Forest fire survival in young, dense *Betula ermanii* stands on scarification sites

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Abstract

A forest fire (May 2019) in northern Japan, provided an opportunity to examine the impact of the disturbance on dense birch (*Betula ermanii*) stands on scarification sites. Two plots (Plot 1, 10×50 m; Plot 2, 20×20 m; 500 m apart) were set up six months after the fire. To assess the severity of the fire, burn marks on tree trunks (scorch height), burnt litter depth, and understory regrowth were examined. Trunk diameter at breast height (DBH) and survival were investigated for all surviving birches (Plot 1; $N = 112$, Plot 2; $N = 115$). Scorch height, which correlates with fire intensity, did not reach the tree canopy. Burnt litter was found only in the surface layer. New leaves and culms from belowground rhizomes were observed in the dwarf bamboo *Sasa kurilensis,* the dominant understory vegetation. Fire severity was low enough to avoid damage to the tree canopy, but damaged tree trunks and aerial parts of understory plants. The survival of *B. ermanii* was similar in Plots 1 and 2 (24.1 and 27.8 %, respectively). Survival probability, estimated by simple logistic regression, was size dependent; the average DBH of surviving birches was larger than that of dead birches. Therefore, the stand structure, including density and size composition, was shifted because young birches (< 7 cm DBH) had a higher mortality. Since no epicormic sprouts were observed, the dominant understory species, *S. kurilensis,* is speculated to inhibit *B. ermanii* seedling growth, and fire may therefore affect regeneration of *B. ermanii* stands. Fire may moderate the negative effects of intraspecific competition among individuals, such as the decreased growth and DBH in high density *B. ermanii* stands on scarification sites. The study outcome may provide a reliable reference when considering the risk management in broadleaf forests.

Key words: soil scarification, forest fires, young birch, *Betula ermanii*

Introduction

Scarification is a silvicultural technique of soil disturbance treatment that removes topsoil and vegetation using heavy machinery (Resco de Dios *et al.*, 2005; Yoshida *et al.*, 2005). In general, it aims to assist the natural regeneration of trees (Zaczek, 2002; Drössler et al., 2017; Fløistad et al., 2018). Many studies have reported the significant advantages of scarification treatment from the perspective of forest management, including enhancement of germination, tree seedling establishment by improving mineral soil substrates, removal of understory plant competitors (Yoshida *et al*., 2005), and reduction in the management costs of forest regeneration (Shono *et al*., 2007). Scarification is a commonly used method in a number of forest biomes with widespread research spanning the globe, e.g., Japan (Umeki, 2003), Europe (Hynynen *et al*., 2010; Nilsson *et al*., 2010; Jäärats *et al*., 2012), the United States (Woolley *et al*., 2012), Canada (Beaudry *et al*., 1997; Giasson *et al*., 2006), with recent reports from south-central Chile (Soto and Puettmann, 2018), and Lebanon (Nakhoul *et al*., 2020).

In understanding the dynamics and effective management of forest stands, it is necessary to understand how forests respond to natural disturbances. Fire is a common natural disturbance in forests worldwide (Hynynen *et al*., 2010; Saursaunet *et al*., 2018). Many studies have incorporated a stepwise categorization of fire severity in order to assess the impact of forest fires. According to previous research, forest fires are classified into several types based on fire intensity (Wang, 2002; Keeley, 2009). In most cases, fuel-related variables, such as litter and shrub cover, are assessed for the establishment of relationships with tree responses. In addition, tree mortality-based fire severity classification directly assesses the impact on the forest stand, ranging from relatively small to broad-scale fires. (Moreira *et al*., 2007; Whittier and Gray, 2016). Indeed, there are several reports on the soil nutrients and microbial communities in scarification sites after mixed-severity fires, and on *Pinus sylvestris* seedlings

after medium intensity fires (Hille and den Ouden, 2004). However, there is little information about the responses during and after fires of broadleaved forest stands after establishment of scarification sites.

Post-fire tree survival not only depends on fire severity, but also on individual tree characteristics. Tree height and trunk diameter at breast height (DBH, measured 1.3 m above ground) typically increase in a size-dependent manner, meaning that young trees in particular are strongly affected by fire (Fernandes *et al*., 2008; Archibald *et al*., 2019; Ray and Landau, 2019). In addition, the ability to sprout (the ability to produce sprouting branches from root or trunk tissue) also affects the extent of recovery. The ability of trees to resprout from the root collar and stem is a species-specific characteristic (Bellingham *et al*., 1994; Masaka *et al*., 2000; Weigel and Peng, 2002; Quevedo *et al*., 2007) that is closely connected to patterns of resource deployment (Sakai and Sakai, 1998). Although there is relatively little information about the effects of fire severity on the number of resprouts, previous studies have shown that different tree species respond differently to increasing fire severity (Masaka *et al*., 2000; Quevedo *et al*., 2007). To assess the impacts of fire on forest stands on scarification sites, field surveys of the fire-related, species-specific characteristics and survival associated with fire in stands with many young trees are needed.

Birch species (*Betula* spp.) are common broadleaf trees that occur in various habitats in the Northern Hemisphere, ranging from boreal to cold-temperate climate zones in Northern America, Eurasia, East Asia, and the circumpolar regions (Perala and Alm, 1990). They are pioneer species with disturbance-related characteristics such as high dispersal ability and fast growth potential in disturbed sites (Perala and Alm, 1990). *Betula ermanii* is a known pioneer species in northern Japan and often forms monospecific, even-aged stands in open sites created after fire or by soil disturbance (Kikuzawa, 1988; Umeki, 2003). However, dwarf bamboos (e.g., *Sasa senanensis* and *S. kurilensis*) in Hokkaido, northern Japan, reproduce

vegetatively from their root systems to form dense carpets after low-severity disturbance, which inhibits seedling emergence and the survival of tree species (Goto, 2004; Noguchi and Yoshida, 2004; Yamazaki and Yoshida, 2018). Therefore, soil scarification, which removes the entire dwarf bamboo layer, has been widely performed (Umeki, 2003; Ito *et al*., 2018).

Large-scale fire disturbance occurred in Hokkaido at a higher frequency before the beginning of the 20th century (Takaoka and Sasa, 1996), but relatively small fires continue to occur sporadically even now. A forest fire which started in Ōmu Town, northwestern Hokkaido, in May 2019, burned a total of 214.79 ha. It was the largest fire in Hokkaido, in terms of area and scale, in the past 30 years (Hokkaido Government, 2019). The fire area included several sites that had been scarified and which had dense regeneration of young birch trees. This provided an opportunity to examine the impacts of fire on the survival of young birch forests.

In this study, the post-fire situation in scarification sites was evaluated to examine the survival (immediately after fire) of a dense, young birch forest. The intention was to clarify: (1) the severity of the fire in the scarification sites; (2) the extent to which the severity of damage affected *B. ermanii* stands on scarification sites; and (3) the characteristics of individual trees that affect survival during fire. The results allow the effects of fire on representative pioneer species in boreal forests to be taken into consideration to improve forest management.

Materials and Methods

Study sites

The study sites were located at the scarification sites in Ōmu Town, northern Hokkaido, Japan (Figure 1a and b). Although the entire area did not burn for the entire month, the fire was first found on 22 May and was finally declared to be under control in this area on 19

June 2019. The fire spread across 214.79 ha, including 165.83 ha of secondary cool-temperate broadleaved forest and 48.96 ha of artificial coniferous forest. There is no record of any previous fires at the study sites, but the current fire burned most of the aboveground parts of the forest floor vegetation (Hokkaido Government, 2019). The weather at the time of the fire was rainy, with a temperature of 12.6 °C, humidity of 82 %, wind velocity of 2.6 m/s, and a southeast wind direction. The elevation of the site ranges from 500 to 560 m. Soil scarification was conducted in several areas in 1989.

Sampling and data collection

In the forest fire sites, two plots were established in burnt *B. ermanii* stands on scarification sites on 30 October 2019. In Plot 1, which was scarified in a rectangular shape in 1989, a 10×50 m quadrat was set up at 560 m altitude. In Plot 2, which was scarified in a square shape in 1989, a 20×20 m quadrat was set up at 503 m altitude. Only trees with at least 0.7 cm DBH were sampled; overall 112 *B. ermanii* were measured and observed on Plot 1, and 115 were measured and observed on Plot 2. Data was collected from 30 October to 1 November, six months after the fire occurred.

To assess the fire severity at the scarification sites, several fire severity indicators were recorded, including the burn marks on tree trunks (scorch height), burnt litter depth, and understory plants. Scorch height, which is correlated with fire intensity, was measured in all individuals. Burnt litter depth was recorded in 1 m ×1 m quadrats randomly repeated three times in each plot and was measured as the depth to which the burn marks reached in the litter layer, after measuring the depth of the litter layer (litter depth) of the plot. To describe forest physiognomy, an unmanned aircraft vehicle (UAV) was used in this study. The real time kinematic – UAV (RTK-UAV), Phantom 4 RTK (DJI Co., Shenzhen, China) was used to assess the abiotic factors, such as fire intensity and behavior variables in the two plots, and

133 in areas around these sites. The device was equipped with a D-RTK 2 high precision global
134 navigation satellite system (GNSS) mobile station, which allowed real-time differentiation
135 between the aircraft and the local GNSS system or a RTK base station. The flight height was
136 set to 100 m to acquire high-resolution orthorectified images. These images were created
137 using the structure-from-motion and multi-view stereo algorithms. The algorithms
138 automatically detect feature points to be matched in disordered digital images, optimize the
139 mutual positions between the cameras and the target, acquire three-dimensional spatial
140 information for the target, and create an orthorectified image with this information.
141 Metashape version 1.5.3 (Agisoft LLC, Saint Petersburg, Russia) was used to process the
142 photographs.

143 Trees in the study plot were tagged, their DBH measured to the nearest 1 cm at 1.3 m above
144 ground level, and the number of new sprouts counted. Tree size measurements included the
145 DBH for all birches and the tree height (measured using a measuring pole) of several
146 representative birches (Plot 1; $N = 6$, Plot 2; $N = 10$, Table 1). Tree survival was divided into
147 binary categories by assessing crown condition by eye: 0, dead, no foliage or sprouts in the
148 crown; 1, alive, foliage survived, and sprouts or inflorescence buds were present in the
149 crown. Several representative trees standing near the plots were cut down and the cambium
150 and crown bud conditions observed to confirm the consistency of these observational
151 categories.

152 *Data analysis*

153 To test for size differences between the surviving and dead individuals, Student's *t*-test was
154 used to compare the differences in mean DBH within each plot. The survival data analysis
155 was performed using generalized linear models (GLM). Logistic regression models that
156 predict post-fire tree mortality are a simple field tool and contribute to fire-effects models.

All statistical analyses were carried out using the statistical software R, version 3.6.2 (R Development Core Team, 2019).

Results

Description of scorched trees, litter, and understory plants after fire

The situation about six months after the fire broke out is shown in Tables 1 and 2 and Figure 2. The other tree species present in the *B. ermanii* stands were *Abies sachalinensis* (Schmidt), *Quercus crispula* Blume, *Phellodendron amurense* Rupr., *Cornus controversa* Hemsl., *Sorbus commixta* Hedlund, and *Salix bakko* Kimura. From the orthomosaic image created from RTK-UAV aerial photographs, large *B. ermanii* trees were confirmed around Plot 2, but none around Plot 1 (Figure 1c and d). The forest floor six months after the fire was dominated by *S. kurilensis* with spreading leaves (Figure 1c and d; Figure 2f). Scorch height did not reach the tree crown in any of the trees with measured tree and branch heights in either plot (Figure 2c and d; Table 1). The mean scorch height in Plot 1 was higher than that in Plot 2 (*t*-test, $P < 0.01$; Table 2). Although the litter depth and burnt litter depth were not significantly different between the plots (*t*-test, $P = 0.105$, 0.125; Table 2), litter depth tended to be deeper in Plot 2 than in Plot 1, and the burnt litter depth was deeper in Plot 1, corresponding to the significant difference in scorch height between Plots 1 and 2 (Figure 2e; Table 2).

Survival mode and probability of survival

The survival in Plot 1 and Plot 2 is shown in Table 3 and Figures 3 and 4. In Plot 1, with a modal DBH of 3 cm and stand density of 2240 trees/ha, all plants with a DBH smaller than 5 cm died. The mean DBH of dead individuals was 5.32 ± 0.35 cm (mean ± standard error (SE)). The DBH of surviving individuals showed a modal value of 10–12 cm with a mean DBH of 10.57 ± 0.69 (mean ± SE). The survival rate was 24.1 %, and the mean DBH of the

181 survivors was significantly greater than that of the dead trees (*t*-test, $P < 0.01$; Table 3 and
182 Figure 4). Despite careful observation, no resprouting from the burnt bases of *B. ermanii*
183 stems was observed in Plot 1.

184 The survival in Plot 2, with a stand density of 2875 trees/ha, showed the same tendency as
185 Plot 1. The modal DBH was 3 cm, and all individuals with a DBH less than 5 cm died. As in
186 Plot 1, no resprouting from the burnt bases of *B. ermanii* stems was observed in Plot 2. The
187 mean DBH of the dead individuals was 4.18 ± 0.20 cm. The most frequent DBH of surviving
188 individuals was 7–8 cm, with a mean DBH of 8.97 ± 0.42 cm. The survival rate was 27.8 %,
189 and the mean DBH of the survivors was significantly greater than that of the dead trees (*t*-
190 test, $P < 0.01$; Table 3 and Figure 4).

191 After estimating the fire survival probabilities of the individual trees with logistic regression,
192 Plot 1 and Plot 2 showed a similar tendency, and survival probability rose as DBH increased
193 (GLM, $P < 0.001$); the DBH with 50 % survival in Plots 1 and 2 was estimated to be 7.35 and
194 7.27 cm, respectively (Table 4 and Figure 5).

195

196 **Discussion**

197 *Field survey of fire severity*

198 Our field survey showed that the fire impact on the scarification sites was not severe in either
199 of the two plots; the observation was based on the results of three indices of fire severity:
200 scorch height, burnt litter depth, and understory plants. Scorch height was less than the clear
201 length (the part of the stem clear of branches) in both plots, regardless of tree size and litter
202 depth (Table 2), indicating that in the *B. ermanii* stands the flames were unlikely to have
203 reached the canopy. In addition, only the surface layer of the understory litter was burned
204 (Table 1, Figure 2). The dominant understory plant, *S. kurilensis*, sprouted new leaves and

205 culms within six months of the fire (Table 1, Figure 2). Previous studies of the post-fire
206 response of *S. senanensis* have reported that 10–40 % of coverage recovered rapidly via
207 belowground culms at low fire severity sites, whereas little recovery was observed at higher
208 severity sites (Goto, 2004). The present observations of *S. kurilensis* were consistent with
209 previous studies, suggesting that most of the culms were strong enough to avoid heat damage
210 (Table 1, Figure 2). Therefore, the larger DBH of the surviving *B. ermanii* in the scarification
211 sites (24.1 % in Plot 1 and 27.8 % in Plot 2) suggests that these stems were sufficiently large
212 to resist fire damage.

213 The scorch height in Plot 1 was higher than that in Plot 2 (Tables 1 and 2). Despite the litter
214 depth of Plot 1 not being significantly different from that of Plot 2, the burnt litter depth of
215 Plot 1 was slightly deeper than that in Plot 2. These results are consistent with the differences
216 in the survival rate (Table 3), thereby suggesting that the fire severity in Plot 1 was slightly
217 greater than that in Plot 2.

218 Abiotic factors, such as topographical conditions (slope and aspect), have a direct influence
219 on fire behavior (Rothermel, 1983). According to the contours assessed via a 10 m digital
220 elevation model, and the orthomosaic photo taken by the RTK-UAV, Plot 1 was closer to the
221 ridge than Plot 2 and there were fewer large trees in the area (Figure 1). This implies that the
222 topographical conditions in Plot 1 would be more easily affected by wind and flame height,
223 suggesting that the differences in fire intensity were caused by topographical and
224 environmental conditions.

225 *Individual avoidance, resistance, and tolerance abilities during fire*

226 Survival probability was clearly size dependent in both plots, with larger trees more likely to
227 survive the fire (Figs. 3, 4, and 5). Large trees are expected to avoid and resist the lethal heat
228 of fires more easily than small trees, since their crowns are further from the ground and their

229 bark is thicker. A difference in fire resistance related to bark thickness is also recognized in
230 fire-prone ecosystems such as the Siberian taiga (Uemura *et al*., 1990) and Australian
231 eucalyptus-dominated forests (Gill and Ashton, 1968). In contrast, the bark of birch species is
232 thin and contains large amounts of terpene, contributing to its low critical temperature for
233 ignition. For example in *B. platyphylla* var. *japonica*, fire survivorship was not size
234 dependent because the trees were completely burned in two DBH classes (< 10 cm and > 20
235 cm) (Masaka *et al*., 2000). However, the survival probability analysis in this study did not
236 show bimodal survivorship. Therefore, the amount of terpene in the bark may not be size
237 dependent in *B. ermanii.* Another interpretation is that the severity of the fire and the
238 condition of the forest stand are responsible for the observed pattern, rather than the
239 characteristics of *B. ermanii.* In other words, it is possible that the forest stands on the
240 scarification sites offered less fuel, such as large trees and thick litter layers, therefore
241 reducing fire severity and *B. ermanii* mortality.

242 Resprouting was not evident in *B. ermanii* six months after the fire, suggesting that this
243 species is less able to resprout and thus has a low tolerance to fire. Although resprouting is
244 considered a common feature in the genus *Betula* (Perala and Alm, 1990; de Groot and Wein,
245 2004), Osumi (2005) reported that there is a critical difference in sprouting ability between
246 two Japanese birch species, *B. platyphylla* var. *japonica* and *B. maximowicziana* (Osumi,
247 2005). Masaka *et al*. (2000) also reported that larger *B. platyphylla* var. *japonica* trees
248 showed high resprouting ability after fire. However, Okitsu (1991) reported that the rate of
249 multiple-stemmed *B. ermanii* trees was 25–30 % at the treeline in areas with heavy snow.
250 Therefore, *B. ermanii* has the potential to resprout, but resprouting is not a common post-fire
251 response.

252 *Effects of a forest fire on stand structure and regeneration*

253 After soil scarification treatment, pioneer tree species dominate and establish dense stands
254 (Umeki, 2003; Karlsson and Nilsson, 2005). Intraspecific competition for light and nutrients
255 strongly affects growth and mortality rates, especially in dense forest stands; therefore,
256 thinning is recommended for dense stands from a silvicultural perspective (Kikuzawa, 1988;
257 Sano and Shibuya, 2015). In the case of this forest fire, tree density decreased by about a
258 quarter in both plots (Table 2; Plot 1, from 2240 trees/ha to 540 trees/ha; Plot 2, from 2875
259 trees/ha to 800 trees/ha). This means that intraspecific competition might be moderated in the
260 post-fire stands.

261 Regeneration strategies drive forest stand persistence through resprouting or seedling
262 recruitment (Pausas and Keeley, 2014). The stand structures on the scarification sites were
263 estimated to be relatively young, with a modal DBH of 3 cm pre-fire. Post-fire, the mean
264 DBH increased and the density of the stands decreased (Figure 2). In addition, among the
265 surviving trees, the trees with a relatively low probability of survival (DBH 7–9 cm; Figure 5)
266 may have been severely damaged by the heat of the fire. In previous studies on *B. ermanii*
267 and *B. platyphylla* var. *japonica*, even when their canopies survived after a forest fire, many
268 of the trees tended to die within a few years (Sasa *et al*., 1992; Masaka *et al*., 2004).
269 Considering these long-term effects, even if the trees survived the fire, their chances of long-
270 term survival are reduced. Thus, the forest stand densities at the scarification sites are likely
271 to be further reduced.

272 On the forest floor of both plots, *S. kurilensis* regenerated new leaves and culms from its
273 belowground parts (Figure 1). It is well known that dwarf bamboo grows densely on forest
274 floors, especially in northern Japan (Kudoh *et al*., 1999; Takahashi *et al*., 2003). It has also
275 been reported that *S. kurilensis* inhibits the establishment and regeneration of tree seedlings
276 (Nakashizuka, 1988). According to the orthomosaic images captured during the RTK-UAV
277 survey, many large, mature trees were observed around Plot 2, but none around Plot 1 (Figure

1). This may be one reason that the birch density was lower in Plot 1 than in Plot 2. Although birch seeds are known to be dispersed over relatively long distances (Perala and Alm, 1990), the amount of birch seeds will decrease as the distance from the mature trees increases.

Conclusion

The present study demonstrated the impacts of fire on dense stands of *B. ermanii* on scarification sites. Low to moderate severity fires were associated with high mortality of young trees (DBH < 5 cm), as estimated by logistic regression models. These results may be useful to managers in the assessment of post-fire production losses of *B. ermanii* stands on scarification sites. With respect to the post-fire response of *B. ermanii*, despite careful observation, there was no resprouting from individual trees, regardless of DBH. Considering the low fire severity and the observed rapid recovery of *S. kurilensis*, *B. ermanii* may be at high risk of post-fire regeneration failure. This knowledge should be useful in both research and management discussions about post-fire regeneration potential in scarification sites.

Author contributions

H.M.: Conceptualization, Investigation, Formal analysis, Writing – Original Draft, Writing – Review & Editing. N.Y.: Investigation, Formal analysis, Writing – Review & Editing. T.H.: Conceptualization, Investigation, Supervision, Writing – Review & Editing.

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Conflicts of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

Data for "Forest fire survival in young, dense *Betula ermanii* stands on scarification sites" will be made available on request.

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Tables

Table 1 Structural properties and scotch heights of representative trees from *Betula ermanii* stands on scarification sites in northern Japan.

	id	DBH (cm)	Height (m)	Clear length (m)	Scorch height (m)
Plot1	81	4.5	4.52	2.44	0.78
	102	5.5	6.55	3.77	0.5
	58	10.5	9.18	3.36	1.2
	59	11.5	8.95	3.66	1
	98	12.1	9.17	3.41	1.05
	111	14.9	12.19	5.17	0.8
Plot2	155	3.7	4.65	3.25	0.5
	218	4.2	5.95	2.85	0.7
	174	5.5	6.46	3.2	1
	164	8	8.26	3.68	0.5
	179	9	8.13	5.07	1
	171	9.2	8.15	4.53	0.6
	185	10	11.5	5.7	0.5
	161	10.4	9.5	5.7	0.6
	233	11.5	10	5.75	1
	221	16.5	12.2	5.06	0.8

6 **Table 2** Details of scarification sites after forest fire.

	Area (m)	density (/ha)	Scorch height (m)	Litter depth (cm)	Burnt litter depth (cm)
Plot 1	10 × 50	2240	1.49 ± 0.10 [a]	2.79 ± 0.77 [a]	1.39 ± 0.38 [a]
Plot 2	20 × 20	2875	0.68 ± 0.03 [b]	4.27 ± 1.16 [a]	0.96 ± 0.19 [a]

7 Means within a column followed by different letters are significantly different ($P < 0.01$), according to a *t*-test.

8

9 **Table 3** Summary of individual *Betula ermanii* survival.

		N	DBH mean ± SE (cm)	Survival rate (%)
Plot1	all	112	5.32 ± 0.35	
	alive	27	10.57 ± 0.69	24.1
	dead	85	3.65 ± 0.17	
Plot2	all	115	5.51 ± 0.28	
	alive	32	8.97 ± 0.42	27.8
	dead	83	4.18 ± 0.20	

10

11

12 **Table 4** Simple logistic regression analysis to determine probability of survival.

		Estimate	Std. Error	z value	Pr (>|z|)
Plot 1	Intercept	-7.554	1.433	-5.272	0.0005
	DBH	1.028	0.216	4.765	< 0.0001
Plot 2	Intercept	-9.434	1.909	-4.941	< 0.0001
	DBH	1.298	0.267	4.858	< 0.0001

13

Figure legends

Figure 1. Map and location of Ōmu Town, Hokkaido, Japan. Location of the two study sites (a) Black dots represent the study plots and the area surrounded by the black line indicates the burnt area traced during a field survey (b) Orthomosaic image of Plots 1 and 2 (c and d). Each plot was set to the position indicated by the black squares (c and d).

Figure 2. *Betula ermanii* stands on scarification sites in Plot 1 (a) and Plot 2 (b). Scorched tree (c); burnt and damaged tree (d); litter layer and burnt litter (e; black layer); and understory vegetation and recovered *Sasa kurilensis* (the dominant species) (f).

Figure 3. Stand structure of *Betula ermanii* in Plots 1 and 2. Histograms were created from individual trunk diameter at breast height (DBH) from each plot.

Figure 4. Individual trunk diameters at breast height (DBHs) of 'alive' and 'dead' *Betula ermanii* in Plots 1 and 2. Asterisks indicate statistically significant differences between the means of dead and alive individuals DBHs within a plot (t-test, $P < 0.01$).

Figure 5. Binary logistic regression analysis of *Betula ermanii* as a function of trunk diameter at breast height (DBH). Black points around the "1" line on the y-axis indicate surviving trees and black points around the "0" line indicate dead trees. The solid blue line represents the probability function derived from the prediction equation and the gray area shows the 90 % confidence interval.

Figure 1

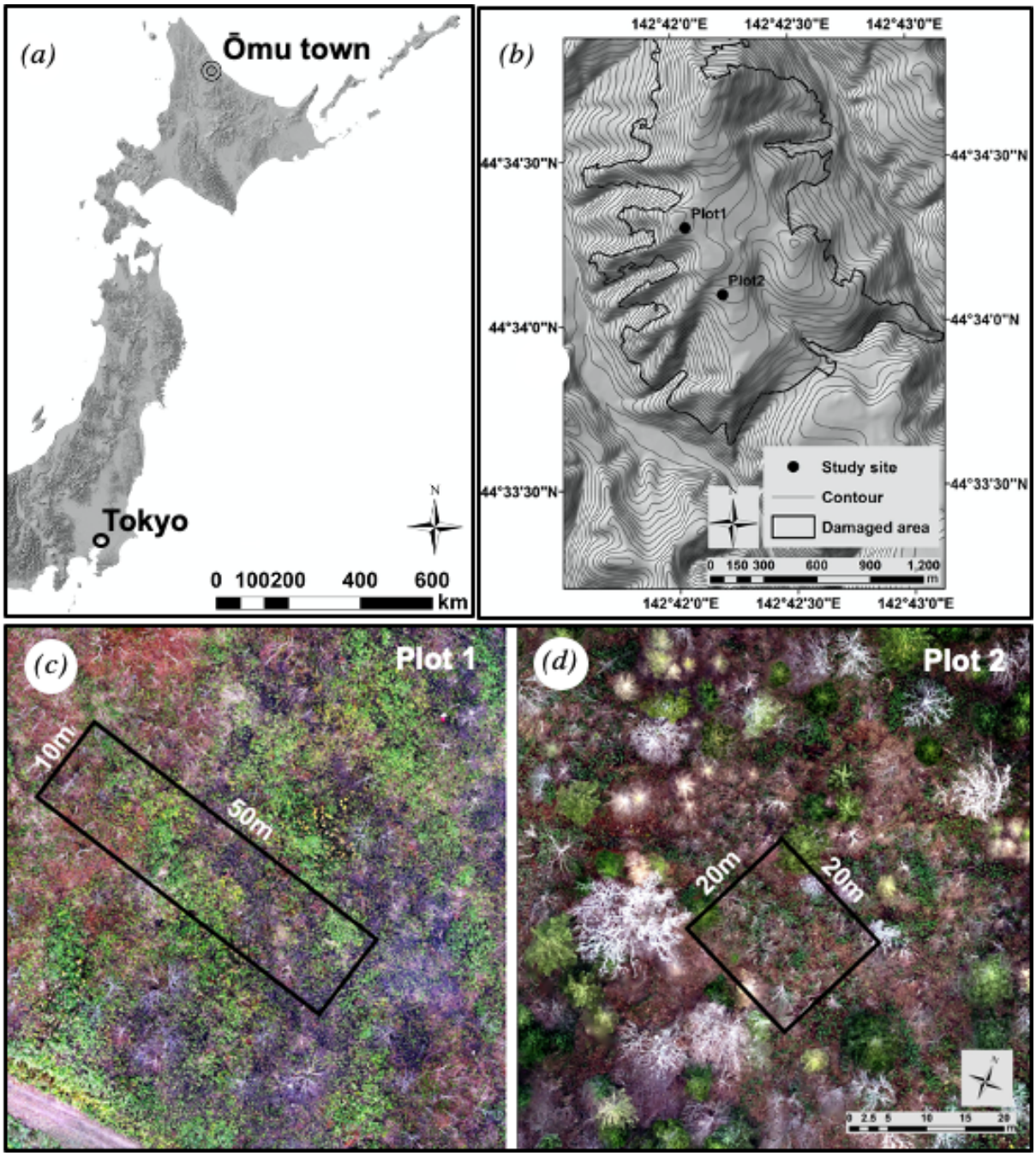

(a)
Ōmu town
Tokyo
N
0 100200 400 600
km
(b)
142°42'0"E
142°42'30"E
142°43'0"E
44°34'30"N
44°34'0"N
44°33'30"N
Plot1
Plot2
Study site
Contour
Damaged area
0 150 300 600 900 1,200
m
(c)
Plot 1
10m
50m
(d)
Plot 2
20m
20m

Figure 2

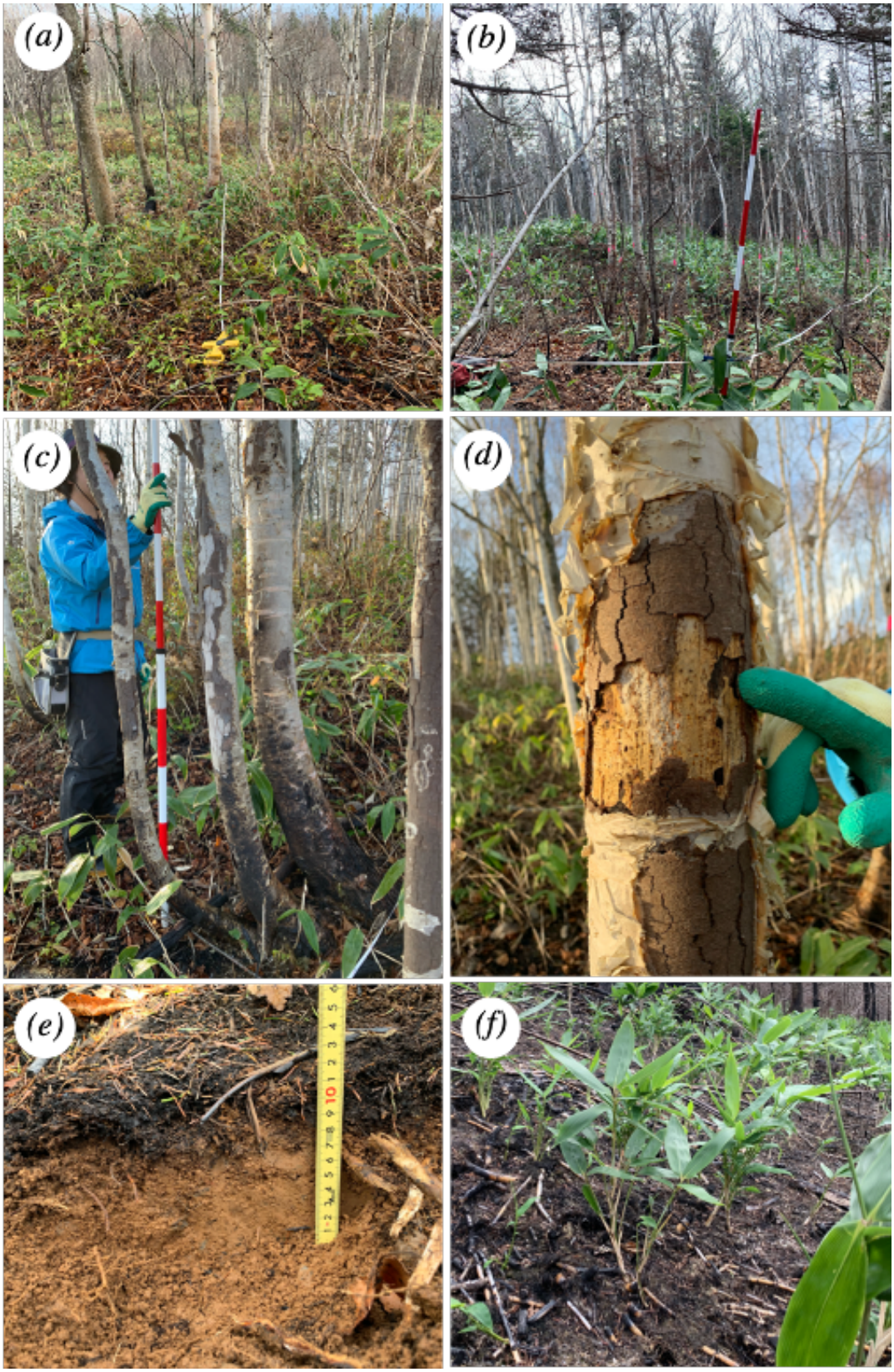


Figure 3

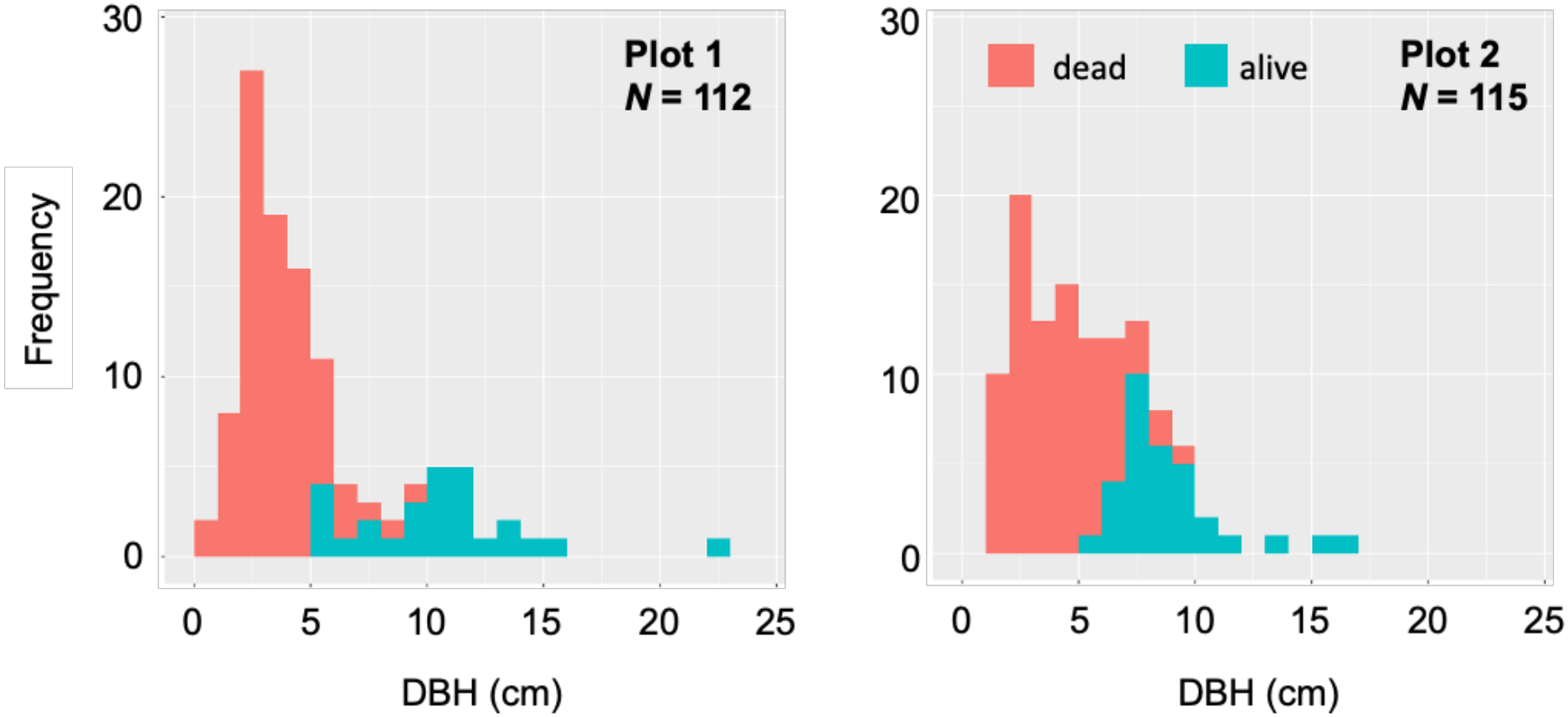

Frequency
30
20
10
0
Plot 1
N = 112
0
5
10
15
20
25
DBH (cm)
dead
alive
Plot 2
N = 115
DBH (cm)

Figure 4

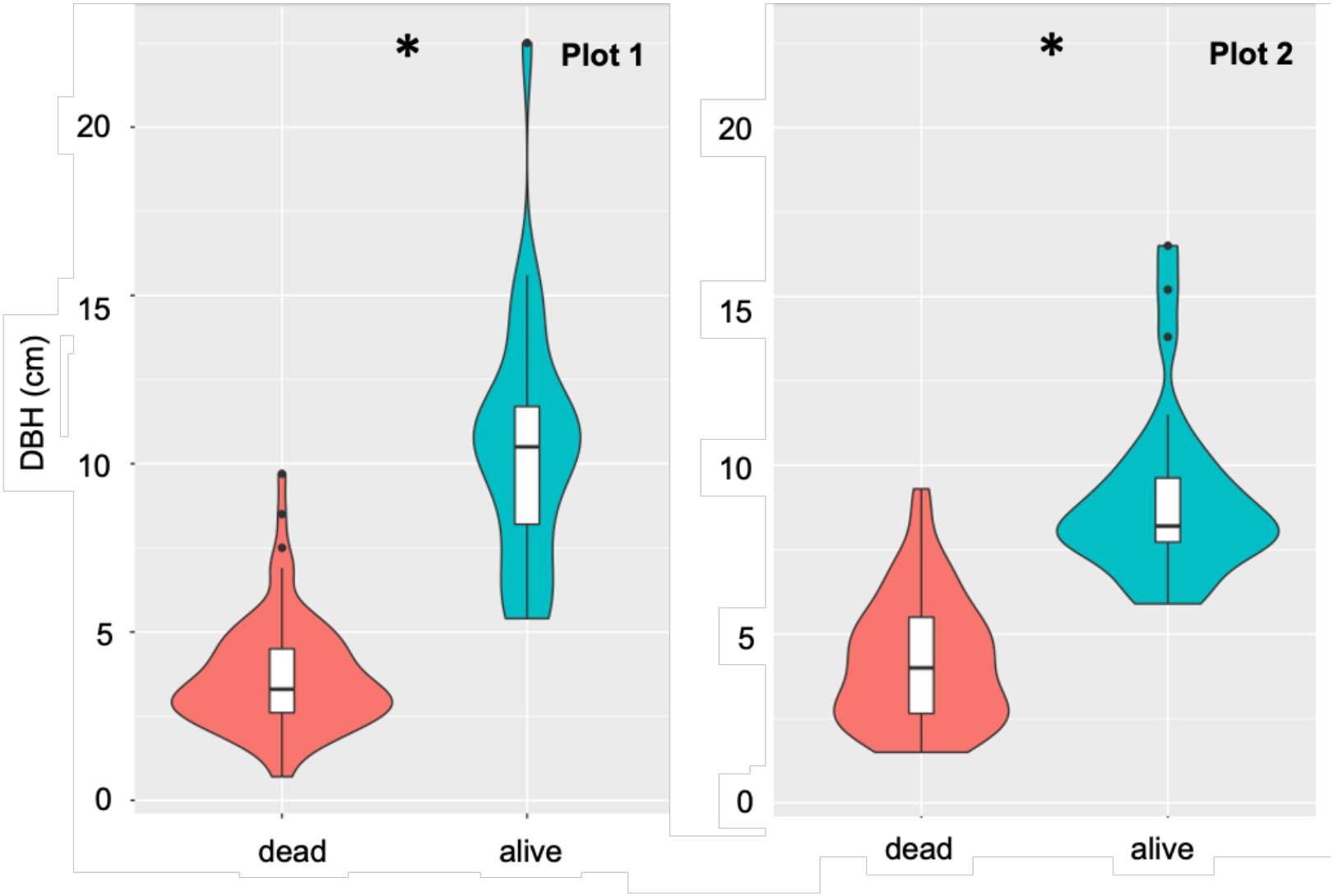
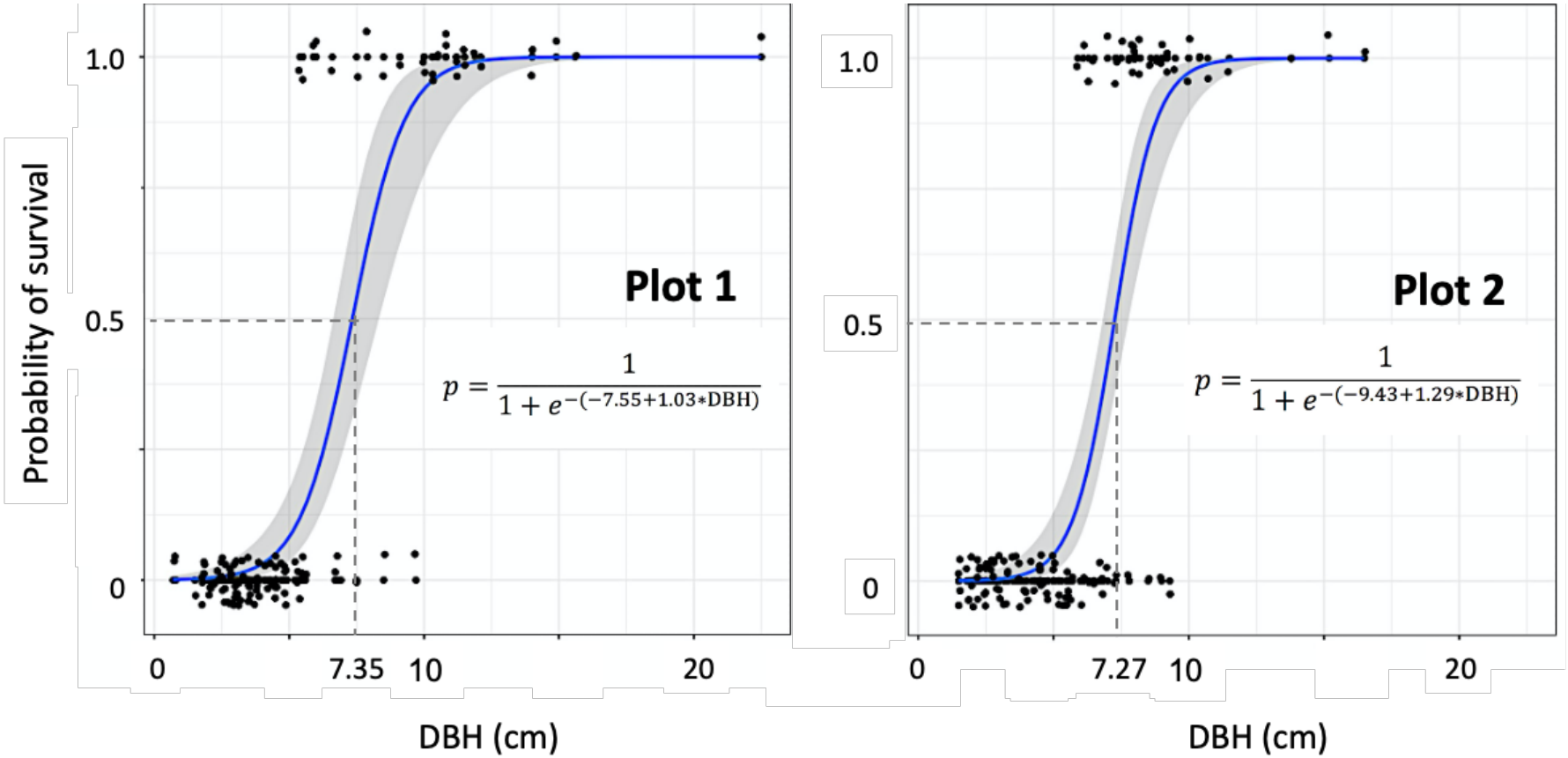


Figure 5


Probability of survival
1.0
0.5
0
Plot 1
$p = \frac{1}{1 + e^{-(-7.55+1.03*\mathrm{DBH})}}$
0
7.35
10
20
DBH (cm)
1.0
0.5
0
Plot 2
$p = \frac{1}{1 + e^{-(-9.43+1.29*\mathrm{DBH})}}$
0
7.27
10
20
DBH (cm)