e.g., pH)

- Safety and ease of use and storage

- Appropriate biodegradability

- Cost effectiveness

Table 3. Some Biocides in Technical Use[8]

Chlorine	**Pros**: broad spectrum of activity, residual effect, advanced technology available, can be generated onsite, active in low concentrations, destroys biofilm matrix and supports detachment
	Cons: toxic byproducts, degradation of recalcitrant compounds to biodegradable products, development of resistance corrosiveness, reacts with extracellular polymer substances in biofilms, low penetration characteristic in biofilms, extremely difficult to remove from surface
Hypochlorine	**Pros**: cheap, effective, destabilizes and detaches the biofilm matrix, easy to handle, used for biofilm thickness control
	Cons: poor stability, oxidizing, rapid aftergrowth observed, toxic byproducts, corrosive, does not control initial adhesion
ClO2	**Pros**: can be generated onsite, activity less pH dependent, less sensitivity against hydrocarbons, effective in low concentrations
	Cons: explosive gas, safety problems, toxic byproducts
Chloramine	**Pros**: good penetration of biofilms, reacts specifically with microorganisms, less toxic byproducts, higher effect because of lower reactivity with water ingredients
	Cons: less effective than chlorine to suspended bacteria, resistance observed
Bromine	**Pros**: very effective against broad microbial spectrum
	Cons: toxic byproducts, development of resistance
Ozone	**Pros**: similar effectiveness as chlorine, decomposes to oxygen, no residues, weakness biofilm matrix
	Cons: oxidizes bromide in seawater, reacts with organic and can form epoxides, degrades humic acids and makes them bioavailable, corrosive, short half-life time, sensitive to water ingredients
H2O2	**Pros**: decomposes to water and oxygen, relatively non-toxic, can easily be generated *in situ*, weakens biofilm matrix, and supports detachment and removal
	Cons: high concentrations (>3%) necessity, frequent resistance, corrosive
Peracetic Acid	**Pros**: very effective in small concentrations, broad spectrum, kills spores, decomposes to acetic acid and water, no toxic byproducts known, penetrates biofilm
	Cons: corrosive, not very stable, increase DOC
Formaldehyde	**Pros**: low costs, broad antimicrobial spectrum, stability, easy application
	Cons: resistance in some organisms, toxicity, suspected to promote cancer, reacts with protein fixing biofilms on surface, legal restrictions
Glutaraldehyde	**Pros**: effective in low concentrations, cheap, non-oxidizing, non-corrosive
	Cons: does not penetrate biofilms well, degrades to formic acid, raises DOC
Isothiazolones	**Pros**: effective at low concentrations, broad antibiotic spectrum
	Cons: problems with compatibility with other water ingredients, inactivation by primary amines
Quaternary ammonia compounds	**Pros**: effective at low concentrations, surface activity supports biofilm detachment, relatively non-toxic, adsorbs to surfaces and prevent biofilm growth
	Cons: inactivation by low pH, Ca+, Mg+, development of resistance

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[8] Videla. *Manual of Biocorrosion*. pp. 232-233.

Water Repellent Treatments

Research into the effectiveness of waterproofers and water repellents for masonry has been driven by growing concerns about rain penetration. Most masonry walls can be expected to leak in conditions of sustained wind-driven rain. Colorless surface treatments for coating masonry walls are increasingly being considered as a readily available and inexpensive preventative or remedial measures. The treatments, which are either sprayed or brushed on, are claimed to protect masonry from water and so reduce the problems associated with rain penetration. If these claims are justified, colorless surface treatments could also provide a means of improving the durability of masonry by reducing its moisture content. This would lead to drier walls with less risk of material being damaged by the chemical interactions between sulfates and cement mortar, frost, and wall tie corrosion.

The desirable properties of any water repellent are good penetration into the brickwork, a high degree of water repellency, breathability, and stability in alkaline materials. To achieve these properties, the characteristics of water repellents require consideration. Although there are many proprietary brands of water repellent treatments available, actual water repelling substances are

relatively small in number and are generally provided by a limited number of companies. The two most common types of water repellents are metal stearates (such as polyoxoaluminium stearates) and organic silicones (Alastair W, 1993).

10. Conclusion

The growth of microorganisms may result in undesirable changes in the properties of the St. Louis Cemetery, sometimes leading their destruction. The microorganisms involved include bacteria, fungi, algae and lichens. In the cemetery, 402 of 645 tombs (64%) have been affected by microorganisms. The impacts of micro-growth on the cemetery are greater on tombs which were built with marble and brick and have base as well as pavement.

In order to develop appropriate management planning for the cemetery, further research in several areas is necessary including:

- A specific micro-growth survey and more extensive sampling through the cemetery

- A study of cause-and-effect relation based on the result of regression especially existing base, pavement for tomb, invasive vegetation

- Microhabitat studies and identification (culture, simulation, standardized test)

- The addition of humidity and light energy data into analysis

- A dose and response analysis for different types of material, especially brick and marble

Further research is needed on biocidal treatment on different materials and for different microorganisms. The use of biocidal solutions may introduce chemicals into the substance that result in formation of soluble salts and initiate salt crystallization damage. Despite the extensive work on the role of bacteria in tomb material, relatively little research has been conducted on antibacterial treatments. And there is a rising concern about using biocides, how they may affect the surrounding environment and human health.

It is time to adapt more environmentally sound treatments for preservation planning. Before employing biocides, we need to carefully study preventive methods, which include all activities aimed at inhibiting biological attack of tomb material. The next recommendation is that microorganisms be manually removed by dry or wet scrubbing or brushing and washing with water. Periodic

cleaning, although, effective in controlling the micro-growth, may be expensive

and labor intensive. In the St. Louis Cemetery, however, there are thirty tombs,

which have been treated with perpetual care. Unfortunately, twenty-one tombs

(70%) of thirty tombs are affected by micro-growth. This fact implies that the

past perpetual care has not deliberately considered micro-growth problems.

Preventive care for micro-growth should be included in the future perpetual

care.

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