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Technical Report 192

# Controlling the invasive moss *Sphagnum palustre* at Kaʻala, Island of Oʻahu

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**Abstract**

*Sphagnum palustre*, a bog moss, was purposely introduced to what is now the Ka‘ala Natural Area Reserve on O‘ahu in the 1960's from the Kohala area of the Big Island of Hawai‘i, where it is indigenous. Though *S. palustre* cannot produce spores, over a 43 fold increase in the size of the core infestation has been observed between 1997 and 2013. Through vegetative reproduction, *S. palustre* now occupies an area estimated at 17.3 acres.

When exposed to three herbicides SAFER Moss & Algae Killer, Lilly Miller Worry Free Moss & Algae Control and St. Gabriel’s Moss Killer (SGMK) in a greenhouse setting, *S. palustre* only responded to SGMK. It contains the active ingredients clove oil and sodium lauryl sulfate. In a growth chamber, we tested extremely low doses of SGMK (the recommended label rate is 25-33% SGMK diluted in water), between 0.3 - 5.0% concentration SGMK solution in water, on healthy *S. palustre.* Within 48 hours 100% mortality was achieved at concentrations greater than or equal to 1.2% SGMK solution.

In the field, we treated *S. palustre* with a 2.5, 5 and 7.5% SGMK solution. The solution was applied at a rate of one liter solution per meter square of moss. Results nine months post-treatment showed only the highest concentration SGMK tested (7.5%) significantly reduced *S. palustre* cover over the control group. Even this dose left close to half of the target pest alive (mean survival = 49% $\pm$ 11% SEM). From this work, we concluded that higher field doses were needed to achieve adequate moss control.

To compare the efficacy of manual removal of moss against that achieved using a 10% and 20% solution of SGMK and to evaluate impacts to non-target species, we established 40, one meter square plots within the infestation (10 replicates per treatment plus a control). Impacts to non-target species were measured using stem counts of plants less than one meter. A significant reduction in *Metrodsideros polymorpha* was evident at the 20% SGMK concentration. Though differences were not significant, reductions in the other three common native species measured (*Cibotium* spp*., Dianella sandwicensis* and *Vaccinium calycinum*) were, on average, higher in the manual removal and 20% SGMK treatments compared to either the control or 10% SGMK group at six months. At 1.5 years, all three treatments effectively reduced *S. palustre* cover compared to the control group. Given that the 10% SGMK was found to be as effective as the higher dose and exhibited fewer non-target impacts, this is the treatment currently recommended and being actively used for control of *S. palustre.*

**Introduction**

Compared to other plant and animal threats, invasive mosses have received little attention in Hawai‘i. On the Island of Hawai‘i, *Sphagnum palustre* occurs naturally across an area <200 sq km at elevations >800 m where it is indigenous (Karlin *et al.* 2012). Due to its utility as a potting medium for orchids and as a substrate for propagating seedlings, people have moved *S. palustre* so that its current distribution, even in its indigenous range, is much greater than it would be naturally (Karlin *et al.* 2012). Sometime in the late 1960s, a member of the University of Hawai‘i at Mānoa Department of Botany purposely transplanted material from Kohala on the Island of Hawai‘i to the top of Ka‘ala (elevation: 1224 m) on the Island of O‘ahu , where it established and spread (Hoe 1971, D. Vitt *pers. comm.*). Ka‘ala is one of the most pristine, intact wet forest ecosystems on O‘ahu. It provides habitat for four endangered plant species (*Cyanea acuminata, Labordia cyrtandrae, Phyllostegia hirsuta and Schiedea trinervis)*, one endangered insect species (*Drosophila substenoptera*), one endangered bird species (*Vestiaria coccinea*) and one endangered snail species (*Achatinella mustelina*) (O‘ahu Army Natural Resource Program Staff 2009).

*Sphagnum palustre* does not reproduce sexually in the Hawaiian Islands (Karlin *et al.* 2012). Its spread is accomplished through vegetative reproduction and intentional or accidental transport of plant material by people, and possibly, feral ungulates. *Sphagnum palustre* has a distribution range that extends into warm-temperate zones which is unusual in that most *Sphagnum* species are found in cold regions (Vitt *et al.* 1975). Fukuta (*et al.* 2012) showed that the optimum temperature for *S. palustre* growth is approximately 20°C (67°C). Indeed, data from weather stations at Kaʻala show this to be a frequently achieved daily temperature (D. Beilman *unpub. data*). In addition, unlike some other species of bog moss which are intolerant to mechanical damage, *S. palustre* showed 80% recovery after extensive trampling (Moyle 1983).

By 1995, *Sphagnum palustre* spread at Kaʻala was worrisome. Karlin and Andrus (1995) wrote: "The species has thrived in the cloud forest it was introduced to, so much so that it endangers the ecological balance of the native ecosystem … It forms an extensive carpet this evidently retards regeneration by the native cloud forest overstory species." The infestation crosses land owned by multiple agencies (the U.S. Army, the Board of Water Supply and the Hawaiʻi Department of Land and Natural Resources (DLNR) Natural Area Reserves System (NAR) making a collective response difficult to coordinate (Fig. 1). To facilitate public access while reducing trampling, DLNR constructed a 750 m boardwalk through Kaʻala bog. *Sphagnum palustre* is established along this access route illustrating the ease with which it is spread along trails. It was likely moved by feral pigs, natural resource conservation staff attempting to control the pigs and various people harvesting growing media (T. Takahama *pers. comm*.). Although the exact rate of growth is only now under investigation, it appears to be more rapid than in its indigenous habitat (Beilman *et al.* 2014). In 1989 or 1990, the distribution of the moss was estimated to be between 30 and 50 square meters (T. Takahama *pers. comm*.). Later in 1997 a visiting biologist (Clarkson 1997) described *S. palustre* as covering "a narrow swathe up to six feet wide, along virtually the whole length of the boardwalk." If this latter estimate is correct, *S. palustre* increased over 43 fold in 16 years.

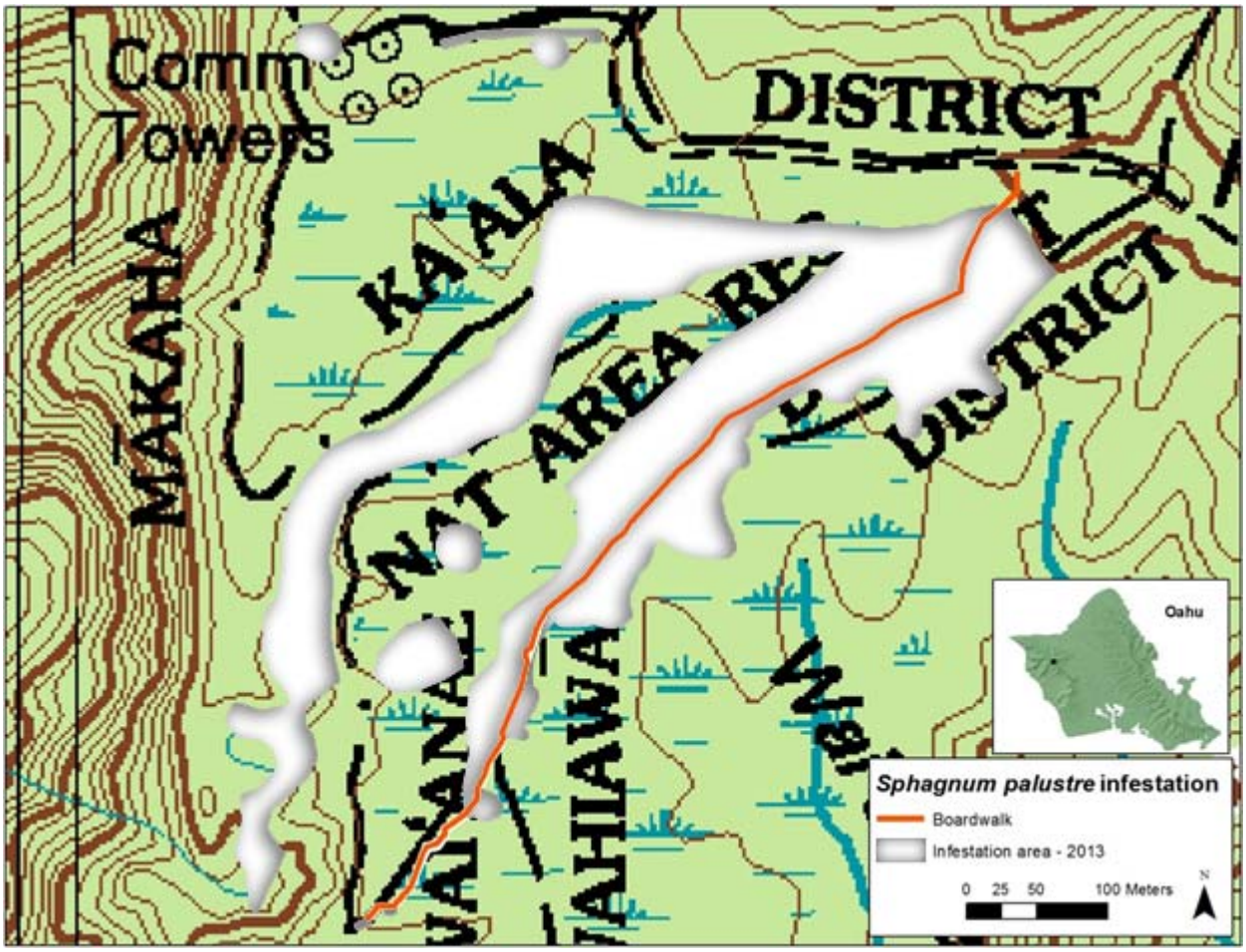


**Figure 1**. *Sphagnum palustre* distribution on O'ahu in 2013. Property on the Northwest side of the Boardwalk belongs to DLNR and Board of Water Supply, property to the Southeast is owned by the Army

*Sphagnum palustre* impacts in Hawai'i are not well documented; nonetheless, bryologists consider it a threat to endemic bryophytes (Waite 2007). Results of a formal Weed Risk Assessment following the model developed by Daehler (*et al.* 2003) demonstrate *S. palustre* is "likely to be invasive in Hawai'i and on other Pacific Islands" (Clifford & Chimera 2009). Elsewhere, *Sphagnum* species are known to strongly modify their habitat. *Sphagnum* has morphological attributes which favor the formation of highly-saturated, heat-retaining, nutrient-poor, acidic soils. These conditions enhance their growth at the expense of vascular plant growth (Van Breeman 1995). In an informal report (1997) of her trip to Ka'ala NAR, Clarkson wrote "pH measurements by Judy {Drexler, USDA Forest Service} revealed that the pH of the substrate of non-*Sphagnum* areas was about 4-5, but under *Sphagnum*, it was considerably lower. *Sphagnum* has the potential to change the Ka'ala bog ecosystem ." In this same report, control methods included "a concerted hand eradication program … with regular follow-ups to ensure removal of fragments/populations that were missed." In addition to the removal of moss by hand, DLNR attempted some chemical control of moss using bleach (Karlin *et al.* 2012) and the O'ahu Army Natural Resource Program (OANRP) tried smothering moss with wood chips. These attempts had minimal effect on curbing moss spread. No single method was deemed safe, effective, and feasible over large areas without undesirable impacts. In 2008, OANRP began a systematic investigation to find a control method for *S. palustre* that met all of these criteria.

Consultation with the Hawai‘i Department of Agriculture (HDOA) pesticides branch (L. Kobashigawa *pers. comm.*) narrowed our list of potential moss control products (bryocides) to those formulated specifically for the control of moss, were registered within with State of Hawai'i, and which, preferably, contained active ingredient(s) exempt from Environmental Protection Agency (EPA) registration. EPA exemptions are provided for products which meet certain minimum risk requirements under section 25(b) of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). This latter class of pesticides has a reduced risk of harming non-target organisms. EPA states "their ingredients, both active and inert, are *demonstrably* safe for the intended use." (EPA Staff 2014) Using these constraints, we identified three bryocides for preliminary screening in the greenhouse (Table 1).

| Trade name | Manufacturer | Active Ingredient(s) (a.i.) |
|---|---|---|
| SAFER® Moss & Algae Killer | Woodstream Corporation Lititz, PA | potassium salts of fatty acids* |
| Lilly Miller® Worry Free® Moss & Algae Control | Lilly Miller Brands, Walnut Creek, CA | sodium lauryl sulfate, citric acid |
| St. Gabriel's Moss Killer | St. Gabriel Organics, Orange, VA | clove oil, sodium lauryl sulfate |

**Table 1.** Products screened in the greenhouse for ability to kill *S. palustre*.

*= Not exempt under section 25(b) of FIFRA

In September 2008, we harvested *S. palustre* from Ka‘ala and put it into four plant flats measuring 91 by 30 centimeters (cm). The moss was approximately eight cm deep in each flat. The flats were maintained for one week in the greenhouse then sprayed with one of the three bryocides at the label rate (a single flat was sprayed with water to serve as a control). After three days all flats remained green and healthy except for the one treated with St. Gabriel's Moss Killer (SGMK) (Fig. 2) which was brown, leached of chlorophyll, and apparently dead. We then proceeded with a laboratory and field study to investigate the efficacy and potential non-target impacts of SGMK compared to manual removal of moss.


**Figure 2.** SGMK product label and directions for use.

**Materials and Methods**

We carried out experiments in a growth chamber under controlled settings to determine the minimum concentration of SGMK required to kill *S. palustre*. Using results from the laboratory experiments, we then tested these low doses in a field setting. Here, we refer to this experiment on the minimum threshold of SGMK efficacy as Experiment I.

We investigated the efficacy of manual removal (hand pull) of *S. palustre* against that achieved with the application of higher doses of SGMK based on the label. An important component of this experiment was to document any non-target impacts to native vascular plant species attributable to each control method. Here, we refer to this comparison of control methods as Experiment II.

*Experiment I*

In order to determine the lowest concentration of SGMK product needed to kill *S. palustre*, we harvested healthy *S. palustre* from Ka'ala on August 6, 2009, and maintained it for one week in a growth chamber at the University of Hawai'i at Mānoa (Temp. 67° F; 12 hour light/dark cycle) prior to testing.

Replicates consisted of three strands of healthy (green) *S. palustre*, one inch long, placed in a petri dish with moist filter paper. Forty-two dishes of *Sphagnum* were prepared in this manner, arranged in rows and randomly assigned to 1 of 5 SGMK treatments plus a control group (Fig. 3).

**Figure 3.** Arrangement of dishes and group assignments prior to treatment. Note that all *S. palustre* was alive prior to treatment and that treatments were randomized within each column for a total of 7 replicates per group.

Numeric codes written on petri dish covers corresponded to the following treatment groups:

1: No treatment (water only)

2: 75 ml SGMK product (5.25 ml a.i.) mixed with 1,425 ml of water (5% concentration)

3: 37.5 ml SGMK product (2.6 ml a.i.) mixed with 1,462.5 ml of water (2.5% concentration)

4: 19 ml SGMK product (1.33 ml a.i.) mixed with 1,481 ml of water (1.2% concentration)

5: 9.5 ml SGMK product (0.67 ml a.i.) mixed with 1,490.5 ml of water (0.6% concentration)

6: 5 ml SGMK product (0.35 ml a.i.) mixed with 1,495 ml l of water (0.3% concentration)

Treatments were applied by dipping moss for one second in SGMK solution (control group dipped in water only) after which the strand was returned to the petri dish. Moss was scored as either green (alive) or brown (dead). Thus, a dish with no living *S. palustre* received a score of 0%, while one with all three strands alive received a score of 100% (Fig. 4). Moss color was recorded one hour post treatment and then every two days over a period of two weeks (August 12-26, 2009).

**Figure 4**. Example of color changes due to treatment.

To compare efficacy of various concentrations of SGMK solution in a field setting we followed plots for nine months starting September 2009. We delineated 40 plots, each one meter square, on the southeast side of the boardwalk at Ka'ala. Plots were not evenly distributed through the infestation because we restricted the experiment to Army land. All plots were at least two meters from the next nearest plot and one meter from any trail. Plots were fully invaded by *S. palustre*, and this cover was at least 90% green (clearly alive) immediately prior to treatment (Fig. 5). There were 10 replicates per treatment group. Each randomly received one of four treatments:


**Figure 5.** Typical invaded plot showing complete, healthy cover of *S. palustre.*

1: Control group (no treatment)

2: 25 ml SGMK product (1.75 ml a.i.) mixed with 975 ml of water (2.5% concentration)

3: 50 ml SGMK product (ml 3.5 ml a.i.) mixed with 950 ml of water (5% concentration)

4: 75 ml SGMK product (ml 5.25 a.i.) mixed with 925 ml of water (7.5% concentration)

Each treatment was applied to 10 plots; however, some substitutions were made following the accidental contamination of four of the plots with a 20% SGMK solution three months into the study. Two contaminated plots fell within the 7.5% treatment and two were from the 2.5% treatment. At that time, we established four new plots, treated them with either a 2.5% or 7.5% SGMK solution and used efficacy data obtained from these four new plots nine months post treatment (August 2010) in lieu of that from the contaminated plots.

We tested SGMK at rates which differed somewhat from the label (Fig. 2) which reads: “Add the desired amount of Moss Killer Concentrate at a 3:1 ratio; 3 parts water to one part Moss Killer [25% concentration] … typically 35-75 gallons of spray solution per acre.” While we used concentrations well below the 3:1 mix ratio, we exceeded the “typical” amount of spray solution per unit area. This is allowable because SGMK is considered a minimum risk product and is exempt from FIFRA. We also consulted with HDOA (L. Kobashigawa, *pers. comm*.) and with the manufacturer (B. Welborne, *pers. comm*.), to make sure rates tested were not in violation of the label. *Sphagnum palustre* is highly

absorbent and hydrophilic requiring substantial SGMK solution for adequate wetting. By adding blue dye to water, we found one liter was barely satisfactory to cover one square meter. SGMK is typically used for relatively sparse moss infestations such as that pictured on the label (B. Welborn *pers. comm*.), not the one meter deep hummocks of continuous *S. palustre* affecting Ka‘ala (Fig. 6).

**Figure 6.** *Sphagnum palustre* hummock.

Efficacy was evaluated using percent cover estimates of living (green) *S. palustre* remaining at nine months post-treatment compared against other treatments. Differences due to treatment were analyzed using a one-way analysis of variance (ANOVA) followed by a Tukey’s honestly significant differences test (Tukey’s HSD). Data were analyzed with Minitab Release 14 software of Minitab Inc. (Ryan *et al*. 2005). Significance during hypothesis testing was characterized by p-values less than 0.05.

*Experiment II*

To compare efficacy of various control methods and to assess non-target impacts attributable to those treatments, on October 2008 we delineated 40 plots, each one meter square. Plots were laid out according to the same conditions described for the field trial portion of Experiment I (*e.g*. locations of plots in relationship to one another, and moss cover). Each randomly received one of four treatments:

1: No treatment (control group)

2: Manual removal (hand pulled, bagged, and removed from field) of all living (green) *S. palustre*

3: SGMK at a rate of 300 ml product (21 ml a.i.) mixed into 1,200 ml of water and applied to one square meter of moss (20% concentration)

4: SGMK applied at a rate of 150 ml product (14 ml a.i.) mixed into 1,350 ml of water and applied to one square meter of moss (10% concentration)

Efficacy was evaluated using percent cover estimates of living (green) *S. palustre* remaining at six months (May 2009) and 1.5 (July 2010) years after treatment compared against other treatments and the control group.

Bryocide was applied using a hand pump sprayer and Turf Mark Blue dye (Becker Underwood, Inc., IA) so that applicators could clearly see complete treatment areas. The attached wand allowed the applicator to more accurately target the moss with minimal overspray onto non-target plants (Fig. 7).

**Figure 7**. OANRP staff treating moss with SGMK.

Impacts to non-target species were measured using stem counts of vascular plant species less than one meter tall, one week before compared to those six months after (May 2009) treatment. Larger size classes (> 1m) were excluded from analysis because the majority of the plant didn't come into contact with any of the treatments. Species which occurred in fewer than seven plots (of each treatment) were excluded from the analysis due to small sample size. Four native plant species were assessed for potential negative impacts from the treatment: *Dianella sandwicensis*, *Cibotium spp., Metrosideros polymorpha* and *Vaccinium calycinum.*

SGMK efficacy and changes in stem count for each of the four species due to treatment were analyzed using an ANOVA followed by a Tukey's HSD. Data was analyzed in the same manner as described for Experiment I.

**Results**

*Experiment I*

In a laboratory setting, doses as small as 0.3% concentration of SGMK resulted in >50% mortality at 48 hours (Fig. 8). Moss survival at that time was significantly reduced in all SGMK treatments compared to the control (Kruskal-Wallis test: H=0.04, df=5, P=0.000.). Only the lowest concentration of SGMK (0.3%) failed to kill 100% of the moss and showed signs of recovery at two weeks. SGMK at concentrations 1.2% and above resulted in 100% mortality after 48 hours. SGMK at concentrations 2.5% and above showed browning within one hour of application. Results from this work suggested 5% SGMK would be more than adequate to achieve suppression in the field.

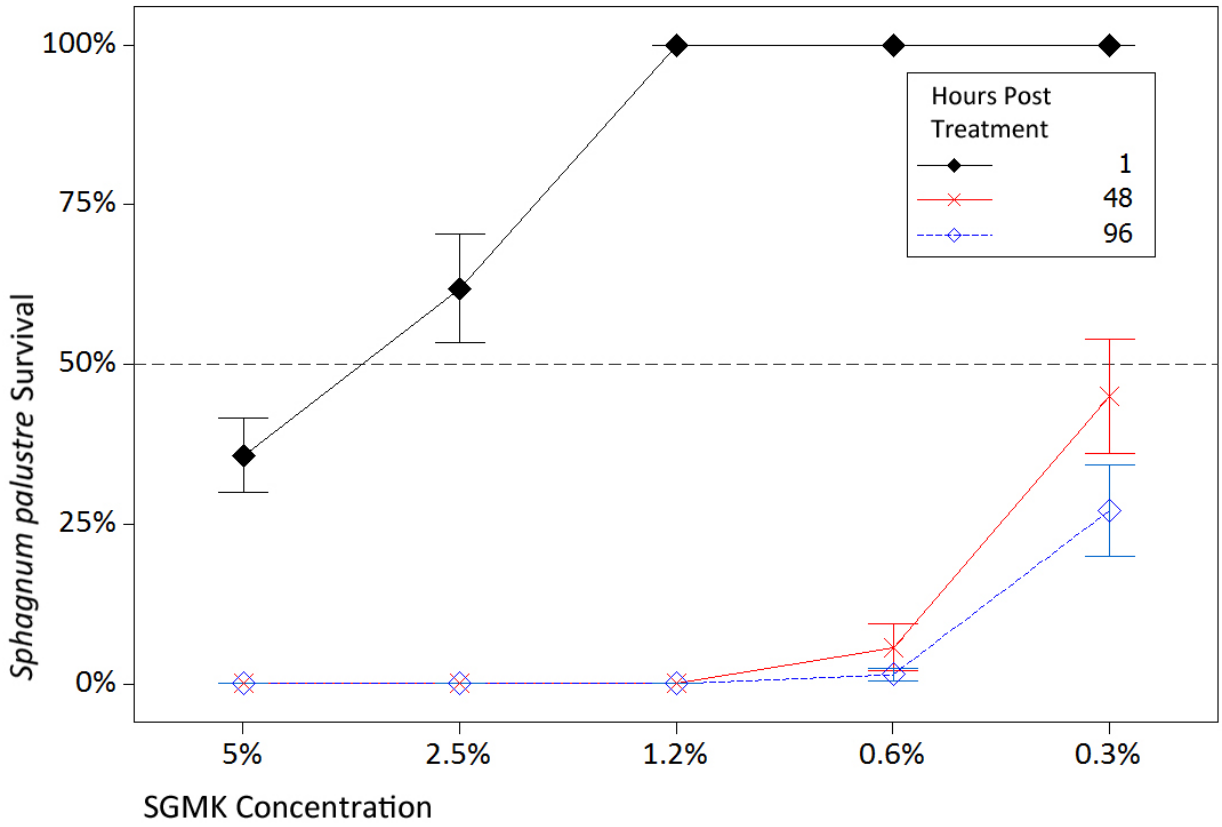


**Figure 8.** *Sphagnum palustre* mortality at one, 48 and 96 hours post treatment when exposed to declining concentrations of SGMK. Bars are + 1 SEM.

Despite the laboratory findings, similar levels of mortality were not realized in a field setting (Fig. 9). Results nine months post-treatment showed only the highest concentration of SGMK solution tested (7.5%) significantly reduced *S. palustre* cover over the control group, and even this dose left close to half of the target pest alive (one-way ANOVA, followed by Tukey's HSD ($F$ (3, 43) = 9.67, $p$ = 0.000).

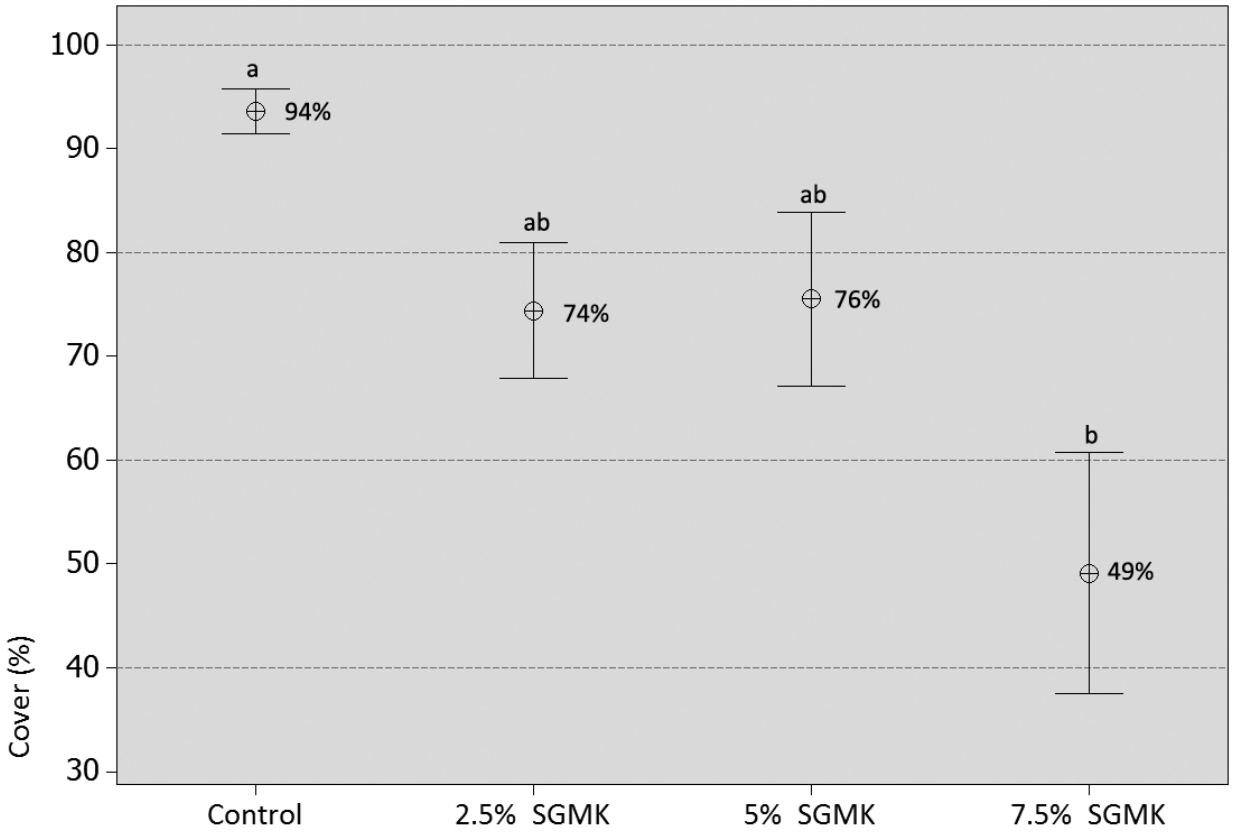


**Figure 9**. *Saphgnum palustre* cover in treatment vs. control plots. Significant differences between groups indicated by letters. Bars are ± 1 SEM.

Based on the findings of the field study, we concluded that concentrations of SGMK higher than 7.5% were needed to achieve moss control.

*Experiment II*

One-and-a-half years post-treatment, *S. palustre* cover remained significantly depressed in treatment plots (manual removal, 10% and 20% SGMK) compared to the control (Fig. 10). No differences between the three treatments were evident and all differed significantly from the control group ($F$ (3, 41) = 72.26, $p$ = 0.000). This was a distinct improvement over the best control method (7.5% SGMK) found in Experiment I.

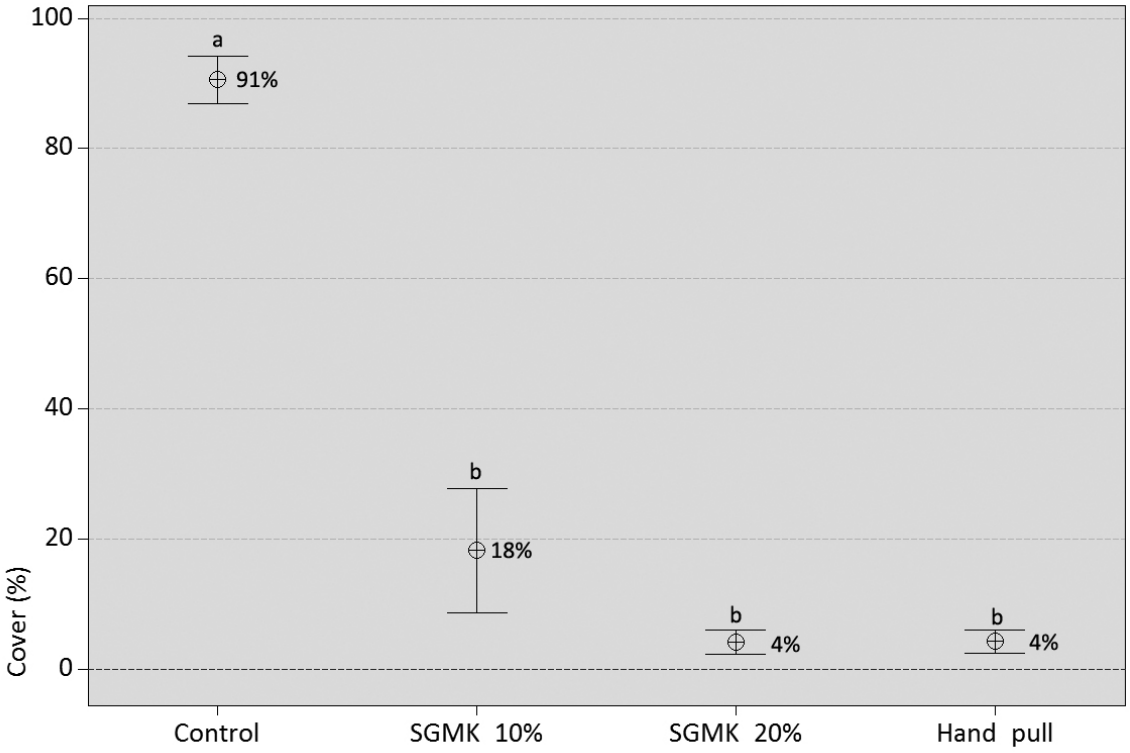


**Figure 10**. Long term suppression of *S. palustre* in treatment vs. control plots. *Sphagnum palustre* cover is shown on the Y axis, treatment type on the X axis. Significant differences between groups are indicated by letters. Bars are ± 1 SEM.

Six months post-treatment, changes in the four non-target plant species were compared by species between treatment groups and the control using a one-way ANOVA (Table 2). A significant decrease in *Metrosideros polymorpha* is evident. Change in species abundance by treatment is shown in Figure 11. No change in species abundance after six months is shown by values equal to zero; a gain in stems is shown as values above zero and a decrease in stems are shown as values falling below zero.

| Species | DF treatment/DF total | F statistic | P-value (* = significant) |
|---|---|---|---|
| *Cibotium spp.* | 3/25 | 0.12 | 0.945 |
| *Dianella sandwicensis* | 3/22 | 2.64 | 0.079 |
| *Metrosideros polymorpha* | 3/49 | 3.97 | 0.013* |
| *Vaccinium calycinum* | 3/43 | 0.45 | 0.719 |

**Table 2**. Results from a one-way ANOVA showing changes in stem count by species due to treatment.

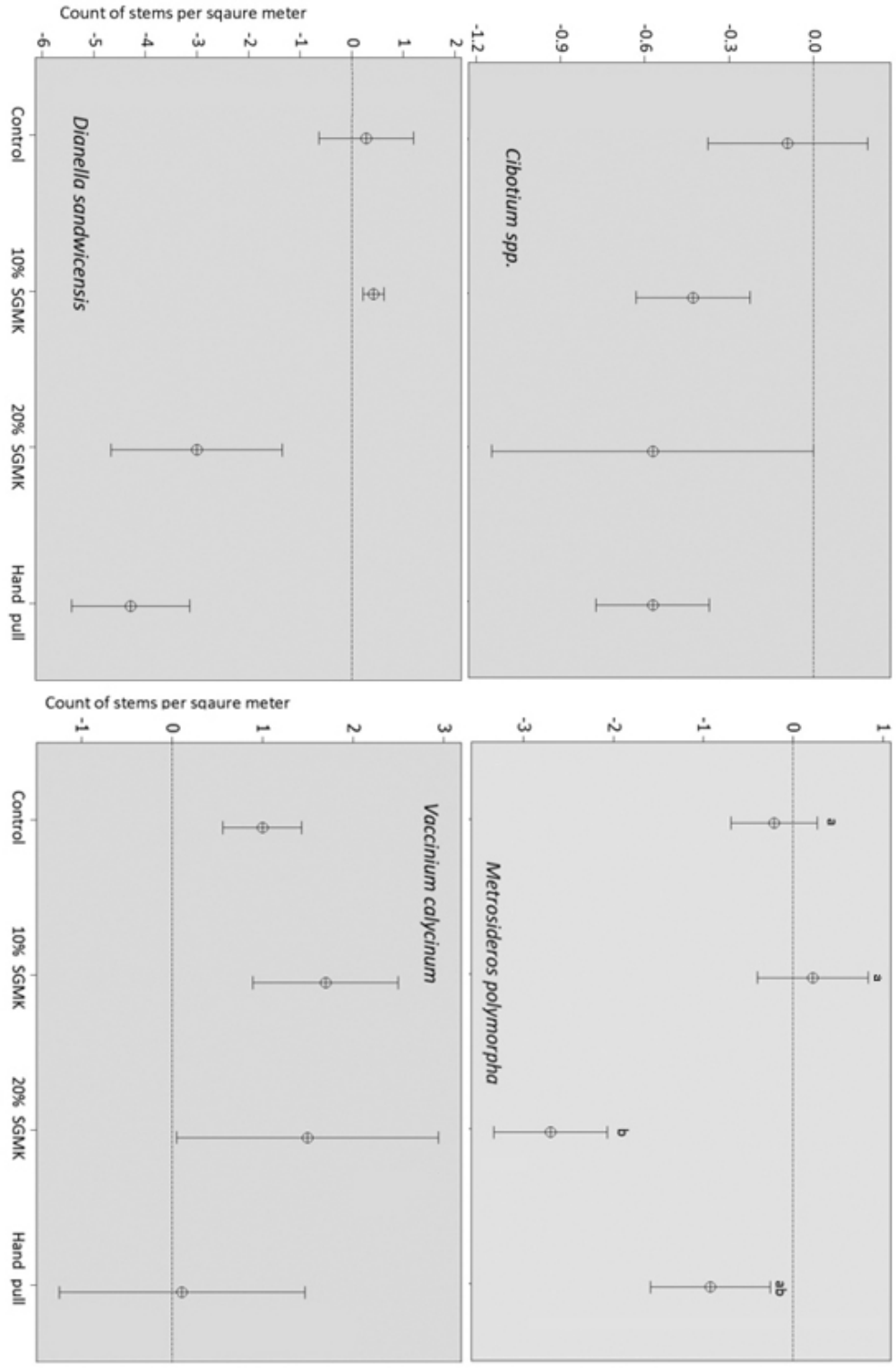


**Figure 11**. Change in native species abundance six months after treatment. Y axis units are change in the number of stems. X axis units are the treatment group. Significant differences between treatment groups were found for *Metrosideros polymorpha*. Those differences are indicated by letters. Bars are $\pm$ 1 SEM.

A significant decrease in stem counts between the control, 10% SGMK groups and the 20% SGMK group for *Metrosideros polymorpha* indicates the latter concentration of SGMK should be avoided. The hand pull group was intermediate between the control, 10% SGMK treatment and the 20% group. Although not significant for the other three common species stem counts were, on average, lower for the 20% SGMK and hand pull treatments compared to either the control or 10% SGMK group.

**Discussion**

*Experiment I*

Growth chamber trails overestimated *Sphagnum palustre* sensitivity to SGMK and 100% mortality was achieved within 48 hours at concentrations $\geq$1.3% SGMK. In the field, these rates did not prove effective. We felt that that the growth chamber trials were unusually successful because of complete moss saturation with SGMK solution. Such saturation is not possible in the field due to the thickness of the moss hummock. In addition rain and debris on top of the moss that prevent total exposure of the moss to the bryocide. It is likely all of these factors contributed to the high survival of *S. palustre* when treated with SGMK solution of <7.5% concentration in the field.

*Experiment II*

One-and-a-half years after treatment, *Sphagnum palustre* cover was significantly affected by treatment with SGMK and manual removal. Analysis showed all three treatments: 10% SGMK, 20% SGMK, and manual removal were equally effective, though on average, *S. palustre* cover remained highest in the 10% SGMK group (18% compared to 4% for the other two treatments). We observed that only the top three cm of moss turned brown after SGMK treatment. For up to three months the layer below the treated layer remained green before eventually dying. We believe that by killing the top layer, lower layers are gradually smothered over time. Indeed one study showed *Sphagnum* is sensitive to smothering by air borne dust (Farmer 1993).

A significant decrease in *Metrosideros polymorpha* in the 20% SGMK treatment and apparent reductions in other native plant species within that treatment as well as the "hand pull" group, show that these control methods are not without undesirable impacts. In addition to being labor intensive (20 gallons of moss was the typical volume of material removed from a single square meter) manual removal contributes to the spread of moss via contaminated equipment and footwear. Indeed attempts at hand removal without secure containment of moss was believed to facilitate its spread prior to adoption of the treatment recommended in this report (T. Takahama *pers. comm*.).

These data suggest that a 10% concentration of SGMK poses fewer risks to non-target species and does not provide significantly better control of moss than at higher concentrations. Our failure to achieve 100% eradication of the moss following a single treatment means that follow-up treatments will be necessary. The moss has been observed to grow at a rate of 4 cm per year (Beilman *et al.* 2014). The slow regeneration of the moss ensures that follow-up treatments need only occur every few years to outpace moss recovery, and if checked annually, eradication is achievable.

**Conclusion**

With our finding that a 10% concentration of SGMK successfully controlled *S. palustre*, we have begun a cooperative effort with DLNR to eradicate the moss from Ka'ala. Together, we have arrested its spread along the boardwalk and treated close to half of the infestation (Fig. 12).

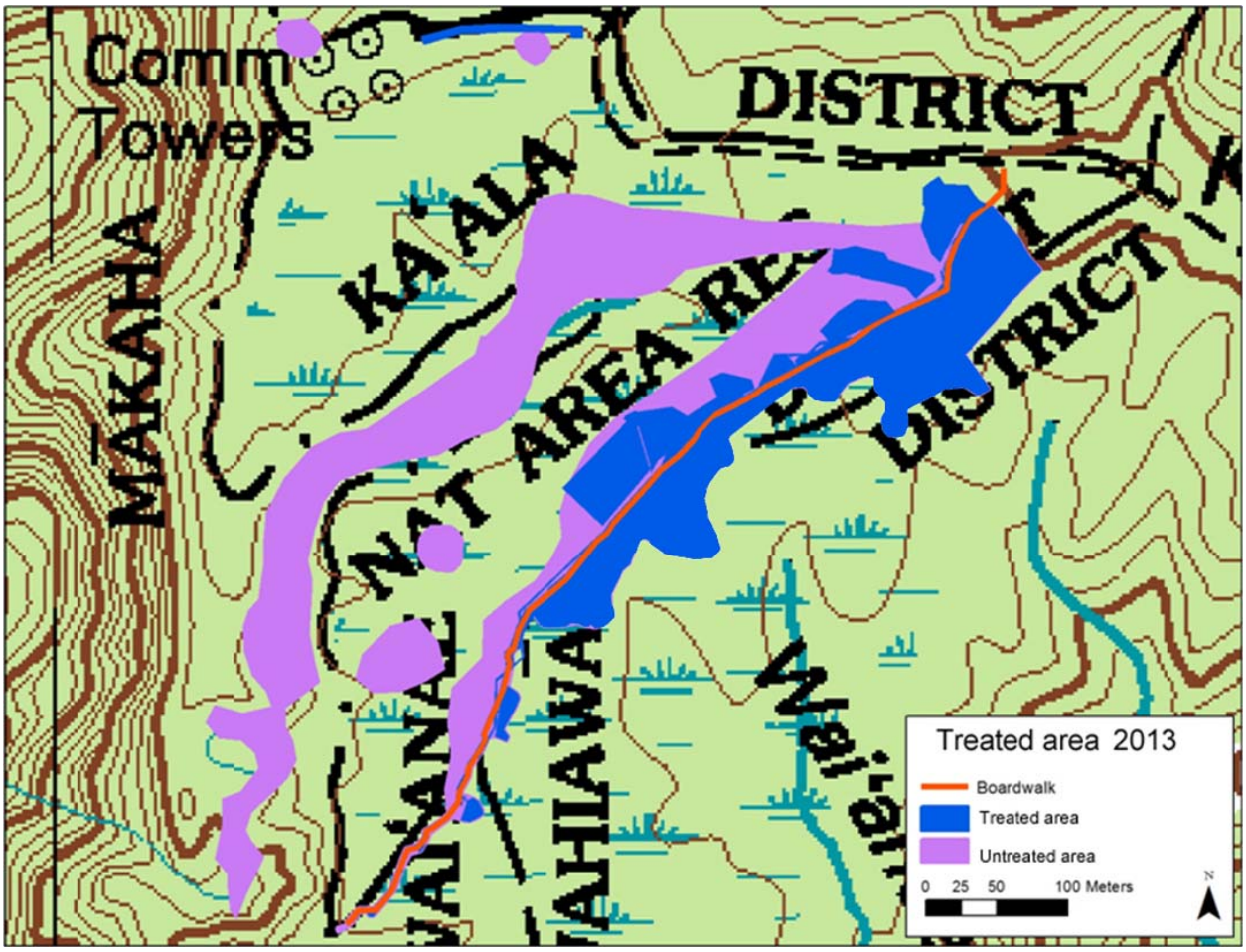


**Figure 12.** Proportion of *S. palustre* infestation treated with a 10% concentration of SGMK as of December 2013.

Recruitment of native woody and herbaceous plants as well as native mosses are commonly observed in formerly infested areas as dead *Sphagnum* is a good growing medium. In addition, native plants persist and thrive in treated plots (Fig. 13.). These experiments show that lab studies alone are not sufficient, and that sustained effort put into studying what had thought to be an intractable pest, can lead to a feasible control technique. As of 2015 we are well on our way to reversing the extent of *S. palustre*. Applied long-term research directly translates into better invasive species management.

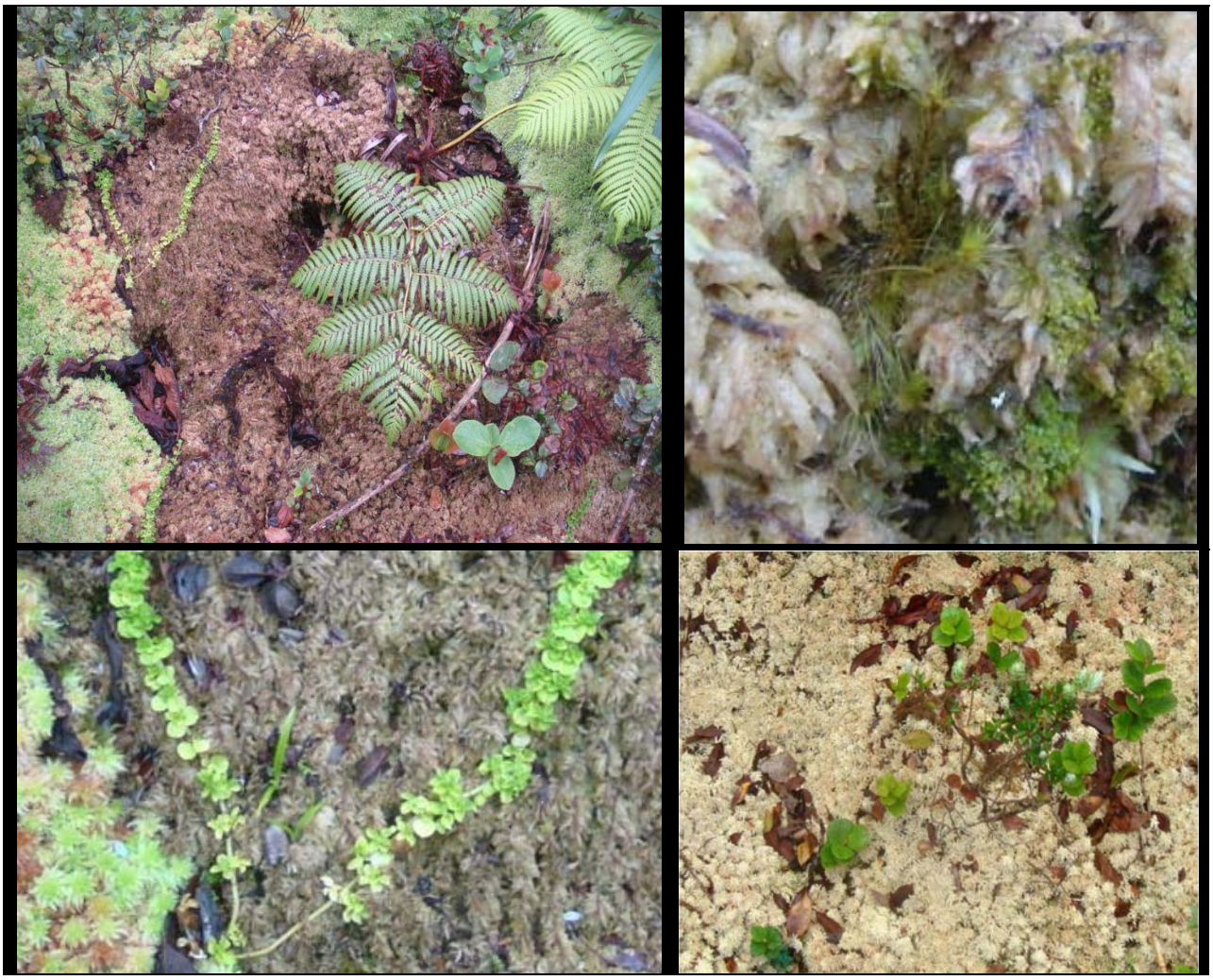

**Figure 13**. Examples of native plant persistence following treatment of *S. palustre.* Clockwise from upper left: *Cibotium spp., Metrosideros polymorpha* and *Nertera granadensis;* native mosses growing from dead *S. palustre*, *Vaccinium calycinum* and *Leptecophylla tameiameiae*; *Nertera granadensis* and Dianella.

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