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Early Colonization of Algal Communities on Polyurethane Bonded Aggregate: a Field and Laboratory Study

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ABSTRACT

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More and more coastlines are changing into urban structures. This change is marked by the application of a wide variety of different materials as revetments, often creating a hard substrate. The realization of such substrates can have large consequences for the flora and fauna inhabiting the coastal areas. Elastocoast® is such a new coastal protection material, made from rocks and polyurethane. It is a hard substrate but with an open structure and a smooth surface. This study examines the first phase of the recovery and growth of the algal community during the storm season of 2007-2008 on a dike in the Netherlands that was refurbished with Elastocoast®, and it describes a short term algal colonization experiment in the laboratory. In the field, 25 weeks after the construction of the Elastocoast® top layer, dike vegetation has returned, though strongly zonated and leaving large patches without any vegetation. Main algal species are *Enteromorpha minima* and *Fucus spiralis*. It is expected that the algal community will fully resemble typical hard substrate communities (as e.g. growing on basalt) when given enough time. The laboratory experiment showed that colonization by micro-algae is not hindered by the smooth surface and can be fast and substantial under favorable circumstances. Elastocoast® therefore seems to be a material which allows algal community recovery to be fast and according to the typical vegetation growing on hard substrates.

ADITIONAL INDEX WORDS: *Early colonization, Dike vegetation, Fucus canopy, Micro-algae*

INTRODUCTION

Ecology of Urban Coastal Structures

Of the world's human population, near 60% lives on or within 100 km of the seashore, and this number is still growing (HINRICHSEN, 1990). Due to this coastal urbanization, coastlines themselves are changing into urban structures. These urban coastlines constitute poorly understood components in the marine environment, since they are rarely investigated and often constructed without any knowledge or concern about the coastal environment. However, they present a new and interesting field of urban ecology, as different types of artificial substrates support different diversities and abundances of sessile marine organisms (HOLLOWAY *et al*., 2002).

Coastal areas are often highly dynamic and under influence of many factors (e.g. disturbance, climate, substratum, predation, disease and human activities (AIROLDI, 2003) resulting in a heterogeneous environment and a high biodiversity. Urban structures can act as surrogate habitats with human-generated heterogeneity that creates or removes occupation opportunities for the different marine organisms (HOLLOWAY *et al*., 2002). Changes in substrate composition as a result of coastal urbanization are therefore expected to influence marine coastal biodiversity.

Polyurethane Bonded Aggregates As a New Revetment Material

Many coastlines are protected by dikes, which are often covered by a hard substrate in the sublittoral zone. These revetments often have a top layer of bitumen, concrete or limestone. Recently, a new revetment material called Elastocoast® (BASF, 2009), has been brought on the Dutch market by Elastogran GmbH, a subsidiary of BASF Germany. This material is comprised of small pieces of rock (preferably granite or limestone) aggregated by polyurethane. It forms a hard, open structure, and the surface of the rocks is smoothed by the polyurethane.

Early Colonization of Algal Communities

Colonization of newly created hard substrates begins with the formation of a biofilm which is comprised of bacteria and micro-algae embedded in a matrix of a.o. polysaccharides and proteins (BAKKER *et al*., 2004 and BHOSLE *et al*., 2005). The chemical composition of the matrix and the composition of the adhering biofilm is, amongst many other factors, influenced by the type of substrate (BAKKER *et al*., 2003 and BHOSLE *et al*., 2005). The formation of a biofilm on hard substrates is thought to be an important factor driving colonization and recruitment of sessile marine organisms such as macro-algae. (BEVERIDGE *et al*., 1997, PATEL *et al*., 2003 and SIBONI *et al*., 2007).

It is difficult to predict how benthic communities occupy a newly created patch. Rocky sublittoral zones in temperate marine waters often show a typical zonation, each zone with its characteristic species (CASTENHOLZ, 1960, DE JONG *et al*., 1989, LEEUWIS, 1988). Previous research in temperate waters (MCCOOK *et al.*, 1997), has shown that mid-shore areas that were cleared from previous canopy, were occupied by a succession of diatoms, green and blue-green ephemeral algae, and were then covered with *Fucus* canopy. However, not only succession determines the species composition. Seasonal changes, moisture availability, disturbances and substrate type all affect occupation (HOLLOWAY *et al.*, 2002, LUBCHENKO *et al.*, 1983, AIROLDI, 2003 and KRAUFVELIN, 2007).

Aim

To assess the colonization potential of benthic algae on newly created revetments consisting of polyurethane bonded aggregates (Elastocoast®), this study describes the early colonization by algae under (1) field conditions on a dike in the Oosterschelde (Netherlands) during the winter season of 2007-2008 and (2) laboratory conditions using artificial communities.

MATERIALS AND METHODS

Field Research

Elastocoast® has been placed on a rudimentary sea dike called ‘the Zuidbout’ in the Oosterschelde estuary. The site measures 490 m^2 and is placed under a 1:3-1:4 slope on the north-west side of the dike (BIJLSMA, 2008). All organisms settled on the old top layer of the dike were removed in order to place the Elastocoast® layer. Sand was distributed by hand over most areas of the Elastocoast® layer while the polyurethane was hardening. Additionally, a small area of the Elastocoast® layer was topped with Vilvoordse limestone, which is a kind of rock prone to be covered by algae (YOUNG *et al*., 1998).

The Zuidbout was monitored during the storm season (October 15th – April 15th) of 2007-2008. A total of 24 plots of 0.25m^2 were marked with waterproof paint, and have been monitored for algal growth. These 24 areas were divided over 4 vertical zones, representing different substrate types. Zone 1 (N): the original top layer of Vilvoordse limestone. The existing canopy in this zone was removed as well; Zone 2 (EV): Elastocoast® on which Vilvoordse limestone was applied; Zone 3 (E): Elastocoast®; Zone 4 (EZ): Elastocoast® with a layer of sand on top to provide a rougher surface. The 4 zones were also horizontally separated in an upper and lower half in order to monitor zonation under influence of tidal regime. The growth of algae was quantified by calculating the percentage of the area that was covered by all algal species together. All 24 squares were visited 6 times during the storm season, on 26-09-2007, 16-10-2007, 16-11-2007, 13-12-2007, 16-01-2008 and 13-03-2008.

A Mann-Whitney-U test (a two-sample non-parametric test) was used to test for differences in algal coverage between investigated areas in the field.

Laboratory Experiment

To quantify early colonization of algae under controlled conditions, a laboratory experiment was carried out using 4 different types of rock (Vilvoordse, Concrete, Basalt and Doornikse), representing typical substrate types. For each type of rock, 3 tiles were cut (4x4x1 cm, except for Doornikse: 2x2x0.5 cm), each subjected to a different treatment: untreated, coated with Elastocoast® or coated with Elastocoast® and sand.

Three triplicate containers were filled with 17 l of freshwater medium (GUILLARD *et al.*, 1975) each. In each container 12 tiles (4 rock types, 3 different treatments per type) were placed vertically in the medium. The medium in the containers was kept at a temperature of 20°C, and was lightly stirred. Light was set to approx. 100 μmol/m^2/s during 8 hours per day. A small inoculum of a diverse mix of freshwater algae (originating from both laboratory cultures and field samples) was added to the containers at the beginning of the experiment.

Figure 1. The location of the Elastocoast site along the Dutch coast. The Zuidbout (insert from Google Earth) is a rudimentary sea dike in the Oosterschelde estuary.

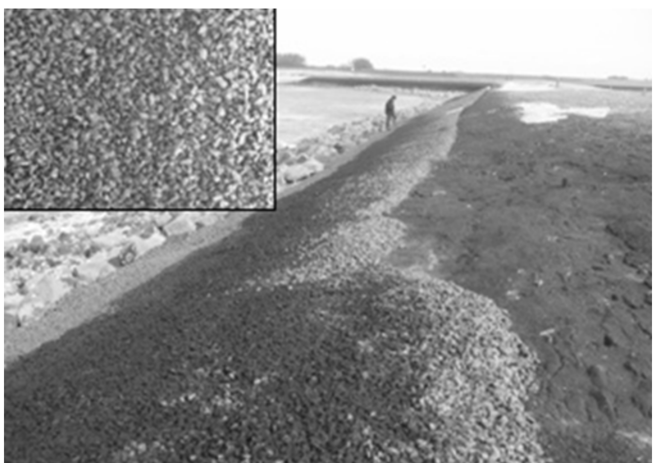

Figure 2. Coverage by algae (dark grey) on the Zuidbout’s Elastocoast revetment (light grey), 25 weeks after placement. Insert: Close-up of Elastocoast® material.

At days 4, 6, 8, 11, 13, 15, 18, 20 and 27 a Pulse Amplitude Modulated (PAM) Fluorometer was used to determine variable fluorescence (F_v) a relative measure of the biomass of the algal community developing on the tiles.

From the increase in F_v during the first 8 days of incubation period, the maximum specific growth rate (SGR) of the algal community was calculated for all rock types and treatments.

The 95% confidence interval (WILSON, 1927) was used to test for differences between the growth rates of all the treatments for the first 8 days of the laboratory experiment.

RESULTS

Field Research

25 weeks after the placement of the new substrates, large patches were colonized by algae. The dominant species were *Enteromorpha minina* and *Fucus spiralis* (Figure 2).

In figure 3, the percentage of surface coverage by algae on the different substrate types and locations during 25 weeks of monitoring is shown. Comparison of the different substrate types in the upper part of the tidal zonation shows that the original toplayer (N) was more densely covered by algae then all other Elastocoast® substrates (E, EV, EZ) (p=0.037). In between upper Elastocoast® areas, the EV area had more coverage then the E and EZ areas (p=0.025). The EZ area had more vegetation then the E area (p=0.025). Comparison of the different treatments in the lower part of the tidal zonation showed no significant difference in algal coverage between the four substrate types (p=0.077), except for E having more vegetation then EV (p=0.046).

Laboratory Experiment

After 27 days of incubation a biofilm comprised of multiple species had formed on all tiles incubated in the laboratory. In Figure 4, the Specific Growth Rate (SGR) of the algal communities developing on the different substrate types and treatments is shown. On Doornikse, algae developed significantly faster when Elastocoast® was applied with sand (p<0.05) On Vilvoordse rock and concrete, the treatment with Elastocoast® and sand resulted in a significantly lower SGR then the treatment with Elastocoast® only (p<0.05). There are no significant differences observed between the other substrate types and treatments (p>0.05).

DISCUSSION

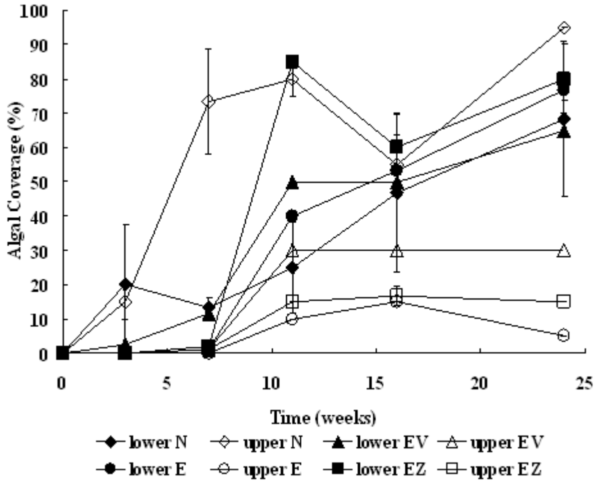

Figure 3. Percentage of coverage by algae of all the areas on the Zuidbout. Shown are the lower and upper halves of the 4 different zones.

In the marine environment, the creation of new unoccupied substrates (which is a form of disturbance) creates colonization opportunities for different marine sessile organisms (ERIKSSON *et al*., 1998 and HOLLOWAY *et al*., 2002). These organisms occupy such a new and empty space by overgrowing or spreading over the newly created patch, and/or by the dispersal of propagules. The size, form, tidal regime and location of the area all determine how a new area is being colonized (AIROLDI, 2003, ERIKSSON *et al*., 1998, HOLLOWAY *et al*., 2002 and KRAUFVELIN, 2007). The Elastocoast® revetment on the Zuidbout provides a rather large unoccupied area, and it was expected that complete recolonization could take a long time (more than 10 years; HA KIM *et al*.,1996 and LEEUWIS, 1988). However, even in winter, the first patches of algal coverage appeared on the Elastocoast® layers. Recolonization may have been favored by a relatively warm winter that season (SLUITER, 2007). The Zuidbout is located in relatively calm waters with a stable tidal regime (LEEUWIS, 1988 and MEYER, 1988), which also might have favored this unexpected early settlement. The colonization of the Elastocoast®

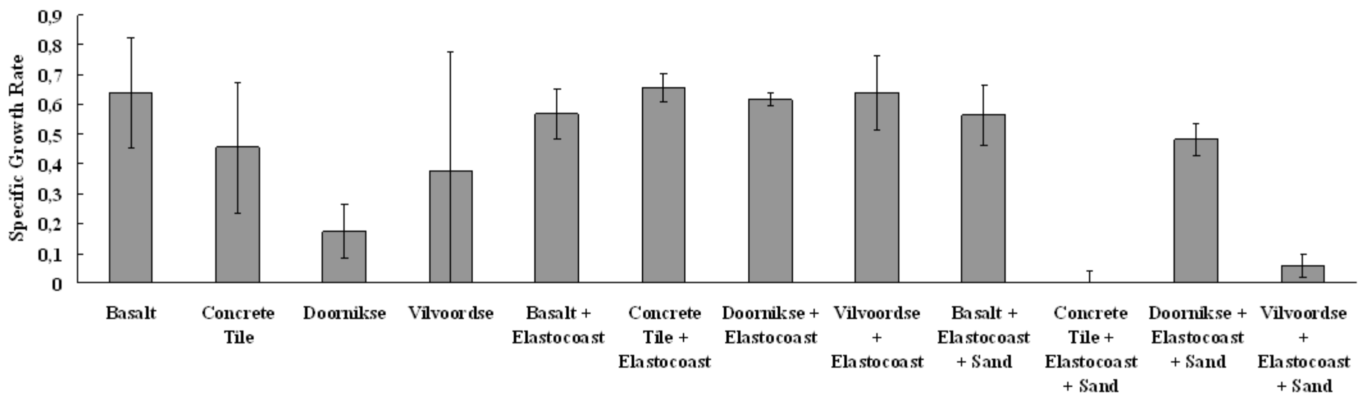

Figure 4 . The Specific Growth Rates (SGR) for the 4 different rock types and 3 different treatments, after 8 days of the experiment.

layer in wintertime suggests that it forms a substrate to which organisms can adhere even under less favorable conditions (low temperature, winds and storms).

Fucus species were observed to be the dominant species colonizing the newly created habitats. *Fucus* species are often found on dikes along the Dutch coasts, growing on substrates such as basalt, concrete and limestone. They play a key role in the marine littoral environment and are important biological components of rocky subtidal areas by creating mosaics of habitats and providing shelter from dehydration, wave battering and thermal stress to many other species (KRAUFVELIN, 2007 and MCCOOK *et al*., 1997). *Fucus* canopy is also important because it can provide a food source for larger animals (KRAUFVELIN, 2007 and SIBONI *et al*., 2007), making full community recovery possible (ATILLA *et al*., 2001, HAUSER *et al*., 2006 and JONES, 1978). The formation of a dense *Fucus* canopy (such as seen in the original vegetation on the Zuidbout) can be a considered as a good indicator of a stable littoral benthic community (LUBCHENKO, 1983). However, it is also demonstrated that communities of *Fucus* species are very vulnerable to environmental changes (ERIKSSON *et al*., 1998). The presence of *Fucus* species on the Elastocoast® revetment therefore indicates that the development of benthic algal communities on Elastocoast® can be comparable to the development on more traditionally used materials as basalt, concrete and limestone.

In this study, algal colonization did not occur homogeneously over the entire test site. Between different substrate types differences in colonization were observed, both in the field and in the laboratory. However, also other factors influenced heterogeneity in the spatial patterns and more or less predictable zonation patterns were observed: a sharp boundary between higher areas with algal colonization and lower parts whithout any vegetation was clearly visible.

This typical zonation pattern (often referred to as the ‘splash zone’ or supralittoral) is observed on many dikes along the Dutch coast (LEEWIS, 1988 and MEYER, 1988) and is caused by species specific responses on the tidal regime. For example, *E. minima* does not grow under the level of average high tide (BREEMAN *et al*., 1982, McCook *et al*., 1997, Meyer, 1988). This predictable zonation pattern can be influenced by wave action, minor differences in substrate (difference in stones and coating as observed in this study), currents and moisture availability (HOLLOWAY *et a*l., 2002, KRAUFVELIN, 2007, LEEUWIS, 1988). All examined areas were above this average high water level, of which the lower halves were right above this level. These areas were submerged for a longer time during high tide than the upper areas. The amount of moisture available on the Elastocoast® layer may therefore be important for early colonizing algae.

Other biological factors also influence the colonization patterns: the mollusks *Littorina* sp. and *Patella vulgata* were seen grazing on the thin layer of early colonizing attached algae. Especially this early stage of algal development is vulnerable to grazing. This may cause patchiness in the distribution of algae in later stages of the development of algal communities (UNDERWOOD, 1998).

This study focused on the recovery of the biological community during wintertime and describes only the early colonization of the algal community. Therefore it is quite likely that changes in the current state of development will occur and that algal coverage will become more homogeneous over time (GONG *et al*., 2005 and HA KIM *et al*., 1996). Since Elastocoast® is an open-pore material, it is also likely that organisms setlle in the deeper layers of the material, which can result in a higher bio-diversity an biomass. However, this was not studied here and further studies to this may be necessary.

For the complete recovery of the biological community ten years or longer may be required (LEEUWIS, 1988). It is therefore proposed to continue monitoring over a longer time span (up to many years) and to extent monitoring to other biological components of the benthic community (meio- and macrofauna species) to provide more solid results regarding ecological suitability of Elastocoast® as protection material on urban coastal structures.

Revetment materials have to meet many requirements. They have to be environment-friendly, strong enough to protect vulnerable coastlines, durable and cost-efficient. All these properties determine whether a material can be used for coastal revetments. These material properties will also have to be tested for Elastocoast.

CONCLUSION

Observation of macro-algae coverage in the field and micro-algae in the laboratory experiment indicate that the polyurethane bonded rock substrate Elastocoast® does not hamper the development of the benthic algal communities on levies and dikes. Since the algae are the basis of the benthic littoral food web, recovery of benthic community after application of Elastocoast® might be expected.

However, the suitability of Elastocoast® is not only determined by the early ecological colonization potential, but also on for example physical characteristics, costs of application and maintenance and integrity of the revetment during exposure to waves over many years.

LITERATURE CITED

AIROLDI, L. , 2003. Effects of patch shape in intertidal algal mosaics: roles of area, perimeter and distance from edge. *Marine Biology*, 143, 639–650

ATILLA, N. and FLEEGER, J.W., 2000. Meiofaunal Colonization of artificial substrates in an estuarine embayment. *Marine Ecology*, 21 (1), 69-83

BAKKER D.P.; BUSSCHER H.J.; ZANTEN J.V.; VRIES J.D.; KLIJNSTRA J.W., and VAN DER MEI H.C., 2004. Multiple linear regression analysis of bacterial deposition to polyurethane coatings after conditioning film formation in the marine environment. *Microbiology*, 150, 1779-1784 (2004)

BAKKER D.P.; KLIJNSTRA J.W.; BUSSCHER H.J., and VAN DER MEI H.C., 2003. The effect of dissolved organic carbon on bacterial adhesion to conditioning films adsorbed on glass from natural seawater collected during different seasons. *Biofouling*, 19, 391-397

BEVERIDGE T.J.; MAKIN J.L.; KADURUGAMUWA J.L. and LI Z., 1997. Interaction between biofilms and the environment, *FEMS Microbiology Reviews*, 20, 291-303

BHOSLE N.B.; GARG A.; FERNANDES L., and CITON P., 2005. Dynamics of amino acids in the conditioning film development on glass panels immerses in the surface waters of Dona Paula Bay. *Biofouling*, 21, 99-107

BIJLSMA, E., 2008. Elastocoast pilots in the Netherlands: Stormseason 2007/2008. Delft, The Netherlands: Delft University of Technology, Master’s Thesis, 93p.

BREEMAN, A. and SINGELENBERG, O., 1982. Een rotskust in Groningen. *Noorderbreedte*, 6 (5)

CASTENHOLZ, R.W., 1960. Seasonal change in the attached algae of freshwater and saline lakes in the lower Grand Coulee, Washington. *Limnology & Oceanography*, 5 (1)

ELASTOGRAN BASF GMBH, 2009. www.elastogran.de/en/content.phtml?siteid=569

ERIKSSON, B.K.; JOHANSSON, G. and SNOEIJS, P., 1998. Long-term changes in the sublittoral zonation of brown-algae in the southern Bothnian Sea. *European Journal of Phycology*, 33, 241-249

GONG, J.; SONG, W. and WARREN, A., 2005. Periphytic ciliate colonization: annual cycle and response to environmental conditions. *Aquatic Microbial Ecology*, 39, 159–170

HA KIM, J. and DEWREEDE, R.E., 1996. Effects of size and season of disturbance on algal patch recovery in a rocky intertidal community. *Marine Ecology Progress Series*, 133, 217-228

HAUSER, A.; ATTRILL, M.J. and COTTON, P.A., 2006. Effects of habitat complexity and abundance of macrofauna colonizing artificial kelp holdfasts. *Marine Ecology Progress Series*, 325, 93–100

HINRICHSEN, D., 1990. *Our Common Seas: Coast in Crisis*. Earthscan, 184p.

HOLLOWAY, M.G. and CONNELL, S.D., 2002. Why do floating structures create novel habitats for subtidal epibiota? *Marine Ecology Progress Series*, 235, 43–52

JONES R.C., 1978. Algal biomass dynamics during colonization of artificial islands: experimental results and a model. *Hydrobiologica*, 59 (3), 165 – 180

JONG DE, D.J., and MEULSTEE C., 1989. Distribution of eelgrasses and large algae in the Oosterschelde and the consequences of the final construction phase of the Oosterschelde barrier to this. *Rijkswaterstaat, The Netherlands*

KRAUFVELIN P., 2007. Responses to nutrient enrichment, wave action and disturbance in rocky shores communities. *Aquatic Botany*, 87, 262-274

LEEWIS, R.J., 1988. De begroeiing van harde substraten in de Oosterschelde en het Grevelingenmeer. *Rijkswaterstaat, The Netherlands*

LEEWIS, R.J., 1988. De begroeiing van kunstmatige harde substraten in de Noordzee. *Rijkswaterstaat, The Netherlands*

LUBCHENCO, J., 1982. Effects of grazers and algal competitors on fucoid colonization in tide pools. *Journal of Phycology*, 18 (4), 544–550

LUBCHENKO, J., 1983. *Littorina* and *Fucus*: Effects of herbivores, substratum heterogeneity and plant escapes during succession. *Ecology*, 64, 1116-1123

MCCOOK L.J. and CHAPMAN A.R.O., 1997. Patterns and variations in natural succession following massive ice scour intertidal seashore. *Journal of Experimental Marine Biology and Ecology*, 214, 121-147

MEYER, A.J. M., 1988. De levensgemeenschappen op harde substraten in de getijdenzone van de Oosterschelde, typologie, kartering, etc. *Bureau Waardenburg, Culemborg, The Netherlands*

PATEL P.; CALLOW N.E.; JOIN L. and CALLOW J.A., 2003. Specificity in the settlement – modifying response of bacterial biofilms towards zoospores of the marine alga *Enteromorpha*. *Environmental Microbiology*, 5, 338-349

GUILLARD; LORENZEN AND NICHOLS, 1975. Protocol for modified Woods Hole (or WC) medium for freshwater culturing of algae (including diatoms) (modified from authors).

SIBONI, N.; LIDOR, M.; KRAMARSKY-WINTER, E. and KUSHMARO, A., 2007. Conditiong film and initial biofilm formation on ceramic tiles in the marine environment. *FEMS Microbiology Letters*, 274, 24–29

SLUITER, R., 2007. Januari 2007: Record zacht, zeer nat en de normale hoeveelheid zon. *KNMI, De Bilt, The Netherlands*

UNDERWOOD, A.J.J., 1998 Grazing and disturbance: an experimental analysis of patchiness in recovery from a severe storm by the intertidal alga *Hormosira banksii* on rocky shores in New South Wales. *Journal of Experimental Marine Biology and Ecology*, 231, 291-306

WILSON, E.B., 1927. Probable inference, the law of succession, and statistical inference. *Journal of the American Statistical Association*, 22, 209-212

YOUNG, M.E., and URQUHART D.C.M., 1998. Algal growth on building sandstones: effect of chemical stone cleaning methods. *Quarterly Journal of Engineering Geology and Hydrogeology*, 31 (4), 315-324

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