



## LETTER

# Reconciling pest control, nature conservation, and recreation in coniferous forests

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**Abstract**

Protected areas are not only crucial for biodiversity and natural processes but also for recreation. Although a benign neglect strategy of dealing with natural disturbances in protected areas is beneficial for nature, public debate on avoiding increased pest population growth has intensified. We evaluated the effect of mechanical pest control measures in decreasing populations of insect pests, maintaining nontarget biodiversity, retaining high recreational value, and keeping economic costs low. Debarking and bark scratching or gouging effectively prevented infestation of felled trees by European spruce bark beetles (*Ips typographus*) and controlled the beetles in recently infested trees. Bark scratching or gouging retained biodiversity at natural levels, whereas debarking decreased biodiversity by 54% with higher economic costs. The public rated bark-gouged trees more positively than debarked trees. We thus urge authorities to promote bark scratching or gouging in the control of bark beetles in protected areas instead of salvage logging and debarking.

**KEYWORDS**boreal forest, climate change, forest management, *Ips typographus*, national park, pest control, salvage logging, saproxylic biodiversity, windstorm

## 1 | INTRODUCTION

Coniferous forests are prone to an increasing number and frequency of large-scale stand-replacing disturbances such as severe wildfires and windstorms (Kurz et al., 2008; Seidl, Schelhaas, Rammer, & Verkerk, 2014). In trees weakened by these natural disturbances, the population density of bark beetles can greatly increase, which leads to extensive outbreaks (Vega & Hofstetter 2015).

Over 39% of the protected areas in Europe are in such naturally susceptible coniferous forests (estimation for Norway spruce, *Picea abies* (L.) H. Karst.; see Supporting Information Appendix S1). Hence, pest control has become a main argument for removing trees affected by disturbances, that is, salvage logging, in protected areas worldwide (Müller

et al., 2018). Nevertheless, conservationist are aware of the high value of natural disturbances for restoring more natural forests from former plantations (Noss et al., 2006) and promoting biodiversity (Müller, Noss, Bussler, & Brandl, 2010; Swanson et al., 2011). Not surprisingly, salvage logging in the ancient Białowieża Forest in Poland (Schiermeier, 2017) and management of overwintering reserves of the monarch butterfly in Mexico (Leverkus, Jaramillo-López, Brower, Lindenmayer, & Williams, 2018) have recently caused substantial public debates. Hence, scientists are increasingly calling for alternative management strategies to handle naturally disturbed forests in protected areas (Thorn et al., 2018). Not surprisingly, the debate on how to best manage naturally disturbed forests is particularly intense in protected areas, as for example, in national parks, where pest management has

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to fulfill additional requirements of biodiversity protection, environmental education, and recreation (IUCN primary objective of national park; [www.iucn.org](http://www.iucn.org)). Consequently, pest management that is poorly perceived by the public can potentially lower the recreational value of a protected area (Berto, 2005). Thus, it is important to consider public perception in the development of different pest management strategies (McFarlane, Parkins, & Watson, 2012).

In Eurasia, the major insect pest is the European spruce bark beetle (*Ips typographus* Linnaeus, 1758). In the main host tree species, *P. abies*, populations erupt after drought and windstorms (Seidl et al., 2016). In Europe between 1950 and 2000, windstorms and outbreaks of *I. typographus* annually damaged 18.7 million m<sup>3</sup> and 2.9 million m<sup>3</sup> of wood, respectively (Schelhaas, Nabuurs, & Schuck, 2003). However, *I. typographus* is a keystone forest species that promotes biodiversity (Beudert et al., 2015) and shares its habitat with several hundreds of species, many of which are endangered (Kazartsev, Shorohova, Kapitsa, & Kushnevskaya, 2018; Thorn et al., 2016).

In the controversy between pest management and conservation, suitable methods of pest control have been sought. One onsite method of pest control that has been promoted, particularly for protected areas, is mechanical bark removal (Kausrud et al., 2012; Wermelinger, 2004). However, the complete removal of bark has profound negative effects on biodiversity, with a loss of around one third of the species (Thorn et al., 2016). Hence, bark scratching has been promoted as an alternative method that removes only enough of the bark to make it inhabitable for *I. typographus* (Thorn et al., 2016). Nevertheless, it remains unclear whether bark scratching is only suitable when applied preventively (i.e., before *I. typographus* colonizes weakened trees), how bark scratching can be standardized to handle larger outbreaks, and how bark-scratched trees are perceived by visitors of protected areas.

In a holistic framework, we compared the effect of no intervention and of debarking, bark scratching, and standardized bark gouging, that is, a deep engraving in the bark made by a newly developed device (Figure 1c) on preventive pest control, pest control after infestation, and biodiversity conservation, and determined the economic costs and public perception of these different bark manipulations (Figure 1a). Our newly developed bark-gouging device can be used at a large scale and provides standardized results.

## 2 | METHODS

### 2.1 | Experimental setup and mechanical bark-damaging methods

Our study was conducted in the Bavarian Forest National Park, a region that has been heavily affected by outbreaks of

the European spruce bark beetle (*I. typographus*) and windstorms during the last three decades (Thorn, Bässler, Svoboda, & Müller, 2017). To simulate wind-thrown trees, we felled 24 healthy mature Norway spruce trees with no traces of *I. typographus* colonization and with similar physical attributes and a diameter at breast height (1.3 m) of  $37 \text{ cm} \pm 3 \text{ cm}$ . Tree trunks were cut into 42 logs of 5 m with a mean diameter of  $31 \text{ cm} \pm 3 \text{ cm}$ ; the trunks were scattered over an area of 4 hectares, thereby simulating a small wind throw, in the northern part of Bavarian Forest National Park (49°04'N, 13°15'E).

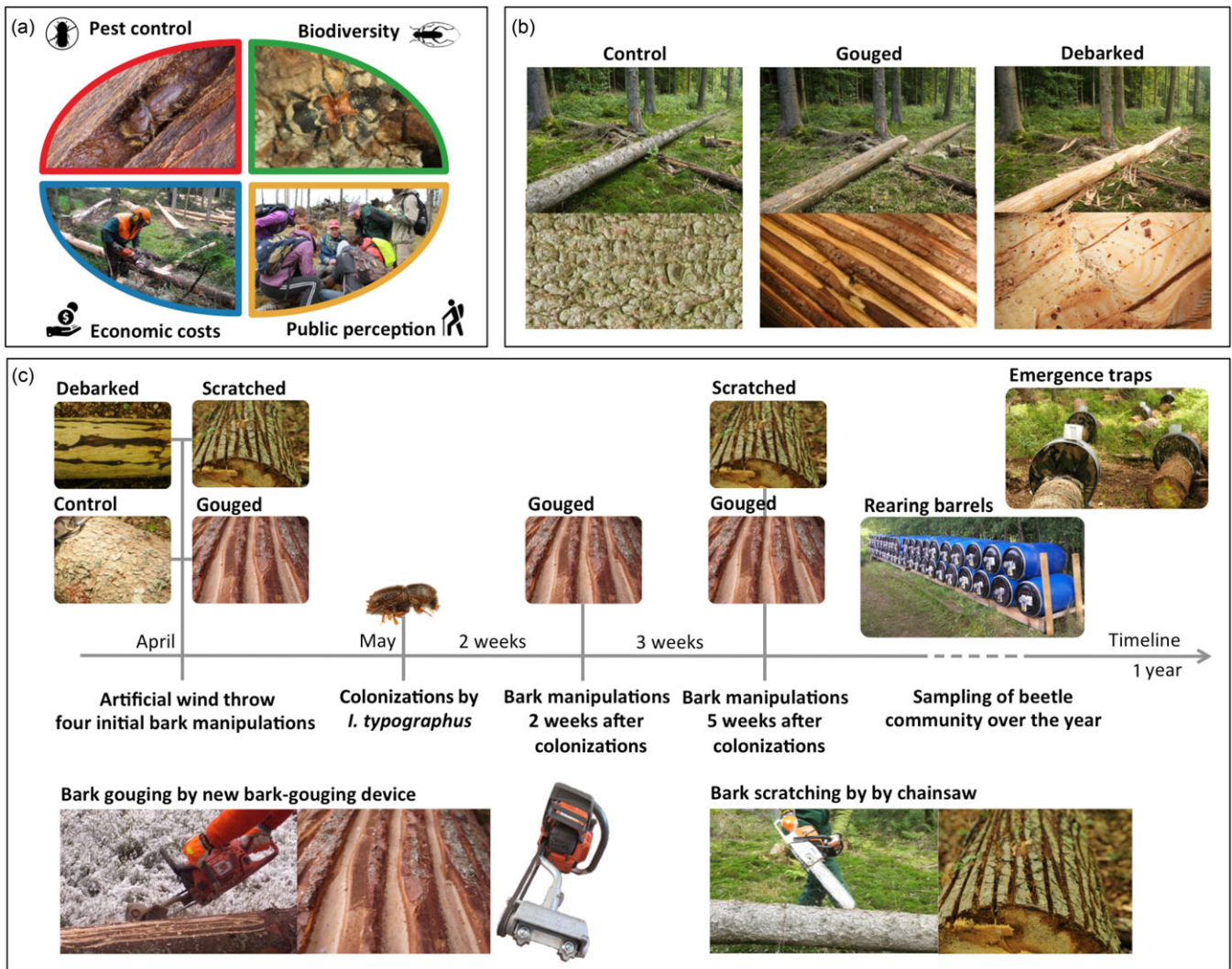
We compared the effect of a nonintervention (benign-neglect) strategy as the control with the effect of debarking or bark damaging. Either the logs were completely debarked using a debarking device (EDER Maschinenbau GmbH, Wolfenbüttel, Lower Saxony, Germany) mounted on a conventional chain saw or the bark on the logs was scratched or gouged. For the latter two methods, the bark was either scratched every 2–3 cm with the front part of the blade of a light-weight chain saw (Stihl MS260, Stuttgart, Germany) (Figure 1c) or, because scratching is difficult to standardize, gouged with a newly developed mechanical bark-gouging device (German Utility Model DE 20 2018 101 049.2; see Supporting Information Appendix S2). The four parallel teeth in groups of two of this gouging device are V shaped with a flat front edge and disrupt the phloem of the bark at every 16 mm with a width of 14 mm and a depth of 9 mm (Figure 1c; Supporting Information Appendix S2).

To test preventive pest control before colonization by *I. typographus*, we randomly selected logs directly after felling and set up six control logs (bark left undamaged), six debarked logs, six scratched logs, and six gouged logs. To test pest control 2 weeks after colonization by *I. typographus*, we gouged six logs. To test pest control 5 weeks after colonization, we scratched six logs and gouged six logs (Figure 1c).

### 2.2 | Economic costs

We recorded the time needed to complete the mechanical debarking, scratching, and gouging of 12 logs of freshly felled trees each by four professional forestry workers, who are familiar with the handling of the devices. The time needed was standardized by tree volume and was used as a surrogate response variable for economic cost in subsequent analyses.

To test the effects of debarking, bark scratching, and bark gouging, we applied generalized linear mixed models with gamma distribution and included the different forestry workers as a random effect. We used multiple comparisons with simultaneous adjustment of *P* values (function *glht* in R-package *multcomp*; Hothorn, Bretz, & Westfall, 2008) to compare the response scores among the different methods of mechanical bark damaging.



**FIGURE 1** (a) Factors relevant to the management of protected areas. (b) Undamaged, gouged, and debarked logs; the scenery photographs at the top were used in the public perception questionnaire. (c) Timeline of experiment showing the methods used

### 2.3 | Biodiversity surveys and pest control

Starting 5 weeks after the first colonization of the logs by *I. typographus*, we collected arthropods with both emergence traps and rearing barrels over 1 year, which covers all potential generations of *I. typographus* (see the time line of the experiment in Figure 1c). We cut off a 70-cm long piece from each of the 42 logs and placed each piece in a rearing barrel. The barrels were closed, and each barrel had a fine wire mesh window on the two ends for ventilation. The pieces of logs were kept in the rearing barrels for 1 year, and emerging insects were automatically trapped. An emergence trap was mounted on the remaining part of each log and was emptied every 2 weeks for 1 year. Emergence traps might never be completely closed because of irregularities and desiccation cracks in the bark (see discussion in Thorn et al., 2016). By contrast, rearing barrels are fully closed but tend to be moister than traps in the field. However, our analyses showed that the

two sampling methods yield highly correlated measures of pest control and biodiversity (Supporting Information Figure S3.1). To standardize the number of *I. typographus* per sampled surface, we measured the surface covered by the emergence traps and rearing barrels (excluding cut surfaces). All sampled beetle specimens were identified to the species level by A. Szallies (Reutlingen, Baden-Württemberg, Germany).

We used the abundance of *I. typographus* as a proxy for the efficiency of pest control and the number of saproxylic beetle species as a proxy for biodiversity. Using quasi-Poisson linear models, we tested the effects of the different bark damaging methods on the response variables pest control and biodiversity. We included sampled surface and trap type as predictors to control for area and sampling method and used multiple comparisons with simultaneous adjustment of *P* values (function *glht* in R-package *multcomp*; Hothorn et al., 2008) to compare the response scores among different bark damaging methods.



## 2.4 | Public perception

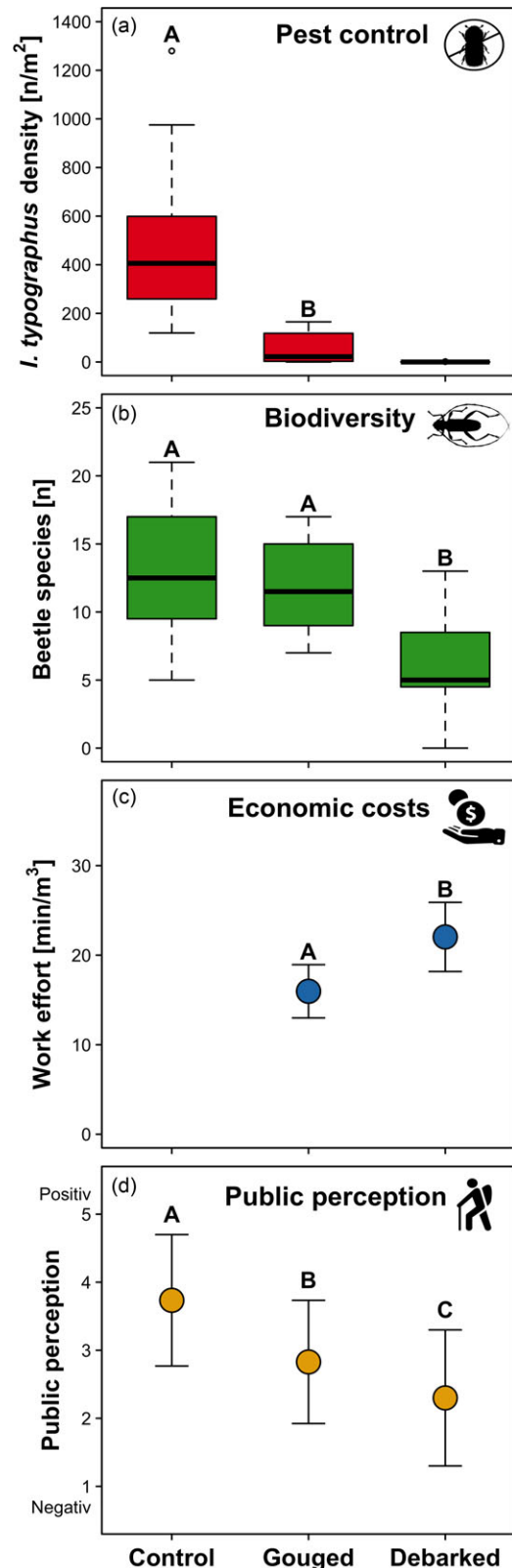
To quantify the public perception of undamaged, gouged, and debarked logs, we took standardized photographs of the same scenery by first felling a spruce tree, then gouging the bark of the tree, and finally debarking the same tree (Figure 1b). Photographs were used in an online questionnaire, which was completed by a representative sample consisting of 1,008 participants (527 females and 481 males) in Germany. The mean age of the participants was  $44.7 \pm 14.3$  years, and 40% had a university degree. The questionnaire stated “Imagine you are on a hike in a national park. You notice a tree trunk close to the trail. It looks like one of the logs in the photos. Please score each photo according to how positive or negative you perceive the appearance of each log.” This procedure resulted in integer response scores from 1 (very negative perception) to 5 (very positive perception) for each photograph.

We used cumulative link mixed models (function *clmm* in R-package *ordinal*; Christensen, 2015) to test the effect of different bark damaging methods on the response scores. Furthermore, we included age, sex, educational level (measured as 1: no educational degree yet, 2: elementary school, 3: lower secondary school, 4: higher secondary school, and 5: university degree), and prior visit of the Bavarian Forest National Park (yes/no) as predictors. We used multiple comparisons with simultaneous adjustment of *P* values (function *glht* in R-package *multcomp*; Hothorn et al., 2008) to compare the response scores among different bark damaging methods. We included the questionnaire ID as a random effect in the model to control for repeated measurements (i.e., each participant scored three photographs). All statistical analyses were completed using the statistical software R 3.3.3 ([www.r-project.org](http://www.r-project.org)).

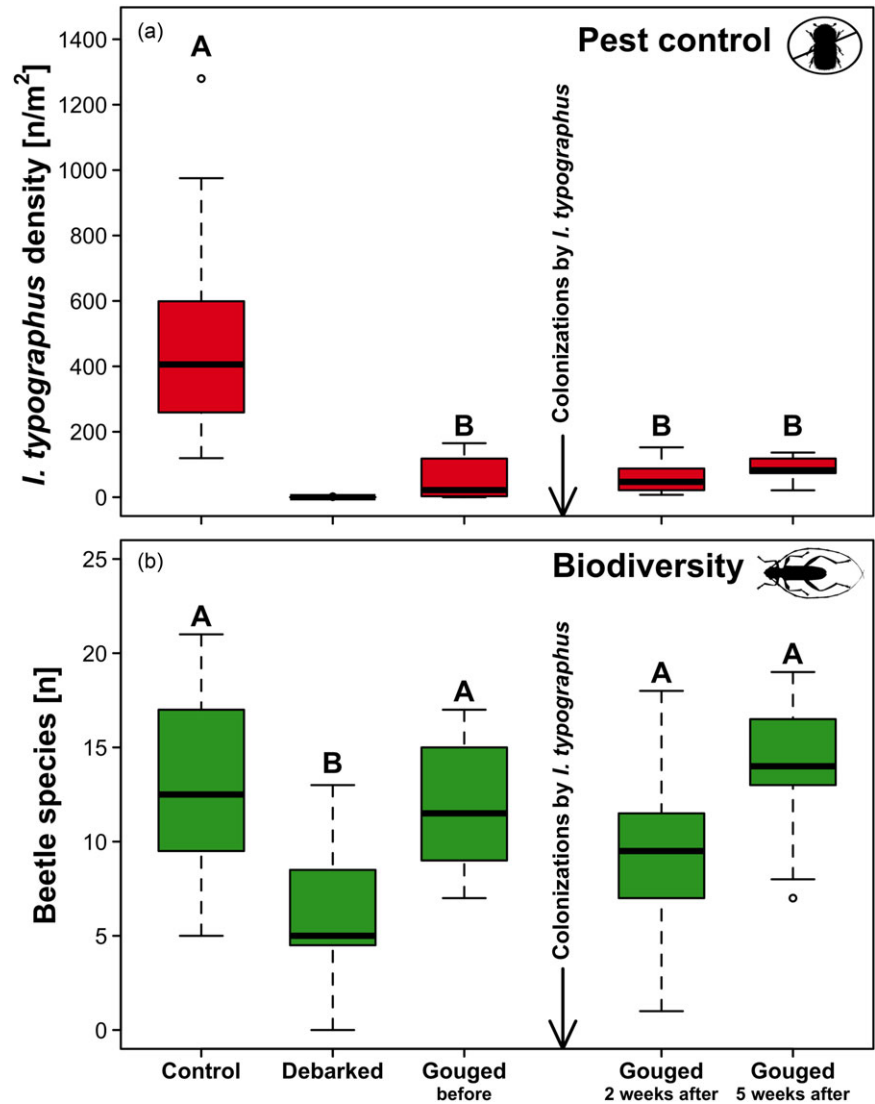
## 3 | RESULTS

### 3.1 | Pest control

Bark gouging with our new device was an efficient preventive method of pest control (i.e., before colonization of felled trees by *I. typographus*) and it is as effective as debarking (Figure 2a, Supporting Information Table S4.1). Compared to a median of 406 individuals of *I. typographus* per meter square emerging from the undamaged log control, the number of individuals decreased to 22 individuals (5% of the control) from logs gouged with our new device and to almost zero individuals from debarked logs (Figure 2a). When logs were gouged with our new device 2 and 5 weeks after infestation with *I. typographus*, the median number of emerging *I. typographus* beetles decreased to 12% and 20% of the control logs, respectively (Figure 3a, Supporting Information Table S4.1). The scratching of logs with a chain saw and the



**FIGURE 2** Effect of bark gouging compared with nonintervention (control) and debarking of fallen Norway spruce trees on (a) pest control, (b) biodiversity, (c) economic costs, and (d) public perception. (a, b) Boxplots showing medians and interquartile ranges (boxes). (c, d) Means and standard deviations. Uppercase letters indicate significant differences between bark manipulations



**FIGURE 3** (a, b) Effect of bark gouging compared to nonintervention (control) and debarking of logs as preventive pest control before colonization by *Ips typographus* and as pest control 2 and 5 weeks after colonization. Effect on (a) pest control and (b) biodiversity. Uppercase letters indicate significant differences between bark manipulations, tested with quasi-Poisson linear models corrected for sampled surface and sampling method

gouging of logs with our new device as a preventive method before infestation were equally effective in pest control and are as effective as debarking (Supporting Information Figure S5.1a). However, when logs had already been infested for 5 weeks, more *I. typographus* beetles emerged from scratched logs (35% of the control) than from gouged logs (20% of the control; Supporting Information Figure S5.1a).

### 3.2 | Biodiversity

Gouged logs had the same high number of saproxylic beetle species as control logs, whereas debarked logs had 54% fewer species (Figure 2b, Supporting Information Table S4.1). Whether bark was gouged before or after infestation had no significant effect on number of species, which was the same as for the control (Figure 3b, Supporting Information Table S4.1). The number of saproxylic beetle species on logs whose bark was damaged by scratching did not differ from that on logs whose bark was gouged (Supporting Information

Figure S5.1b). The community composition of saproxylic beetles on control logs differed from that on debarked logs. The community compositions of saproxylic beetles on control logs and on logs scratched or gouged before infestation or after 5 weeks of colonization did not differ from each other but did differ from that on logs gouged 2 weeks after colonization (Supporting Information Figure S6.1, Table S6.1).

### 3.3 | Economic costs and public perception

The cost of gouging logs with the new device was 28% lower than the cost of debarking (Figure 2c, Supporting Information Table S4.1). Scratching logs with a chain saw took 67% more time than debarking and would therefore be more expensive (Supporting Information Figure S5.2).

The public perceived control logs without any bark damage most positively, followed by gouged logs, and last by debarked logs (Figure 1d, Supporting Information Table S4.1). Participants that had visited the Bavarian Forest National Park before

had in general more positive ratings. Men had in general more positive ratings than woman.

## 4 | DISCUSSION

Our study demonstrated that biodiversity conservation and a positive public perception could be most efficiently achieved by a nonintervention strategy toward wind-thrown spruce trees. However, if pest control of bark beetles is required, our results indicated that our new bark-gouging device combines the management requirements of protected areas. Bark gouging of wind-thrown trees is less expensive than debarking (with the potential of saving millions of Euros in one protected area; Supporting Information see Appendix S7), more positively perceived by the public, and as effective as debarking for pest control, but the levels of biodiversity are kept as high as with nonintervention. Thus, we recommend bark gouging as the preferable onsite method of bark beetle management.

Timely intervention is an important factor for ensuring a decrease in the pest population (Wermelinger, 2004). In addition to preventive management of wind-thrown trees, management can be most efficiently applied between the colonization of the tress after the spring flight of the beetles and the emergence of the new generation, which opens up a time frame of around 5 weeks (Wermelinger, 2004). Our results showed that bark gouging applied 2 and 5 weeks after colonization decreased the abundance of *I. typographus* by 80-90%, which did not significantly differ from preventive bark gouging. The effectiveness by bark gouging onsite for recently infested trees is thus as effective as removing infested trees by salvage logging, which decreases the abundance of *I. typographus* to 10% of an untreated control (Thorn et al., 2014).

Any type of postdisturbance management should be applied with caution and with the lowest negative impact on the associated biodiversity, particularly, in protected areas (Thorn et al., 2018). Weslien (1992) lists over 140 arthropod species associated with *I. typographus*, and Thorn et al. (2016) has found 39 wood-inhabiting fungal species, 121 saproxylic beetle species, and 84 parasitoid wasp species in trees colonized by *I. typographus*. Our new bark-gouging device reduces the breeding habitat of *I. typographus*, but did not have collateral damage on the diversity of other saproxylic beetles. By contrast, debarking decreased biodiversity by 54%. This decrease is comparable to the effect of post-storm logging at the stand scale, which reduces the number of saproxylic beetle species to about 70% of that of an unlogged control (Thorn et al., 2014, 2018).

We found that logs with undamaged bark received the most positive public perception, followed by bark-gouged logs, and debarked logs received the most negative public perception. This finding extends earlier findings at the landscape scale,

where green trees were most positively perceived compared to trees affected by disturbances to the scale of a single trunk (Clement & Cheng 2011; Hartel, Réti, & Craioveanu, 2017; O'Brien, 2006). The negative perception of completely debarked logs might, therefore, be explained by their relative nonnatural appearance. To obtain the most positive public perceptions, a nonintervention strategy should, hence, be preferred. Whenever pest control is required, bark gouging should be applied instead of debarking to foster a more positive perception by visitors. Interestingly, participants who had visited the Bavarian Forest National Park before had in general more positive ratings. Thus, previous impressions and the potential knowledge obtained during previous visits to the national park would positively affect the perception of fallen and mechanically damaged trees (Müller & Job 2009).

Outbreaks of bark beetles occur on different spatial scales, ranging from small groups of trees up to a landscape level of several kilometer square (Vega & Hofstetter 2015). For infested areas of a few hectares, our results indicated that bark gouging using our new device would be the most cost-effective alternative to debarking, and would yield higher levels of biodiversity. Furthermore, the standardized application of the bark-gouging device would enable reliable pest control by contracted third parties, even for larger areas. Although scratching the bark of fallen trees with a chain saw is more time consuming and, therefore, more expensive than gouging the bark with the new device (Supporting Information Figure S5.2), scratching a single wind-thrown tree or several trees or scratching recently infested trees would be feasible and would have a similar effect on pest control and the same positive effect on beetle biodiversity as gouging, and shows better effects than debarking (Supporting Information Figure S5.1). For large-scale bark beetle outbreaks, bark gouging could be limited by the budget, manpower, and the limited time frame to treat all trees. However, after initial large-scale disturbance events, the population of *I. typographus* first increases in small cells, and the connectivity of these cells promotes large-scale outbreak events (Seidl et al., 2016). In this case, our new standardized bark-gouging device would be ideal to downregulate the population increase in these smaller cells and, thus, would lower the probability of large-scale outbreak events. Furthermore, bark gouging could become applicable for large-scale outbreaks if harvester heads for bark gouging were developed.

The benefits of bark gouging for pest control, biodiversity protection, economic savings, and public perception are not limited to the needs of the 39% of the protected areas in Europe facing the controversy of pest control (Supporting Information Appendix S1). This method could also be an economically attractive alternative for small outbreaks in alpine regions or in areas with sensitive soils where salvage logging is particularly problematic (Lindenmayer, Thorn, & Banks, 2017).

The control of a few bark beetle pest species with a high impact is a concern in forests of high economic value worldwide (Vega & Hofstetter 2015). Further research should, thus, focus on the applicability of bark gouging as a control measure of bark beetle pest species with an ecology similar to that of *I. typographus*, namely *Dendroctonus ponderosae* (North America), *Dendroctonus frontalis* (Central America), and *Dendroctonus rufipennis* (Central and North America). Research of pest control should always consider the effectiveness of the control measure, direct and indirect effects on biodiversity, and how visitors in the forests for recreation perceive the measures. If these aspects are neglected, as is done with salvage logging, other unsolvable problems, such as the effect on biodiversity, could arise. The best evidence-based management of disturbed forests stands is only possible if multiple aspects of protected area management are considered.

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## CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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