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THE BIODETERIORATION OF MATERIALS AS A PART OF HYLOBIOLOGY

by

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1. Introduction

The newly coined word "hylobiology" is meant to denote the special branch of biology dealing with the biotic phenomena associated with materials (Greek ὕλη = matter, material). According to Webster's

* This study is based on a first rough draft in Dutch, finished in 1959. In the meantime I had the opportunity to discuss the views presented here with many of my colleagues. I owe much to these discussions which clarified a number of points. In this respect I wish to mention gratefully the comments from the "Group of Experts on the Biological Deterioration of Materials of the Committee for Scientific Research of the Organization of Economic Co-operation and Development" to which I presented parts of the present publication. The term "biodeteriogen" was suggested to me by Dr. H. O. W. EGGINS.

Especially I wish to thank my wife, Mrs. Dr. E. H. HUECK- VAN DER PLAS, technical secretary to the above committee, whose constant interest and aid in the present study was of much importance.

dictionary, a material is "the substance or matter of which any thing is made or to be made". Apparently it is human use, or intended use, which turns "matter" into "material". Strictly speaking, therefore, "materials" is an ambiguous term depending on time and circumstances for its meaning. In practice, however, hardly ever confusion will arise about such items as iron, wood and plastics, in that they are to be considered as materials. Hylobiology may thus be understood to deal with the relationship between the living organisms and the essentially non-living materials. It is especially the influence of organisms on materials that calls for separate consideration. The reverse, viz. the influence of materials on organisms, exists also, but we may very well consider this as being part of ecology.

It, furthermore, requires another methodological approach.

On practical grounds, therefore, the study of the influences of organisms on materials will be taken to constitute a separate entity. Some aspects of this relationship will be the subject of the present study.

2. The Nature of Hylobiology

As stated above, it is taken that materials have only a meaning because of their use by man. A consideration of the influence of organisms on materials, therefore, will have an anthropocentric basis. It thus appears permissible to distinguish these influences into such that are favourable to man, and such that are unfavourable. The results of the influence on the materials will be that some or other change in properties of the materials will be noted. If this change is desirable from the point of view of man, the influence is a favourable one, and if it is undesirable, it may be considered unfavourable. It will be clear that, through this distinction, two large fields of study are indicated.

The desirable changes in materials brought about by organisms are the subject of technical (micro-) biology, which may point at considerable achievements in the fermentation industry and sewage plants. Undesirable changes lead us to the study of the biodeterioration of materials.

Whereas technical microbiology has received already very much attention, and can be considered a well-established part of science, its counterpart, the biodeterioration of materials, is still in its infancy, though many empirical data are available (cf. G. H. Greathouse and C. L. Wessel, 1954). Great gaps, however, exist in fundamental knowledge such as taxonomy of deterioration organisms, ecology and chemistry of the breakdown process. Generally, deterioration phenomena are considered from the point of view of the materials-technologist, whose inclination will not easily give rise to a systematization of the phenomena as a part of biological science. In the following it will, therefore, be attempted to systematize the various aspects of the biodeterioration of materials from the point of view of a biologist.

As a starting point, the following definition of biodeterioration of materials will be adopted which is based on the considerations given above. We understand by the biodeterioration of materials: "any undesirable change in the properties of a material caused by the vital activities of organisms". This definition delimitates biodeterioration from its neighbouring fields of study, viz. "Corrosion" and "Wear" of materials, which comprise the undesirable changes brought about respectively by chemical agents and mechanical (physical) influences.

At a first glance, the biodeterioration of materials has much in common in its methodology with phytopathology and more remotely with human pathology, especially that part of it dealing with infectious diseases. One wonders, whether this is a mere superficial analogy or whether there exists a real relationship between these branches of biology. The basic question here appears to be whether the phenomena we find in biodeterioration have something in common with diseases of animals or plants.

Many descriptions of the notion "disease" have been furthered (cf. A. C. Drogendyk, 1961), depending on which specific aspects of disease are held to be important. For the present purpose, the following functional definition may be appropriate: "a disease is a process developing from the interaction of a noxious agent and the reaction of the organisms to this, leading to a disturbance of the harmonious whole of vital functions to such a degree that they surpass the normal variations in these vital functions". This notion of disease contains some elements which lend themselves for a comparison of biodeterioration and pathology. For the sake of this comparison it is taken that we will denote with "morphology" both anatomy of organisms and the structure of materials. The result is tabulated in Table 1.

It appears from this table that pathology and biodeterioration have undoubtedly two features in common, viz. (a) deviations of normalcy which are the result of (b) a (noxious) process. Admittedly, the phenomena are much simpler with materials because of their less complicated structure in comparison with organisms. The situation is different in relation to the reaction of organisms, which is held to be an essential part of the notion of disease.

Table 1. Comparison of aspects of biodeterioration and pathology

Aspects	Pathology			Biodeterioration of Materials
	Human-	Animal-	Plant-	
impairment of normal function of subject				
a) morphological	present	present	present	present
b) physiological	present	present	present	absent
c) psychological	present	behavioural changes may be present	absent	absent
phenomena are part of a process	yes	yes	yes	yes
reaction of subject to noxious agent	active	active	active	passive
"feed back mechanisms" in the process	many	many	present	generally absent but may be built in

One may quote E. Gäumann (1946) in support of this, who, in discussing plant diseases, states (page 11) "Jedenfalls liegt aber ein Wesenszug der Erkrankung im Eintreten einer augenfälligen manifesten Reaktion des betroffenen Organismus, bleibt diese aus, so wird man eher von einer Schädigung sprechen". Certainly we will not find that materials develop a fever, grow tumors or will be able to heal wounds as organisms do. The background is that organisms do contain many mechanisms which counteract the noxious agent, and contribute to the self-stabilization of the organism. With gross simplification this is denoted in the table by the presence or absence of feed-back mechanisms. An organism is, cybernetically speaking, a system which, as a whole, is open, but which contains many sub-systems that are virtually closed (A. C. Drogendyk, 1961).

A material, on the other hand, is generally an open system. At first sight, therefore, it appears that this may well constitute a fundamental difference between pathology and biodeterioration. More detailed inspection of this question reveals, however, that much depends on the philosophical outlook of the investigator whether he will take this difference as being fundamental, or only as gradual.

As stated above, materials only derive their meaning from their association with man. Now, man is certainly able to close the circuit of the system, noxious agent → material, by acting on the signal of the presence of the noxious agent and taking appropriate measures to counteract the influence of the noxa. Such feed-back mechanisms may even be built in for automatic functioning, as is shown by the example of mothproofing agents of the permanent type. These substances are "dyed" on the wool. It can be shown (R. ZINKERNAGEL, 1949) that in this combination they are not toxic to any appreciable extent. If, however, the wool is eaten by a larva of the clothes moth, the poison is released by the enzymes of the gut and it subsequently kills the aggressor. The system is so well balanced that negligible amounts of wool give rise to this result, leaving the wool functionally unimpaired. An analog to wound healing of the same man-made nature, though not in the biotic sphere, is the use of self-sealing fluids inside tyres as a remedy against puncturing. The conclusion is that in materials elementary feed-back systems ("defence mechanisms") may be built in or can, at least, be provided by man. Again, however, the situation in the case of materials is much simpler than in the case of organisms exposed to the action of noxious agents.

The other feature that at first sight distinguishes pathology from biodeterioration, viz. the presence of active reactions in organisms as contrasted to passivity in materials, may also be questioned. If one adopts a materialistic-mechanistic view on life, the so-called active "reactions" of an organism are no more than a complicated system of physical and chemical reactions set in motion by the noxious agent. In materials, where e. g. the cellulolytic breakdown of cellulose is directly comparable with some basic phenomena in certain plant diseases, physical and chemical reactions too are the primary response to noxious agents. The difference is then of a quantitative nature only, because organisms constitute much more complicated systems with well developed self-regulatory mechanisms. If, however, one adopts the view that life is something more than a complicated physico-chemical system, the "active" reaction of organisms to noxious agents may well be essential to life and, therefore, differ qualitatively from the "passive" reaction of materials.

It may be doubted, however, whether this non-material difference is open to experimentation.

The overall conclusion of these considerations is then that biodeterioration and pathology differ at any rate in that they describe phenomena of systems of a different degree of complexity. Apart from this quantitative difference, qualitative differences may exist due to the fact that materials in our context are non-living matter in contrast to living organisms. Otherwise, all essential features of diseases may be taken to be present in principle in cases of biodeterioration of materials. One may wonder, therefore, whether "hylopathology" may exist as complementary to phytopathology and zoopathology. E. E. HUBERT (1931), on the ground that no definite boundary can be shown to exist between the invasion of dead and living wood by fungi, already suggested that a "woodpathology" be instituted. The present author, however, is of opinion that there is no pressing need for such a new term. The notion "pathology" has a long history, and because of this tradition many will have difficulty in recognizing the familiar features of disease in biodeteriorating materials. It is more important to show that pathology and biodeterioration have much in common, and perhaps even a common basis, as was shown above. In this respect, it may be advantageous for a systematic treatment of biodeterioration to investigate whether the basic questions in pathology may be put in biodeterioration too.

In the description of contagious diseases, the following questions are generally brought forward systematically (Table 2). The equivalents in biodeterioration are added.

Table 2. Systematics of pathology and biodeterioration

Question	Pathology	Biodeterioration
What phenomena do we observe?	Symptomatology including diagnosis	Symptomatology including diagnosis
What is the cause of the phenomena?	Etiology	Etiology
How do the phenomena develop?	Pathogenesis	Deteriogenesis
How does the disease (the complex of biodeterioration phenomena) spread?	Epidemiology	Ecology (Partly)
How can the disease (complex of biodeterioration phenomena) be checked?	Medicine a) curative b) preventive	Control of biodeterioration a) curative control (practically non-existent) b) prevention of biodeterioration

It will be clear from this table that most questions in pathology have their equivalent in biodeterioration. Some difficulty exists in the comparison of epidemiology and ecology. The wider notion of ecology, being the study of the external factors influencing the development of biodeterioration phenomena, is preferred to a notion including only the study of the spread of infection in a population. This would lead to difficulties in defining individuals and populations in species of materials. Since the study of the epidemics of contagious diseases has many ecological features, it was thought best to tabulate ecology in the case of biodeterioration.

This difficulty will be discussed more in detail in the appropriate chapter. For a systematic treatment of biodeterioration, the above classification will be followed.

Before doing so, a similar development must be pointed out in plant-pathology. H. MORSTATT (1923, 1933) already favoured a systematization of plant-pathology along the lines provided by human pathology. E. GÄUMANN (1946) systematically compared his phytopathological definitions with those common in medicine. J. G. HORSFALL and A. E. DIMOND (1959), in the provocative introduction to their treatise of plant-pathology, agree with this point of view. They furthermore state that the science of understanding the nature of the diseased plant must complement the art of treating the sick plant. It is the present author's conviction that in the study of biodeterioration the scientific understanding of these phenomena in materials needs to be stressed. The art of dealing with deteriorating materials should benefit by it.

3. Symptomatology

3.1. Classification of symptoms

A classification of phenomena in biodeterioration is possible in different ways, depending on the aspect which is to be stressed. Essentially we want to describe processes initiated by organisms and leading to certain observable symptoms.

Stressing the first aspect, we may classify the phenomena of biodeterioration as due to:

1. Mechanical processes
2. Chemical processes
   a) assimilatory
   b) dissimilatory
3. Soiling ("fouling")

Some examples of the above may be given in order to clarify the point. Under category 1 *Mechanical processes* we may comprise: damage due to rodents, especially if non-nutrients like plastics, are attacked. Some types of insect damage belong to this category too. The majority of biodeterioration phenomena is comprised in category

2 Chemical processes. In the assimilatory type (2a) materials serve as a source of nutrition to organisms. This is a very common process leading to phenomena of biodeterioration as e. g. shown by cellulose containing materials breaking down under the influence of cellulolytic micro-organisms. However, there are many other ways in which organisms may cause damage to materials, such as those comprised in category 2b. Here the substrate is not used as a source of carbon, but corrosion of biotic origin is the predominant feature. Instances are the attack of metals by sulphate-reducing bacteria and the damage caused by fungi to optical glass. The third category (soiling or fouling) is a rather special one. Here the mere presence of organisms is objectionable. The fouling of ships' hulls — a problem of great economic importance — may be quoted as an example. Other instances, however, are the clogging of pipelines by iron bacteria and the overgrowth by fungi of plastics which themselves are invulnerable to micro-organisms. The process underlying this category, is the settling of or invasion by organisms. G. Theden (1959), in describing the resistance of materials against fungi, has offered a systematization which, apart from comprising our categories 2 and 3, leaving out category 1, adds a category of toxic materials. Since changes in the material ought to be absent in that case, it does not fit the above system, which has a somewhat other starting point in that it aims at a more dynamic description of biodeterioration processes. G. Theden's distinction between destructible and sub-destructible materials appears to offer no special advantage. The distinction will always be rather arbitrary.

The processes described above will lead to certain observable phenomena. These may be either morphological (structural), or functional. In the following table a number of observable symptoms is given, each, by way of illustration, with an example of cases of biodeterioration in which this special symptom is present. It must be stressed that in many cases of biodeterioration more than one symptom may be noted. The appropriate notion for this appears to be "biodeterioration-syndrome" (syndrome in medicine is "a set of symptoms which occur together" W. A. N. Dorland, 1957).

It appears to be possible on the basis of this list (which must be considered tentative) to arrive at a more or less standardized description of biodeterioration-syndromes. If the cause of such a syndrome is known, or surmised, and something of its (constant) development into a specified set of symptoms can be shown, we may well arrive at a notion of entities in biodeterioration comparable with diseases in human- and plant-pathology. Such an entity we might call a "biodeteriose" or, for short, "deteriose".

Table 3. Symptoms in cases of biodeterioration of materials

Symptoms		Examples
1. Morphological symptoms	1.1. Staining	Superficial growth of mildew as in weathered cotton or paint.
	1.2. Efflorescences	Raised overgrowth by organisms as in fouling ships' hulls by barnacles and algae.
	1.3. Discolorations	Discoloration of plastics (PVC) attacked by certain micro-organisms. Precipitation of FeS by sulphate reducing bacteria.
	1.4. Pitting	Pitting corrosion of ships' hulls associated with sulphate reducing bacteria.
	1.5. Lesions	Undefined parts of the material are broken away as in rodent damage or in damage to wool by clothes moths.
	1.6. Disfigurement	Positive changes in structure as in the blistering of paints possibly sometimes associated with fungi.
	1.7. Disorganization	Breaking of emulsions as caused by bacteria.
	1.8. Fibrillisation	Loss of coherence in fibrous materials as in wool attacked by micro-organisms.
	1.9. Impenetrations	The invasion of the lumen of certain natural fibres by fungi.
2. Functional symptoms		
2.1. Changes in primary properties of materials	2.1.1. Changes in mechanical properties	Loss in breaking strength of cotton fabric and changes in elasticity modulus in plasticized PVC as caused by micro-organisms.
	2.1.2. Changes in electrical properties	Changes in the conductivity of insulating materials attacked or invaded by fungi.
	2.1.3. Changes in optical properties	Opacity of glass caused by the etching activity of a fungal overgrowth.
	2.1.4. Changes in chemical properties	Breakdown of cellulose, plasticizers, etc. as caused by micro-organisms.
2.2. Changes in secondary properties of materials	2.2.1. Development of odour	Musty odour associated with many cases of mildewing of materials.
	2.2.2. Development of heat	Heating of hay by micro-organisms.

3.2. Diagnosis

Diagnosis is the art of distinguishing one deteriose from another, or from non-deterioration phenomena. It is in this field that still much is to be done. A number of experiences is available. However, we are far away from a systematical approach to the problem of recognizing true cases of biodeterioration. The absence of easy methods for the identification of biodeterioration may well be the main factor of the underestimation in practice of the occurence of such phenomena. Of course, obvious symptoms exist, such as lesions due to rodents, which are unmistakable evidence of the presence of biodeterioration. Much more difficult, however, are such cases as the breakdown of a plasticizer in PVC leading to a stiffening of the plastic. This latter symptom, however, may have different causes apart from the breakdown of the plasticizer by fungi. Plasticizer may get lost by migration, evaporation, sublimation, oxidation, etc. As will be shown in the chapter on etiology, even the presence of micro-organisms in such a case is not in itself sufficient proof of a causal relationship. Only in those cases where the development of a deteriose of known description arising from the action of specified organisms is given beforehand, the consideration of the symptoms together with the identification of the associated organisms may be a sufficient basis for the authentication of a case of biodeterioration. At present, we generally have to rely on circumstantial evidence.

For a few materials which, in this respect, have had the attention of scientists for some time already, some useful diagnostic methods exist. In the case of attack by micro-organisms of cotton, for example, one may have recourse to a number of microscopical techniques showing the presence of mycelial threads, and the possible presence of defects in the fibre-wall (Congored-test). A summary is given by G. BECKER (1960).

A well-documented diagnosis is possible in the case of attack of wool by keratin-eating insects (R. ZINKERNAGEL, 1948). Similar methods exist in wood technology. The better knowledge is generally due to the fact that the causative organisms and their effects have been studied thoroughly. In the case of "new" materials, such as plastics, the etiology of possible deterioses is generally not known, which makes identification difficult.

A few general methods exist, and will be discussed here.

a) Identification of the presence of micro-organisms

Though the mere presence of micro-organisms is not sufficient proof of their being the causative agent, it certainly is a valuable indication.

A number of classical colouring methods are available for the purpose (cf. G. BECKER, 1960, M. LANGERON, 1952, G. R. F. ROSE et al, 1955). Less known, but especially valuable in the case of plastics, is the use of UV-light (H. J. HUECK, 1959), since many micro-organisms become fluorescent. It must be noted that the absence of (micro)-organisms is no proof against biodeterioration, because the association may have been rather loose, as frequently happens in cases of dissimilatory chemical damage. The organism may also have died before the investigation, as sometimes occurs with sulphate reducing bacteria, which are very sensitive to exposure to oxygen.

b) Demonstration of vulnerability of the substrate

A prerequisite for biodeterioration being present is the vulnerability of the material in question. This can be shown by applying some or other form of general biological stress. The use of a soil burial test (cf. R. G. H. SIU, 1951) is indicated for the purpose. A very practical method, though time-consuming, is the one used by L. R. SNOKE (1957) possibly based on the method of C. E. ZOBELL (1946). An enrichment culture is used. It is observed whether the addition of the material in question gives rise to an increase in oxygen consumption, or a similar quantity dependent on microbiotic activity. Though in the article in question the use was restricted to cables in the marine environment, it will be clear that the principle has wider applicability. If in addition some or other change in material properties can be noted, the method gains in reliability, since false positive results must be expected, if one relies only on indirect evidence. Impurities in the materials and chemical reactions may easily fake an oxygen consumption not related to the main issue.

c) "Post hoc, propter hoc" methods

In case of suspected biodeterioration, e. g. emulsions with a foul odour, musty textile, etc., the biotic nature of the deterioration is often shown by the addition to the system of antibiotics, fungicides, etc. The disappearance of biodeterioration symptoms is then taken as an indication of biodeterioration having been present. The method is not without objections. In the case of the use of quaternary ammonium compounds for disinfecting purposes e. g. in oil-wells, the improvement noted may be the result of the killing action on sulphate reducing bacteria, but it may also be due to the general anti-corrosive activity of these compounds, which may provide a protective surface layer. Because of the indirect nature of such evidence, one must be well aware of the old medical warning "post hoc, propter hoc?" meaning to indicate that improvements after the use of some or other remedy are not necessarily due to that remedy.

Neither of these general methods will provide in itself an unambiguous answer in suspected cases of biodeterioration. A combination of these, together with other circumstantial evidence, such as a knowledge of the existence of favourable environmental conditions, may provide near-certainty. Absolute proof, though seldom required, can only be offered when the primary cause is tracked down. Considerations about this will be given in the next chapter.

4. Etiology

4.1. General considerations

An organism causing biodeterioration will be called a biodeteriogen. How can we differentiate the biodeteriogens from other often similar, organisms present in cases of biodeterioration? The solution of this question in relation to human infectious diseases has been provided by R. Koch (1882), when he formulated his famous Kochian principles (Koch's postulates). It is easy to adapt these principles to the present case. We may read them as follows:

1. A biodeteriogen must be present in or near materials showing phenomena of biodeterioration, in such numbers and such a distribution that their presence may explain the phenomena in question.
2. It must be possible to isolate the biodeteriogen from the material showing phenomena of biodeterioration and grow it in pure culture.
3. It must be possible, with the pure cultures thus obtained, to reproduce under controlled conditions, phenomena of biodeterioration comparable to the original phenomena.

In many texts (cf. W. A. N. Dorland, 1957), a fourth principle is added which requires that the micro-organism must be observed in and recovered from, the experimentally diseased specimen. It may be taken, however, that this is inclusive in the last part of the third principle, when the organisms are taken to constitute an integral part of the phenomena.

Though, admittedly, these rather strict requirements cannot always be fulfilled, they are nevertheless a firm and time-honoured basis on which to establish the etiologic relationship of a given (micro)-organism to a given disease. In our case, we should insert the analog to disease in materials, viz. "deteriose". It is here that we may point at the importance of defining deterioses as separate entities in the biodeterioration of materials. It is apparently impossible in most practical cases of biodeterioration to show at length that Koch's postulates have been fulfilled. If, however, a known set of symptoms (syndrome) has been described as pertaining to a certain deteriose, the diagnosis will be greatly facilitated.

Though the application of Koch's postulates is rather self-evident in biodeterioration studies, they are not always adhered to in technological literature. The positive value of such a procedure can be demonstrated by two practical cases. R. C. TOMASHOT and A. L. HAMILTON (1956) showed that certain types of polyester reinforced with glass-fibres suffered a reduction in strength, if incubated with fungi in pure culture. At the same time, however, they could show that in blank media strength was also reduced. The cause proved to be the humidity of the media. This case of deterioration apparently did not fulfil the first and the third postulates. Since fungi favour humid environments, an association of fungi with this type of deterioration may be frequent without their being causative.

Another example is provided by G. BONDE and B. LUNN (1958). They showed that a type of deterioration in lead-covered cables, known as phenol-corrosion and hitherto assumed to be caused by a high content of phenol in the covering bitumen, in reality was due to acids produced by the microbiological breakdown of the jute imbedded in the bitumen. The wrong earlier diagnosis was caused by studying the case without trying to reproduce the phenomena under controlled conditions, and without using sufficient blanks. The original evidence consisted only of a correlation of high phenol content with the deterioration phenomena in a restricted number of cases.

The second and third postulates would have been helpful here.

4.2. Types of biodeteriogens

Biodeteriogens belong to many groups of flora and fauna. Though usually biodeterioration is thought to be associated with fungi, bacteria and insects, it must be pointed out that biodeteriogens occur in many more systematical groups.

In Table 4 examples of the widespread occurrence of biodeteriogenic activity amongst representants of fauna and flora are given. Data were derived from handbooks, reviews by G. H. GREATHOUSE and C. L. WESSEL (1954) and G. BECKER (1962), scattered literature data and own experience. A fully annotated review will be presented elsewhere.

4.3. Biodeteriogens and materials

Combinations of biodeteriogens and materials, even if they may in principle be able to produce symptoms of biodeterioration, do not always do so and, if so, they will not always produce these symptoms to the same degree. Apart from outside influences in this, it is well-

Table 4. Biodeterioration of materials as caused by organisms in different taxonomical groups

Taxonomical group	Biodeterioration phenomena
1. Vertebrata	Rodent damage. Incidentally birds may damage or spoil materials.
2. Tunicata	*Didemnum* spec. may be important in some cases of "fouling".
3. Arthropoda	
3.1. Crustacea	Barnacles, causing "fouling" of ships' hulls. *Limnoria* spec. damage wood and other materials by boring activities.
3.2. Insecta	Numerous biodeteriogens occur in this group. A few important groups are termites, dermestids, clothes-moths, woodboring beetles, storage insects, etc. The range of materials attacked is wide.
3.3. Arachnoidea	Mites (Tyroglyphidae) often occur as a secondary biodeterioration phenomenon after a primary growth of micro-organisms.
3.4. Myriapoda	Biodeteriogenic importance unknown.
4. Annelida	Representants of this group are observed on fouled ships' hulls.
5. Nematoda	Biodeteriogenic importance unknown.
6. Tentaculata	Bryozoa occur on fouled ships' hulls.
7. Mollusca	Boring mussels (*Teredo, Pholas, Xylophaga,* a. o.) cause damage to wood and sometimes plastics. Rock borers (*Lithophaga* spec.) penetrate calcareous rocks.
8. Echinodermata	Sea urchins attacking steel constructions.
9. Coelenterata	Sea-anemones and corals have some importance in the fouling of ships' hulls.
10. Porifera	Boring sponges may penetrate coral reefs and calcareous shells.
11. Protozoa	Protozoan species occur in industrial slimes (paper mills) presumably as secondary biodeteriogens. The biodeteriogenic importance of this group has had scant attention.
12. Protophyta	
12.1. Schizomycetes (bacteria)	Many biodeteriogens belong to this group which, however, deserves to be investigated more thoroughly. Of the numerous phenomena may be mentioned: Assimilatory breakdown of cellulose, keratin (wool), plasticizers; Dissimilatory attack of materials by *Desulfovibrio spec., Thiobacillus thiooxidans,* etc.; Slime formation by iron bacteria; Spoiling of oil emulsions by Pseudomonads.
12.2. Schizophyceae (Blue green Algae)	Fouling and pollution of swimming pools and water basins.

Table 4 continued

Taxonomical group	Biodeterioration phenomena
13. Thallophyta	
13.1. Flagellata	Biodeteriogenic importance unknown.
13.2. Diatomeae	Biodeteriogenic importance unknown.
13.3. Chlorophyceae	Green algae give rise to overgrowths on bricks and other building materials. In the case of asbestos-cement the algae are corrosive by the production of organic acids. They may constitute a nuisance in swimming pools. Moreover they contribute to the fouling of ships' hulls and marine structures.
13.4. Phaeophyceae	Fouling of ships' hulls and marine structures.
13.5. Rhodophyceae	Biodeteriogenic importance unknown.
13.6. Fungi	Many biodeteriogens occur in this group. As such may be mentioned: Assimilatory breakdown of cellulose, plasticizers, wood and other materials; dissimilatory breakdown of glass and concrete overgrowths (fouling) on plastics, building materials, etc.; present in industrial slimes and in spoiled emulsions and jet-fuel.
13.7. Lichenes	Biodeteriogenic importance unknown. Corrosion or overgrowth of building materials may be suspected.
14. Bryophyta	Biodeteriogenic importance unknown.
15. Pteridophyta	Biodeteriogenic importance unknown.
16. Spermatophyta	Plant roots may damage subterranean structures by corrosion and mechanical action.

known that not all strains of micro-organisms possessing biodeteriorating potencies, possess this property to the same degree. This quantitative aspect of the relation biodeteriogen and material may be described concerning the organisms with a term borrowed from phytopathology (E. Gäumann, 1946), viz. aggressivity.

Especially in quantitative tests as for rotproofness of textiles, it appears to be desirable to stress that the affinity of certain micro-organisms to certain materials has not only a qualitative aspect, but also a quantitative one. Controls for measuring the aggressivity of the organism used, therefore, are a necessity. The potency of biodeteriogens in this respect can only be measured in terms of the effect on specified materials inoculated under specified conditions. The choice of the substrate to be acted upon, is difficult. In the case of the soil burial test, H. J. Hueck (1960) advocated the use of a degradation curve obtained with untreated (blank) cotton fabric. It was shown afterwards in interlaboratory tests (H. J. Hueck and J. v. d. Toorn, 1965) that such a standard, though useful with blank cotton, was no use in experiments involving tests with fabric treated with Cu-naphthenate. Apparently still much thought will have to be given to this problem.

On the side of the material the complementary property is that of susceptibility of the material and the degree of resistance it offers to biotic attack.

In principle we may expect that these properties will depend on the chemical composition and physical properties of the material in question. In practice this offers complications as in textiles, wood, plastics, which materials by their very nature do not possess a composition that can be defined exactly. Even if we only take into account the substance "cellulose" present in textiles and wood, we run into difficulties. It is well-known e. g. that differences in chain length of cellulose and the degree of cristallinity greatly influence its resistance to attack (R. G. H. Siu, 1951). Thus we have to cope with the situation that the degree of aggressivity in biodeteriogens is to be measured with the change of materials under influence of their attack. The materials, however, in practice vary in degree of resistance they offer to biodegradation. It will be clear that the outcome of such experiments cannot be evaluated in exactly defined scales of aggressivity of the organism and resistance of the material. Only rigorous standardization of test-materials may eventually solve this problem. With unambiguously defined substrates only, we may hope e. g. to determine representative breakdown constants, etc. Already in one of the most important and best investigated biodeterioration processes, viz. the breakdown of cellulose, this offers great problems that until now have not been solved satisfactorily for practical purposes (J. A. Gascoigne and M. M. Gascoigne, 1960).

Because of the wide range of variation in aggressivity and resistance, the interrelation between material and biodeteriogens may range from an innocuous existence next to each other to a rapid destruction of the material. Apparently we are dealing with either a balanced or unbalanced situation. Environmental factors greatly influence this balance. They will be discussed in the chapter on ecology. But, even in the case of equally favourable environmental circumstances, some couples of materials and biodeteriogens will show a greater degree of unbalance than other couples.

A similar situation exists in human pathology. J. J. van Loghem (1957), referring to P. J. van Beneden (1878), points out that in contagious diseases all variations between innocuous commensalism and virulent parasitism exist. Generally parasites appear to be more specialized organisms than commensals. Specialization certainly also exists among biodeteriogens. Whereas fungi like *Cladosporium cladosporioides* can be found on many materials we find iron bacteria and sulphate reducing bacteria only in much more specialized environments. Furthermore we may point to clothesmoth larvae, which are restricted to keratin.

It might be interesting to see whether this specialization correlates with the balance of the relation between material and biodeteriogen.

The present author hesitates to offer an opinion, because no reliable data appear to be available in this respect. Furthermore, it is clear that in biodeterioration, comparisons should be made first of all with saprophytes, parasitism by definition being excluded.

5. Biodeteriogenesis

5.1. Introduction

In analogy to equivalent nomenclature in phytopathology (H. Morstatt, 1933, E. Gäumann, 1946), we may distinguish the following phases in the development of biodeterioration phenomena:

a) infection (infestation); the establishment of a stable contact between the material and the biodeteriogen.

b) incubation; the phase after the establishment of a stable contact until the symptoms of biodeterioration become observable.

c) manifestation; the phase in which symptoms of biodeterioration are observable.

The nomenclature in phytopathology is first of all meant for microorganisms. In the biodeterioration of materials we are also dealing with other organisms, e. g. insects. In that case, the word "infestation" appears to be more appropriate. In the following, however, we will generally speak of "infection", taking infestation to be tacitly included.

5.2. Infection

A chance contact between a biodeteriogen and the appropriate material is not yet an infection. A stable contact requires that all other factors which are necessary to further development, be it potentially, are also present. Such further factors may be in phytopathology, according to E. Gäumann (1946),

a) suitable environmental factors

b) presence of a suitable infection mechanism including a "porte d'entrée".

It remains to be seen whether this holds good in the simpler situation of biodeterioration of materials. As to the influence of environmental conditions, no doubt exists in our case. Humidity and temperature are well-known limiting factors for the development of fungi in materials. This not only pertains to the relative humidity of the environmental air, but also to the water content and the temperature of the material exposed to attack (S. S. Block, 1953). Another case is offered by the overgrowth of optical glasses which is only possible when organic nutrients are available in the near neighbourhood.

By the infection mechanism is meant the total apparatus necessary for penetration or further attack of the substrate. This may be mechanical or enzymatic systems on the side of the attacker, and the presence of penetrable layers or apertures on the part of the substrate. Rudiments of such a mechanism may be observed in some materials. Unpublished observations of my laboratory in relation to soil burial test of electric cables indicate that fungi first of all penetrated the protecting bituminous layers, using tiny protruding fibres of the jute embedded in this mass. In further stages, the jute guided the fungi to the inner metal core of the cable on which after some time an imprint of the jute could be observed.

This may be explained, according to G. Bonde and B. Lunn (1958), by acid production of the micro-organisms in the fibres. It must be added that penetration of the bitumen itself, was apparently possible too, since mycelial threads could be observed in this mass. The jute, however, was preferred, which is rather obvious. Cables, among materials, are the more complicated ones as to structure, and it is clear that it is this very structure that leads to complications in the process of infection. Generally, however, no obstruction whatsoever is offered by the material in contact with a biodeteriogen if environmental conditions are favourable for further development of the attacker. It may be pointed out that this lack of natural defence mechanisms of materials may be a contributory factor in the low specificity required on the side of the attacking organism. An example may elucidate this. If fungal spores infect leaves of plants, the following processes may be noted (E. Gäumann, 1946). Under influence of the leaf an appressorium may be formed. Then the hyphe penetrates from this appressorium, the cuticula consisting of cutine and suberine. Usually this is a mechanical process, few micro-organisms possess appropriate enzymes. After this, the cellulose containing cell wall of the epidermis is penetrated. This is generally an enzymatic process. The enzyme cellulase occurs widespread among micro-organisms. Then the attacking hyphe has to possess mechanisms to resist the reactions of the living cell which follow when the hyphe enters the cell lumen. Many fungi find their way between cells and possess pectinases for the purpose. In contrast to this complicated process in plants, conditions are much simpler in materials. Cellulose or other vulnerable materials may be available at a first contact. This means that much simpler infection mechanisms suffice. Since so many micro-organisms already possess the enzyme cellulase as a part of their infection-system, it stands to reason that so many species of fungi can be found that are able to attack cellulose as a material.

The simpler situation, in this respect, present in materials as compared with living plants therefore appears to account for the low degree of specificity generally found in the causative agents of biodeterioses. On the other hand, it must be recognized that exclusive substrates themselves already may lead to specialization of the attacker, as is shown e. g. by the few species of insects able to attack wool.

5.3. Incubation

The incubation period is an important notion in diseases. This period in which the disease is latent is mainly due to the mutual adaptation of pathogen and subject. Furthermore it will cover the period that the deviations from normalcy are so slight that they escape notice. In the case of biodeterioration of materials, we may doubt whether the first phenomenon exists. If so, it is due only to an adaptation process in the biodeteriogen. As adaptive enzymes are not uncommon, this may be surmised. Exact data are not known to the author. On the other hand, the existence of a lag period between infection and manifestation of symptoms cannot be doubted. We must recall the essentially anthropocentric nature of material. As manifestation of symptoms we therefore will take only those that are relevant for the use of materials, as e. g. loss of strength in cellulolytic decay of cotton. It can be shown that in blank cotton it takes some time before strength is impaired, cf. H. J. Hueck (1960).

Before that stage, other changes may be noted such as changes in pH of aqueous extracts, changes in swelling properties, etc. (R. G. H. Siu and E. T. Reese, 1953). Especially if the cotton is treated with (suboptimum concentrations of) fungicides, the lag time may grow considerably (H. J. Hueck, 1960; A. C. Kempton et al, 1963). This points to the important analogy with pathology that the length of the incubation period is also due to the resistance of the substrates. The more complicated the structure of the material, the more probable a significant incubation period will become.

In the case of biodeterioration of electric cables referred to on page 22 it is clear that the manifestation of symptoms of corrosion on the metal sheath is chronologically much delayed with respect to the initial infection of the outer coverings. The impairment of insulating properties of the whole sheath will even be much later. Accordingly, we arrive at the conclusion that a certain lag between the observation of significant symptoms and the initial infection may occur, possibly due to an adaptation of enzyme systems in the biodeteriogen and, at any rate, due to qualitative and quantitative developments in the process of attack of the material. This lag period may be considered to be an analog to the incubation period in human diseases.

5.4. Manifestation

Deterioses generally manifest themselves by localized symptoms. Analogs to systemic diseases are few, as e. g. the bacterial contamination of emulsions. Because of the simple structure of most materials, the localization of the symptoms is mainly governed by external factors and less so by intrinsic affinities of the biodeteriose to certain parts of the material. This dependence on external factors causes that the pattern of symptoms and the rate of development is generally not very specific in deterioses. Some characteristic patterns may be noted, e. g. the development of "weather-stains" on mildewed cotton-fabric. They come into existence by the preferential development of fungi along warp and weft leading to a pattern of star-shaped stains. The rate of development, however, is governed mainly by external factors. A contributory factor in the multitude of patterns of symptoms encountered in deterioses is that materials may have any shape that suits the intended use. A description of the complex of symptoms (biodeterioration-syndrome) connected with specific deterioses, therefore, will have to be given in rather general terms. Only if we consider deterioses as processes by which a specific cause gives rise to a certain set of symptoms, we may expect to arrive at an unambiguous description of deterioses and the separation of functional entities within the study of biodeterioration.

6. Ecology of Biodeterioration

6.1. Introduction

In biology the relation between organisms and their environment is studied in ecology. A usual sub-division is the one in autecology and synecology, the first of which describes the relation of the single organism to its physical environment, whereas the latter takes into account the interrelations with other organisms. Because of the abiotic nature of materials, we may very well approach the relationship of biodeteriogens and their substrates from the point of view of autecology.

In this chapter we will restrict ourselves to a very special aspect of this relationship, viz. the spreading of biodeterioses.

This spreading is governed by the usual ecological factors involved in the occurrence of organisms viz.:

a) habitat
b) food
c) milieu (environment).

For human infectious diseases, the spread of the disease is studied in epidemiology. If taken in its broadest sense ("the field of science dealing with the relationship of the various factors which determine the frequencies and distributions of an infectious process, a disease, or a physiological state in a human community" W. A. N. DORLAND, 1957), this notion might be easily translated in an analogous one for biodeterioses. We will refrain from doing so, because the spreading of biodeterioses has only a slight resemblance to some special cases of the spreading of human disease. It more resembles endemic disease, where the cause of the disease presumably is omnipresent, but the outbreak is governed by the breakdown of the individual resistance. Obviously, the rule in biodeterioration is that outbreaks of biodeterioses are mainly governed by the presence or absence of favourable ecological conditions, the causative agent generally having a wide distribution. On the other hand, we cannot fully deny the existence of more specialized mechanisms of spread such as in the infestation of wool by carpet-beetles. It may be interesting, therefore, to see what meaning a few common notions in the spread of diseases have in biodeterioration. As such we will consider the source of infection, the transference of the biodeteriogen, and the distribution of biodeterioses.

6.2. Sources of infection

If infection exists, its implication is that an outside reservoir of biodeteriogens exists from which the receiving substrate may be invaded. Even if the biodeteriogen is present in a passive or non-deteriogenic state on the substrate in question it must have come from elsewhere. The source of infection then may be a substrate, homologous or heterologous, that had already been infected earlier.

The existence of homologous sources of infection is rather self-evident as e. g. in the case of cellulosic materials.

More interesting is the existence of heterologous substrates, because especially in the case of materials we are dealing with substrates that are "man-made" and do not exist in nature as e. g. in the case of plastics. Hence these materials must have been invaded initially from heterologous sources of infection. In many cases, these heterologous materials will be chemically related, as shown by the biodeterioration of wool by carpet-beetles. Wool on the sheep is not attacked to any appreciable extent. The natural source of infestation by keratin-eating insects appears to be coming from birds' nests (G. E. WOODROFFE and B. J. SOUTHGATE, 1950) and keratin containing debris (A. D. J. MEEUSE, 1952). In the case of plastics, it is more likely that hitherto unexplored potentialities of the micro-organisms are coming to the fore. Whether true adaptation occurs e. g. by mutation of micro-organisms, remains to be seen. It must be pointed out that the chemical breakdown potentialities of micro-organisms in the realm of plastics, are largely unexplored. On the other hand, rather unimportant activities of organisms in natural conditions may lead to disproportionate damage in materials. As an instance we may quote rodent damage to PVC-coated cables. Normally, damage due to rodents is associated with their feeding activities. In the case of undigestible PVC, other gnawing activities (cf. H. J. HUECK and J. LA BRIJN, 1959) come out and may lead to appreciable damage.

Last but not least it must be mentioned that non-deteriogenic stages of organisms (such as spores and hypopus) may develop into deteriogenic stages. In the non-deteriogenic phase they may already be present on the receiving substrate. In due time, and under favourable conditions, this will lead to "auto-infection", though, as stated above, this is a rather short term view (but a practical one) on the phenomena. Ultimately, the biodeteriogen will have come from elsewhere.

6.3. Transference of the biodeteriogen

In the field of biodeterioration, little experience is available on the transport of biodeteriogens. In general, however, we may expect that the problem will be much the same as in phytopathology (cf. E. GÄUMANN, 1946, C. T. INGOLD, 1953, P. H. GREGORY, 1961). Supposedly we will then have to distinguish transference by direct contact and indirect transference.

This latter possibility can be seen to fall apart in transference by autonomic displacement of the biodeteriogen, and in the passive transport by different agents such as wind, water, animals and man. It will be clear that, for the control of biodeterioration, knowledge of such mechanisms may be valuable. Admittedly, this field of study is as yet largely unexplored in relation to biodeterioration.

6.4. Distribution and spreading of the biodeteriose

In this chapter we will have to consider an analog to the epidemic or endemia in human or organismal populations. In biology, a population means a distinct group of individuals. This latter notion, however, is already in biology hardly definable (M. JEUKEN, 1952).

In materials we must expect that individuality is a still more abstruse concept. We will, therefore, refer to "material-units" as being "a substance or a composition of substances used in discrete units for any technical purpose". We may then pose the question what factors govern distribution and spreading of a biodeteriose over groups of such units. For this we will have to look for the autecology of the biodeteriogen. As stated earlier, three groups of factors must then be considered, viz. habitat, food and milieu (environment). The habitat, obviously, is the material in question for many micro-organisms. If we take other organisms into account, however, such as insects, the material in question is only part of the habitat. Likewise it must be pointed out that, in the case of micro-organisms, food and habitat are often identical. In the case of dissimilatory activity, food and habitat fall apart as in the case of the etching of optical glass by fungi. Most important appears to be the influence of the environmental factors. Temperature and humidity have an overwhelming influence. This influence has two aspects. First of all, the geographical distribution of biodeteriogens is mainly governed by these environmental factors. The practical omnipresence of man makes that his materials have no sharply defined distribution, so that habitat and food in our considerations cannot be limiting factors. The distribution of the biodeteriogens on the other hand, may be such a limiting factor. A clear example is given by the termites, which do not occur in the colder regions.

Many biodeteriogens, however, have a world-wide distribution. In that case, a second aspect of the influence of temperature and humidity comes to the fore. Even in regions where biodeteriogens usually are present, it is many times the microclimate in the direct environment of the material that governs the occurrence of a biodeteriose (cf. S. S. BLOCK, 1953). This is especially true in the case of micro-organisms where the control of humidity and water content has been a time-honoured means of controlling biodeterioration in vulnerable materials such as cotton, wood, etc.

In the spreading of human infections, two types may be distinguished (J. J. van LOGHEM, 1956), viz. one of a parasitic nature, characterized by epidemics of organisms not continually present in the majority of the population and causing acute outbreaks of the disease, generally with a distinctly geographical distribution, such as epidemics of *Salmonella*. On the other hand, one of a commensalic nature, characterized by the endemic occurrence of cases of disease caused by organisms apparently continually present in the majority of the population and leading to sporadic outbreaks, such as is the case with the common cold. The difference between these two types may be attributed to the more or less aggressive nature of the interrelation of the disease agent and its host, and the more or less exclusive parasitic nature of the micro-organism. It will be clear that, in materials, the biodeteriogens are seldom very exclusive in their appetites, so that they can often maintain themselves in the habitat, without directly causing biodeterioration of materials. The outbreak is mainly governed by environmental conditions and seldom limited by the natural resistance of materials, if this was not artificially increased by the application of fungicides. Therefore, we must expect that the spreading of biodeterioses will be mainly of the nature of the commensalic infection. This means that individual outbreaks are sporadic, i. e. often without definite geographical link-up and mainly governed by the individual resistance of the material-unit as situated in its environment.

7. The Control of Biodeterioses

7.1. Introduction

In medicine, curative and preventive measures are equally important, but this is not the case in the biodeterioration of materials. Apart from the fact that regenerative mechanisms in materials are practically non-existent, it must be noted that in the biodeterioration of materials generally only economic values count. The ethical consideration that every human individual is worth saving, is unappropriate in materials. Curative methods, therefore, are only encountered in cases where either very valuable or unique specimens, such as museum-pieces are threatened, or where materials are at stake, with which curative control is technically and economically feasible. Instances of the latter case are wood and ships' hulls. The usual practice is that methods of prevention are looked for. It appears to be useful to distinguish, on the one hand, hygienic measures which aim at the biodeteriogen and with which we try to prevent the infection of the material, and, on the other hand, prophylactic measures which aim at the material and with which we try to increase the natural resistance of the material to infection.

7.2. Material-hygienics

We may distinguish, in this respect, two different types of measures. First of all, there are those hygienic measures with which we try to prevent the initiation of contact between biodeteriogen and material, such as the erection of impenetrable barriers, anti-moth clothes-bags, cleaning of storage rooms in order to remove sources of infection, etc. Secondly, there are desinfective measures with which we try to check the spread of the biodeteriogen after the initiation of contact between biodeteriogen and material. As such we may consider chemical treatments with biocides (bactericides, fungicides), the drying of vulnerable materials (fire hoses), and the sterilization by heat of goods infested with insects.

In living beings, the application of chemical treatments is always a matter of grave concern, involving a careful study of etiology, pathogenesis and epidemiology, because of possible harmful side-effects. The relative ease with which we may control phenomena of biodeterioration by the application of biocides has led to a certain neglect of a balanced study of causative factors.

A timely warning, however, appears to be appropriate. Already in the control of insects for agricultural purposes, a distinct trend may be observed that leads to a more considerate use of biocidal chemicals.

The main problems that have cropped up here are the appearance of resistant forms, the disturbance of the balance of nature, and the toxic residues which may in the long run lead to a considerable toxic load in the human population.

Two of these problems are connected also with the indiscriminate use of biocides for the protection of materials against biodeterioration, viz. the selection of resistant forms, and a contribution to the toxic load of the human race. A disturbance of the balance of nature appears to be a rather remote possibility in our case, though the widespread use of bacteriostatically finished textiles may perhaps have some doubtful aspects. We must admit that at the moment the amount of biocides used for material protection is still negligible compared with that used in phytopathology.

Nevertheless it may be wise to look, already at an early moment, for alternative methods of protection. Hygienic measures of a biological and physical nature, as well as prophylactic measures to be discussed in the next paragraph, should be studied.

Finally, more specific treatments such as those developed in the mothproofing of wool may be considered.

7.3. Material prophylaxis

Measures increasing the natural resistance of materials to biodeterioration have been known for some score of years. One of the best examples is the protection of wool by mothproofing agents of the permanent type, such as Eulan and Mitin. These compounds are bound to the fibre, which otherwise is not altered for all practical purposes. It even is non-toxic to insects. Only after ingestion of the wool by keratin-degrading organisms, such as larvae of carpet-beetles and clothesmoths, the toxic substance is released, inactivating and finally killing the attacker. Another example of this principle is the modification of cellulose e. g. by acetylation, cyanoethylation or the introduction of chloroacetamide groups.

This makes the cellulose invulnerable to the action of the cellulolytic enzymes of the biodeteriogens, without becoming toxic to the invader. Because the attacker remains alive, chances of the selection of resistant organisms are less than with toxic impregnations. Furthermore, we may expect that the contribution of such treatments to the overall human toxic load will be less. A further search for such treatments may, therefore, be advocated. Such treatments must take into account, on the one hand, the properties of the material to be protected and, on the other hand, the properties and the vulnerabilities of the biodeteriogen. The study of such treatments thus appears to be a fine task for hylobiology, both aspects material and organisms being of equal importance and necessity.

8. Glossary of New Terms and Definitions

Hylobiology	= the special branch of biology dealing with the biotic phenomena associated with materials.
Biodeterioration of materials	= any undesirable change in the properties of a material caused by the vital activities of organisms.
Biodeteriogenesis	= the development of symptoms of biodeterioration.
Biodeterioration-syndrome	= a set of symptoms of biodeterioration which occur together.
(Bio)deteriose	= an entity in the biodeterioration of materials of which a single cause is known or surmised and consisting of a biodeterioration process developing into a characteristic biodeterioration-syndrome.
Biodeteriogen	= an organism causing biodeterioration.

9. Summary

The biodeterioration of materials is considered from the point of view of a biologist. As such it is part of hylobiology which deals with the biotic phenomena associated with materials.

It is discussed that phenomena of biodeterioration have some resemblance with phenomena of human and plant-disease. Also in the methodological approach they have something in common. Differences and similarities are reviewed in some detail.

On the basis of the notions thus formed it appears to be possible to provide a systematic description of the biodeterioration of materials as a part of hylobiology. Symptomatology, including diagnosis, etiology, biodeteriogenesis and the ecology of biodeterioration are stated to constitute important aspects of any case of biodeterioration. The necessity of the application of the Kochian principles to the study of the biodeterioration of materials is stressed. Attempts at providing adequate descriptive terms for the description of biodeterioses are made.

Zusammenfassung

Die „Biodeterioration“ von Werkstoffen als ein Teil der „Hylobiologie“

Die Beeinträchtigung von Werkstoffen durch Lebewesen (Biodeterioration) wird aus der Sicht eines Biologen betrachtet. So gesehen ist sie ein Bestandteil der „Hylobiologie“, die sich mit den in Verbindung mit Werkstoffen auftretenden Erscheinungen der Lebenswelt befaßt.

Es wird erörtert, daß Erscheinungen der Biodeterioration Ähnlichkeit mit Erkrankungen von Mensch und Pflanze haben. Auch im methodologischen Vorgehen bestehen Gemeinsamkeiten. Unterschiede und Ähnlichkeiten werden teilweise im einzelnen behandelt.

Auf der Grundlage entsprechend gebildeter Begriffe scheint es möglich, die Beeinträchtigung von Werkstoffen durch Lebewesen als Teil der Hylobiologie systematisch zu beschreiben. Symptomatologie, einschließlich Diagnostik, Ätiologie, Biodeteriogenesis und Ökologie der Biodeterioration bilden wichtige Gesichtspunkte für jeden Fall von Biodeterioration. Die Notwendigkeit, die Kochschen Prinzipien auch bei der Untersuchung von Beeinträchtigungen von Werkstoffen durch Lebewesen anzuwenden, wird betont. Es wird versucht, adäquate deskriptive Begriffe für die Beschreibung von Biodeteriosen zu bilden.

Résumé

La « biodétérioration » des matériaux faisant partie de l'« hylobiologie »

La détérioration biologique des matériaux est examinée selon le point de vue d'un biologiste. Elle fait partie de l'hylobiologie et traite des rapports entre les organismes vivants et les matériaux.

La discussion porte sur la ressemblance entre les phénomènes de la détérioration biologique et ceux des maladies de l'homme et des plantes. Il y a également quelque chose de commun dans les méthodes d'étude. Les différences et les similitudes sont examinées en détail.

Sur la base des notions ainsi définies, il semble possible de réaliser une description sytématique de la détérioration biologique des matériaux dans le domaine de l'hylobiologie. Chaque cas de détérioration biologique comporte des aspects importants dans les domaines suivants: la symptomatologie y compris le diagnostic, l'étiologie, la génèse de la détérioration biologique, l'écologie. On insiste sur la nécessité d'appliquer les principes de Koch à l'étude de la détérioration biologique des matériaux. On essaie de définir des termes descriptifs appropriés à la description des « biodétérioses ».

Resumen

La "biodeterioración" de materiales, una parte de la "hilobiologia"

Se considera la biodeterioración de materiales desde el punto de vista biológico. Este campo es una parte de la "hilobiología" que estudia las relaciones entre fenómenos bióticos y sustratos materiales.

Se discute si los fenómenos de la biodeterioración presentan alguna semejanza con los fenómenos de las enfermedades humanas y vegetales. También sus metodologías presentan seme janzas y analogías. Se revisan en cierto detalle las diferencias y analogías.

Según estas nociones parece posible demostrar que una descripción sistemática de la biodeterioración de sustratos materiales es una parte de la hilobiología, incluyendo diagnosis, etiología, biodeteriogenesis y ecología de biodeterioración, constituyen importantes aspectos de cualquier caso de biodeterioración. Es obvia la necesidad de aplicar los principios de Koch al estudio de la biodeterioración de sustancias materiales. Se intenta establecer una terminología adecuada para la descripción de las biodeteriosas.

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