Research Article

Analysis of factors contributing to the dispersal of *Casuarina junghuhniana* Miq. in a volcanic mountain

Brian Rahardi[1*], Serafinah Indriyani[1], Luchman Hakim[1], Agus Suryanto[2]

[1] Biology Department, Faculty of Mathematics and Natural Sciences, Brawijaya University, Jl. Veteran Malang 65145, Indonesia

[2] Mathematics Department, Faculty of Mathematics and Natural Sciences, Brawijaya University, Jl. Veteran Malang 65145, Indonesia

[*]corresponding author: brian_rhardi@ub.ac.id

Abstract: *Casuarina junghuhniana* or mountain ru, she oak or cemara is a species from Indonesia which grows in the highland area at an altitude between 2000 - 3000 m above sea level (asl). One of the highland area in Eastern Java (Jawa Timur) of Indonesia is Bromo Tengger Semeru National Park (TNBTS). The study site was on the Tengger Sea of Sands, Eastern Java, Indonesia where it is affected by volcanic activity. This tree, from some references, has not been well studied yet although it has been reported as a tree native to Indonesia. The lack of the study poses problems when there is a program related to planting the tree on a certain location in TNBTS for rehabilitation purposes. This study attempted to construct a Structural Equation Model that mapped some factors observed in the study site related to *C. junghuhniana* population. Explored factors for their relationship with each other included the number of male and female individuals, growth-related indicators, and environmental factors consisting of altitude and the tree population. Formative factors which consist of parameters related to growth, environmental factors and factor associated with the diffusion of new individuals, may contribute to population growth while population growth was the opposite. The individual growth might not significantly contribute to the population of *C. junghuhniana*; instead, the population growth was affected by the tree individuals. Generative reproduction contributed the least to the dispersal as it may rely more on vegetative reproduction by adventitious shoots from roots.

Keywords: pioneer, structural equation model, volcanic

Introduction

Casuarina junghuhniana was reported as an endemic tree species from Indonesia (Plant Use English Contributors, 2016). This is supported by previous studies providing information about this tree as an exotic species that is originated from Indonesia. One of the main habitats of this tree is the Bromo Tengger Semeru National Park (TNBTS). Meanwhile, this area geographically plays multiple important roles, including cultural, natural conservation site and tourism (Hakim and Soemarno, 2017). Some rehabilitation projects to some area by planting the tree using conventional methods were successful. However, some other projects were not too successful because of the extreme environmental condition, which is a mix between low temperature and ash accumulation. A method for understanding how the spreading process is taking place be hopefully useful for future rehabilitation projects.

C. junghuhniana is a member of the Casuarinaceae family and has many environmental functions (Pinyopusarerk and Boland, 1995). For

example, it can live at various altitudes and under adverse conditions where other plants experience difficulties to grow in the first place (National Research Council, 1984). In other words, it has an ecological function as a pioneer species (Jayaraj, 2010). However, there are very few Indonesian publications about the tree and little information known about its dispersal or what factors mainly contribute to it. For this research, information from more well-known *C. equisetifolia* more or less was used. For area rehabilitation, TNBTS has been using *C. junghuhniana* in some places (Rencana Pengelolaan Taman Nasional Bromo Tengger Semeru 1995 - 2020, 1995). According to an interview with some of the national park staffs, they were having difficulties when propagating the tree in certain areas. In an area further from volcanic disturbance, for example, the Northern part of Tengger Sea of Sands, human-assisted propagation was reported to be relatively successfully carried out. Nearer to the source of volcanic disturbance, the tree seemed to survive naturally. Such difficulties prevent them from taking effective conservation action.
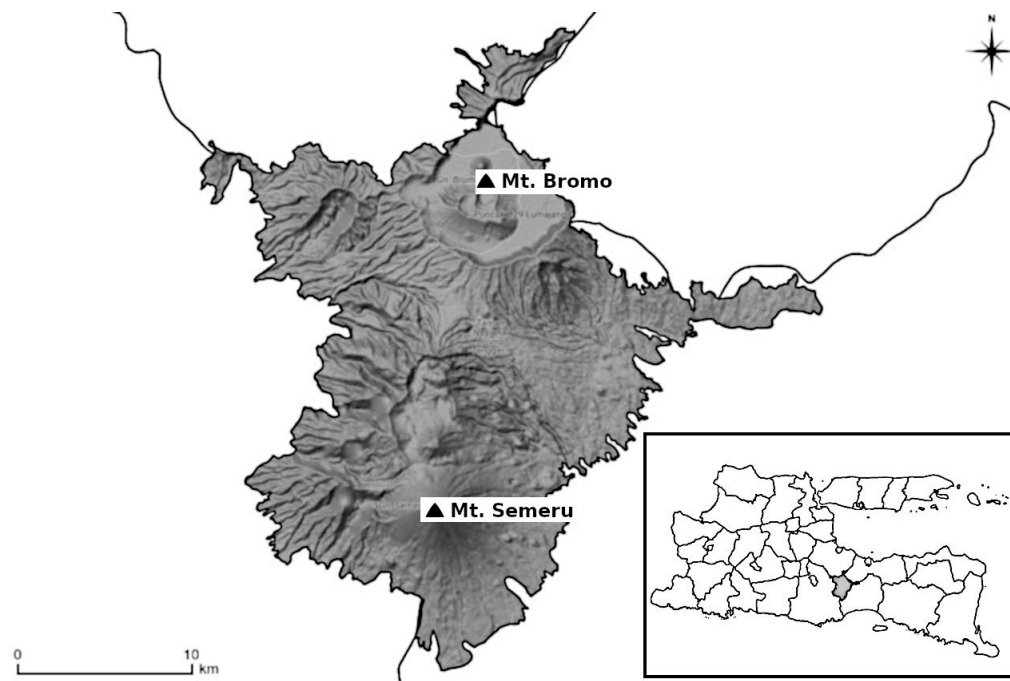

Figure 1. Bromo Tengger Semeru National Park administrative border in Eastern Java, Indonesia. The area has Mt. Bromo and Mt. Semeru, and both are active volcanoes.

This study attempted to develop more understanding of *C. junghuhniana* dispersal in an area with volcanic disturbance. Information obtained from the study can be used as an additional reference for park management and conservation of the species. This study explored some of the many factors involved in the mechanism of *C. junghuhniana* dispersal in the Bromo Tengger Semeru National Park. It is expected that through good management and conservation, then local people can get sustainable benefits from the tree. Furthermore, with appropriate conservation and sustainable management, it is hoped that *C. junghuhniana* can be a local resource with long-term future use.

Materials and Methods

This study location is as shown in Figure 1, it is in Jawa Timur (East Java Province), at coordinates of 8.0219° S and 112.9524° E. Five mountains were formed after the prehistoric eruption of Tengger. Those mountains formation created a unique feature of Tengger Sea of Sands. They are Mt. Bromo (2,392 m asl), Mt. Batok (2,470 m asl), Mt. Widodaren (2,650 m asl), Mt. Kursi (2,581 m asl) and Mt. Watangan (2,662 m asl). Only Mt. Bromo that is still active at the time this study was conducted and also as a source of volcanic ash. Because of certain features between the highland region and volcanic activity, this area has a suitable environment for the species. In this area, local

people use the tree for many purposes, for example, ceremonial purpose, as building materials and a source of firewood (Hakim and Miyakawa, 2013).

In this exploratory research, sampling plots were selected from the Google satellite image. Google satellite images through Google map and Google earth were readily available, which was sufficient for spatial references. The areas which showed denser coverage was assumed to have a higher probability of *C. junghuhniana* population. Random coordinates from the map were selected using QGIS sampling points generator inside the boundary of Tengger Sea of Sands as candidates for field survey and data collection. Some plots which were generated using QGIS were very difficult to reach therefore safer plots nearest to the generated plot were chosen instead. Data were collected using direct observation and referring to the Google satellite image (Google Maps, 2017) from 48 sampling plots inside Block of Tengger Sea of Sand study site. The number of sampling

plots was considered sufficient for a Partial Least Square (PLS) based Structural Equation Model analysis (Hair, 2014). However, a larger sampling number would provide better accuracy, especially with more arrows between latent factors. For collecting the data, the 48 plots were distributed on five small mountains in the Tengger Sea of Sands (Bachri et al., 2015) in the study site. During this study, spatial data with attributes of Table 1 were collected from field surveys from locations shown in Figure 2. Data from field surveys were supported by on-line information from Google Maps. The online data were considered to be free and reliable for this level of study. The population of *C. junghuhniana* was assumed to grow very slow after studying the coverage from Google Earth satellite images from 2004 to 2018. The area coverage increase was nearly unnoticeable. The data was analyzed by employing a PLS based Structural Equation Model.
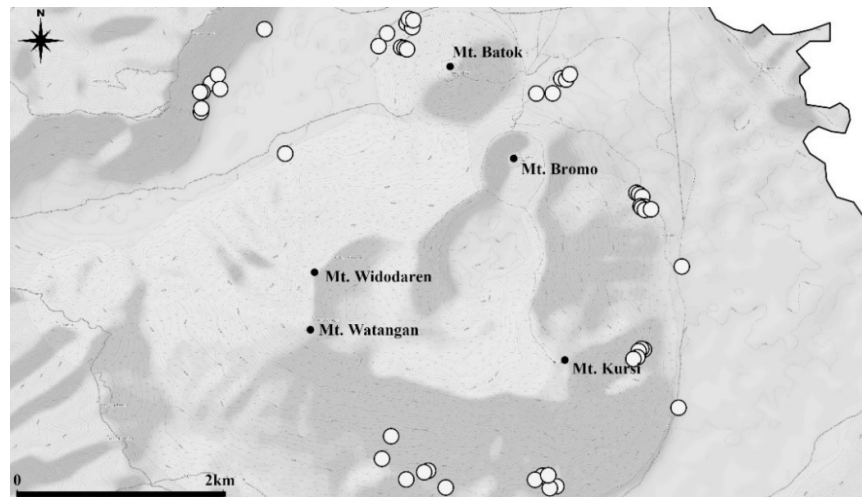

Figure 2. Sampling points of the study site.

Table 1. Observed parameters of *C. junghuhniana* population cluster

No.	Parameters	Unit
1.	Tallest tree height	cm
2.	Shortest tree height	cm
3.	Widest circumference	cm
4.	Narrowest circumference	cm
5.	Coverage	ordinal
6.	Altitude	m
7.	Presence of Fruits	ordinal
8.	Male tree	ordinal
9.	Ash coverage	ordinal

A multilayer map consisting of vector and raster data was developed using QGIS, a free and open-source general-purpose GIS software (QGIS Development Team, 2014). National Park boundary map of the study site was obtained from the TNBTS office. The map was then georeferenced and converted to ESRI shapefile (ESRI, 2000) vector data format. The location of each sampling plot was recorded using a mobile phone with GPS Essentials (Schollmeyer, 2014) free software installed. The current version can save records to GPX files and easily converted to CSV using GPSBABEL (Lipe et al., 2017) then imported to QGIS software in the form of delimited

text. Attribute data were appended to location data to build complete GIS data for analysis and visualization. Collected data consist of several easily observable properties (Table 1) of *C. junghuhniana* referring to plant sociology (Braun-Blanquet, 1932). The data were about physical properties including the tallest and shortest tree height, biggest and smallest trunk circumference from the population in a sampling plot. The tree height was measured by calculating the relationship between inclination and the observer's distance to the tree. The trunk circumference was measured by considering DBH (Diameter at Breast High). Population description includes classification of a number of individuals, classification of coverage which represents a percentage of area covered by *C. junghuhniana* population. The populations were described by their stratification consisting of layers of co-existing vegetation species. In this paper, three-level of stratification were used, i.e. trees, shrubs, and herbs. Stratification can indicate the level of support of an area to living vegetation there.

Environment factors were built from the following parameters: elevation data and soil cover classification, which was readily available from Google Satellite image. Elevation data was extracted from Google Earth elevation data using TCXConverter (TCX Converter USER MANUAL, 2014).

Soil area with cover was classified into three categories. First, soil which was fully covered with volcanic ash form. Second, soil which was covered with shorter vegetation as a combination of grass and ash, and the third, soil which was covered with denser and taller vegetation. Data then underwent SEM (Structural Equation Model) analysis using PLSPM (Partial Least Square Path Model) in R (Sanchez, 2013).

Structural Equation Model is a suitable statistical tool to build a hypothesis in this study. PLSPM is a free and open-source library package of R (R Core Team, 2014) for conducting Path Model analysis. This package is another variant of Structural Equation Model analysis. R library package plsdepot (Sanchez and Sanchez, 2012) was used for PLS based PCA (Principal Component Analysis). All observed data were treated as reflective as they represented the internal process of population growth.

Results and Discussion

Profile data about the population of male, female and unidentified population is shown in Figure 3. It shows that the number between male and female individuals was almost equal, and both of them were very low compared to the number of individuals that could not be identified. The low availability number of generative reproduction organs may become a limiting factor of dispersal by seeds.
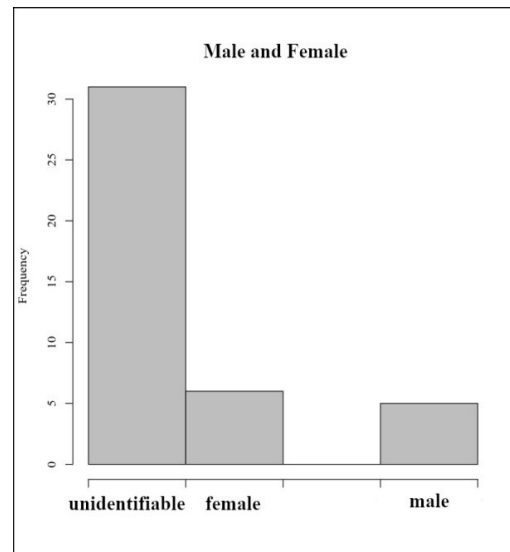

Figure 3. Histogram of collected data regardless of sampling points showing male, female and unidentified population.

This may be very important for TNBTS for making the decision for tree conservation. *C. junghuhniana* trees that produced fruit as an indicator for female trees were only observed in the eastern part of Mt. Kursi. There were six from 48 plots where trees with fruits or female flowers which indicate the female individual was observed. Moreover, there were only five plots where male trees could be identified by their male flowers. However, in Pananjakan, the observation resulted in an almost equal male-female ratio. In contrast, in Tengger Sea Sands, the observed tree could not be identified as male or female.

The structural model in Figure 4 showed *C. junghuhniana* seeds did not contribute to the growth of the population. Instead, the population growth supported seeds production, which could be seen as an additional method of survival. The value shown by the interaction between seeds and population growth were relatively very small. This may indicate the insignificance of seeds presence. PLSPM graphic in Figure 4 shows the tree relies on vegetative reproduction concluded by the relationship between each factor. There are two negative correlations between fruit and growth.

This may be because *C. junghuhniana* population in TNBTS did not rely on fruit and

seeds but used other means of reproduction. Principal Component Analysis (PCA) as shown in Figure 5 in the form of a circle of correlation, shows how observed factors correlate with each other contributing to the presence of this tree in the study site. The Principal Component Analysis shows that both fruits and male tree factors are separate from other factors. From the analysis of this result, seeds maybe not the main method of reproduction for the tree. The lower probability of the seeds germination in the harsh environment may contribute to vegetative reproduction dominance over generative reproduction (Douglas, 1981).
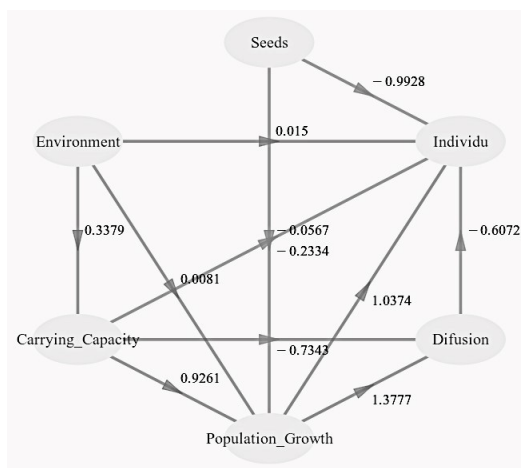

Figure 4. Some components of *C. junghuhniana* population growth described by the PLSPM graph.

According to the National Research Council (1984), members of the Casuarinaceae family propagate using both generative and vegetative methods. *C. junghuhniana* is a dioecious species, therefore only half of the total population is capable of producing seeds. Although it can propagate well by seeds in plantations (Sengloung et al., 2003), this was not evident in the study site, which suggests propagation and dispersal by seeds could have been limited. There is still an indication of a dispersal pattern of aggregation of new trees in clusters (Seidler and Plotkin, 2006). Seeds are spread by the wind as they are very small and very lightweight. According to Buvaneswaran et al. in 2014 that in 1 kg contains $5 - 6 \times 10^5$ of Casuarina seeds. However, half of them may be immature and not viable for germination (Buvaneswaran et al., 2014). However, this tree's ability to reproduce with vegetative organs is beneficial for survival. In the study site, most of the trees were neither male

nor female. This may be due to variances in generative and vegetative reproduction in certain areas. From the generative reproduction aspect, new trees from lightweight seeds as *C. junghuhniana* are usually separated from larger parent clusters. However, relying solely on seeds will result in a disadvantage for survival in the accumulation of volcanic ash within the TNBTS. Accumulation of volcanic ash will bury the seeds making it too deep to grow shoots. Although generative reproduction gives an advantage in genetic diversity, it has less influence on the population of *C. junghuhniana* because the population in the study area is large enough to sustain survivability (Kliman et al., 2008). Usually, in a population with low genetic diversity, it will suffer the bottleneck effect which eventually leads to extinction.

A new individual from seeds as light as *C. junghuhniana* is usually separated from the larger cluster. Relying solely on seeds will result in a disadvantage to its survival in soil covered with ash in TNBTS. The genetic variation effect has less influence on the population of *C. junghuhniana* is large enough to sustain survivability (Kliman et al., 2008).
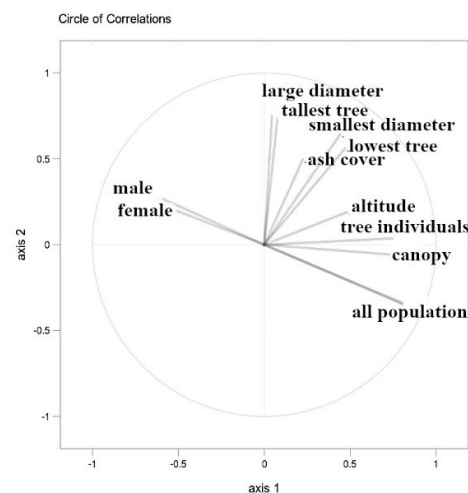

Figure 5. Principal Component Analysis (PCA) from contributing factors.

A strategy for the tree restoration may be different for each location, and this seems to apply to Tengger Sea Sands of TNBTS where seeds may offer a less significant contribution to reproduction and population growth. Propagation and dispersal patterns could be observed, and according to Darwin (1876) and Renner (2014), it was indicating a successful survival strategy adapted to

the conditions of the current study site. It can be assumed that the reproduction and dispersal of this tree as a result of growing adventitious shoots from roots that assist its survival. The appearance of an adventitious shoot growing from a *C. junghuhniana* root is shown in Figure 6, where the root was buried under volcanic ash from Mt. Bromo, and a new shoot emerged at five to six meters from its parent cluster.

Figure 6. An adventitious shoot from the root of *C. junghuniana*.

The unique cluster pattern of this tree population results in a relatively continuous cover separated by unsuitable conditions for growing around each cluster. In addition, this clustering pattern can be explained by the distribution of seeds from the tree, which is particularly lightweight and can travel some distance to find other local environments that are suitable for germination and growth. Note that the explanation refers to the behaviour of pollen dispersal (Bullock and Clarke, 2000). In some areas, this tree dispersal occurs by a natural process, and in some other areas of the national park, by human-assisted propagation program. Most of these human-assisted efforts have been successfully carried out; however, in some other areas, the program was unsuccessful.

A case in point was the unsuccessful attempts to plant new trees from seeds from a nursery into the area of Tengger Sea of Sands. Usually, assisted propagation is started by planting seeds in plastic bags, then after four to six months, the saplings are introduced to the location of restoration. New trees are grown from seeds collected from various locations of the national park. However, in the Southern area between Mount Watangan and Mount Kursi, *C. junghuhniana* plantation program was having difficulties. The newly planted saplings died due to freezing temperatures. Some TNBTS

staffs identified frost formation ("embun upas") as the cause of failure in introducing the new saplings. In some areas of the national park, the man assisted propagation programs have been successfully carried out. On the contrary, in some other areas, the program was unsuccessful. Previous attempt to plant new trees from seed grown in nursery facility into the area of Tengger Sea of Sands is not successful.

Conclusion

C. junghuhniana propagates using both generative and vegetative methods in a unique way that contributes to its survival in the Tengger Sea of Sands. These findings suggest that in general, it may have more probability to survive the environment if it is grown from an already surviving vegetative shoot. Considerably more work will need to be done to determine whether it will truly survive when it is assisted by a human. There is, therefore, a definite need for TNBTS to conduct small scale trials in human-assisted propagation.

Acknowledgements

References

Bachri, S., Stötter, J., Monreal, M. and Sartohadi, J. 2015. The calamity of eruptions, or an eruption of benefits? Mt. Bromo human–volcano system a case study of an open-risk perception. *Natural Hazards and Earth System Science* 15: 277–290. https://doi.org/10.5194/nhess-15-277-2015

Braun-Blanquet, J. 1932. *Plant Sociology : The Study of Plant Communities.* 1st ed. McGraw-Hill book company, USA.

Bullock, J.M. and Clarke, R.T. 2000. Long distance seed dispersal by wind: measuring and modelling the tail of the curve. *Oecologia* 124: 506–521.

Buvaneswaran, C., Sivakumar, V., Prasanth, R.S. and Kumar, N.K. 2014. Transfer of Tree Cultivation Technologies to Krishi Vigyan Kendras (KVKs) of Tamil Nadu and Puducherry. Institute of Forest Genetics and Tree Breeding, Coimbatore.

Darwin, C. 1876. *The Effects of Cross and Self Fertilization In The Vegetable Kingdom*. Cambridge University Press, London.

Douglas, D.A. 1981. The balance between vegetative and sexual reproduction of *Mimulus primuloides* (Scrophulariaceae) at different altitudes in California. *Journal of Ecology* 69: 295. https://doi.org/10.2307/2259832

ESRI. 2000. *Using ArcMap*. Environmental System Research Institute, New York, USA.

Google Maps. 2017. Bromo [WWW Document]. URL maps.google.com

Hair, J.F. (Ed.), 2014. A primer on partial least squares structural equations modeling (PLS-SEM). SAGE, Los Angeles.

Hakim, L. and Miyakawa, H. 2013. Plant trees species for restoration program in Ranupani, Bromo Tengger Semeru National Park Indonesia. *Biodiversity Journal* 4: 387–394.

Hakim, L. and Soemarno, M. 2017. Biodiversity conservation, community development and geotourism development in Bromo-Tengger-Semeru-Arjuno Biosphere Reserve, East Java. *Geo Journal of Tourism and Geosites* 20: 220–230.

Jayaraj, R.S.C. 2010. *Casuarina junghuhniana* (Casuarinaceae) in India. *Australian Journal of Botany* 58: 149. https://doi.org/10.1071/BT09210

Kliman, R., Sheehy, B. and Schultz, J. 2008. Genetic Drift and Effective Population Size. Nat. Educ. 1.

Lipe, R., Parker, R., Mottram, A. and Klein, O. 2017. GPSBabel. gpsbabel.org, Boston, MA.

National Research Council, 1984. Casuarinas Nitrogen-Fixing Trees for Adverse Sites. National Academy Press.

Pinyopusarerk, K. and Boland, D.J. 1995. *Casuarina junghuhniana* - a Highly Adaptable Tropical Casuarina [WWW Document]. URL http://factnet.winrock.org/fnrm/factnet/factpub/FACTSH/C_jung.html (accessed 5.10.16).

Plant Use English contributors. 2016. Casuarina junghuhniana, in: Plant Resources of South-East Asia. PlantUse English.

QGIS Development Team. 2014. QGIS 2.2 Geographic Information User Guide. Open Source Geospatial Foundation Project.

R Core Team. 2014. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rencana Pengelolaan Taman Nasional Bromo Tengger Semeru 1995 - 2020 (No. II), 1995. Taman Nasional Bromo Tengger Semeru, Malang.

Renner, S.S. 2014. The relative and absolute frequencies of angiosperm sexual systems: Dioecy, monoecy, gynodioecy, and an updated online database. *American Journal of Botany* 101: 1588–1596. https://doi.org/10.3732/ajb.1400196

Sanchez, G. 2013. PLS path modeling with R. Berkeley Trowchez Ed.

Sanchez, G. and Sanchez, M.G. 2012. Package 'plsdepot.' Partial Least Sq. PLS Data Anal. Methods V 01 17.

Schollmeyer, M. 2014. GPS Essentials Manual. mictacle.com, Seattle, WA.

Seidler, T.G. and Plotkin, J.B. 2006. Seed dispersal and spatial pattern in tropical trees. *PLoS Biology* 4: e344. https://doi.org/10.1371/journal.pbio.0040344

Sengloung, R., Nangwongprom, K., Kaveeta, L., Bhumibhamon, S. and Pipatwatthanakul, D. 2003. Provenance Variation on Growth Performance and Some Floral Biology of *Casuarina junghuhniana* Miq., in: XII World Forestry Congress. Presented at the XII World Forestry Congress, Canada.

TCX Converter USER MANUAL, 2014. tcxconverter.com.

This page is intentionally left blank