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A 20-Year Reassessment of the Health and Status of Whitebark Pine Forests in the Bob Marshall Wilderness Complex, Montana, USA

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Abstract

Abstract—*Whitebark pine plays a prominent role in high elevation ecosystems of the northern Rocky Mountains. It is an important food source for many birds and mammals as well as an essential component of watershed stabilization. Whitebark pine is vanishing from the landscape due to three main factors: white pine blister rust, mountain pine beetle outbreaks, and successional replacement by more shade-tolerant species. Between 1990 and 1994, 116 research plots were established to determine the health and status of whitebark pine populations in the Bob Marshall Wilderness Complex in Montana, USA. In the summers of 2013 and 2014, we assisted volunteers or "citizen scientists" from the Bob Marshall Wilderness Foundation in remeasuring 25 of these 116 plots to assess changes in the health and status of whitebark pine over the past 20 years. Methods from the original study were simplified to accommodate volunteer crews' inexperience. Results of this remeasurement effort show that mortality of mature whitebark pine trees in the Bob Marshall Wilderness Complex has more than doubled in the last two decades (to 80 percent from 35 percent) with white pine blister rust now present in all surveyed stands. Most tree deaths were from white pine blister rust (>60 percent), but a large increase in mountain pine beetle attacks was also noted. As blister rust kills more stands dominated by whitebark pine, the trees will be replaced with the more shade-tolerant subalpine fir and Engelmann spruce, further inhibiting regeneration of the shade-intolerant species.*

Keywords: white pine blister rust, mountain pine beetle, wildland fire, whitebark pine decline, fire exclusion, citizen science

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INTRODUCTION

Whitebark pine (*Pinus albicaulis*) is both a keystone species and a foundation species in high elevation forests throughout the western United States and Canada (Ellison et al. 2005; Tomback and Achuff 2010). Its large seeds are an important food source for many animals including black bears (*Ursus americanus*), grizzly bears (*Ursus arctos horribilis*), and red squirrels (*Tamiasciurus hudsonicus*) (Kendall 1980), and most importantly, Clark's nutcrackers (*Nucifraga columbiana*) (Tomback 1982). Whitebark pine has a mutualistic relationship with the nutcracker in that it relies on the bird to disperse the species' heavy, wingless seeds, thereby promoting regeneration (Tomback 1982). Whitebark pine also plays an important role in watershed stabilization (Arno and Hoff 1989).

Whitebark pine is disappearing from the upper subalpine landscape due to three main factors: white pine blister rust (WPBR) caused by the fungus *Cronartium ribicola*, mountain pine beetle (*Dendroctonus ponderosae*) outbreaks, and successional replacement by more shade-tolerant species. WPBR is an exotic disease that attacks most five-needle pines, but it is particularly deadly to whitebark pine (Arno and Hoff 1989; Bingham 1972; Hoff et al. 1980). Blister rust is currently present throughout most of the range of whitebark pine, reducing cone production and killing trees (Schwandt et al. 2010; Tomback and Achuff 2010). Although the mountain pine beetle is native to western North America, current climate-driven severe outbreaks have killed many cone-bearing whitebark pine, thereby severely depressing regeneration potential of the pine (McKinney and Tomback 2007; Schwandt et al. 2010). Finally, the suppression of wildfires over the last 100 years has led to successional replacement of whitebark pine by more shade-tolerant species including subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*) (Arno 1986; Keane et al. 1994; Murray et al. 2000). These factors have contributed to a nearly range-wide decline in whitebark populations; as a result, the species was recently listed as a candidate species under the U.S. Endangered Species Act (USDI Fish and Wildlife Service 2011).

The purpose of this study was to use voluntary public participation or "citizen science" (Bonter and Hockachka 2009) to remeasure plots initially established between 1990 and 1994 and determine changes in the status of whitebark pine populations over the last 20 years across parts of the Bob Marshall Wilderness Complex (BMWC), a large wildland preserve in northwestern Montana (Keane et al. 1994). The Keane et al. (1994) original study intensively inventoried high elevation forests to develop a spatial classification of upper subalpine cover types and forest decline by using satellite imagery and extensive plot sampling. In the summers of 2013 and 2014, staff and volunteers with the Bob Marshall Wilderness Foundation (BMWF) used protocols established by Keane et al. (1994) to locate the original plots and then sample tree characteristics.

METHODS

Study Area

The BMWC is an isolated, roadless region of more than 600,000 ha in northwestern Montana and consists mostly of the Great Bear, Bob Marshall, and Scapegoat Wilderness Areas. This landscape was formed during periods of glaciation, which left jagged peaks, carved basins, and valleys filled with alluvial outwash (Alt 1985; Deiss 1958; Keane et al. 1994). Large stand-replacing fires historically occurred throughout the BMWC, reducing the subalpine fir understory and maintaining whitebark pine dominance. These fires left behind large open areas where Clark's nutcrackers cached whitebark seeds, thereby helping the pine species to recolonize the burned area. About 44 percent of the BMWC has the potential to support whitebark pine forests (Keane et al. 1994).

The Continental Divide runs along the east side of the BMWC, creating wide variations in the plant communities and general climate. The climate west of the divide is known for its cool, wet winters and short, warm, dry summers. Average annual precipitation ranges from 50 cm yr^{-1} in the driest valleys to more than 275 cm yr^{-1} on the Swan Range (Keane et al. 1994). East of the Continental Divide, the winter temperatures fluctuate widely, and the summers are longer than on the west side and are moderately warm. Constant and frequently high winds are common along the east side of the divide. Average annual precipitation ranges from 40 cm yr^{-1} in the valleys to 150 cm yr^{-1} along the Sawtooth Range (National Weather Service 1981).

Field Data Collection and Analysis

In the original study by Keane et al. (1994), a detailed ecological inventory was conducted in various whitebark pine stands across the entire BMWC and surrounding areas using ECODATA methodology (Hann et al. 1989; Keane et al. 1990). Circular 400-m^2 macroplots were established in representative portions of stands where whitebark pine had a density greater than 10 mature (greater than 15 cm diameter at breast height [DBH]) trees ha^{-1}. Information about stand structure, fire history, fuels, topography, soils, and plant community were also recorded at each macroplot. All trees greater than 2 cm DBH were sampled for age, size, and health. WPBR severity was evaluated for each whitebark pine tree as an estimation of number of cankers per tree, number of infected trees within the macroplot, and proportion of tree foliage killed by WPBR. Presence of mountain pine beetle was also recorded for each whitebark pine snag and living tree. Causes of mortality were estimated for dead trees when evidence existed.

At the beginning of the 2013 and 2014 field seasons, Forest Service personnel from the Rocky Mountain Research Station trained both the director and staff crew leader of the BMWF in a simplified sampling protocol designed to accommodate the lack of experience by volunteer crews. The methods of Keane et al. (1994) were streamlined so that only sapling and tree data (species, status, health) were remeasured to make it easier for BMWF crews to accurately assess rates of change. The BMWF staff then trained and supervised volunteers in data collection throughout the two summers with help from the authors. The original plots were not permanently marked because they were in wilderness areas, so staff and volunteers located each plot center using photographs, plot sheets, and global positioning system (GPS) coordinates from the original study. In all cases, plot centers were approximately located to within 1 to 4 m of the original plot; therefore, we could not track health and mortality of individual trees within plots (fig. 1). Once plot center was established, new GPS coordinates were recorded, and photos were taken in the cardinal directions. The height (m), live crown base height (m), DBH (cm), canopy position (open-grown, dominant, codominant, intermediate, suppressed), and health (healthy, sick, dying, dead) were measured on all live trees at least 10.0 cm DBH by using the Keane et al. (1994) techniques. BMWF crews also measured height, DBH, decay class, and cause of death for whitebark pine snags. Living saplings (trees less than 11.5 cm DBH and greater than 1.37 m in height) were tallied by species and diameter class. Percent crown kill was recorded for all mature and sapling whitebark pine (Keane et al. 1994).

The data were summarized by identifying the total number of both live and dead whitebark pine sampled at each plot in 1994 and again in 2014. These numbers were then used to calculate mortality estimates (number, density, percentages) and percent change. Mortality by agent was determined from detailed notes recorded by field crews. A two-tailed T-test was used to determine if the changes were significant.

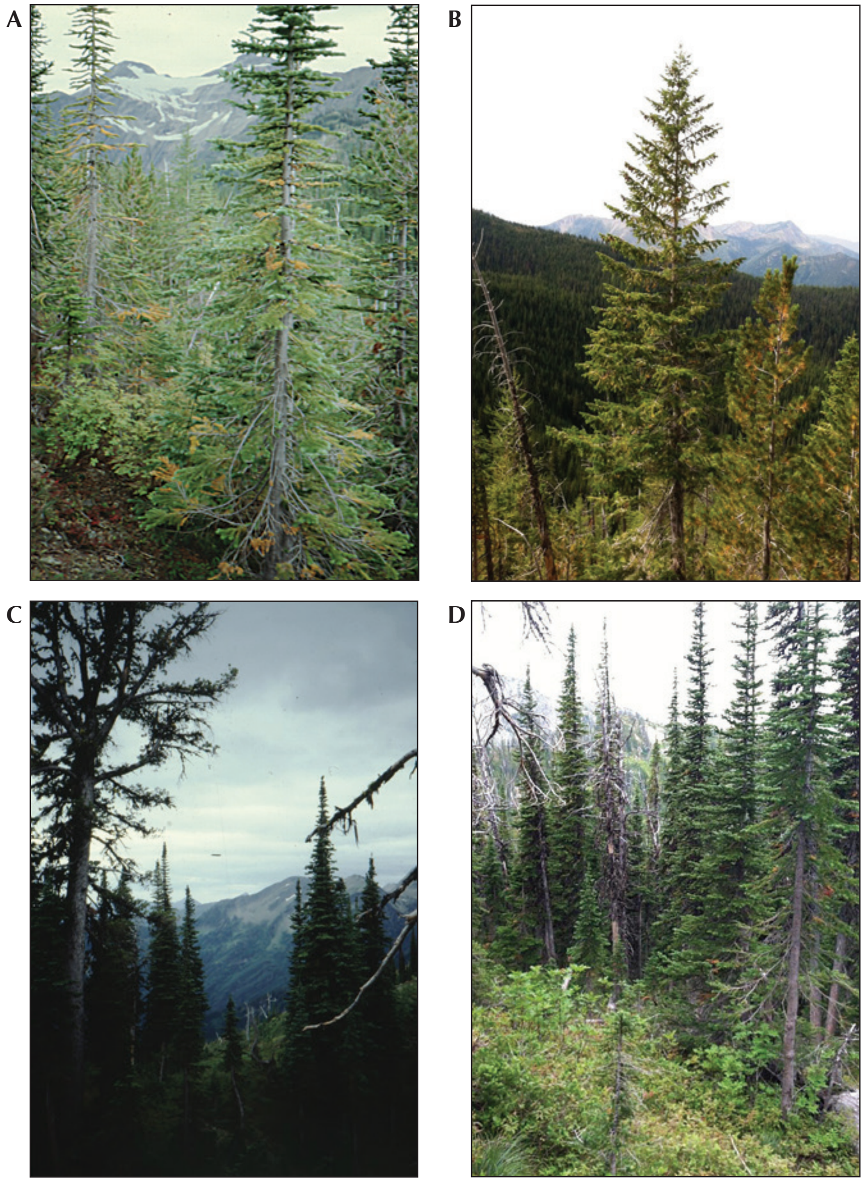

Figure 1—Examples of visual changes in whitebark pine stands on measured stands in the Bob Marshall Wilderness Complex: (A) Grant Ridge 1 (1994) compared to (B) the same stand photographed in 2014; (C) a second site, Grant Ridge 2 (1994), compared to the same stand (D) in 2014.

RESULTS

Only 25 of the original 116 plots were visited because of time and access challenges (fig. 2). The BMWF crews measured characteristics of 570 mature trees, of which 189 were mature whitebark pine trees. Of all whitebark pine trees measured, 156 were dead and only 33 were still alive. The 25 BMWF-sampled stands mostly consisted of mature but scattered whitebark pine, subalpine fir, and occasional Engelmann spruce with an understory almost entirely of subalpine fir. A total of 562 whitebark pine trees (365 live, 197 dead) were measured by Keane et al. (1994) on the same 25 plots, but in 2013–2014, BMWF crews measured only 265 (46 live, 219 dead) (table 1 and fig. 3). We assumed that 319 live trees died and 100 of them fell during the 20 year period.

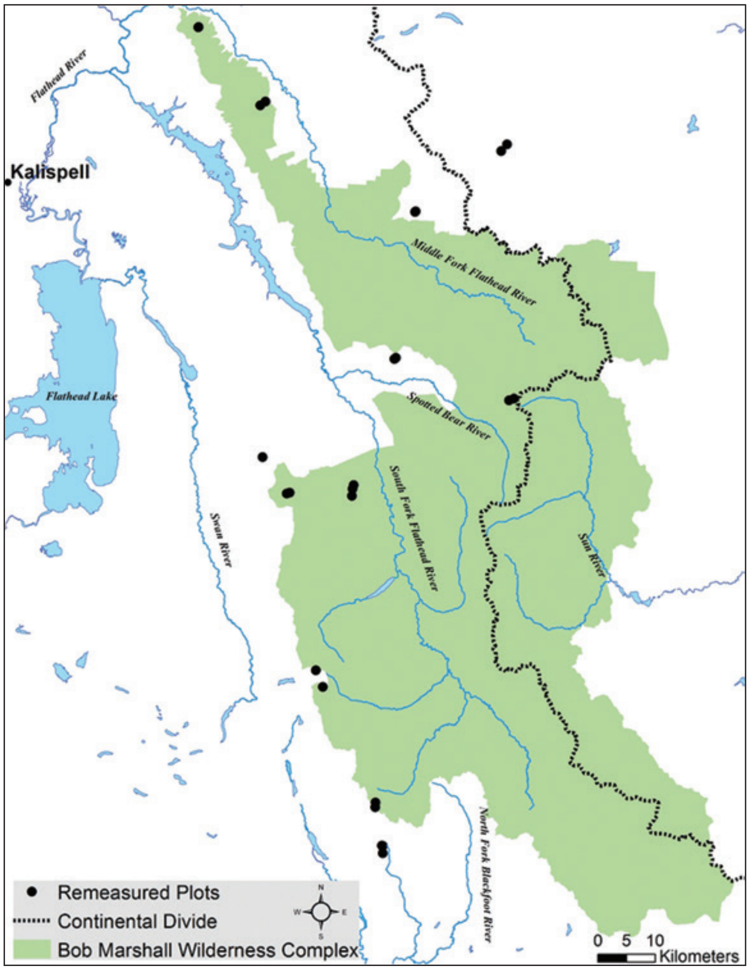

Figure 2—Locations of the plots (black dots) that were remeasured by the Bob Marshall Wilderness Foundation crews in 2013 and 2014.

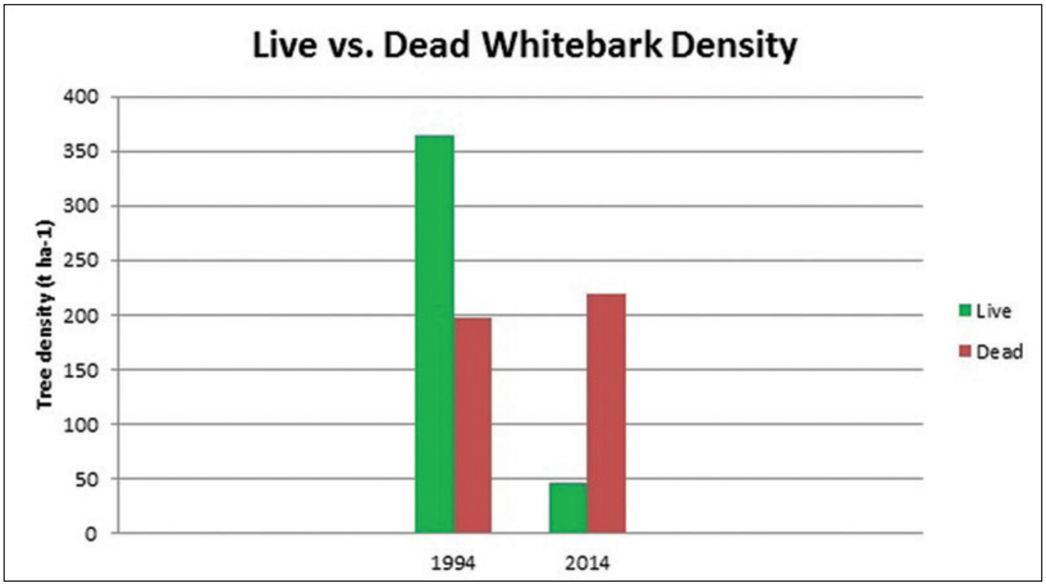

Figure 3—Live and dead whitebark pine tree density (trees ha^{-1}) as measured on 25 plots in the Bob Marshall Wilderness Complex sampled in 1994 and 2014.

Overall, live tree density (trees ha^{-1}) of whitebark pine trees decreased by 87 percent between 1994 and 2014 (table 1). WPBR was responsible for most of the additional whitebark pine mortality; it was present in all of the BMWF plots that contained mature whitebark pine. In the original 1994 sample, 63 percent of live mature whitebark pines were infected with blister rust. In 2014, only 13 percent of live mature whitebark pine trees were visibly infected with WPBR; rust-caused mortality decreased by 79 percent over the same time period (table 1).

In 1994, only 1 percent of living whitebark pine trees showed insect damage. In contrast, mountain pine beetle attacks were observed in 8 of the 25 plots measured in 2014, affecting more than 50 percent of the mature remaining whitebark pine. Over the same time period, beetle-caused mortality increased from 3 percent to 10 percent (table 1). Recent fires had burned parts of 8 of the 25 BMWF plots and accounted for 12 percent of the total whitebark pine mortality. In the original study, only 1 of the 116 plots was affected by fire, accounting for only 5 percent of total mortality (table 1).

Table 1—Summary of and comparison between 1994 and 2014 of the proportion of mature (>10 cm DBH) live and dead whitebark pine trees affected by health and mortality factors on the 25 plots in the Bob Marshall Wilderness Complex. Unknown mortality agents increased because BMWF crews were inexperienced at determining cause of death of whitebark pine trees.

Whitebark pine attribute	1994	2014	% change
Live tree density (trees ha^{-1})[a]	365	46	–87 [b]
Dead tree density (trees ha^{-1})[a]	197	219	+11
Percent mortality (%)	35	83	+137 [b]
Healthy[c] trees (trees ha^{-1})	22	7	–68
Live but damaged trees (trees ha^{-1})	343	39	–89 [b]
Mortality by agent (%)			
White pine blister rust (trees ha^{-1})	63	13	-79 [b]
Mountain pine beetle (trees ha^{-1})	3	10	+233 [d]
Wildland fire (trees ha^{-1})	5	12	+140 [d]
Unknown (trees ha^{-1})	29	65	+124 [d]

[a] Density is reported here, but the values in the first four cells also represent the total number of trees sampled: 365 live trees and 197 dead trees in 1994, and 46 and 219 trees, respectively, in 2014. The total number of live and dead trees in 1994 and in 2014 do not match because of snagfall from fires, wind, and other factors.
[b] Significant at the level of $P \leq 0.05$.
[c] "Healthy" is defined as a tree with no crown damage from blister rust.
[d] Not enough samples in 2014 to indicate significance from all agents of mortality.

DISCUSSION

The findings of this citizen-science remeasurement effort indicate that the whitebark pine mortality rate has more than doubled on the plots sampled in the BMWC over the last 20 years, primarily as a result of blister rust infection, and to a lesser extent from mountain pine beetle and wildfire (fig. 4). A similar study conducted by Smith et al. (2008) in a string of national parks stretching from Jasper National Park in Alberta, Canada, south through Glacier National Park in Montana along the Canadian-U.S. border also showed significant increases in the mortality of whitebark pine due to blister rust infections. They also observed higher infection levels on the moister west side of the Rocky Mountains than on the east side, similar to that observed by Keane et al. (1994) in the BMWC. A later study by Smith et al. (2013) found

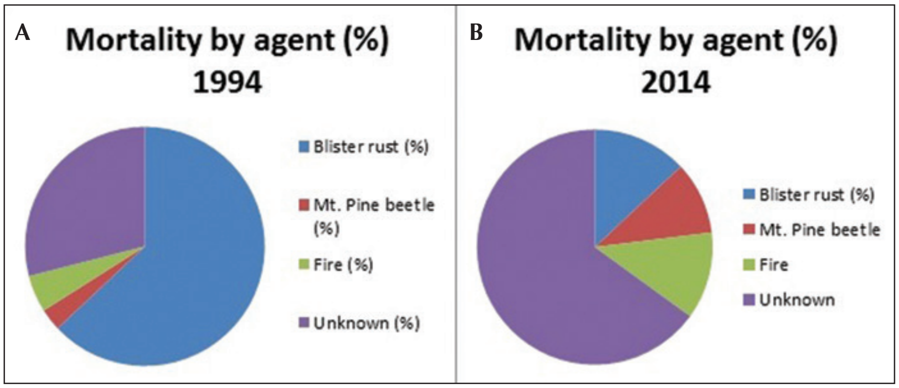

Figure 4—Proportion of whitebark pine tree mortality from the four agents (where "unknown" means crew was unable to determine cause of tree mortality), Bob Marshall Wilderness Complex, (A) 1994 and (B) 2014.

further evidence of decline in whitebark populations due to WPBR. However, it also showed a slowing of infection and mortality rates, suggesting some level of natural selection in areas with high infection rates (Smith et al. 2013). The results of our study indicate that WPBR infection rates have also slowed in the BMWC since 1994. This suggests that many of the originally sampled whitebark pine trees died from blister rust between 1994 and 2013, leaving fewer surviving trees to act as hosts for WPBR. It also suggests some level of natural rust resistance in the living mature populations.

CONCLUSIONS

As managers concentrate their resources on long-term management of whitebark pine in subalpine forests, citizen scientists can play a supporting role through monitoring and evaluation work. The citizen science approach was used for this study because of the great cost of funding wilderness research and a lack of funding for whitebark pine projects. Trained staff with the Bob Marshall Wilderness Foundation and volunteers collected most of the field data for this study. Citizen science can be a valuable tool in that it can increase ecological monitoring capacity, and at the same time, it can provide a hands-on conservation learning experience for volunteers.

In some instances, however, the use of volunteers may compromise data accuracy and detail; citizen science may be inappropriate for more complex monitoring efforts. Even though we are confident that the data collected by the BMWF volunteers and staff were of sufficient quality for coarse estimates of whitebark pine mortality, we had to simplify plot methods so inexperienced crews could collect useful, accurate field data. We provide the following recommendations to improve the efficiency and integrity of citizen science projects: (1) each group of volunteers should be led by a highly skilled crew leader who will provide meaningful training and ongoing quality control; (2) whenever possible, an agency or organization representative specific to the monitoring or data collection effort should accompany volunteer groups—both to help with training and to enrich the volunteers' learning experience; (3) data collection should be limited to objective and easily repeatable methods; (4) citizen science should supplement, not replace, paid monitoring efforts. In many cases, repeatedly training new volunteers is less efficient and economically prudent than relying on paid service. However, when carefully planned and executed, citizen science projects have the potential to provide valuable data to the scientific community while enhancing participants' knowledge of conservation issues.

MANAGEMENT IMPLICATIONS

The continued decline of whitebark pine across the BMWC has broad-reaching implications. In addition to killing mature trees, WPBR can severely reduce cone crops of surviving trees by attacking cone-bearing branches. As cone crops decrease, Clark's nutcrackers may cease to visit declining stands, and even if they do visit, it may become more common for nutcrackers to reclaim most of the cached seed, reducing the potential for subsequent whitebark pine natural regeneration (Barringer et al. 2012; McKinney and Tomback 2007; McKinney et al. 2009; Tomback 1982). Research by Tomback (2007) found that declines in nutcracker populations might correspond with declines of whitebark pine cone crops. If crops continue to decline, it is speculated that Clark's nutcrackers might move out of subalpine areas to forage on lower elevation pine species. Such a foraging shift could drastically disturb the regeneration cycle of whitebark pine, further emphasizing the need to plant WPBR-resistant seedlings (Tomback et al. 2001, 2007). As the number of mature cone-bearing whitebark trees continues to dwindle, regeneration of this species may be reduced; this may lead to an overall change in stand structure throughout the BMWC as faster growing, more shade-tolerant species become dominant. Planting rust-resistant whitebark pine seedlings after wildfires and treatments is essential for the restoration of the species.

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