Prediction of the Thermal Conductivities of Wood Based on an Intelligent Algorithm

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For thermal comfort and energy-saving performance, a floor-heating method is superior to conventional heating modes, *e.g.*, radiator, fan coil, *etc*. The floor-heating method has been developed to be a primary indoor heating form. Wood is the most common floor surface material. Due to the anisotropy of wood, it is difficult to obtain a general theoretical formula for its thermal physical properties. In this paper, intelligent algorithms were adopted to predict thermal conductivities of wood. First, the study elaborated frequently used testing methods of thermal conductivity. Next, 130 types of common wood species were measured to form a database of thermal properties. With this database, intelligent algorithms were used to make predictions. For the thermal conductivity predictions that were conducted with support vector machine, the degree of fit between the predicted results and the measured results was not less than 0.87 (k-fold validation). This study validated the feasibility of the usage of the intelligent algorithm for the research and prediction of the thermal conductivities of wood.

Keywords: Wood; Floor heating; Support Vector machine; Thermal conductivity

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INTRODUCTION

Since the supplying water temperature of a floor heating system is lower than that of a conventional heating system, such as a radiator, its energy consumption can be provided by renewable energies, *e.g.*, solar energy, air source, and shallow geothermal energy. This characteristic allows floor heating systems to save greater amounts of energy, leading to its popularity. The study by Márquez *et al*. (2017) compared and analyzed the heating effects of different end forms of heating systems, *i.e.*, fan-coil, floor heating, and a combination of the two. The results showed that a floor heating system is superior in terms of both energy consumption and indoor comfort. Zhou and He (2015) conducted experiments on wooden floor heating systems with different heat storage materials and different heating pipes. Research by Shin *et al*. (2015) showed that the floor surface temperature distribution of oak wood was more even than other covering panels, such as linoleum, which means that wooden surfaces can provide a more comfortable indoor heating environment. The heating performance of wooden floors is closely related to the thermal properties of wood. The recent studies about this theme have concentrated on the thermal conductivity of wood. The publications have been primarily divided into theoretical studies and experimental studies:

1) Theoretical studies include model formulas and empirical formulas, *e.g.*, calculation models of the basic structural units of wood. Research involving the calculation

model of the effective thermal conductivity of wood has gradually developed from the earlier empirical formula to the calculation model of the basic structural units of wood. For example, in the study conducted by Thunman and Leckner (2002), measurable parameters were employed, *e.g.*, density, moisture content, and shrinkage, to calculate the effective thermal conductivity of wood. They also developed a calculation model of the effective thermal conductivity at different combustion stages. A study by Guo *et al*. (2013) was based on the linear heat source model, which numerically calculated the effective thermal conductivity and specific heat capacity of bulk wood particles by the least square method. According to the experimental and numerical results, the empirical relationships between the effective thermal conductivity of wood particles and the water content, as well as the porosity were obtained. The results showed that the thermal conductivity had nothing to do with the size of the wood particles. Meanwhile, the empirical relationship between the specific heat capacity and the water content was obtained.

2) Experimental studies have been primarily conducted at the macroscale and microstructural levels. At the macroscale level, the studies primarily have concentrated on the effective thermal conductivity (neglecting the wood structure and composition). Wood is a typical porous material, and the heat transfer process in wood is the result of the heat transfer in the solid, liquid, and air phases that are present in the wood. Therefore, the thermal conductivity of porous materials such as wood is usually defined as an effective thermal conductivity or an apparent thermal conductivity. At the microscale level, the relevant studies have extended from the effective thermal conductivity to the real thermal conductivity. These studies have concentrated on the thermal properties of wood elements, such as the thermal conductivity of the cell walls. The study by Vay *et al*. (2013), focused on the heat conductivity properties of wood from a cellular view *via* scanning thermal microscopy (SThM). It was found that heat conductibility along the axis direction of the wood cell was higher than that of the cross-section direction. Fan *et al.* (2006) established a fractal dimension model of the effective thermal conductivity of horizontal grain wood, which was validated with experiments conducted *via* an improved transient plane source measurement method. Afterwards, Lagüela *et al.* (2015) measured the axial and radial heat conductivity of different wood specimens *via* the hot-disk transient technique. Their study demonstrated that the heat transfer rate was greatly affected by the direction of the wood grain. Since the measurements were conducted while the wood was in the drying state, moisture percentage effects were not considered.

In this study, 130 wood specimens, belonging to different families, were tested with a thermal constant analyzer in order to measure their thermal conductivities. Then, an intelligent model was established using support vector machines to predict the thermal conductivities of the tested wood specimens.

EXPERIMENTAL

Measuring Equipment and Theory

Experimental apparatus

The experiment was conducted with a thermal constant analyzer (TPS2200) produced by Hot Disk located in Gothenburg, Sweden, as shown in Fig. 1a. The analyzer can measure the volume specific heat, thermal conductivity, and thermal diffusion coefficient of different materials, *e.g.*, metal, wood, plastic, *etc.* Since there is a mathematical relationship between the thermal conductivity and thermal diffusion coefficient, the two parameters can be measured with the same probe, as shown in Fig. 1b. The device is also equipped with a vessel for testing heat capacity, which is not figured in the following text.

(a) Thermal constant analyzer (TPS2200) **(b)** Polyimide coated probe

Fig. 1. Experimental apparatus

Transient plane source method

The thermal conductivity and thermal diffusion coefficient were determined based on the transient plane source (TPS) method. Figure 2 is the test sketch map, and as shown, the probe was clamped above and below the tested specimen.

Fig. 2. Sketch map of the thermal property measurement testing procedure

The specimens were processed into two parts with the same square shape prior to testing. As depicted in He (2005), the temperature distribution of the probe along with time and space can be expressed according to Eq. 1,

$$T(\vec{r},t) = T_0 + \int_0^t \int_{V'} \frac{Q(\vec{\varepsilon},t')}{\rho c} \times \frac{1}{[4\pi\alpha(t-t')]^{\frac{3}{2}}} \times exp\left(-\frac{(\vec{r}-\vec{\varepsilon})^2}{4\alpha(t-t')}\right) d^3\vec{\varepsilon}dt' \quad (1)$$

where r is the radius, t is the time, $Q = Q(\vec{r},t)$ is a function of space and time, Q is the power dissipation per unit volume [$J/(s{\cdot}m^3)$], T_0 is the initial temperature, α is the thermal diffusion coefficient, ρ is the density, c is the thermal capacity, and V' is the heat source volume. Equation 1 can be simplified according to Eq. 2,

$$T(\vec{r},t) = T_0 + \frac{Q_0/\rho c}{(4\pi\alpha t)^{\frac{3}{2}}} exp\left(-\frac{(\vec{r}-\vec{r}_0)^2}{4\alpha t}\right) \quad (2)$$

where Q_0 is the power of the heat source at the initial time [$J/(s{\cdot}m^3)$]. The mathematical relationship between the thermal conductivity and thermal diffusion coefficient is shown in Eq. 3,

$$\alpha = \lambda/\rho \quad (3)$$

As shown in Fig. 1b, the probe is a double helical structure and provides constant heating power. Therefore, the probe can be simplified into a series of isometric concentric circles for analysis purposes, in order to simplify the calculation. For a probe with a cylinder number of *m* and a maximum radius of *a*, the length of the metal wire is calculated according to Eq. 4,

$$L = \sum_{l=1}^{n} 2\pi l \frac{a}{m} = (m+1)\pi a \tag{4}$$

On the basis of the above simplified analysis (Eq. 4), one of the single rings was taken for analysis. In the cylindrical coordinate, the coordinates of any point on the sample surface can be expressed as $\boldsymbol{p}=(r,\theta,z)$ and the coordinates of any point on the metal ring can be written as $\boldsymbol{q}=(r', \theta', z')$. There is an equality relationship between the two coordinates, as demonstrated in Eq. 5,

$$(\boldsymbol{p}-\boldsymbol{q})^2=r^2+r'^2+(z-z')^2-2rr'\cos(\theta-\theta') \tag{5}$$

At the plane of $z'=0$ on the cylindrical coordinate grid, temperature variation of the sample surface can be written as Eq. 6,

$$T(r,\theta,z,t) - T_0 = \frac{2\pi b Q_0 e^{-(r^2+b^2+z^2)/(4\alpha t)}}{\rho c (4\pi\alpha t)^{\frac{3}{2}}} I_0\left(\frac{rb}{2\alpha t}\right) \tag{6}$$

where $I_0(x) = \frac{1}{2\pi}\int_0^{2\pi} e^{x cos\theta}\, d\theta = \frac{1}{2\pi}\int_0^{2\pi} e^{x sin\theta}\, d\theta$ is the first type of correctional Bessel function with zero order and b is the radius of a single ring.

The output power of a single ring is supposed to be constant; therefore, when $u(t')$ is the unit step function, the mathematical equation of the output power is shown in Eq. 7,

$$Q = Q_0\delta(r'-b)\delta(z')u(t') \tag{7}$$

Integration should be made towards to the output power of a single ring and the probe power can be formulated according to Eq. 8,

$$Q = Q_0 \sum_{i=1}^{m} \delta\left(r' - \frac{ia}{m}\right)\delta(z')\,u(t') \tag{8}$$

Since the probe is defined at the surface of $z'=0$, the temperature rise equation of the probe surface can be written as Eq. 9,

$$\Delta T(r,\tau) = \int_0^{\tau} \frac{Q_0 I_0 \sum_{i=1}^{m} i^2\, exp\left(-(\frac{r^2}{a^2}+i^2/m^2\right)/(4\sigma^2))r}{2\pi^{\frac{3}{2}} bm(m+1)\alpha\sigma^2} d\sigma \tag{9}$$

where $\sigma = \frac{\alpha(t-t')}{b^2}$ represents the integration variable and $\tau = \frac{\sqrt{\alpha t}}{b}$ is the dimensionless time constant. By searching for the mean values of $\Delta\overline{T}(r,\tau)$, the temperature rise function can be formulated as Eq. 10,

$$\Delta\overline{T}(\tau) = \frac{Q_0}{\pi^{3/2} b\lambda} D(\tau) \tag{10}$$

where $D(\tau)$ is given by Eq. 11,

$$D(\tau) = \frac{1}{m^2(m+1)^2}\int_0^{\tau} \frac{d\sigma}{\sigma^2} \sum_{k=1}^{m} k \sum_{l=1}^{m} l\, exp(-(k^2+l^2)/(4\sigma^2 m^2)) \times I_0\left(\frac{kl}{2m^2\sigma^2}\right) \tag{11}$$

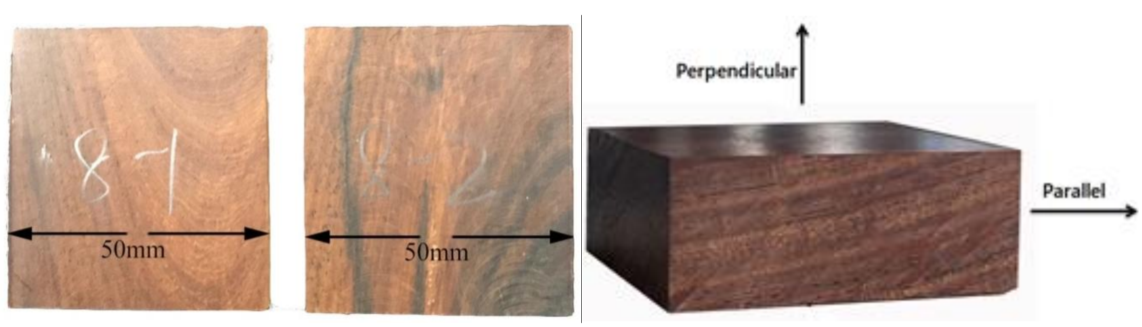
It can be seen from Eq. 10 that there is a proportional relationship between the average surface temperature rise function of the probe $\Delta\overline{T}(\tau)$ and function of $D(\tau)$. When using the thermal constant analyzer, the thermal conductivity (λ) can be computed with an equation between $\Delta\overline{T}(\tau)$ and $D(\tau)$ where $D(\tau)$ is the function of τ. Therefore, when variables such as the number of wire loops is fixed, the value of $D(\tau)$ can be computed with τ. In addition, $\Delta\overline{T}(\tau)$ is the function of τ, which can be calculated during the heating process. The computation theory can be clearly elaborated with the above formulations. However, there are also shortcomings that exist in the calculation process. It can be concluded from the above analysis that $D(\tau)$ cannot be directly obtained, because the value of τ is decided by the thermal diffusion coefficient (α), heating time (t), and probe radius (b), but the thermal diffusion coefficient is unknown, *i.e.*, it needs to be measured. Therefore, it can only be computed *via* the iteration method, which is a time-consuming and complicated process. Therefore, in subsequent work it is intended to adopt the intelligent method for data processing and prediction works.

Data Collection and Preprocessing

Experimental data collection

This experiment measured 130 species of wood, which belonged to 39 different families (Table S1). The experimental specimen samples were processed from the original specimens, whose size was 210 mm x 105 mm x 20 mm (length by width by thickness). Figure 3(a) shows the processed specimen for measuring thermal conductivity and thermal diffusion coefficient, which was 50 mm x 50 mm x 20 mm (length by width by thickness). These specimens had been oven-dry to remove moisture before each test. So the influence of moisture content in the measured values was avoided.

Since the study was conducted under the context that applying wood floor to the floor heating system, the measurement directions were defined as shown in Fig. 3(b), rather than the real axial and radial directions of the wood. In this study, the two directions were defined according to the pavement of wood floor, the direction perpendicular to the floor was defined as 'Perpendicular', while the direction parallel to the floor is defined as 'Parallel'. Thermal conductivities of the two directions were measured for the reason that 'Perpendicular' thermal conductivity affects the heat release to the room, which will determine the indoor temperature distribution, while 'Parallel' thermal conductivity affects the heat diffusion along the floor, which will determine the temperature uniformity of the floor.



(a) The processed specimens **(b)** Definition of the two measurement directions

Fig. 3. Specimens for measuring the thermal conductivity

Data preprocessing

It was stated in the above section that the thermal properties of wood can be computed from the transient temperature data. Therefore, it is necessary to extract features that can reflect the temperature-changing characteristics. For the study of the thermal conductivity, transient temperature rise diagram is necessary, as shown in Fig. 4.

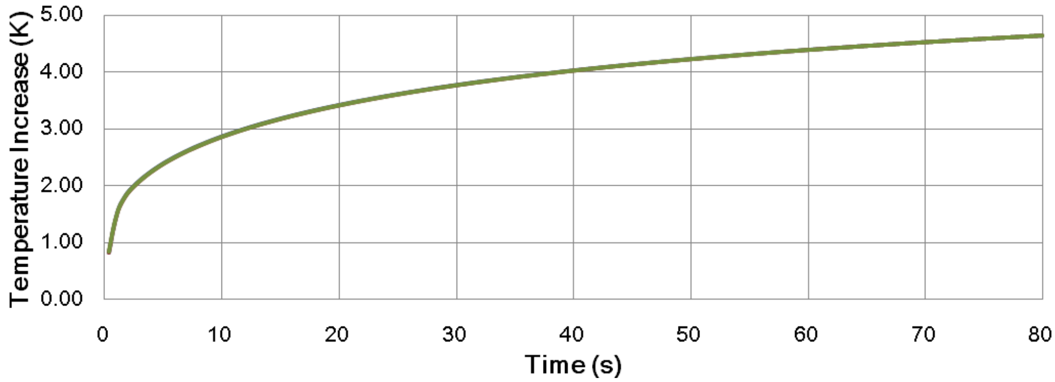


Fig. 4. Transient temperature rise diagram of anisotropy thermal conductivity (*Monterey pine*)

According to the suggestions from the Hot Disk company, the number of gathered temperature data points of each test should be approximately 200. As described by the study objective in the first section, intelligent models for predicting the thermal properties of wood needed to be constructed in this study. If 200 data points are all set as model inputs, then it is almost impossible to obtain a valid and efficient model. In order to consider the regularity of the temperature change, feature extraction should be conducted towards to the temperature data. As shown in Fig. 4, the temperature curve was similar to the water temperature variations in the thermal response test (TRT) (Gehlin 2002). The data processing method of TRT, *i.e.*, a logarithmic curve, was adopted for feature extraction, and the detailed linear fitting equation is shown as Eq. 12,

$$\Delta T = A\,ln(t) + B \qquad (12)$$

where ΔT is the temperature increment, [K]; t is the time, [s]; and A and B are the coefficients that were extracted from the temperature process data. The measured data of 130 kinds of wood were processed with the above formula (Eq. 12). All of the degrees of fitness (R^2) values were larger than 0.98 and the partial fitting results are plotted in the following diagrams (as shown in Fig. 5).

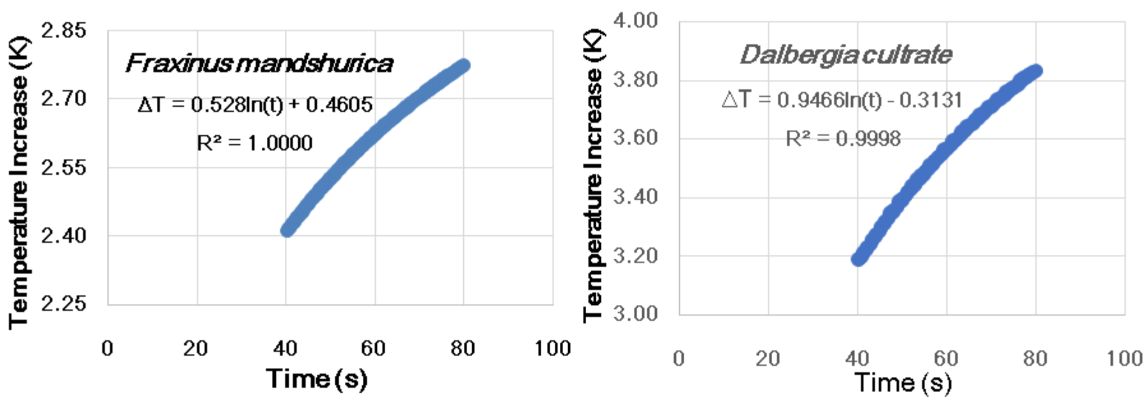


Fig. 5. Transient temperature rise scatter diagrams of different specimens

Evaluation of the model accuracy should be calculated with several error indexes, *e.g.*, the mean relative error (*MRE*), the max relative error (*MAE*), the mean square error (*MSE*), and the absolute fraction of variance (R^2). The formulations of the above error indexes are expressed as Eqs. 15 through 18, respectively.

$$MRE = \frac{1}{n}\sum_{i-1}^{n}\frac{|X_c(i)-X_r(i)|}{(X_{r-max}-X_{r-min})} \times 100\% \quad (15)$$

$$MAE = max_i\left(\frac{|X_c(i)-X_r(i)|}{(Xr-min_{r-max}} \times 100\%\right) \quad (16)$$

$$MSE = \sqrt{\frac{1}{n}\sum_{i-1}^{n}\frac{|X_c(i)-X_r(i)|}{(X_{r-max}-X_{r-min})}} \times 100\% \quad (17)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(X_c(i)-X_r(i))^2}{\sum_{i=1}^{n}(X_c(i)-X_{c-mean})^2} \quad (18)$$

where X_c is the output of the model, X_{c-mean} is the average output of the model, X_r is the experimental value, X_{r-max} is the maximum experimental value, and X_{r-min} is the minimum experimental value.

There are usually two validation ways, *e.g.*, holdout validation and k-fold validation. For holdout validation: the data is split into training set and testing set, and then the model is trained and tested separately; while for k-fold validation, which is also called cycle validation. In the data preprocessing progress, the data is split into *k* subsets averagely. Then the training and testing processes are conducted for *k* times. In each time, one subset is defined as testing set for once, while the rest *k-1* subsets are defined as training set. In turn, every subset can be treated as testing set for once. The prediction errors of each time are averaged to denote the final validation errors of the model.

Intelligent Algorithms

Many kinds of intelligent algorithms have been developed for the prediction or classification work in the last decades, such as Artificial Neural Network (ANN), Support Vector Machines (SVM), Adaptive Network-based Fuzzy Inference System (ANFIS) and Radial Basis Neural Network (RBN), *etc*. In these intelligent algorithms, SVM is commonly recognized to be suitable for the process of small data set. Because the number of experimental data is not so big, SVM was adopted for the prediction work in this study.

SVM is a machine learning algorithm basing on the statistical learning theory. Its principle is to construct the optimal separating hyperplane by mapping the input vector into a high-dimensional feature space according to the prior selected non-linear operator. SVM was born in the 90s of the last century; since then, it has been applied into more and more widely fields, such as predictions of outdoor/indoor temperature, wind speed, solar radiation, *etc.* (Paniagua-Tineo *et al*. 2011; Cai *et al*. 2015; Mohandes *et al*. 2004; Chen *et al*. 2011).

RESULTS AND DISCUSSION

Models for Predicting Thermal Conductivity

As mentioned in the above text, both 'Perpendicular' and 'Parallel' values of thermal conductivity need to be studied. Therefore, two separate models were trained in order to predict each of the two conductivity values. The two models have same input parameters, *e.g.*, the sample density, together with the slope term (*A*) and intercept term (*B*) from Eq. 12. Although the two thermal conductivities were trained as outputs of two separate SVM models, their data was measured under the same testing conditions. The experiments were repeated 3 times and conducted under the following conditions: a heating power of 50 mW and an application period of 80 s. There were 390 sets of data generated from the experiment (as shown in Table S2), in which 360 of the sets were picked out at random to train the SVM model, while the remaining 30 sets were gathered for testing.

In the k-fold validations, the *k* value was selected as 13, meaning that the whole data was divided into 13 subsets averagely after the data sequence was disturbed, so as to keep the random selection of the training data. And then 13 times of training and validation process were conducted for each model. For the training parameters of SVM model, their values were given as ‘svmtrain(y_1_train,x_train,'-s 4 -t 2 -c 50 -g 180')’.

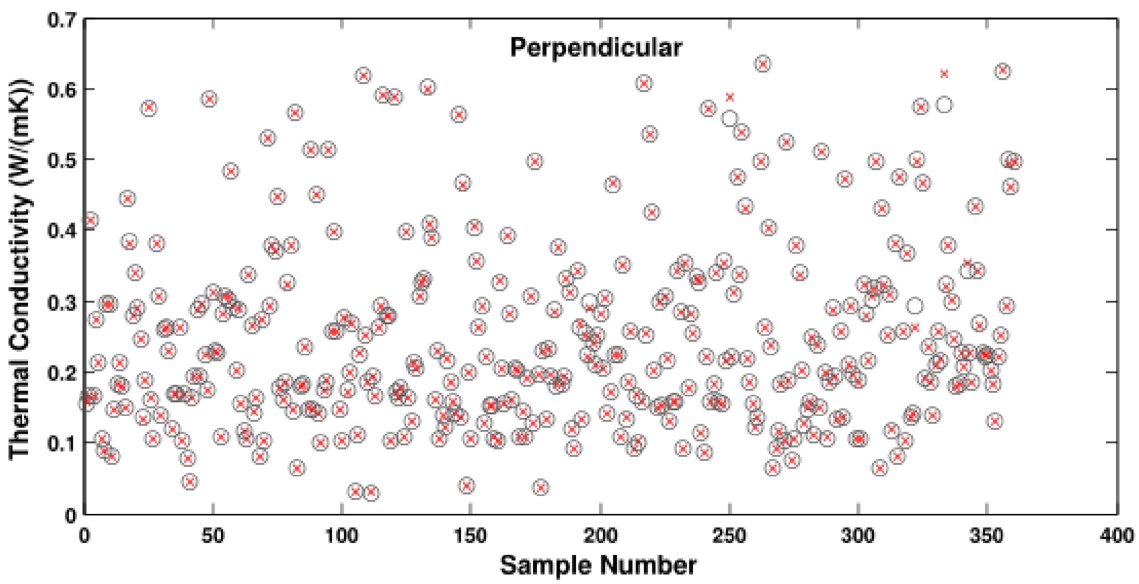
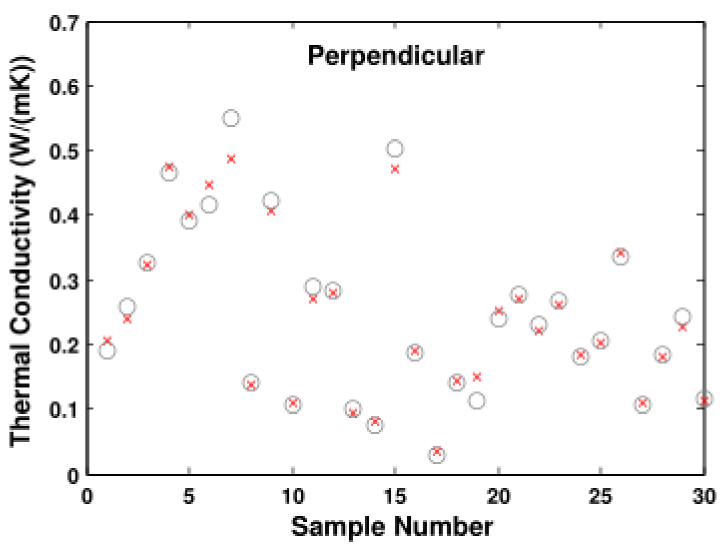


Fig. 6. Training results of the Perpendicular thermal conductivity



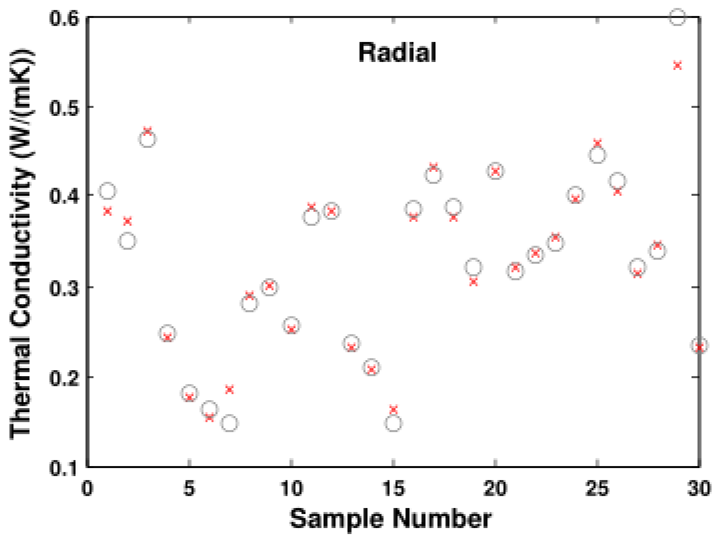


Fig. 7. Validation results of the two thermal conductivities

The model prediction results are listed in Figs. 6 and 7. In these figures, the 'x' means the output of SVM model, and '○' means an experimental value. The horizontal axis represents the sample number, while the vertical axis represents the thermal conductivity, whose unit is W/(m·K). Training results of the Perpendicular thermal conductivity are not shown here to save space. Good coincidence between prediction value and experimental value can be found in the figures. The detailed prediction errors are given in Table 1, which shows that the holdout validation results were superior to k-fold validation results. For both of the two validation methods, the degree of fitness of the training data sets was as high as 0.99, while the degree of fitness of the testing data sets was 0.87 or higher. The results demonstrated that the model was effective for an anisotropic thermal conductivity module.

Table 1. Prediction Errors of Thermal Conductivity

Thermal Conductivity		Data Set	MRE%)	MAE(%)	MSE(%)	R^2
holdout validation	Perpen-dicular	Training data	0.1271	7.1687	0.4348	0.9993
		Testing data	2.2473	12.0598	2.4356	0.9821
	Parallel	Training data	0.1202	3.1695	0.2580	0.9996
		Testing data	2.2393	11.5298	2.2198	0.9789
k-fold validation	Perpen-dicular	Training data	0.1355	6.7599	0.4078	0.9994
		Testing data	4.3397	29.8905	5.5189	0.8940
	Parallel	Training data	0.1264	3.3281	0.2403	0.9997
		Testing data	5.0247	31.3020	5.3212	0.8710

CONCLUSIONS

1. The thermal properties of 130 species of wood that belonging to different families were tested with a Hot Disk thermal constant analyzer to generate the initial training database. The prediction works were then conducted towards to these woods based on intelligent algorithm.
2. SVM was adopted for the prediction of the thermal conductivity. In order to simplify the calculation process, feature extraction was adopted and separate models for predicting the Perpendicular and the Parallel thermal conductivity (relative to the floor) were established. The testing degrees of fitness of the two models both were at least 0.87, while holdout validation results were even better.
3. The success prediction of thermal conductivity with inputs of term A and B validated the fact that there may exists a mathematical relationship between thermal conductivity and $\boldsymbol{ln(t)}$, not only with $\boldsymbol{D(\tau)}$, although the specific equations has not been found.

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APPENDIX

Table S1. Detailed List of the Wood Specimens Measured in Experiment

No.	Latin name	Family	No.	Latin name	Family
1	*Pterocarpus macrocarpus*	Papilionaceae	66	*Khaya sp.*	Meliaceae
2	*Pterocarpus pedatus*	Papilionaceae	67	*Eusideroxylon zwageri*	Lauraceae
3	*Pterocarpus erinaceus*	Papilionaceae	68	*Spirostachys africana*	Euphorbiaceae
4	*Dalbergia latifolia*	Papilionaceae	69	*Guibourtia conjugata*	Caesalpiniaceae
5	*Dalbergia frutescens var. tomentosa*	Papilionaceae	70	*Terminalia sp.*	Combretaceae
6	*Pterocarpus indicus*	Papilionaceae	71	*Triplochiton scleroxylon*	Sterculiaceae
7	*Dalbergia melanoxylon*	Papilionaceae	72	*Dryobalanops sp.*	Dipterocarpaceae
8	*Dalbergia cochinchinensis*	Papilionaceae	73	*Berlinia sp.*	Caesalpiniaceae
9	*Dalbergia bariensis*	Papilionaceae	74	*Koompassia sp.*	Caesalpiniaceae
10	*Dalbergia oliveri*	Papilionaceae	75	*Hevea brasiliensis*	Euphorbiaceae
11	*Dalbergia retusa*	Papilionaceae	76	*Aucoumea klaineana*	Burseraceae
12	*Millettia stuhlmannii*	Papilionaceae	77	*Calophyllum sp.*	Guttiferae
13	*Dalbergia louvelii*	Papilionaceae	78	*Excentrodendron hsienmu*	Tiliaceae
14	*Dalbergia cultrata*	Papilionaceae	79	*Pericopsis elata*	Papilionaceae
15	*Diospyros celebica*	Ebenaceae	80	*Betula alnoides*	Betulaceae
16	*Cassia siamea*	Caesalpiniaceae	81	*Pterocarpus angolensis*	Papilionaceae
17	*Baphia nitida*	Papilionaceae	82	*Sindora sp.*	Caesalpiniaceae
18	*Bulnesia sp.*	Zygophyllaceae	83	*Shorea sp.*	Dipterocarpaceae
19	*Cordia sp.*	Boraginaceae	84	*Swintonia sp.*	Anacardiaceae
20	*Combretum imberbe*	Combretaceae	85	*Pometia sp.*	Sapindaceae
21	*Swartzia madagascariensis*	Papilionaceae	86	*Ochroma sp.*	Bombacaceae
22	*Ulmus sp.*	Ulmaceae	87	*Platymiscium sp.*	Papilionaceae
23	*Pterocarpus tinctorius*	Papilionaceae	88	*Dicorynia sp.*	Caesalpiniaceae
24	*Colophospermum mopane*	Caesalpiniaceae	89	*Marmaroxylon racemosum*	Mimosoideae
25	*Gluta sp.*	Anacardiaceae	90	*Loxopterygium sagotii*	Anacardiaceae
26	*Streblus sp.*	Moraceae	91	*Tabebuia sp.*	Bignoniaceae
27	*Phoebe sp.*	Lauraceae	92	*Andira sp.*	Papilionaceae
28	*Platycladus orientalis*	Cupressaceae	93	*Humiria balsamifera*	Humiriaceae
29	*Lindera sp.*	Lauraceae	94	*Diplotropis sp.*	Papilionaceae
30	*Myroxylon balsamum*	Papilionaceae	95	*Brosimum sp.*	Moraceae

31	*Guibourtia tessmannii*	Caesalpiniaceae	96	*Martiodendron sp.*	Caesalpiniaceae
32	*Pterocarpus soyauxii*	Papilionaceae	97	*Vouacapoua americana*	Caesalpiniaceae
33	*Microberlinia sp.*	Caesalpiniaceae	98	*Manilkara sp.*	Sapotaceae
34	*Paraberlinia bifoliolata*	Caesalpiniaceae	99	*Platonia insignis*	Guttiferae
35	*Intsia sp.*	Caesalpiniaceae	100	*Hymenaea sp.*	Caesalpiniaceae
36	*Tectona grandis*	Verbenaceae	101	*Diospyros sp.*	Ebenaceae
37	*Peltogyne sp.*	Caesalpiniaceae	102	*Prunus sp.*	Rosaceae
38	*Entandrophragma cylindricum*	Meliaceae	103	*Xylia sp.*	Mimosoideae
39	*Mangifera sp.*	Anacardiaceae	104	*Terminalia tomentosa*	Combretaceae
40	*Lophira alata*	Ochnaceae	105	*Aglaia sp.*	Meliaceae
41	*Fraxinus sp.*	Oleaceae	106	*Afzelia sp.*	Caesalpiniaceae
42	*Fraxinus mandshurica*	Oleaceae	107	*Swietenia sp.*	Meliaceae
43	*Quercus sp.*	Fagaceae	108	*Xanthostemon sp.*	Myrtaceae
44	*Quercus sp.*	Fagaceae	109	*Berchemia discolor*	Rhamnaceae
45	*Caesalpinia paraguariensis*	Caesalpiniaceae	110	*Guibourtia coleosperma*	Caesalpiniaceae
46	*Juglans sp.*	Juglandaceae	111	*Machaerium sp.*	Papilionaceae
47	*Dipteryx sp.*	Papilionaceae	112	*Samanea saman*	Mimosoideae
48	*Bombax sp.*	Bombacaceae	113	*Campnosperma sp.*	Anacardiaceae
49	*Buchenavia sp.*	Combretaceae	114	*Buxus sp.*	Buxaceae
50	*Vatairea sp.*	Papilionaceae	115	*Erythrophleum sp.*	Caesalpiniaceae
51	*Hieronyma sp.*	Euphorbiaceae	116	*Anadenanthera macrocarpa*	Mimosoideae
52	*Fagus sylvatica*	Fagaceae	117	*Chlorophora sp.*	Moraceae
53	*Erythrophleum fordii*	Caesalpiniaceae	118	*Staudtia sp.*	Myristicaceae
54	*Pinus sp.*	Pinaceae	119	*Cynometra sp.*	Caesalpiniaceae
55	*Pinus sylvestris*	Pinaceae	120	*Swartzia leiocalycina*	Papilionaceae
56	*Pinus sp.*	Pinaceae	121	*Baphia kirkii*	Papilionaceae
57	*Pseudotsuga sp.*	Pinaceae	122	*Dalbergia cearensis*	Papilionaceae
58	*Tsuga sp.*	Pinaceae	123	*Dalbergia tucurensis*	Papilionaceae
59	*Pinus radiata*	Pinaceae	124	*Acer sp.*	Aceraceae
60	*Litchi chinensis*	Sapindaceae	125	*Dipterocarpus sp.*	Dipterocarpaceae
61	*Euphoria longan*	Sapindaceae	126	*Liriodendron tulipifera*	Magnoliaceae
62	*Cinnamomum sp.*	Lauraceae	127	*Michelia sp.*	Magnoliaceae
63	*Daniellia sp.*	Caesalpiniaceae	128	*Palaquium sp.*	Sapotaceae
64	*Aquilaria sp.*	Thymelaeaceae	129	*Acacia sp.*	Mimosoideae
65	*Cylicodiscus gabunensis*	Mimosoideae	130	*Toona sinensis*	Meliaceae

Table S2. Listing of Density, Function Coefficient, Parallel Thermal Conductivity, and Perpendicular Thermal Conductivity

No.	Latin name	Density (g/cm^3)	Function coefficient (gradient term A)	Function coefficient (gradient term B)	Parallel conduct. (W/mK)	Perpend. conduct. (W/mk)
1	*Pterocarpus macrocarpus*	1.165171	0.618300	-0.017000	0.161854	0.432371
1	*Pterocarpus macrocarpus*	1.165171	0.619800	-0.011800	0.155029	0.446106
1	*Pterocarpus macrocarpus*	1.165171	0.621300	-0.007700	0.159181	0.434052
2	*Pterocarpus pedatus*	1.102950	0.597300	0.316700	0.126526	0.576902
2	*Pterocarpus pedatus*	1.102950	0.604500	0.292600	0.135651	0.533575
2	*Pterocarpus pedatus*	1.102950	0.610100	0.291200	0.135282	0.527667
3	*Pterocarpus erinaceus*	0.928731	0.579100	0.221200	0.183496	0.431954
3	*Pterocarpus erinaceus*	0.928731	0.585700	0.190300	0.195902	0.400747
3	*Pterocarpus erinaceus*	0.928731	0.589000	0.174700	0.190493	0.405785
4	*Dalbergia latifolia*	0.919562	0.623400	0.397700	0.202100	0.343478
4	*Dalbergia latifolia*	0.919562	0.620300	0.443500	0.200035	0.349706
4	*Dalbergia latifolia*	0.919562	0.626200	0.427900	0.202559	0.339315
5	*Dalbergia frutescens var. tomentosa*	1.302713	0.492500	0.069900	0.200076	0.549978
5	*Dalbergia frutescens var. tomentosa*	1.302713	0.495800	0.062700	0.186524	0.573295
5	*Dalbergia frutescens var. tomentosa*	1.302713	0.497700	0.064600	0.186792	0.570284
6	*Pterocarpus indicus*	0.447992	1.115300	-0.338500	0.086823	0.240520
6	*Pterocarpus indicus*	0.447992	1.119200	-0.342300	0.093358	0.226009
6	*Pterocarpus indicus*	0.447992	1.121300	-0.352300	0.088745	0.234749
7	*Dalbergia melanoxylon*	1.212328	0.446600	-0.337000	0.355354	0.386427
7	*Dalbergia melanoxylon*	1.212328	0.446700	-0.340800	0.340824	0.401112
7	*Dalbergia melanoxylon*	1.212328	0.444500	-0.345300	0.339145	0.407174
8	*Dalbergia cochinchinensis*	1.206870	0.484000	0.187400	0.294592	0.393226
8	*Dalbergia cochinchinensis*	1.206870	0.481100	0.147100	0.279869	0.415921
8	*Dalbergia cochinchinensis*	1.206870	0.482900	0.095000	0.290005	0.400216
9	*Dalbergia bariensis*	1.109172	0.481500	0.051800	0.292508	0.396600

9	*Dalbergia bariensis*	1.109172	0.482600	0.098700	0.293197	0.394006
9	*Dalbergia bariensis*	1.109172	0.485200	0.059700	0.296942	0.386043
10	*Dalbergia oliveri*	1.029013	0.551800	-0.147500	0.252634	0.354907
10	*Dalbergia oliveri*	1.029013	0.550000	-0.133500	0.258457	0.349730
10	*Dalbergia oliveri*	1.029013	0.549300	-0.106800	0.250210	0.359739
11	*Dalbergia retusa*	1.111832	0.520400	-0.055800	0.263943	0.379434
11	*Dalbergia retusa*	1.111832	0.520700	-0.047200	0.262607	0.381018
11	*Dalbergia retusa*	1.111832	0.520900	-0.045200	0.268553	0.374366
12	*Millettia stuhlmannii*	0.704358	0.629400	0.238500	0.231822	0.293131
12	*Millettia stuhlmannii*	0.704358	0.627700	0.258800	0.229216	0.297553
12	*Millettia stuhlmannii*	0.704358	0.627500	0.272100	0.229516	0.297397
13	*Dalbergia louvelii*	0.891003	0.541400	0.354700	0.293332	0.317385
13	*Dalbergia louvelii*	0.891003	0.539300	0.365600	0.283237	0.329343
13	*Dalbergia louvelii*	0.891003	0.538900	0.374700	0.279472	0.334545
14	*Dalbergia cultrata*	0.982438	0.528000	0.460500	0.209495	0.462264
14	*Dalbergia cultrata*	0.982438	0.525800	0.457600	0.216793	0.451862
14	*Dalbergia cultrata*	0.982438	0.516000	0.502800	0.192974	0.519831
15	*Diospyros celebica*	1.002307	0.523100	0.473900	0.191892	0.508537
15	*Diospyros celebica*	1.002307	0.538700	0.363600	0.205341	0.453025
15	*Diospyros celebica*	1.002307	0.549000	0.243900	0.223425	0.405447
16	*Cassia siamea*	1.040916	0.428300	0.025600	0.337041	0.450427
16	*Cassia siamea*	1.040916	0.423600	0.049700	0.342502	0.442231
16	*Cassia siamea*	1.040916	0.423900	0.054600	0.367169	0.415692
17	*Baphia nitida*	1.285356	0.423700	-0.117800	0.322692	0.472019
17	*Baphia nitida*	1.285356	0.424200	-0.120200	0.327810	0.463150
17	*Baphia nitida*	1.285356	0.424400	-0.114600	0.326353	0.464167
18	*Bulnesia sp.*	0.860297	0.604800	-0.512900	0.229640	0.323331
18	*Bulnesia sp.*	0.860297	0.602500	-0.512200	0.229348	0.327073
18	*Bulnesia sp.*	0.860297	0.602300	-0.487000	0.227833	0.329218
19	*Cordia sp.*	0.987425	0.516200	0.098400	0.609024	0.168040
19	*Cordia sp.*	0.987425	0.516600	0.099700	0.576984	0.176316
19	*Cordia sp.*	0.987425	0.516600	0.122900	0.601212	0.170123
20	*Combretum imberbe*	1.228766	0.441600	-0.232800	0.567351	0.245577
20	*Combretum imberbe*	1.228766	0.439900	-0.201100	0.588419	0.239569
20	*Combretum imberbe*	1.228766	0.439900	-0.179100	0.571114	0.247132
21	*Swartzia madagascariensis*	1.083138	0.481300	0.493700	0.465255	0.250270

21	*Swartzia madagascariensis*	1.083138	0.481300	0.493000	0.468362	0.248175
21	*Swartzia madagascariensis*	1.083138	0.482800	0.490400	0.465004	0.248877
22	*Ulmus sp.*	0.507920	0.979100	-0.381200	0.212949	0.132173
22	*Ulmus sp.*	0.507920	0.974400	-0.366600	0.207972	0.135876
22	*Ulmus sp.*	0.507920	0.973500	-0.361200	0.203419	0.138670
23	*Pterocarpus tinctorius*	0.992981	0.540700	0.178900	0.377942	0.244073
23	*Pterocarpus tinctorius*	0.992981	0.540700	0.183500	0.377160	0.244513
23	*Pterocarpus tinctorius*	0.992981	0.540800	0.188500	0.377713	0.243997
24	*Colophospermum mopane*	1.297750	0.433200	-0.093800	0.414519	0.351685
24	*Colophospermum mopane*	1.297750	0.431300	-0.080100	0.397757	0.369210
24	*Colophospermum mopane*	1.297750	0.430800	-0.076200	0.398090	0.369766
25	*Gluta sp.*	0.827704	0.617800	-0.149700	0.390349	0.181512
25	*Gluta sp.*	0.827704	0.616000	-0.150500	0.392499	0.181783
25	*Gluta sp.*	0.827704	0.615500	-0.140000	0.392814	0.182387
26	*Streblus sp.*	1.074903	0.490600	0.000700	0.307764	0.366963
26	*Streblus sp.*	1.074903	0.487700	0.026400	0.306516	0.372701
26	*Streblus sp.*	1.074903	0.486800	0.015100	0.296193	0.384275
27	*Phoebe sp.*	0.525604	0.981300	-0.387300	0.122730	0.225797
27	*Phoebe sp.*	0.525604	0.975400	-0.381500	0.121518	0.229888
27	*Phoebe sp.*	0.525604	0.974300	-0.370500	0.118499	0.235295
28	*Platycladus orientalis*	0.735277	0.622500	-0.062500	0.476453	0.147375
28	*Platycladus orientalis*	0.735277	0.622200	-0.048000	0.460912	0.152735
28	*Platycladus orientalis*	0.735277	0.621900	-0.041300	0.465912	0.151491
29	*Lindera sp.*	0.721878	0.628100	0.232100	0.416335	0.164444
29	*Lindera sp.*	0.721878	0.629800	0.226800	0.425144	0.160477
29	*Lindera sp.*	0.721878	0.631200	0.223400	0.404970	0.166793
30	*Myroxylon balsamum*	0.939866	0.518800	0.556400	0.590882	0.170246
30	*Myroxylon balsamum*	0.939866	0.519500	0.556000	0.558872	0.177710
30	*Myroxylon balsamum*	0.939866	0.519700	0.553800	0.585200	0.170566
31	*Guibourtia tessmannii*	0.805228	0.598500	-0.203600	0.473571	0.159659
31	*Guibourtia tessmannii*	0.805228	0.599500	-0.229300	0.483411	0.156683
31	*Guibourtia tessmannii*	0.805228	0.599500	-0.225400	0.474448	0.158878
32	*Pterocarpus soyauxii*	0.729505	0.664900	-0.154700	0.356234	0.169853

32	*Pterocarpus soyauxii*	0.729505	0.670200	-0.163500	0.351205	0.169085
32	*Pterocarpus soyauxii*	0.729505	0.672800	-0.172300	0.355554	0.165925
33	*Microberlinia sp.*	0.909226	0.524300	-0.230000	0.634575	0.153207
33	*Microberlinia sp.*	0.909226	0.524000	-0.227500	0.625293	0.155393
33	*Microberlinia sp.*	0.909226	0.522700	-0.181900	0.619872	0.157165
34	*Paraberlinia bifoliolata*	0.676283	0.540700	-0.194000	0.563798	0.164840
34	*Paraberlinia bifoliolata*	0.676283	0.537800	-0.193600	0.573171	0.164614
34	*Paraberlinia bifoliolata*	0.676283	0.536600	-0.200800	0.575657	0.164661
35	*Intsia sp.*	0.901845	0.581400	-0.305500	0.549891	0.146972
35	*Intsia sp.*	0.901845	0.580800	-0.289400	0.537605	0.149921
35	*Intsia sp.*	0.901845	0.581400	-0.278100	0.537056	0.149693
36	*Tectona grandis*	0.686852	0.734400	-0.633500	0.381557	0.132480
36	*Tectona grandis*	0.686852	0.732000	-0.628200	0.379527	0.134080
36	*Tectona grandis*	0.686852	0.731400	-0.590900	0.370113	0.137436
37	*Peltogyne sp.*	1.168446	0.438300	0.241400	0.444329	0.316106
37	*Peltogyne sp.*	1.168446	0.437800	0.295800	0.430290	0.324053
37	*Peltogyne sp.*	1.168446	0.437700	0.295800	0.435110	0.322261
38	*Entandrophragma cylindricum*	0.741889	0.662100	-0.070500	0.306886	0.199311
38	*Entandrophragma cylindricum*	0.741889	0.663400	-0.063400	0.309998	0.197215
38	*Entandrophragma cylindricum*	0.741889	0.664200	-0.050000	0.311907	0.195823
39	*Mangifera sp.*	0.639062	0.798800	0.150600	0.140295	0.297228
39	*Mangifera sp.*	0.639062	0.797800	0.158800	0.147250	0.286109
39	*Mangifera sp.*	0.639062	0.798600	0.153000	0.141898	0.295397
40	*Lophira alata*	0.941912	0.544900	0.364600	0.499367	0.183433
40	*Lophira alata*	0.941912	0.542300	0.381600	0.499316	0.185917
40	*Lophira alata*	0.941912	0.542200	0.380500	0.497418	0.186145
41	*Fraxinus sp.*	0.665602	0.705900	-0.217500	0.162172	0.327200
41	*Fraxinus sp.*	0.665602	0.704100	-0.195700	0.160910	0.331019
41	*Fraxinus sp.*	0.665602	0.703500	-0.192200	0.167996	0.319902
42	*Fraxinus mandshurica*	0.577673	0.946600	-0.313100	0.102602	0.288487
42	*Fraxinus mandshurica*	0.577673	0.942800	-0.308300	0.104438	0.287049
42	*Fraxinus mandshurica*	0.577673	0.941800	-0.302000	0.103875	0.289129
43	*Quercus sp.*	0.747687	0.603000	0.701000	0.267280	0.276848
43	*Quercus sp.*	0.747687	0.601500	0.710300	0.251895	0.292222
43	*Quercus sp.*	0.747687	0.600700	0.717900	0.257163	0.287863

44	*Quercus sp.*	0.576364	0.822100	-0.217500	0.146048	0.272421
44	*Quercus sp.*	0.576364	0.819500	-0.192900	0.140659	0.282038
44	*Quercus sp.*	0.576364	0.818800	-0.201200	0.139954	0.284770
45	*Caesalpinia paraguariensis*	1.107699	0.456900	-0.037700	0.324405	0.402546
45	*Caesalpinia paraguariensis*	1.107699	0.456200	-0.039200	0.327469	0.401155
45	*Caesalpinia paraguariensis*	1.107699	0.454800	-0.040000	0.322830	0.407661
46	*Juglans sp.*	0.673362	0.740400	-0.124700	0.186434	0.265836
46	*Juglans sp.*	0.673362	0.736700	-0.105800	0.179454	0.276921
46	*Juglans sp.*	0.673362	0.735900	-0.103600	0.184797	0.271398
47	*Dipteryx sp.*	0.987204	0.463600	0.250100	0.421900	0.298544
47	*Dipteryx sp.*	0.987204	0.460700	0.257300	0.403784	0.313720
47	*Dipteryx sp.*	0.987204	0.459300	0.258800	0.409781	0.312514
48	*Bombax sp.*	0.518998	0.992000	-0.608800	0.105173	0.256243
48	*Bombax sp.*	0.518998	0.992600	-0.646300	0.106220	0.254233
48	*Bombax sp.*	0.518998	0.994400	-0.651800	0.105624	0.255607
49	*Buchenavia sp.*	0.681548	0.733400	0.003900	0.165903	0.299841
49	*Buchenavia sp.*	0.681548	0.732400	0.007200	0.170413	0.294427
49	*Buchenavia sp.*	0.681548	0.732900	0.002700	0.171532	0.292437
50	*Vatairea sp.*	0.867096	0.647000	-0.054500	0.195592	0.329352
50	*Vatairea sp.*	0.867096	0.644000	-0.042400	0.187906	0.343531
50	*Vatairea sp.*	0.867096	0.642900	-0.026000	0.188234	0.344199
51	*Hieronyma sp.*	0.811421	0.663800	-0.115000	0.185556	0.330955
51	*Hieronyma sp.*	0.811421	0.663300	-0.109900	0.183008	0.334187
51	*Hieronyma sp.*	0.811421	0.664100	-0.095500	0.187891	0.327057
52	*Fagus sylvatica*	0.764708	0.652300	0.187000	0.163120	0.379943
52	*Fagus sylvatica*	0.764708	0.651700	0.184800	0.166327	0.373473
52	*Fagus sylvatica*	0.764708	0.651700	0.187100	0.164552	0.376757
53	*Erythrophleum fordii*	0.989414	0.501100	0.379700	0.286028	0.379769
53	*Erythrophleum fordii*	0.989414	0.500000	0.386700	0.289418	0.376531
53	*Erythrophleum fordii*	0.989414	0.500300	0.381700	0.283669	0.383283
54	*Pinus sp.*	0.478365	0.956300	-0.425200	0.158022	0.187301
54	*Pinus sp.*	0.478365	0.953000	-0.428900	0.158341	0.188216
54	*Pinus sp.*	0.478365	0.952800	-0.410100	0.153720	0.193617
55	*Pinus sylvestris*	0.531608	0.887700	-0.165300	0.148717	0.227529
55	*Pinus sylvestris*	0.531608	0.884700	-0.134000	0.144614	0.233700

55	*Pinus sylvestris*	0.531608	0.884200	-0.106100	0.146604	0.231999
56	*Pinus sp.*	0.653822	0.799400	-0.304500	0.156493	0.269121
56	*Pinus sp.*	0.653822	0.797500	-0.299400	0.158013	0.267464
56	*Pinus sp.*	0.653822	0.796900	-0.303200	0.158650	0.267226
57	*Pseudotsuga sp.*	0.452062	1.056500	-0.034500	0.102312	0.230175
57	*Pseudotsuga sp.*	0.452062	1.050100	-0.018100	0.100422	0.236348
57	*Pseudotsuga sp.*	0.452062	1.048900	-0.002300	0.099825	0.237874
58	*Tsuga sp.*	0.386462	1.294600	-0.364400	0.076975	0.204913
58	*Tsuga sp.*	0.386462	1.287400	-0.337400	0.078013	0.205244
58	*Tsuga sp.*	0.386462	1.285200	-0.332600	0.075482	0.211044
59	*Pinus radiata*	0.426624	0.917800	0.107900	0.158625	0.215889
59	*Pinus radiata*	0.426624	0.912300	0.126700	0.152820	0.220610
59	*Pinus radiata*	0.426624	0.909800	0.136200	0.185939	0.185502
60	*Litchi chinensis*	0.865412	0.571100	0.359600	0.515161	0.163573
60	*Litchi chinensis*	0.865412	0.569100	0.320300	0.524361	0.161631
60	*Litchi chinensis*	0.865412	0.569100	0.325300	0.531801	0.159026
61	*Euphoria longan*	0.874470	0.577200	0.836700	0.447850	0.181437
61	*Euphoria longan*	0.874470	0.579100	0.855300	0.450539	0.179422
61	*Euphoria longan*	0.874470	0.581100	0.892700	0.434954	0.183783
62	*Cinnamomum sp.*	0.631014	0.737700	-0.079000	0.273697	0.181002
62	*Cinnamomum sp.*	0.631014	0.743900	-0.087800	0.281624	0.173678
62	*Cinnamomum sp.*	0.631014	0.747300	-0.086700	0.289524	0.167803
63	*Daniellia sp.*	0.525293	0.928600	0.154200	0.134436	0.227641
63	*Daniellia sp.*	0.525293	0.927000	0.172600	0.136329	0.228070
63	*Daniellia sp.*	0.525293	0.926400	0.179400	0.135985	0.228828
64	*Aquilaria sp.*	0.342625	1.305200	-0.519900	0.065463	0.236521
64	*Aquilaria sp.*	0.342625	1.299400	-0.504200	0.065003	0.240161
64	*Aquilaria sp.*	0.342625	1.298800	-0.492100	0.063606	0.244507
65	*Cylicodiscus gabunensis*	0.838227	0.597900	0.329500	0.497513	0.151014
65	*Cylicodiscus gabunensis*	0.838227	0.599100	0.324100	0.498026	0.150112
65	*Cylicodiscus gabunensis*	0.838227	0.600100	0.327600	0.502603	0.148604
66	*Khaya sp.*	0.834070	0.615500	0.239100	0.193305	0.370173
66	*Khaya sp.*	0.834070	0.612300	0.242700	0.186921	0.385277
66	*Khaya sp.*	0.834070	0.611400	0.245100	0.191201	0.378844
67	*Eusideroxylon zwageri*	0.979415	0.485100	0.445300	0.286687	0.403248
67	*Eusideroxylon zwageri*	0.979415	0.486000	0.431400	0.291831	0.394354
67	*Eusideroxylon zwageri*	0.979415	0.488700	0.420800	0.296161	0.384380
68	*Spirostachys africana*	0.989715	0.539100	-0.002500	0.313044	0.299917

68	*Spirostachys africana*	0.989715	0.537600	0.001600	0.302798	0.310832
68	*Spirostachys africana*	0.989715	0.537500	0.003200	0.306778	0.306859
69	*Guibourtia conjugata*	1.084004	0.457600	-0.096100	0.384623	0.338527
69	*Guibourtia conjugata*	1.084004	0.456700	-0.100700	0.381157	0.342777
69	*Guibourtia conjugata*	1.084004	0.457000	-0.095000	0.378836	0.345324
70	*Terminalia sp.*	0.476664	1.015100	-0.644800	0.130715	0.198399
70	*Terminalia sp.*	0.476664	1.012400	-0.690200	0.128557	0.202408
70	*Terminalia sp.*	0.476664	1.013400	-0.685400	0.129360	0.201078
71	*Triplochiton scleroxylon*	0.294327	1.417400	-0.547800	0.030682	0.422248
71	*Triplochiton scleroxylon*	0.294327	1.412400	-0.523100	0.030837	0.423086
71	*Triplochiton scleroxylon*	0.294327	1.412400	-0.526900	0.030157	0.432364
72	*Dryobalanops sp.*	0.653053	0.820700	0.337600	0.107503	0.373806
72	*Dryobalanops sp.*	0.653053	0.815100	0.360300	0.104982	0.386938
72	*Dryobalanops sp.*	0.653053	0.813600	0.370500	0.101882	0.398209
73	*Berlinia sp.*	0.673009	0.816700	-0.070200	0.081968	0.476651
73	*Berlinia sp.*	0.673009	0.815400	-0.065600	0.080330	0.485764
73	*Berlinia sp.*	0.673009	0.815700	-0.065500	0.080584	0.484326
74	*Koompassia sp.*	0.919015	0.557500	0.063000	0.204677	0.425149
74	*Koompassia sp.*	0.919015	0.554900	0.066600	0.200009	0.437072
74	*Koompassia sp.*	0.919015	0.554600	0.060400	0.201790	0.433320
75	*Hevea brasiliensis*	0.729811	0.707600	0.032100	0.155545	0.347050
75	*Hevea brasiliensis*	0.729811	0.704100	0.044100	0.150145	0.360980
75	*Hevea brasiliensis*	0.729811	0.695100	0.068400	0.142357	0.386808
76	*Aucoumea klaineana*	0.480767	0.911500	-0.409700	0.134792	0.240608
76	*Aucoumea klaineana*	0.480767	0.907800	-0.386200	0.134135	0.242808
76	*Aucoumea klaineana*	0.480767	0.907100	-0.358500	0.130825	0.249668
77	*Calophyllum sp.*	0.767951	0.688300	0.337500	0.225691	0.254496
77	*Calophyllum sp.*	0.767951	0.685000	0.344100	0.223241	0.258571
77	*Calophyllum sp.*	0.767951	0.684400	0.347400	0.222262	0.260136
78	*Excentrodendron hsienmu*	0.967439	0.445300	0.729200	0.498767	0.268891
78	*Excentrodendron hsienmu*	0.967439	0.448800	0.712400	0.511882	0.259351
78	*Excentrodendron hsienmu*	0.967439	0.450900	0.694100	0.512827	0.256615
79	*Pericopsis elata*	0.659547	0.728500	0.064100	0.178374	0.286079
79	*Pericopsis elata*	0.659547	0.723700	0.065900	0.177868	0.291264
79	*Pericopsis elata*	0.659547	0.722100	0.072700	0.169415	0.304472

80	*Betula alnoides*	0.691240	0.643600	-0.319700	0.227081	0.288412
80	*Betula alnoides*	0.691240	0.642300	-0.360600	0.217076	0.301826
80	*Betula alnoides*	0.691240	0.642400	-0.369700	0.225371	0.292397
81	*Pterocarpus angolensis*	0.595328	0.643600	-0.319700	0.112801	0.321098
81	*Pterocarpus angolensis*	0.595328	0.642300	-0.360600	0.112496	0.323899
81	*Pterocarpus angolensis*	0.595328	0.642400	-0.369700	0.109509	0.331477
82	*Sindora sp.*	0.623389	0.795400	-0.054200	0.162426	0.262398
82	*Sindora sp.*	0.623389	0.794600	-0.090500	0.163002	0.262201
82	*Sindora sp.*	0.623389	0.795100	-0.098400	0.162956	0.262154
83	*Shorea sp.*	0.449577	0.916000	0.071700	0.135095	0.235423
83	*Shorea sp.*	0.449577	0.910000	0.095000	0.133764	0.239919
83	*Shorea sp.*	0.449577	0.908800	0.112500	0.130237	0.245437
84	*Swintonia sp.*	0.871661	0.566800	0.166100	0.225411	0.373741
84	*Swintonia sp.*	0.871661	0.563200	0.170700	0.216391	0.391845
84	*Swintonia sp.*	0.871661	0.561500	0.174200	0.221848	0.386181
85	*Pometia sp.*	0.650265	0.875100	-0.249900	0.107120	0.324426
85	*Pometia sp.*	0.650265	0.869000	-0.229900	0.102626	0.340312
85	*Pometia sp.*	0.650265	0.867200	-0.215800	0.103058	0.340469
86	*Ochroma sp.*	0.227389	1.848700	-0.427400	0.045187	0.163573
86	*Ochroma sp.*	0.227389	1.720300	-0.093200	0.039499	0.202276
86	*Ochroma sp.*	0.227389	1.612200	0.178900	0.036619	0.234925
87	*Platymiscium sp.*	1.061543	0.512500	0.133500	0.240884	0.428739
87	*Platymiscium sp.*	1.061543	0.508800	0.140900	0.235342	0.444772
87	*Platymiscium sp.*	1.061543	0.507200	0.134200	0.224991	0.463766
88	*Dicorynia sp.*	0.720713	0.561800	0.139200	0.287348	0.300849
88	*Dicorynia sp.*	0.720713	0.556100	0.164800	0.277343	0.315991
88	*Dicorynia sp.*	0.720713	0.554300	0.171300	0.274516	0.321603
89	*Marmaroxylon racemosum*	0.933722	0.525800	0.837800	0.241757	0.403719
89	*Marmaroxylon racemosum*	0.933722	0.519600	0.867200	0.236663	0.419308
89	*Marmaroxylon racemosum*	0.933722	0.523300	0.849400	0.252704	0.391712
90	*Loxopterygium sagotii*	0.754428	0.682000	-0.376700	0.183595	0.318539
90	*Loxopterygium sagotii*	0.754428	0.678700	-0.344100	0.183316	0.321262
90	*Loxopterygium sagotii*	0.754428	0.678400	-0.309700	0.180495	0.327625
91	*Tabebuia sp.*	0.881257	0.534700	0.365100	0.299567	0.317376
91	*Tabebuia sp.*	0.881257	0.530300	0.386000	0.307522	0.315799

91	*Tabebuia sp.*	0.881257	0.528900	0.397900	0.300256	0.324634
92	*Andira sp.*	0.765733	0.535400	0.055900	0.332481	0.284964
92	*Andira sp.*	0.765733	0.533100	0.059600	0.327352	0.292442
92	*Andira sp.*	0.765733	0.532500	0.067400	0.327022	0.293341
93	*Humiria balsamifera*	0.794814	0.718300	0.437000	0.143253	0.359031
93	*Humiria balsamifera*	0.794814	0.713500	0.455100	0.139537	0.371177
93	*Humiria balsamifera*	0.794814	0.711200	0.466200	0.142181	0.368251
94	*Diplotropis sp.*	0.814358	0.593400	0.124200	0.229285	0.335510
94	*Diplotropis sp.*	0.814358	0.590200	0.144300	0.222811	0.346256
94	*Diplotropis sp.*	0.814358	0.589900	0.146700	0.222837	0.347663
95	*Brosimum sp.*	0.878494	0.566800	0.309000	0.292391	0.290324
95	*Brosimum sp.*	0.878494	0.562700	0.320100	0.288183	0.298616
95	*Brosimum sp.*	0.878494	0.561000	0.321700	0.281360	0.307076
96	*Martiodendron sp.*	0.880864	0.544800	1.089200	0.264063	0.344469
96	*Martiodendron sp.*	0.880864	0.539700	1.102800	0.263982	0.351948
96	*Martiodendron sp.*	0.880864	0.538100	1.111600	0.268228	0.348580
97	*Vouacapoua americana*	0.942338	0.546700	-0.064900	0.218213	0.412650
97	*Vouacapoua americana*	0.942338	0.543800	-0.061600	0.222247	0.410848
97	*Vouacapoua americana*	0.942338	0.543200	-0.050800	0.217221	0.419992
98	*Manilkara sp.*	0.973081	0.557100	0.658000	0.253659	0.345894
98	*Manilkara sp.*	0.973081	0.553000	0.672000	0.247038	0.357864
98	*Manilkara sp.*	0.973081	0.551800	0.671800	0.237684	0.372249
99	*Platonia insignis*	0.767178	0.667300	-0.245000	0.210669	0.289081
99	*Platonia insignis*	0.767178	0.662200	-0.234300	0.212701	0.291922
99	*Platonia insignis*	0.767178	0.660100	-0.225900	0.204773	0.302762
100	*Hymenaea sp.*	0.794748	0.650200	-0.359500	0.187399	0.340787
100	*Hymenaea sp.*	0.794748	0.648600	-0.395400	0.185573	0.346121
100	*Hymenaea sp.*	0.794748	0.648800	-0.406100	0.185143	0.346477
101	*Diospyros sp.*	0.927915	0.617700	-0.105100	0.181763	0.389713
101	*Diospyros sp.*	0.927915	0.613100	-0.087000	0.182305	0.395038
101	*Diospyros sp.*	0.927915	0.611700	-0.085600	0.180329	0.401372
102	*Prunus sp.*	0.548866	0.949500	-0.311200	0.110726	0.268363
102	*Prunus sp.*	0.548866	0.941200	-0.286800	0.107469	0.279472
102	*Prunus sp.*	0.548866	0.937700	-0.276800	0.103920	0.288229
103	*Xylia sp.*	0.988551	0.501900	0.133600	0.311069	0.349481
103	*Xylia sp.*	0.988551	0.497600	0.148000	0.300697	0.365732
103	*Xylia sp.*	0.988551	0.495700	0.150800	0.305541	0.364575
104	*Terminalia tomentosa*	1.063786	0.546000	-0.119400	0.201658	0.450593

104	*Terminalia tomentosa*	1.063786	0.545700	-0.165400	0.204858	0.444925
104	*Terminalia tomentosa*	1.063786	0.546800	-0.174700	0.205030	0.442926
105	*Aglaia sp.*	0.761030	0.664200	-0.101800	0.194385	0.316354
105	*Aglaia sp.*	0.761030	0.662200	-0.077000	0.193898	0.319218
105	*Aglaia sp.*	0.761030	0.662000	-0.044400	0.193121	0.320592
106	*Afzelia sp.*	0.889125	0.628200	-0.205100	0.176047	0.388489
106	*Afzelia sp.*	0.889125	0.630300	-0.212200	0.178356	0.380489
106	*Afzelia sp.*	0.889125	0.630700	-0.211400	0.181016	0.375500
107	*Swietenia sp.*	0.480581	0.901200	-0.076700	0.119546	0.270334
107	*Swietenia sp.*	0.480581	0.896500	-0.107300	0.117223	0.278452
107	*Swietenia sp.*	0.480581	0.893500	-0.103400	0.118549	0.277659
108	*Xanthostemon sp.*	1.236086	0.420700	-0.272000	0.340130	0.454455
108	*Xanthostemon sp.*	1.236086	0.418500	-0.250700	0.331770	0.469812
108	*Xanthostemon sp.*	1.236086	0.417900	-0.219000	0.343227	0.456330
109	*Berchemia discolor*	0.955796	0.440300	-0.059100	0.343249	0.407776
109	*Berchemia discolor*	0.955796	0.441400	-0.065200	0.335285	0.416392
109	*Berchemia discolor*	0.955796	0.442500	-0.055500	0.342491	0.404910
110	*Guibourtia coleosperma*	0.961755	0.480000	0.493800	0.247727	0.465509
110	*Guibourtia coleosperma*	0.961755	0.485600	0.476800	0.251969	0.449494
110	*Guibourtia coleosperma*	0.961755	0.489200	0.473300	0.254810	0.440842
111	*Machaerium sp.*	1.036025	0.540200	-0.167800	0.257045	0.365273
111	*Machaerium sp.*	1.036025	0.536700	-0.158300	0.257025	0.369606
111	*Machaerium sp.*	1.036025	0.536800	-0.153800	0.258110	0.368141
112	*Samanea saman*	0.649719	0.735000	-0.223400	0.148626	0.326778
112	*Samanea saman*	0.649719	0.730000	-0.233700	0.146187	0.335043
112	*Samanea saman*	0.649719	0.728700	-0.243900	0.142051	0.343955
113	*Campnosperma sp.*	0.517803	0.874900	-0.212000	0.107579	0.315994
113	*Campnosperma sp.*	0.517803	0.873000	-0.200400	0.106137	0.320752
113	*Campnosperma sp.*	0.517803	0.872300	-0.210400	0.104986	0.323791
114	*Buxus sp.*	0.856124	0.540600	-0.090200	0.228593	0.402760
114	*Buxus sp.*	0.856124	0.544700	-0.104000	0.227389	0.400029
114	*Buxus sp.*	0.856124	0.545600	-0.100200	0.236131	0.385738
115	*Erythrophleum sp.*	0.735967	0.555700	0.899600	0.263818	0.330459
115	*Erythrophleum sp.*	0.735967	0.558700	0.894300	0.258199	0.334473
115	*Erythrophleum sp.*	0.735967	0.560600	0.886700	0.267426	0.321362
116	*Anadenanthera macrocarpa*	0.963992	0.468700	0.488000	0.278381	0.438481

116	*Anadenanthera macrocarpa*	0.963992	0.470100	0.479000	0.294035	0.415687
116	*Anadenanthera macrocarpa*	0.963992	0.471600	0.478800	0.298703	0.407231
117	*Chlorophora sp.*	0.658406	0.842400	0.290700	0.092128	0.410363
117	*Chlorophora sp.*	0.658406	0.844500	0.271500	0.091936	0.410606
117	*Chlorophora sp.*	0.658406	0.846700	0.269100	0.093083	0.403008
118	*Staudtia sp.*	0.874887	0.658700	-0.272700	0.184866	0.339750
118	*Staudtia sp.*	0.874887	0.654100	-0.298100	0.173794	0.365157
118	*Staudtia sp.*	0.874887	0.652100	-0.291100	0.176034	0.362301
119	*Cynometra sp.*	0.956749	0.535500	-0.139700	0.260568	0.363228
119	*Cynometra sp.*	0.956749	0.524600	-0.094800	0.275848	0.357458
119	*Cynometra sp.*	0.956749	0.524600	-0.072500	0.283005	0.350148
120	*Swartzia leiocalycina*	1.268000	0.398900	0.240900	0.338884	0.498649
120	*Swartzia leiocalycina*	1.268000	0.400200	0.247900	0.333596	0.502014
120	*Swartzia leiocalycina*	1.268000	0.401000	0.242800	0.317597	0.519360
121	*Baphia kirkii*	1.103675	0.419300	0.793100	0.242629	0.598341
121	*Baphia kirkii*	1.103675	0.430100	0.764200	0.252181	0.555863
121	*Baphia kirkii*	1.103675	0.438200	0.739900	0.281730	0.493626
122	*Dalbergia cearensis*	0.764343	0.684800	0.188000	0.142700	0.387019
122	*Dalbergia cearensis*	0.764343	0.694900	0.153500	0.149112	0.364188
122	*Dalbergia cearensis*	0.764343	0.701000	0.150800	0.153943	0.349516
123	*Dalbergia tucurensis*	0.705964	0.664700	-0.063000	0.150726	0.385740
123	*Dalbergia tucurensis*	0.705964	0.674300	-0.094300	0.167175	0.347733
123	*Dalbergia tucurensis*	0.705964	0.677700	-0.100500	0.169788	0.339051
124	*Acer sp.*	0.653885	0.672600	0.184900	0.173153	0.336741
124	*Acer sp.*	0.653885	0.684500	0.146900	0.183838	0.311365
124	*Acer sp.*	0.653885	0.691100	0.126100	0.184221	0.305166
125	*Dipterocarpus sp.*	1.117999	0.511100	-0.069600	0.197430	0.519449
125	*Dipterocarpus sp.*	1.117999	0.529400	-0.121800	0.212043	0.456446
125	*Dipterocarpus sp.*	1.117999	0.539600	-0.155700	0.215487	0.432719
126	*Liriodendron tulipifera*	0.540571	0.876100	-0.352900	0.108838	0.312070
126	*Liriodendron tulipifera*	0.540571	0.872300	-0.387300	0.105287	0.321855
126	*Liriodendron tulipifera*	0.540571	0.871400	0.391600	0.105963	0.320668
127	*Michelia sp.*	0.455938	0.998100	-0.181200	0.109204	0.237761
127	*Michelia sp.*	0.455938	1.001600	-0.167800	0.106548	0.241026
127	*Michelia sp.*	0.455938	1.002500	-0.155300	0.107437	0.239839
128	*Palaquium sp.*	0.532069	0.973000	-0.125900	0.113845	0.243335

128	*Palaquium sp.*	0.532069	0.983600	-0.151000	0.116823	0.234508
128	*Palaquium sp.*	0.532069	0.988300	-0.159600	0.116958	0.232273
129	*Acacia sp.*	1.034903	0.410000	0.155400	0.212391	0.676609
129	*Acacia sp.*	1.034903	0.427500	0.099300	0.258711	0.545133
129	*Acacia sp.*	1.034903	0.434200	0.084600	0.262054	0.527250
130	*Toona sinensis*	0.435651	1.008600	-0.087500	0.155046	0.171287
130	*Toona sinensis*	0.435651	1.014600	-0.097100	0.159820	0.164715
130	*Toona sinensis*	0.435651	1.017300	-0.116100	0.156972	0.166762