

Article

Sustainable Removal of Green Growth on Surfaces: Efficacy of Non-Chemical Alternatives to Algaecides

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Abstract

Chemical green growth removers designed to control algae, which are classified as biocidal products, are used in open-air environments and, in some cases, over large areas such as roofs, façades, fences, or pavements, and can have adverse environmental effects. To minimise the use of green growth removers, users must have access to information on appropriate non-chemical alternatives against the target organisms. In this study, the authors developed an efficacy test for non-chemical green growth removal methods using a high-pressure cleaner with cold and hot water. After determining a dose-response curve concerning the efficacy of high water temperature on green growth control, naturally infested surfaces of a wooden fence and sandstone were treated with different water pressures and temperatures: 15 and 70 °C for both surfaces, 60, 70, 90, and 100 bar for the wooden fence, and 120 and 170 bar for sandstone. The results after six months showed that all treatments on the wooden fence remained highly effective (>96%). The efficacy of the treatments on the sandstone was lower, with the highest efficacy of 90% achieved with cold (15 °C) water and a water pressure of 170 bar. In summary, the methods used demonstrated high efficacy, constituting a sustainable alternative for algaecides. The regreening after six months remained low if thorough removal of the green growth was ensured.

Keywords: algaecides; biocides; environmental contamination; green growth removal; high-pressure cleaner; hot water

1. Introduction

Chemical green growth removers designed to control algae and lichens are used in outdoor environments and, in some cases, for large areas such as on roofs, façades, or pavements. In the European Union (EU), they are regulated as biocidal products under the Biocidal Products Regulation 528/2012. Examples of active substances used in these products are benzalkonium chloride in various chain lengths or nonanoic acid. During these applications, the active substances can leach into the environment in various ways and to different extents [1–3]. Being designed to interact with organisms, they can have adverse effects on the environment. Benzalkonium chloride, for example, has been shown to affect the microbial community in soil and therefore has the potential to lead to antimicrobial resistance in soil [4]. Environmental exposure mainly occurs through runoff after application. Furthermore, these products are frequently applied by spraying, and it is to be expected that the spray mist may also drift into adjacent compartments [1].



Received: 13 July 2026

Revised: 27 August 2026

Accepted: 4 September 2026

Published: 10 September 2026

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The active substances may also be washed out by rainfall. For example, concentrations of benzalkonium chloride in runoff water after roof treatment remain within a range that would affect aquatic insects for up to 13 months [5].

Use of biocidal products needs to be limited to the minimum necessary, and alternative measures should be applied, where possible (Article 17(5) of EU Biocidal Products Regulation 528/2012). While information on the proper and efficacious use of biocidal products is generated during their product authorisation, this information is lacking for alternative measures [6]. In addition, these alternatives do not have to undergo an approval process to prove their efficacy and demonstrate that no unacceptable risks arise from their use. Local authorities, as well as non-professional users, would like to use non-chemical alternatives, but due to the lack of performance data on the efficacy of these alternatives, they do not have the knowledge to replace established chemical products [7]. For other biocidal product applications, research has already been carried out to find effective non-chemical alternatives (for example: [8–10]).

Target organisms found in the green growth on different surfaces, like buildings, and in urban habitats are, for example, green algae of the classes Trebouxiophyceae, Chlorophyceae, Streptophyta, and Charophyceae [2,11,12]. They can lead to aesthetic and structural damage, depending on the building material [13]. A non-chemical alternative for their control is hot water, applied with or without high water pressure. It is well known that these green growth organisms are less heat stress-tolerant when they are hydrated because then they are metabolically active [14]. A clear dose-response curve describing the impact of hot water temperature on microorganisms of green growth has yet to be established, to our knowledge. However, there is already general evidence that temperatures of 70 °C, achieved using microwaves over a period of several minutes on fully hydrated biofilms, resulted in devitalisation of the algae [15]. Both the metabolic products of the biofilm organism and the chemical cleaning of the biofilm roughen the surface and can affect the regrowth positively [16], but mechanical cleaning can also cause damage to the stonework [17].

Several service providers in Germany use heat during their cleaning services for surfaces covered with green growth, lichen, and dirt. The devices always need to be combined with a mechanical tool, like brushes or high water pressure, which are adapted to the treated surface materials. The high-pressure devices can often be adjusted up to 300 bar, and a maximum temperature of almost 100 °C. For non-professional users, it is common practice to use high-pressure cleaners with cold tap water only.

To determine the most efficacious water pressure and temperature for such treatments, the authors developed an efficacy test for non-chemical green growth-removing methods. For this purpose, a dose-response curve was determined for the efficacy of water temperature and impact time on green growth (Section 3.1). Afterwards, efficacious temperatures and pressures were determined on naturally infested surfaces (Section 3.2). The findings show, for the first time, the water temperature and pressure necessary for an efficacious removal of green growth.

2. Materials and Methods

2.1. Dose-Response Curve of Water Temperature and Impact Time for Green Growth Organisms

2.1.1. Establishing Infested Test Surfaces Under Laboratory Conditions

Green covering was obtained from an exterior facade made of metal, from concrete blocks stored outside, and from wooden gates from the property of the Julius Kühn Institute, Germany, using a sponge and water. The green algae in these aqueous solution samples were mainly of the classes Chlorophyceae and Trebouxiophyceae (determination by Oxford Nanopore sequencing technology, Oxford, UK, conducted by [18]). These results are very

comparable to [11] in Germany and partly comparable to the results of [19] in Spain and to results of a study in Western Ireland in that the genus *Chlorella* (class Trebouxiophyceae) was frequently found on stone monuments here as well [12].

For propagation purposes, the aqueous solution was placed on a polyester fleece (VIVAPOL[®]-irrigation fleece, Reimann—Spinnerei und Weberei GmbH, Emsdetten, Germany) in a plastic transport tray (50 cm × 32 cm × 9 cm) under a transparent plastic cover (Sunware B.V., Tilburg, Netherlands), as high humidity is a key factor in the cultivation of green algae [20,21]. The maintenance of high humidity (90–100%) and moderate temperatures below 20 °C represents optimal conditions for green algae growth [21–24]; therefore, a temperature of 15 °C was chosen. Light intensity (170 PPFD) with a blue LED light of 380 nanometres and duration (10 h night; 14 h day) were designed to ensure optimal conditions for green algae growth [24]. In the same way, several transport trays were equipped and placed in a climate chamber (RUMED[®], Rubarth Apparate GmbH, Laatzen, Germany). A daily CO₂ supply was used to increase the CO₂ concentration in the chamber from 0.04% to 0.08% for one hour. Increasing the CO₂ concentration moderately can increase algae growth [25]. A nutrient solution (Ferty 2 Mega, Hauert HBG Dünger AG, Grossafoltern, Germany) was added daily (composition: 16% N₂, 6% P₂O₅, 26% K₂O, 1.6% MgO in a 1.25% solution) as in pre-trials, good growth rates were observed with this solution. The green covering produced this way was placed on pieces of the polyester fleece with a size of 50 cm², each placed in a small plastic box of 10 cm × 10 cm × 5 cm (Baumann Saatzuchtbedarf, Waldenburg, Germany). All boxes were stored in a climate cabinet with a temperature and day/night regime, with CO₂ supply and a daily added nutrient solution, as described above, and had eight weeks to grow. After treatments, the fleece pieces were placed in new, small plastic boxes, covered with a transparent lid, and put back into the climate cabinet under the same conditions as before.

2.1.2. Determination of Dose-Response Curve for Hot Water and Impact Time

The fleece pieces for the different treatments, as well as the untreated control, were rinsed in water to wash away excess green coating. After that, 500 mL of water was heated in a beaker to the desired temperature, and the temperature was maintained. Six different water temperatures (50, 60, 70, 80, 90, and 100 °C) were investigated with impact times of 36 and 72 s. The pieces of fleece covered with green growth were immersed in the water for the respective impact time. All treatments were repeated ten times, always accompanied by an untreated control. After that, each fleece piece was placed in a clean storage box with a transparent lid for further storage in the climate cabinet as before.

2.1.3. Treatments with a Biocidal Product

A treatment with a biocide was selected as a positive control. The purpose was to demonstrate that the test setup works in principle and to evaluate whether the alternative method using hot water can produce a comparable result under the given conditions.

The biocide is authorised in Germany (<https://echa.europa.eu/de/information-on-chemicals/biocidal-products>, accessed on 19 May 2026) for algicidal treatment of mineral and wooden surfaces for non-professional use. The biocide is not approved for the disinfection of fleece surfaces. Nevertheless, the authors assume that the biocidal treatment is suitable for verifying the validity and reliability of the experiment designed to determine the dose-response curve for hot water. The product consists of an emulsifiable concentrate with 207.3 g/L nonanoic acid as the active ingredient. Two concentrations were used: 5% as recommended for wooden surfaces and 15% as recommended for mineral surfaces. The solution was applied with a hand-operated one-litre fine sprayer (Gloria[®] Akku-Feinsprüher

Hydronette li-on, GLORIA Haus- und Gartengeräte GmbH, Witten, Germany) and an application rate of 100 mL/m².

2.1.4. Determination of Efficacy

To determine efficacy, EPPO standard PP 1/117 (weeds on hard and semi-permeable surfaces) [26] was used, which can also be adapted to assess the efficacy of biocidal products. The adapted assessment involves a general estimation of the total green growth cover per defined area and is expressed as a percentage. The green growth portion was determined before treatment, as well as at various points in time after treatment. To do that, regular RGB images (red, green, and blue wavelengths) were taken using a Sony Alpha 6000 camera (Sony Corporation, Tokyo, Japan) with a 3.5–6.5 focal length. The images were analysed using a software analysis program for green coverage ratios from digital photos [27]. The efficacy was then determined by the relation of the green growth portion (ggp) of the treated sample to the green growth portion of the untreated control, with the formula according to [28]:

$$\text{Efficacy (\%)} = (1 - \text{ggp of treatment (\%)} / \text{ggp of untreated control (\%)})) \times 100 \quad (1)$$

The results are expressed as the efficacy of algae control of the treatments, determined at a specific point in time, in the range of 0% (=same green growth as untreated control) and up to 100% (=no green growth).

2.2. Temperatures and Pressures on Organic and Mineral Surfaces

2.2.1. Description of the Cleaning Device

The trials to determine efficacious temperatures and pressures for naturally infested surfaces were conducted by the company “Hans Schulz Gebäudereinigung GmbH Braunschweig, Germany” using the professional equipment of the falch[®] trail jet 15 d (falch gmbh, Blaubeuren-Seissen, Germany) (Figure 1). This company offers professional cleaning of facades, paved paths, and more.

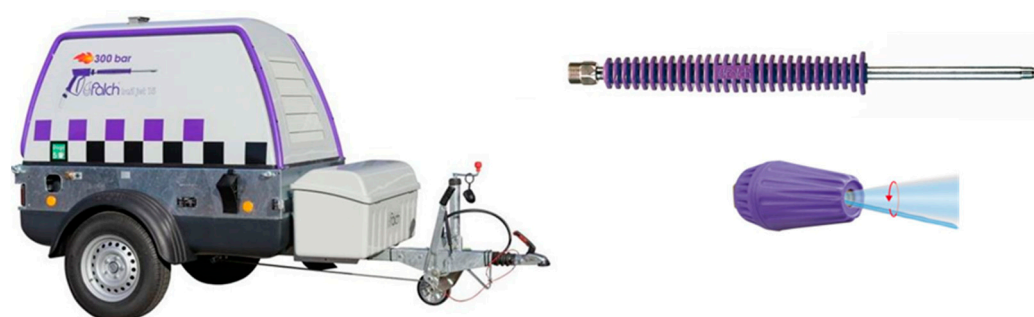


Figure 1. falch[®] trail jet 15 d up to 300 bar and up to 95 °C, lance and nozzle, reproduced with friendly permission from falch[®] gmbh, 2026 [29–31].

The falch[®] device operates at water pressures ranging from 50 to 300 bar. With the instant water heater, water temperatures up to 95 °C can be achieved. To ensure the correct water temperature during trials, the temperature directly at the nozzle was measured and compared with the water heater’s displayed temperature. The results showed that the chosen temperature was maintained both directly at the nozzle outlet and at a distance of 15 cm.

2.2.2. Choice of Test Pressure and Temperature

From several pre-trials testing different pressures on mineral and wooden surfaces, it was concluded that pressures between 60 and 100 bar for wooden surfaces and pressures

between 120 and 170 bar for mineral surfaces are a good compromise between cleaning efficiency and stress placed on the material by pressure. In addition, recommendations from service providers regarding usual water pressure on mineral and organic surfaces were taken into account.

Pre-trials with different temperatures on different surfaces and the information gained from the dose-response curves concerning the lethal impact of temperatures on the green growth organisms were taken into account when setting the tested temperatures for the trials at 15 °C and 70 °C. 15 °C was cold tap water temperature; 70 °C was determined as a sufficiently lethal temperature for the green growth organisms in the laboratory test (see Section 3.1). A benefit of including cold tap water (15 °C) in the test is that the results might not only be relevant for professional cleaning but also for non-professional high-pressure cleaners. Many non-professional high-pressure cleaners lack a water heating system and instead use cold tap water. The chosen pressures can be achieved by commercially available high-pressure cleaners for non-professional users. Additionally, the time necessary to clean each replicate was recorded to assess whether there were differences in the cleaning times until the surface was free of green growth for the different pressure and temperature combinations.

2.2.3. Description of Test Surfaces

To test an organic and an inorganic surface, two naturally infested surfaces were chosen. To be suitable for the trials, the surfaces had to be evenly overgrown. Furthermore, the length of the test surfaces had to be sufficiently long to allow for adequate replicates. Weathering conditions for each replicate had to be approximately the same. This was ensured by only using test surfaces facing the same direction and without inconsistent shading. A slatted fence made of pine near Braunschweig (Germany) was chosen as an organic test surface. The fence was several decades old, not painted, and had never been cleaned. One replicate of a treatment of the wooden fence consisted of 10 fence slats, each with a front size of 5 cm × 100 cm. As a mineral surface, coloured sandstone was chosen near Braunschweig. The sandstone was the base of an iron fence built approximately 100 years ago. Coloured sandstone mainly consists of quartz and hematite, which is responsible for the red colour. The sandstone elements had a front size of 100 cm × 40 cm; one element represented one replicate of a treatment.

2.2.4. Test Set-Up

On the wooden surface of a fence, two water temperatures of 15 and 70 °C with four water pressures of 60, 70, 90, and 100 bar were investigated along with an untreated control, with five replicates each. The mineral surface of the coloured sandstone base of an iron fence was treated with the same temperatures as the wooden fence (15 and 70 °C) but with higher water pressures of 120 and 170 bar and an untreated control. The sandstone trial was conducted with three replicates. The choice of the physical parameters is explained in Section 2.2.2. The cleaning time per treatment was determined and calculated in seconds per m² to provide an overview of the time required for each treatment.

2.2.5. Evaluation of Data

As described in Section 2.1.4, the green growth portion was determined two days, six weeks, and six months after treatment via a digital software program [27]. The efficacy of the treatments was then calculated in relation to the untreated control with the Formula (1) according to [28] two days, six weeks, and six months after treatment.

2.2.6. Statistical Analyses

The statistical analyses were adjusted to the number of data points collected and carried out separately for the slatted fence (five replicates) and the sandstone base (three replicates) as follows:

Slatted fence: statistical analysis was performed using R (version 4.4.0) [32]. The normality of the data distribution was tested for each time point using the Shapiro–Wilk test. When the data met the assumption of normality, an analysis of variance (ANOVA) was conducted to test for differences among treatments. When the assumption of normality was violated, the Kruskal–Wallis test was used as a non-parametric alternative. For the Kruskal–Wallis test, post-hoc pairwise comparisons were carried out using the agricolae package (version 1.3-7) [33] with Bonferroni correction for multiple testing. Data processing and summarisation were performed using the dplyr package (version 1.1.4) [34]. Differences were considered statistically significant at $p < 0.05$.

Sandstone base of iron fence: statistical analysis was performed in R [32] using a two-way analysis of variance (ANOVA) to evaluate the effects of treatment, assessment, and their interaction on efficacy. For the parameter cleaning time, a one-way analysis of variance was performed. Estimated marginal means (EMMs) and 95% confidence intervals (CI) were calculated using the emmeans package (version 1.10.6) [35]. Pairwise comparisons between treatments within assessment times within each treatment were conducted using Tukey-adjusted post hoc tests. Differences were considered statistically significant at $p < 0.05$.

3. Results and Discussion

3.1. Dose-Response Curve Concerning the Efficacy of Water Temperature and Impact Time on Green Growth Control

Dose-response curves were obtained two days after treatment for exposure times of 36 s and 72 s (Figure 2) at the respective water temperatures, as well as for 5% and 15% biocide solutions.

A temperature of 50 °C and a contact time of 36 s did not have a visible effect on the green growth organisms; increasing the time to 72 s at the same temperature, efficacy rose up to over 60% (Figure 2). This is in line with the results of [36,37], showing a higher effect of hot water after longer contact times, already starting from 40 °C. However, the contact times chosen in these studies (5 to 60 min) were too long to be applied to green growth removal techniques.

A temperature of 60 °C and a contact time of 36 s led to an efficacy above 80% two days after treatment, while higher temperatures and/or longer contact times led to an efficacy above 90% (Figure 2). The impact of temperature on green growth at 50, 60, and 70 °C for 72 s is clearly visible on the fleece pieces (Figure 3). An increase in efficacy with increasing temperatures in the range of 20, 40, and 60 °C for six hours was also achieved in other studies on thermal control of hydrated lithobionts (algae, cyanobacteria, fungi, and lichens living on rocks) [14].

The biocide (100 mL/m²) treatment led to a very low and stable green portion two days after treatment (Figures 2 and 3) with 97% efficacy (5% and 15% biocide solution, resp.).

The review study by [15] also showed that thermal control measures at 70 °C were effective at removing lithobionts and were comparable to the applied biocide, which served as the positive control in the study.

Based on our results, it can be concluded that the thermal control of green growth with water temperatures of 70 °C and contact times of 36 or 72 s was comparably effective as the results obtained for the positive control with a biocide.

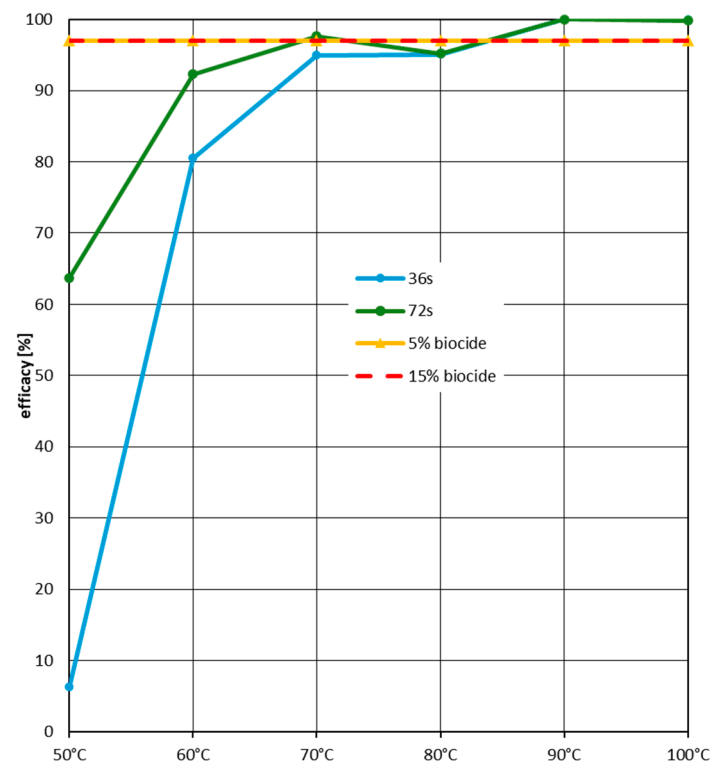


Figure 2. Efficacy of hot water treatment after 36 and 72 s of impact on green growth. The efficacy of the biocide solution of 5 and 15% is also presented as the positive control but does not depend on temperature, as indicated by the x -axis. Assessment two days after treatment, $n = 10$ replicates.

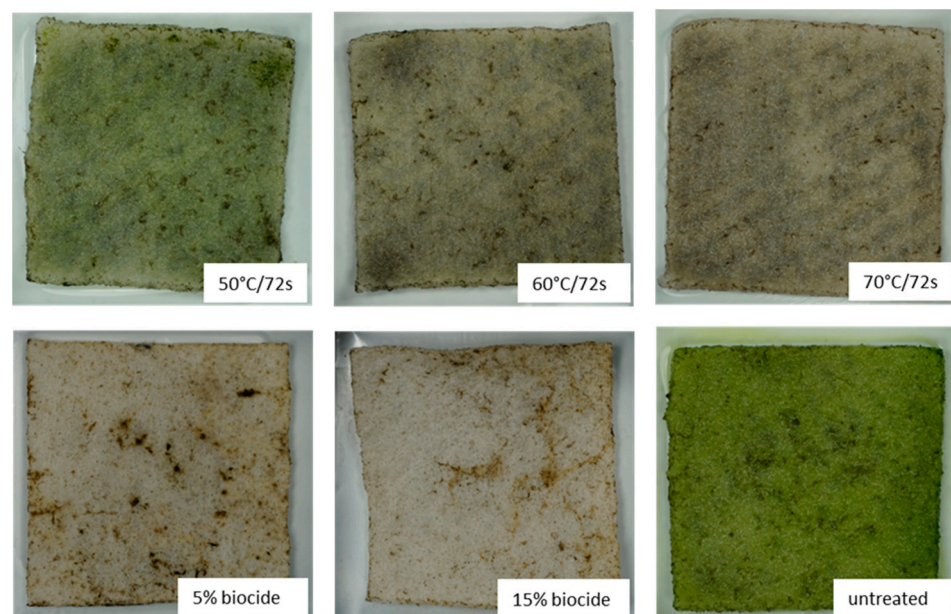


Figure 3. Exemplary pictures of green growth on fleece treated at different temperatures, treated with biocide solutions as positive control, and the untreated control two days after treatment.

3.2. Determination of Efficacious Water Temperatures and Pressures on Organic and Mineral Surfaces

3.2.1. Wooden Fence

Two days after being treated with different water pressures and temperatures, the surface of the slatted fence was free of green growth (Figure 4). All temperature and water pressure combinations were equally effective in terms of the results at this point. The

only difference between the treatments was the time taken for cleaning. The cleaning time increased significantly for lower pressure and cooler water, from 121 s/m² for the treatment 70 °C/100 bar to 165 s/m² for the treatment 15 °C/60 bar.

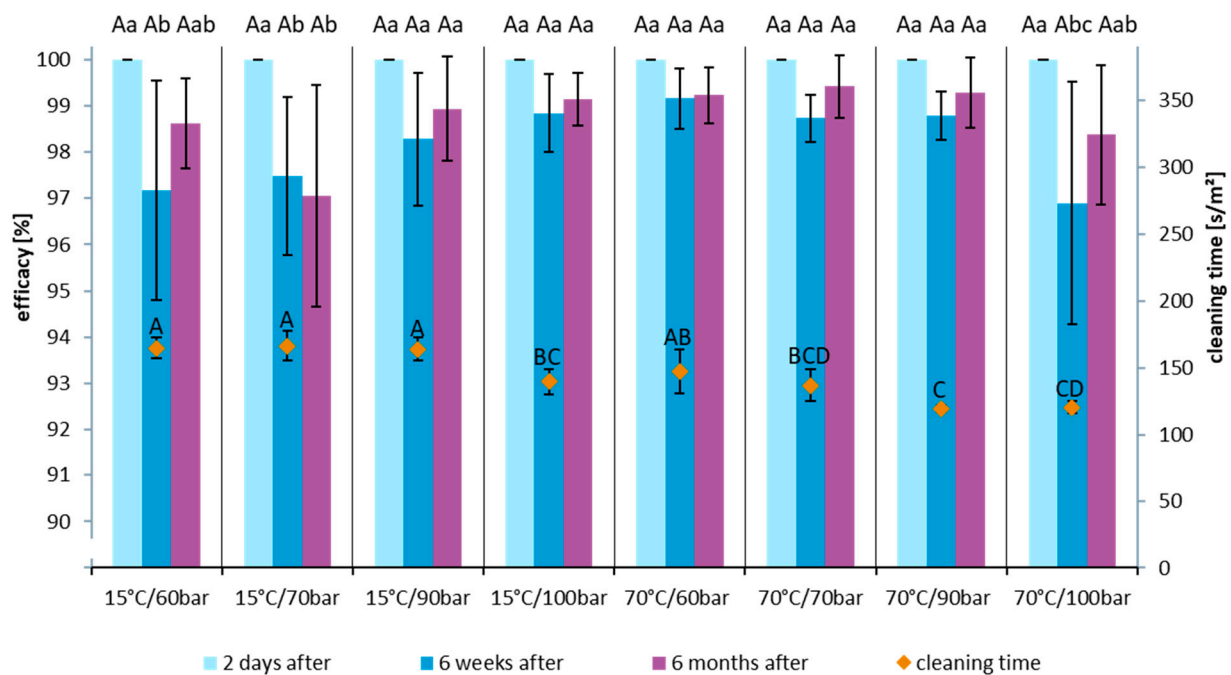


Figure 4. Cleaning time and efficacy of temperature/high-pressure treatments on green growth on a wooden fence after two days, six weeks, and six months. Mean values are presented with the standard deviation. Significant differences in cleaning time are indicated between treatments; bars with capital letters indicate significant differences between the treatments at the given assessment date; bars with lowercase letters indicate significant differences within a treatment. The y-axis is truncated and starts at 90% (n = 5 replicates).

The efficacy stayed at a high level of above 96% for all treatments after six weeks and still after six months (see picture examples in Figure 5). After six months for the treatment 15 °C/70 bar, there was a significant decrease in efficacy in comparison to the efficacy after two days from 100% to 97%, with very sparse regreening visible on the wood. However, between the different treatments at the same point in time, there was no significant difference at any assessment date (Figure 4).



Figure 5. Examples of the fence panels with different treatments after six months.

For long-term efficacy, the green growth must be removed as thoroughly as possible, as many algae and lichens are capable of forming resting stages under unfavourable

conditions [14]. The removal of the organisms is one of the factors responsible for regrowth that can be influenced, unlike the macro- and microclimates, which also play a significant role in recolonisation [38]. Ref. [39] showed partial recovery after 8 days for wet lichens after 24 h thermal treatments at 40 °C. Removal can be done, for example, by high-water pressure, as it was done in this study, or by brushing.

3.2.2. Sandstone Surface

The trial with the treatments of the sandstone also required a longer cleaning time as the pressure dropped and the water cooled, though not significantly: from 153 s/m² at 70 °C/170 bar to 233 s/m² at 15 °C/120 bar, as was similar for the wooden fence (Figure 6).

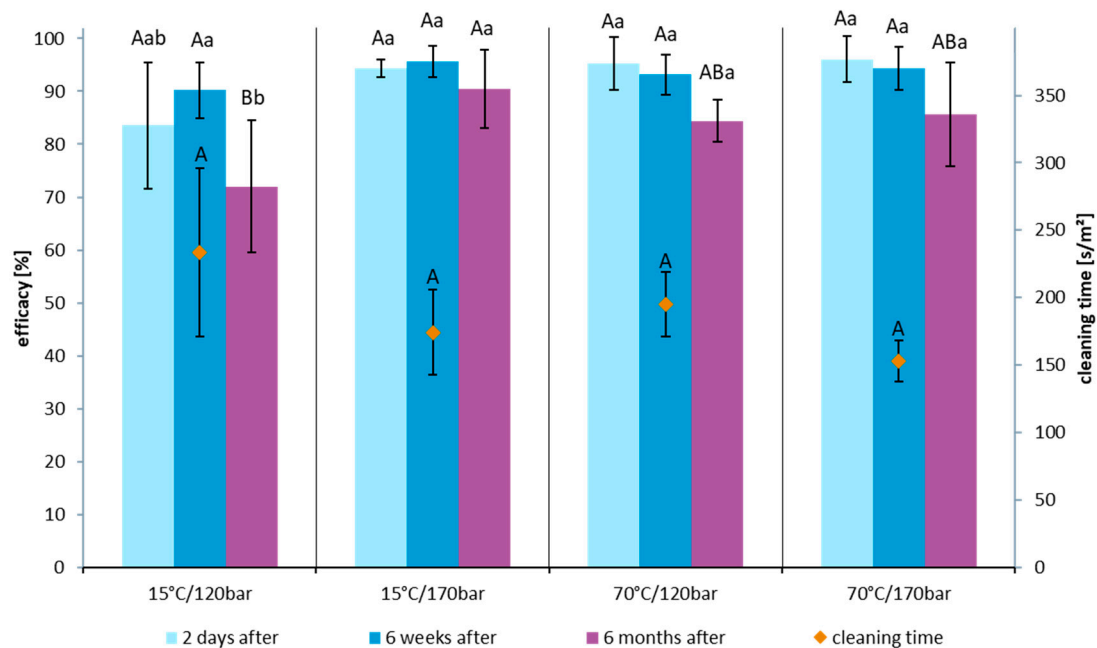


Figure 6. Cleaning time and efficacy of temperature/high-pressure treatments on green growth on sandstone. Mean values are presented with the standard deviation. Significant differences in cleaning time are indicated between treatments; bars with capital letters indicate significant differences between the treatments at the given assessment date; bars with lowercase letters indicate significant differences within a treatment (n = 3 replicates).

Two days and six weeks after the trial, treatments at 15 °C/170 bar, 70 °C/120 bar and 70 °C/170 bar showed an efficacy of around 95%, while the treatment at 15 °C/120 bar had an efficacy of 84% and 90% only (two days and six weeks after the trial, respectively). However, there were no significant differences in efficacy between the treatments. In all treatments, the green growth could not be completely removed (Figures 6 and 7).

Six months later, the highest efficacy was 90% (15 °C/170 bar), which differed significantly from the lowest efficacy of 72% (15 °C/120 bar). However, there were no significant differences for the treatments at 70 °C/170 bar (86% efficacy) and 70 °C/120 bar (84% efficacy) compared to any other treatment at this point.

This experiment confirms that there is a relationship between water pressure and water temperature concerning the cleaning time: to achieve a similarly clean result, cleaning with cold water at the same pressure takes longer than with water heated to 70 °C. The sandstone surface treated with cold water and the lowest pressure will regreen in the long-term assessment (Figure 7). The beneficial effect of temperature on the effective removal of wet lichen from stone surfaces has also been described by [39], although applying much longer contact times.

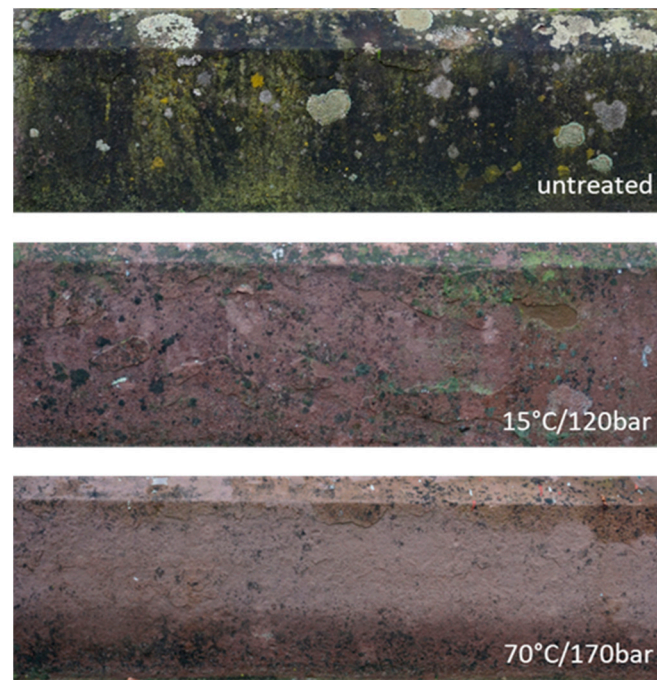


Figure 7. Examples of sandstone segments with different treatments after six months.

3.2.3. Overall Discussion

Similarities between results for the two surfaces are few; in both trials, with the slatted fence and the sandstone, it could be observed that to achieve a similarly clean result, cleaning with cold water at the same pressure takes longer than with water heated to 70 °C. The regreening of the sandstone seems somewhat easier after treatments with cold water and low pressure (120 bar), showing a significant difference from cold water and high-pressure (170 bar) treatment. However, at the wooden fence, efficacy is not significantly lower than that of hot water and high-pressure treatment if efficacy after six months is compared between the treatments. Another study concluded that this might not only be due to a higher mortality of algae at higher temperatures but might also be linked to better detachment of algae after treatments at higher temperatures [40]. By simultaneously applying high-pressure cleaning and hot water, algae and lichen might be removed to a greater extent. This mechanical removal of the green growth is also key to avoiding regrowth. Since there was no significant difference among the different tested pressures at 70 °C water temperature, it could not be verified whether the green growth was only removed by the mechanical treatment with water pressure or whether it was also controlled before the detachment.

Literature on hot water and pressure treatments for controlling green growth on exterior mineral and organic surfaces and on their efficacy is rare. However, research has been conducted on biofilms in heritage conservation on mineral surfaces and their removal [41]. Here, on mineral surfaces, the combination of different methods, for example, mechanical cleaning with a scalpel followed by laser treatment, is often recommended for better efficacy [15,40]. To reduce the use of biocidal products, ref. [42] also recommends water and brushing, as this combination seems sufficiently effective. As long as the green growth organisms are not completely mechanically removed from the mineral surfaces, it is very likely that regrowth will start again, where both the climate and the microclimate play a role [38].

The study was conducted with green growth consisting of different species (see Section 2.1.1). This approach is comparable to other studies using green growth collected

outdoors [40,42]. As only a mixed population of different algae species was tested, no species-dependent conclusions can be derived regarding the efficacy of the method.

If hot water is used for the treatment, non-target organisms might be affected if they cannot avoid the heat by moving away. To approach this topic, the authors conducted a pre-trial. The experiment used worst-case conditions: application of 100 °C hot water (12 L/m²) on loose sand as treated substrate (5% water content). Temperature was measured at different depths in the sand. Data showed that there would be a high risk to non-target organisms directly on the treated surface with temperatures up to 80 °C and still a risk down to 5 cm depth to soil organisms with a temperature of 40 °C for 4.5 min. The temperature at a depth of 10–20 cm was only slightly increased. Considering that this set-up represented a worst case, the risk for non-target organisms after the treatment of vertical surfaces seems low, as water cools down during run-off. Horizontal surfaces treated with hot water would normally not have a sandy surface but would rather be paved. The stones would already absorb a high quantity of energy, reducing the temperature in deeper soils. Based on the results and considering the non-persistent nature of hot water, the risk for non-target organisms seems acceptable. In cases of sensitive environments, cold water can be used as it is sufficiently effective.

4. Conclusions

The dose-response curve shows that water temperatures above 70 °C have comparable efficacy on green growth on polyester fleece as a biocidal product that is authorised for green growth removal on wooden and mineral surfaces.

In the trials with naturally infested surfaces, different combinations of water pressure and temperature were tested. It can be concluded that 70 °C leads to a shorter cleaning time than cold (tap) water, regardless of the surface type or pressure applied. If thorough mechanical removal of green growth was ensured, regreening after six months stayed at a low level.

Based on the results, the authors recommend the following device parameters for the efficacious and sustainable removal of green growth. If time is a key factor, raising the water temperature to 70 °C can improve cleaning speed.

- Wooden structures: 15 °C at 60 bar water pressure—These parameters showed high efficacy while reducing the stress on the wood and reducing the energy needs of the method.
- Sandstone structures: 15 °C at 170 bar water pressure—Again, these parameters showed high efficacy while reducing the stress on the inorganic material and energy needs of the method.

The methods demonstrated high efficacy, constituting a sustainable alternative to biocidal algicides.

Author Contributions: All authors contributed to this work in conceiving and designing the experiments. Conceptualisation, validation, writing—review and editing, and supervision, S.W.; formal analysis, investigation, writing—original draft preparation, visualisation, and project administration, U.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the German Environment Agency (Umweltbundesamt) through the project FKZ 3723 65 4020. The views expressed herein are those of the authors and do not necessarily represent the opinion or policy of the agency.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Acknowledgments: The authors would like to thank Sabrina Kraus, Katja Michaelis, Marie Reppe, and Alexandra Friesen for their valuable comments and constructive feedback during the scientific review of this work. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

°C	Degree Celsius
CO ₂	Carbon dioxide
ggp	Green growth portion
JKI	Julius Kühn Institute
K ₂ O	Potassium oxide
MgO	Magnesium oxide
N ₂	Nitrogen
P ₂ O ₅	Phosphorus pentoxide
PPFD	Photosynthetic photon flux density (μmol/m ² /s)
RGB	Red, green, blue wavelengths

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