Noname manuscript No.
(will be inserted by the editor)

Exploring the Diversity and Conservation Status of Tree Species with TreeeX

Stefan Jänicke · Emily Beech · Malin Rivers

Received: date / Accepted: date

Abstract The GlobalTreeSearch database provides the names of all tree species known to science and the countries where these trees grow. TreeeX is a visual exploration system that supports multifaceted analyses of the GlobalTreeSearch data. Investigating research questions on biodiversity and conservation on a global or national scale are visually supported by interactive choropleth maps that color countries according to frequency, diversity, or uniqueness of prevalent tree species. By combining the GlobalTreeSearch and ThreatSearch data sets additional information on the conservation status of trees can be visualised globally and nationally through TreeeX. Similarities and differences in tree diversity, endemism and conservation status to other countries can be analyzed in detail. Several examples outline the system's capability of delivering insights concerning the geographical diversity of tree species.

Keywords TreeeX · BGCI · biodiversity · conservation

1 Introduction

The importance of trees for the ecological system has been discussed in a multitude of publications. Trees are essential for human and other animal life on Earth in that they capture energy from the sun and convert it into food in the form of their seeds, fruits, leaves and roots. In addition to providing

S. Jänicke
IMADA
University of Southern Denmark
Odense, Denmark
E-mail: stjaenicke@imada.sdu.dk

E. Beech & M. Rivers
Botanic Gardens Conservation International
Richmond, United Kingdom
E-mail: {emily.beech,malin.rivers}@bgci.org

food, they also define the habitat of other species that depend on tree species for their survival. Humans, for example, need trees as resources for food, for building material, for medicine, and we often choose woodlands for recreational purposes [13]. Also, trees have a significant role for stabilizing the Earth's systems include water purification, soil stabilization, food provision, carbon storage and oxygen production; thus, the necessity of preserving forests and woodlands is a well-known fact [23].

If tree species are lost, opportunities to develop new solutions to pressing economic, social, health and industrial problems will also be lost. Despite the importance of individual tree species many are at risk of extinction.

In order to assess the risk of extinction for trees and monitor progress the Global Tree Assessment was launched in 2015. The Global Tree Assessment aims to have a conservation assessment for every known tree species by the year 2020 [22,25]. The Global Tree Assessment will be used to inform, prioritise, monitor, and manage tree species diversity on a global, regional, and/or national level. The first step towards the Global Tree Assessment was the development of a list of all the world's tree species. Researchers of Botanic Gardens Conservation International (BGCI) combined over 500 published sources on regional, taxonomic, and country-specific tree diversity [3] and made the resultant geographical mapping of tree species available in the form of the GlobalTreeSearch online database [4] and the ThreatSearch online database [5]. Users of the GlobalTreeSearch database are provided with a textual search interface that allows for searching tree species and/or tree genera for a given country. The search result is a textual extract of the database listing family, taxon name and corresponding author of the tree species that match the given query. Though lists for individual queries can be downloaded in a tabular format, a comparative analysis of the geographical diversity of tree growth is not supported. The ThreatSearch database also has a textual search interface, that returns any species that have been evaluated with regards to its extinction risk. Species can be filtered on those that are "threatened", i.e. of high risk of extinction in the near future, as well as the scope (Global, Not Global) and the year of the assessment.

TreeeX was designed in order to provide multifaceted visual access to the GlobalTreeSearch and ThreatSearch data. As the geographical mapping is given on the country-level, TreeeX supports analyses on the biodiversity of tree species with interactive choropleth maps that illustrate different scenarios. Next to comparing the distribution of different tree species, the system allows for exploring aspects on species richness and uniqueness. In addition, similarities and differences of a selected country compared to other countries can be analyzed.

By combining the GlobalTreeSearch and ThreatSearch data, additional information on the conservation status (risk of extinction) for trees for each country can also be visualised.

2 Related Work

Geovisualisations as a means of illustrating aspects on biodiversity have been frequently used; exhaustive overviews of related techniques from thematic cartography and geovisualisation are provided by Slocum et al. [29] and by Andrienko et al. [2].

Usually, thematic maps are based on a qualitative data set for a small geographical area, be it a national park or a whole country. Debinski et al. [11] use a geographical information system (GIS) to categorize habitats, and to determine relationships between remotely sensed habitat categorizations and species distribution patterns in the Greater Yellowstone Ecosystem. Thematic maps have also been used for a qualitative study of vegetation in Madagascar to draw implications and recommendations for the conservation of biodiversity [12]. Similarly, Madden [21] uses various heat maps to assess vegetation patterns in Great Smoky Mountains National Park. Setturu et al. [27] use categorial maps to visualise landscape dynamics in National Parks of Central Western Ghats. Categorial pixel-based dot maps, where each tree species or genera in the study receives a certain color, can be used to visualise detailed information on the regional distribution of tree species [15, 26]. Predominance tag maps can be used to overlay such maps with textual information on locally predominant tree species [24].

Geovisualisations are further central to analyzing time-dependent tree cover changes. Carnaval et al. [7] use heat maps to model the spatial range of the Brazilian Atlantic forest under three climatic scenarios (current climate, 6000 and 21,000 years ago) in order to predict patterns of current biodiversity. Based on analysis of nearly 30,000 Landsat images, Kim et al. [20] illustrate worldwide forest-cover change from 1990 to 2000 with heat maps. Heat maps are also used by Hansen et al. [14] to visualise tree cover, forest loss, and forest gain, and by Allen et al. [1] for the analysis of worldwide locations of substantial tree mortality and forest die-off from hotter drought in the Anthropocene.

Linked views that interlink geospatial and temporal information are also valuable for exploring biodiversity data. Jänicke et al. [18] use GeoTemCo [16, 17] for the geospatial-temporal mapping and biodiversity analyses of the benthic invertebrate fauna. CommonGIS, a similar system, is used to combine forest ecosystem models with exploratory data visualisation for the analysis of long-term simulation results [8].

Image processing techniques are used for generating information about the diversity of trees in forests. While Clark et al. [9] use high spectral and spatial resolution imagery for the automated species-level classification of individual tree crowns in a tropical rain forest, Simons et al. [28] propose a point-based rendering method to support the remote sensing of forests. Musasabi [19] aims at simulating the growth and changes of forests depending on the species of the tree and the land conditions.

3 TreeeX System

TreeeX is an interactive choropleth map that is colored according to four different analysis modes: species analysis, global diversity, country of interest and threat status.

3.1 Species Analysis

The interface enables comparing the distributions of different tree species visually. When multiple species are prevalent in a country, the different colors are overlaid using a subtractive color mixing scheme. As the number of colors that can be easily distinguished by humans is limited by 12 [30], though extendable, comparing a maximum of three tree species is suggested, which results in a color map consisting of seven distinctive colors in the CMYK color model as illustrated in Figure 1. Applying this color coding, Figure 7 compares the distribution of the three most widespread tree species.

species	**C**	**Y**	**M**	**K**
A	50	0	0	0
B	0	50	0	0
C	0	0	50	0
$A \wedge B$	50	50	0	0
$A \wedge C$	50	0	50	0
$B \wedge C$	0	50	50	0
$A \wedge B \wedge C$	50	50	50	0

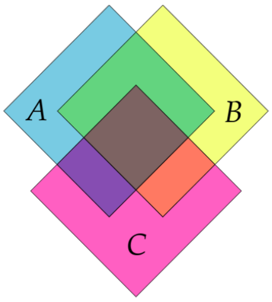

Fig. 1 CYMK color mixing for the species A, B and C

3.2 Country of Interest

Focusing on a single country c_i, each country c_j of the choropleth map is colored in red with a saturation level according to the similarity of tree species $T(c_i)$ and $T(c_j)$ of c_i and c_j. Two coloring modes are possible. The Jaccard index defined as

$$J(c_i, c_j) = \frac{|T(c_i) \cap T(c_j)|}{|T(c_i) \cup T(c_j)|}$$

considers the cardinalities of both sets of tree species, thus, providing a general view on the similarity of the biodiversities of c_i and c_j. On the other hand, when the user likes to see the countries sharing most of c_i's tree species, thus, providing similar habitat conditions, the cardinality of $T(c_j)$ is disregarded and only the overlap size compared to the richness of tree species of c_i is considered as

$$I(c_i, c_j) = \frac{|T(c_i) \cap T(c_j)|}{|T(c_i)|}.$$

Figure 2 illustrates the difference of both metrics when choosing South Korea as c_i. For exploration purposes, each country is attached with a bar chart reflecting the proportions of shared and non-shared species. The center bar colored green illustrates the amount of shared species, the orange bar on the left the amount of tree species only prevalent in c_i, and the purple bar on the right the amount of tree species only prevalent in c_j. When hovering the bar chart, a popup window is shown that provides several information, and it can be expanded for a more detailed investigation of individual tree species.

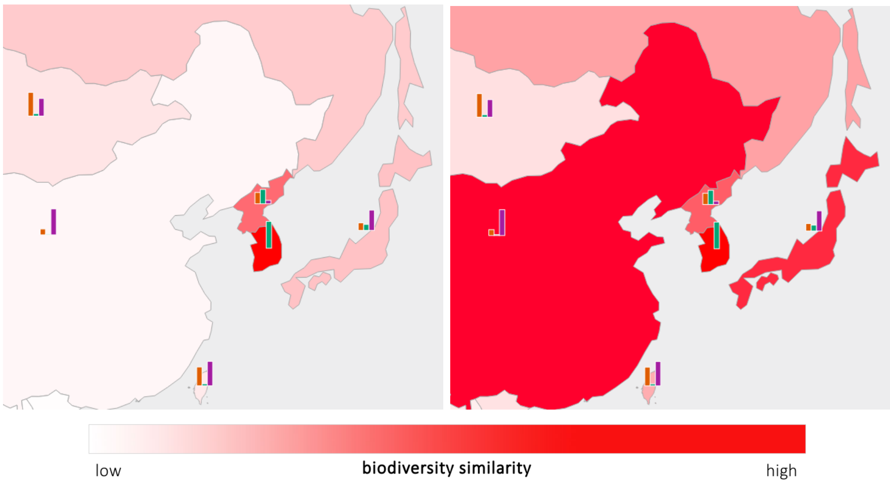

Fig. 2 Comparing South Korea's biodiversity to other countries. Using the Jaccrd index to define similarity highights North Korea with the most similar biodiversity of trees (left). Applying the intersection metric shows China and Japan as most similar countries (right) as the majority of South Korea's tree species are also endemic to those countries.

3.3 Threat Analysis

In addition to visualising tree diversity, by adding information on the conservations status of trees (from the ThreatSearch database), we can also visualise the percentage of tree species in a country have been assessed using a red-green color gradient. Countries having a green hue have assessed the majority of their trees while red colors indicate that the majority of tree species is still to be assessed. In addition, the breakdown of assessment categories is drawn in the form of a bar chart for each country giving a more detailed view on its assessment status. A teal bar shows the number of extinct tree species, an orange bar the number of threatened tree species, a purple bar the number of possibly threatened tree species and a green bar the number of tree species that have been assessed as not threatened. In addition, a pink bar illustrates the number of tree species with an unclear (data deficient) assessment status. The scope of assessments can be dynamically defined. It is possible to filter only for assessments that are done on a global scale, or those on a non-global scale, i.e. national and regional scales. In addition, assessments with an unknown scope can be taken into account. Figure 3 reflects the percentages of tree species that have been globally assessed. In the Americas, the assessment statuses decrease the more a country is located to the South. However, the percentages of threatened species are also high in South America.

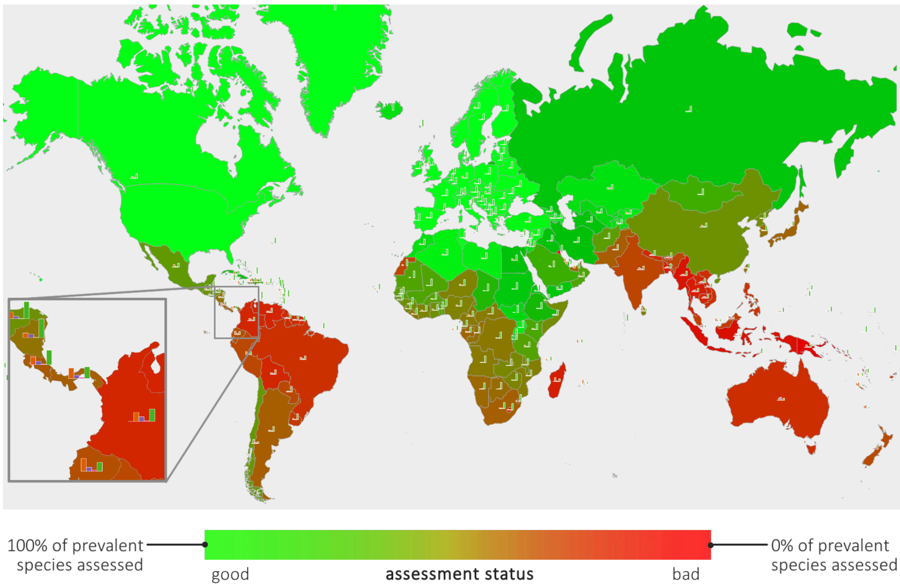

Fig. 3 The coloring of a country in the threat analysis illustrates its assessment status.

3.4 Global Analysis

Various research questions on tree diversity can be investigated in this mode for a given set of countries. The choropleth map can be colored according to three different aspects of global diversity:

Frequency. Countries are colored in red with a saturation level according to the total of different tree species divided by the total of the country with most tree species. Currently, the database holds Brazil with 8,982 tree species as country with the highest biodiversity (see Figure 4).

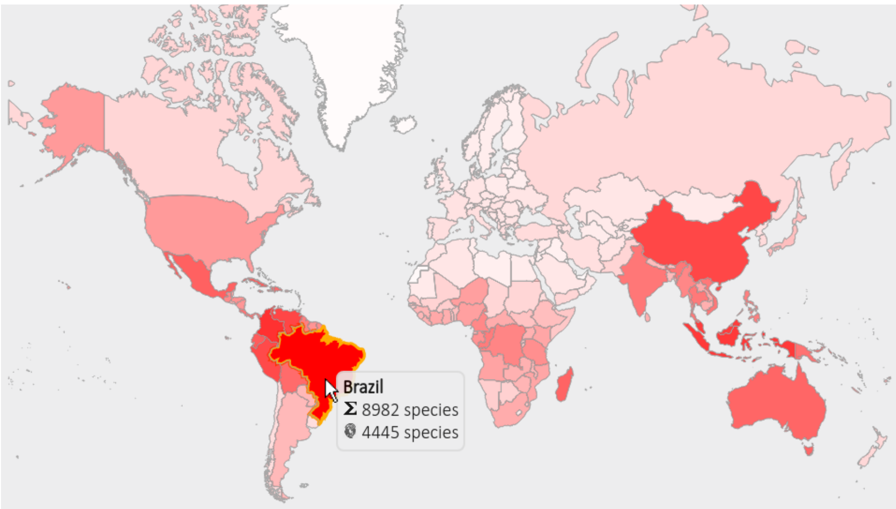

Fig. 4 Color coding according to the total of tree species. Brazil has the highest biodiversity with 8,982 different tree species.

Uniqueness. Countries are colored in red with a saturation level according to the uniqueness of tree species, which is the number of tree species unique in a country divided by the country's total of tree species. Currently, Madagascar is listed as the country with the most unique biodiversity as 3,087 out of 3,315 tree species only grow in Madagascar (see Figure 5).

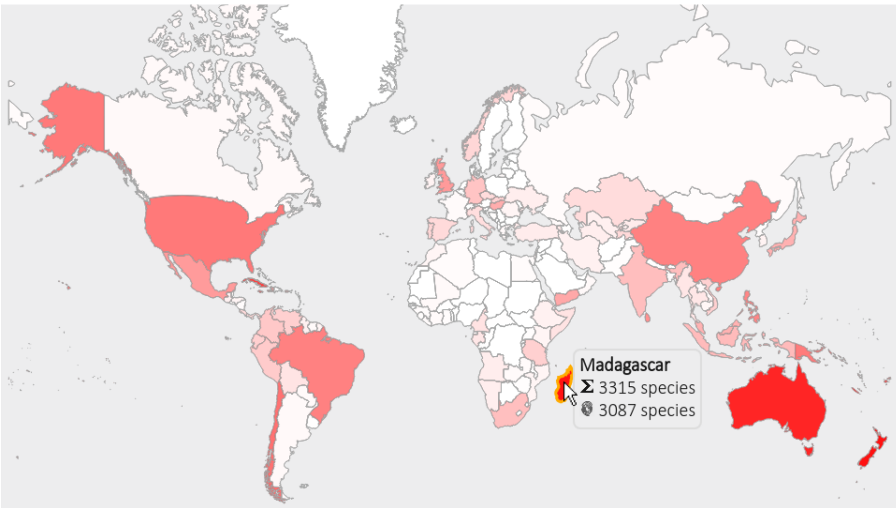

Fig. 5 Color coding according to the uniqueness of tree species. Madagascar has the highest ratio of unique tree species.

Diversity. The Country-of-Interest functionality gives a comparative view on the similarities of tree species of a chosen country compared to all other countries. In order to generate a global view on the changing biodiversity among the given set of countries, this mode takes the similarities of all country tuples at once into account. Therefore, a $n \times n$ distance matrix $D = [d_{ij}]$ for n countries is calculated. d_{ij} denotes the dissimilarity of tree species between the countries c_i and c_j, which is defined as $d_{ij} = 1 - J(c_i, c_j)$. Then, a classical multidimensional scaling (MDS) algorithm [6] is executed that determines a position $p_i = (x_i, y_i, z_i)$ in the 3D space $S = [0,1]_x \times [0,1]_y \times [0,1]_z$ for each country c_i while preserving distances between countries as best as possible. S is then scaled to the RGB cube, and the color for a country is determined by:

$$R_i = \frac{\frac{r_{max} - r_x}{2} + x_i}{r_{max}} \cdot 255$$

$$G_i = \frac{\frac{r_{max} - r_y}{2} + y_i}{r_{max}} \cdot 255$$

$$B_i = \frac{\frac{r_{max} - r_z}{2} + z_i}{r_{max}} \cdot 255.$$

r_x defines the spanned range of all x-values, thus, determined as $r_x = x_{max} - x_{min}$. r_y and r_z are defined equally, and $r_{max} = \max\{r_x, r_y, r_z\}$. Countries to be taken into account in this analysis mode can be selected interactively by the user of the system. Figure 6 shows the result when all countries are taken into account.

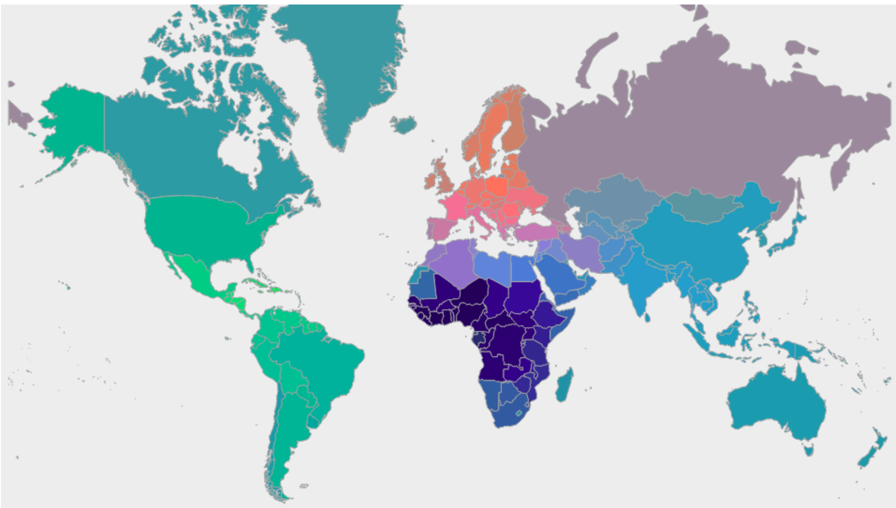

Fig. 6 Color coding according to MDS of countries' tree species similarities. For each country, a high-dimensional vector represents prevalent tree species. MDS is applied to project all countries into a three-dimensional space, and the resulting positions are used to define RGB colors. The more similar colors among countries are, the more similar their corresponding biodiversities.

4 Working with TreeeX

In order to illustrate the value of the proposed system to investigate different research questions on the biodiversity of tree species, this section outlines typical workflows with TreeeX.

4.1 Species Analysis

Figure 7 shows the three most widespread tree species *Ximenia americana* (native to 91 countries, yellow), *Dodonaea viscosa* (native to 90 countries, blue) and *Talipariti tiliaceum* (native to 80 countries, pink). None of those species is endemic in Europe. On the other hand, many countries close to the equator host all the three species.

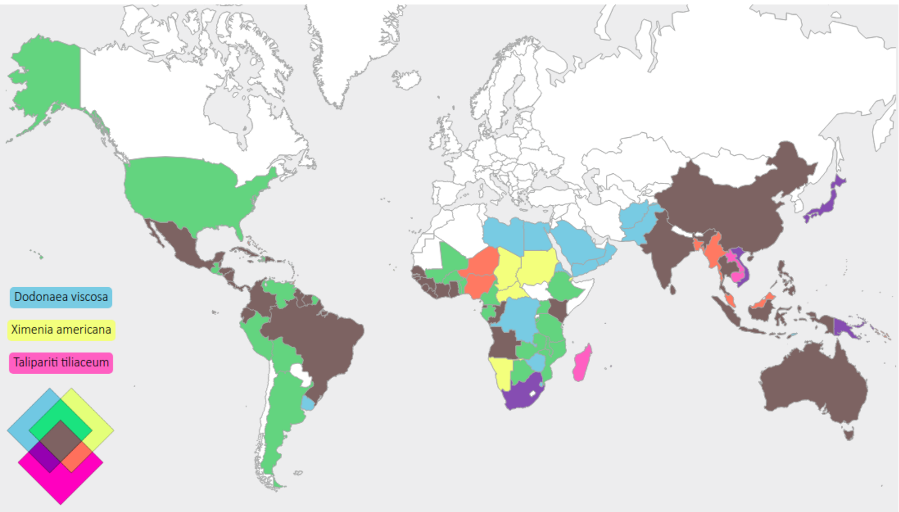

Fig. 7 Distribution areas of the three most widespread species *Ximenia americana* (native to 91 countries, yellow), *Dodonaea viscosa* (native to 90 countries, blue) and *Talipariti tiliaceum* (native to 80 countries, pink).

Researchers already stated that around 58% of all tree species are single country endemics [3]. When browsing the tree species for a certain country, those unique species are marked with a fingerprint icon. Taking Chile with a total of 158 species as an example, unique and common species are already visible in the popup window as illustrated in Figure 8a. The three pepper tree species prevalent in Chile are not unique, which deserves a more detailed investigation of the distribution areas with the species analysis functionality. The resultant choropleth map marks Chile as the only country where all three species grow (see Figure 8b).

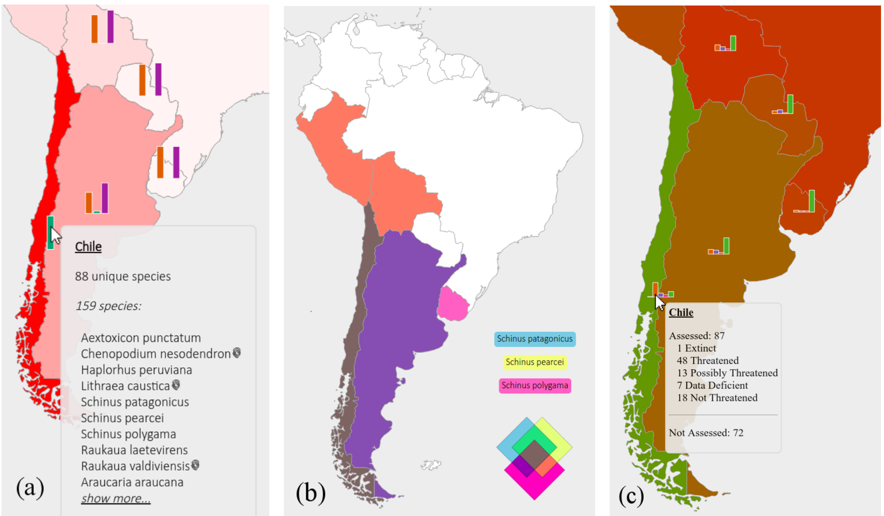

Fig. 8 Analyzing tree species in Chile. (a) Browsing 159 tree species native to Chile. (b) Distribution areas of the three pepper tree species native to Chile. (c) Status of tree species' threat assessments in Chile.

4.2 Country of Interest

Countries sometimes have focused conservation assessment effort to national level assessments, considering only the species distribution and status within the particular country. If species are single country endemics, i.e., only exist in one country, a national assessment is also considered a global assessment. If a species is found in more than one country, the national assessment is only valid for the country in question and a separate global level assessment is required for Global Tree Assessment.

The Country of Interest view explores how many of native tree species of a chosen country are endemic to the country. For example, when choosing the country of Haiti in the Caribbean, the application displays that Haiti has 1,077 native species of tree (see Figure 9a). Of those 1,077 species, 208 species are unique to Haiti and found nowhere else in the world. This provides the scale of the national task to complete the red list assessments of endemic Haitian species.

The Country of Interest view allows us also to compare which species two countries have in common. This can identify cross-country collaborations necessary to produce a global assessment for the Global Tree Assessment. It can also calculate the numbers of endemic and non-endemic species for each of the two countries. For example, comparing Haiti to the Dominican Republic, as can be seen in Figure 9b, these two countries have a very high shared diversity. Both Haiti and Dominican Republic have around 260 species only found in their respective countries, and 804 species are shared between the two

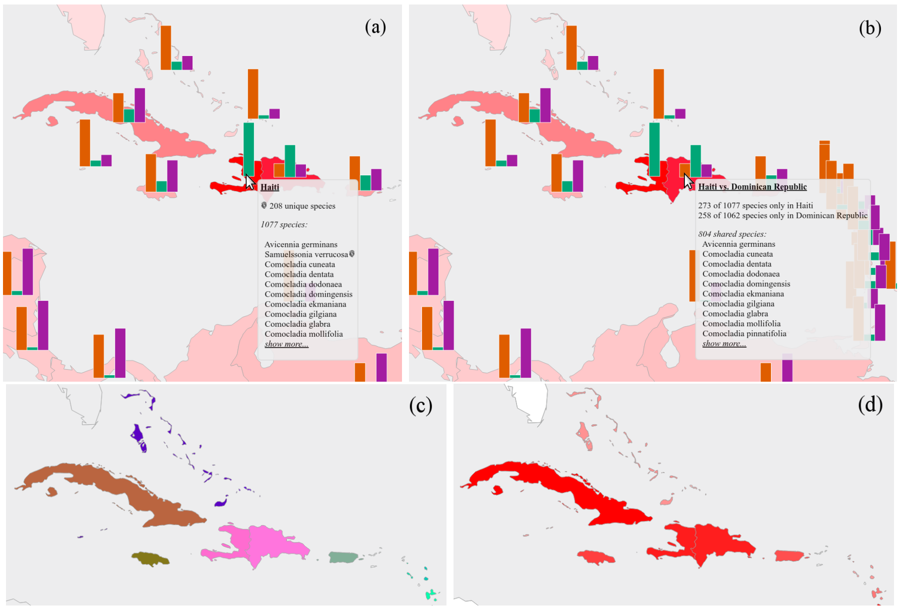

Fig. 9 Tree diversity in the Caribbean. (a) Listing 1,077 tree species endemic in Haiti. (b) Comparing the tree diversities of Haiti and Dominican Republic; 804 species are native to both countries. (c) Comparative analysis of tree diversities in the Caribbean. (d) Frequency analysis of tree species native in the Caribbean.

countries. Therefore, significant effort is needed across the island to produce assessments for species native to both Haiti and Dominican Republic.

The role of Panama's biodiversity has been the subject of interest due to the global importance of the Panama Canal [10]. Figure 10a illustrates a high similarity to the tree species prevalent in Costa Rica, and the farther away from Panama to the north or to the south the amount of overlap decreases. That Panama lies in the center of a continuum of a north-south biodiversity change is depicted in Figure 10b. Allowing visualisation of the distribution of tree species can help to identify patterns in biodiversity across several countries and be used for targeting conservation action.

4.3 Threat Analysis

This analysis combines the names and country distributions from GlobalTreeSearch with conservation assessments from ThreatSearch. The threat analysis illustrates the continuing progress towards the 2020 target of the Global Tree Assessment. It allows us to identify countries where significant effort is still needed to assess all native tree species to that country. This is used for prioritisation for Global Tree Assessment. For each country it calculates the number of tree species assessed and not assessed per country. Of the assessed species, it allows us to view the broad conservation categories (Extinct, Threat-

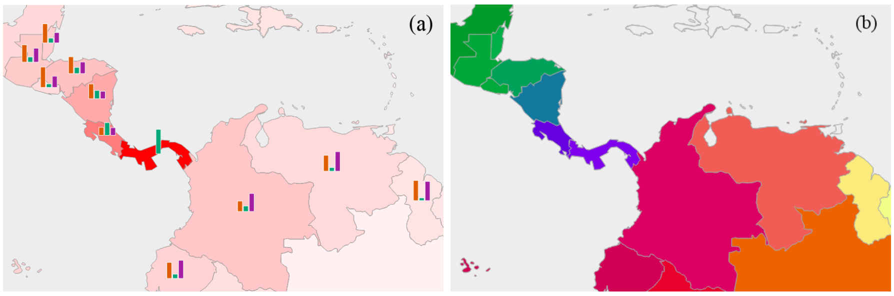

Fig. 10 Analyzing the role of Panama. (a) Focusing on Panama using the Jaccard index for country coloring. (b) North-south continuum of tree diversity change with Panama in the center is visible.

ened, Possibly Threatened, Not Threatened and Data Deficient). You can also filter on the scope of the assessment (Global vs Not Global), a key measure for the Global Tree Assessment.

For example, for Chile we can see that 89 species have been assessed, and 70 tree species are still to be assessed (see Figure 8c). Of the assessed species, 1 is Extinct, 48 Threatened, 13 Possibly Threatened, 7 Data Deficient and 20 Not Threatened. The coloring indicates that Chile has a higher proportion of its total tree flora assessed than surrounded countries in South America. This data can be used by countries for their national reporting on the progress towards biodiversity targets such as CBD (Aichi targets) or other policy commitments. In addition, TreeeX offers easy-to-use and easy-access information on the conservation status of trees on both global and national level, facilitating use of the information to prioritise conservation action.

4.4 Global Analysis

A global overview is essential when planning a comprehensive global project such as the Global Tree Assessment. Being able to visualise differences in tree diversity and endemism across the world allows us to identify the countries of the highest tree species diversity. The global overview shows the patterns across the world with similar levels of diversity (see Figure 6). Tree diversity varies across temperate and tropical regions. There is also tree diversity hotspots in South America and South East Asia. The global analysis allows a clear visual representation of tree diversity and for the Global Tree Assessment it gives us an idea of the location of the project's partners that will contribute the highest number of tree conservation assessments.

Regional comparisons between the countries can be made by zooming in. For the Caribbean, the tree diversities vary from island to island as can be seen in Figure 9c. The most species are found in Cuba and Hispaniola (Haiti and Dominican Republic), with other smaller islands having fewer native species (see Figure 9d). Based on this information, national project partners that have the largest task to complete their national tree assessments are identified and appropriate support can be given to help them achieve the Global Tree Assessment 2020 goal.

5 Conclusion

TreeeX is an application that supports the comparative geographical analysis of tree diversity and conservation status on both a global and national level. The GlobalTreeSearch and ThreatSearch data portals only provide limited search functionality, i.e., genus, species or country level, with no visual output. TreeeX combines the two database and provides an interactive choropleth map and enables a multifaceted visual access to a rich database fundamental for research on the biodiversity of tree species.

TreeeX can show progress globally towards achieving the global conservation assessments for all trees. It can also be used on a national level to inform countries about their tree diversity, endemism and the current level of threat. This can directly feed into national reporting against policy targets.

TreeeX currently helps to answer some of the research questions that the Global Tree Assessment is working to address, however the portal could be extended to cover further questions. For example, an extension of the TreeeX portal is planned to include the display of visual information on different taxonomic levels (species, genus, family). In addition, future developments will include incorporating species-specific conservation actions currently in place, both *ex situ* and *in situ,* allowing countries to monitor and prioritise conservation actions for tree species.

The TreeeX interface is designed so it can also be used for data sets with overlapping geographical data on various levels such as regions, countries, states, districts etc. In order to foster future research, TreeeX is implemented as a user configurable JavaScript library[1] based on D3.js.

References

1. Allen, C.D., Breshears, D.D., McDowell, N.G.: On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. Ecosphere **6**(8), 1–55 (2015). Art129
2. Andrienko, N., Andrienko, G.: Exploratory Analysis of Spatial and Temporal Data: A Systematic Approach. Springer (2005)
3. Beech, E., Rivers, M., Oldfield, S., Smith, P.P.: GlobalTreeSearch: The first complete global database of tree species and country distributions. Journal of Sustainable Forestry **36**(5), 454–489 (2017)
4. BGCI: GlobalTreeSearch online database (2018). Botanic Gardens Conservation International. Richmond, U.K. Available at `www.bgci.org`. Accessed on 07/12/2018.
5. BGCI: ThreatSearch online database (2018). Botanic Gardens Conservation International. Richmond, U.K. Available at `www.bgci.org`. Accessed on 07/12/2018.
6. Borg, I., Groenen, P.: Modern Multidimensional Scaling: Theory and Applications. Springer (2005)

[1] `http://treeex.vizcovery.de`

7. Carnaval, A.C., Moritz, C.: Historical climate modelling predicts patterns of current biodiversity in the Brazilian Atlantic forest. Journal of Biogeography **35**(7), 1187–1201 (2008)
8. Chertov, O., Komarov, A., Mikhailov, A., Andrienko, G., Andrienko, N., Gatalsky, P.: Geovisualization of Forest Simulation Modelling Results: A Case Study of Carbon Sequestration and Biodiversity. Comput. Electron. Agric. **49**(1), 175–191 (2005)
9. Clark, M.L., Roberts, D.A., Clark, D.B.: Hyperspectral discrimination of tropical rain forest tree species at leaf to crown scales. Remote Sensing of Environment **96**(3), 375–398 (2005)
10. Condit, R., Robinson, W.D., Ibáñez, R., Aguilar, S., Sanjur, A., Martínez, R., Stallard, R.F., García, T., Angehr, G.R., Petit, L., Wright, S.J., Robinson, T.R., Heckadon, S.: The Status of the Panama Canal Watershed and Its Biodiversity at the Beginning of the 21st CenturyLong-term ecological studies reveal a diverse flora and fauna near the Panama Canal, harbored within a corridor of forest stretching from the Caribbean to the Pacific, but deforestation, land degradation, erosion, and overhunting remain threats. BioScience **51**(5), 389–398 (2001)
11. Debinski, D., Kindscher, K., Jakubauskas, M.: A remote sensing and GIS-based model of habitats and biodiversity in the Greater Yellowstone Ecosystem. International Journal of Remote Sensing **20**(17), 3281–3291 (1999)
12. Du Puy, D.J., Moat, J.: Vegetation mapping and classification in Madagascar (using GIS): implications and recommendations for the conservation of biodiversity. Chorology, taxonomy and ecology of the floras of Africa and Madagascar pp. 97–117 (1998)
13. Fitzjohn, R.G., Pennell, M.W., Zanne, A.E., Stevens, P.F., Tank, D.C., Cornwell, W.K.: How much of the world is woody? Journal of Ecology **102**(5), 1266–1272 (2014)
14. Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R., Kommareddy, A., Egorov, A., Chini, L., Justice, C.O., Townshend, J.R.G.: High-Resolution Global Maps of 21st-Century Forest Cover Change. Science **342**(6160), 850–853 (2013)
15. Heiden, U., Holzwarth, S., Pinnel, N., Reichmuth, A., Raczko, E., Heurich, M., Müller, J., Wang, Z., Skidmore, A., Ali, A., Wang, T., Darvishzadeh, R., Wegmann, M.: Laboratory for Essential Biodiversity Variables (EBV) Concepts – The "Data Pool Initiative for the Bohemian Forest Ecosystem". In: Living Planet Symposium 2016 (2016). URL `http://elib.dlr.de/104845/`
16. Jänicke, S., Heine, C., Scheuermann, G.: GeoTemCo: Comparative Visualization of Geospatial-Temporal Data with Clutter Removal Based on Dynamic Delaunay Triangulations. In: Computer Vision, Imaging and Computer Graphics. Theory and Application, pp. 160–175. Springer (2013)
17. Jänicke, S., Heine, C., Stockmann, R., Scheuermann, G.: Comparative Visualization of Geospatial-temporal Data. In: Proceedings of the International Conference on Computer Graphics Theory and Applications and International Conference on Information Visualization Theory and Applications (VISIGRAPP 2012), pp. 613–625 (2012)
18. Jänicke, S., Scheuermann, G.: Utilizing GeoTemCo for Visualizing Environmental Data. In: O. Kolditz, K. Rink, G. Scheuermann (eds.) Workshop on Visualisation in Environmental Sciences (EnvirVis). The Eurographics Association (2014)
19. Kato, T., Kato, A., Okamura, N., Kanai, T., Suzuki, R., Shirai, Y.: Musasabi: 2D/3D Intuitive and Detailed Visualization System for the Forest. In: ACM SIGGRAPH 2015 Posters, SIGGRAPH '15, pp. 79:1–79:1. ACM, New York, NY, USA (2015)
20. Kim, D.H., Sexton, J.O., Noojipady, P., Huang, C., Anand, A., Channan, S., Feng, M., Townshend, J.R.: Global, landsat-based forest-cover change from 1990 to 2000. Remote Sensing of Environment **155**, 178–193 (2014)
21. Madden, M.: Vegetation modeling, analysis and visualization in US National Parks. International Archives of Photogrammetry and Remote Sensing **35**, 1287–1293 (2004)
22. Newton, A., Oldfield, S., Rivers, M., Mark, J., Schatz, G., Garavito, N.T., Cantarello, E., Golicher, D., Cayuela, L., Miles, L., et al.: Towards a global tree assessment. Oryx **49**(3), 410415 (2015)
23. Poorter, L., van der Sande, M.T., Thompson, J., Arets, E.J.M.M., Alarcón, A., Álvarez-Sánchez, J., Ascarrunz, N., Balvanera, P., Barajas-Guzmán, G., Boit, A., Bongers, F., Carvalho, F.A., Casanoves, F., Cornejo-Tenorio, G., Costa, F.R.C., de Castilho, C.V.,

Duivenvoorden, J.F., Dutrieux, L.P., Enquist, B.J., Fernández-Méndez, F., Finegan, B., Gormley, L.H.L., Healey, J.R., Hoosbeek, M.R., Ibarra-Manríquez, G., Junqueira, A.B., Levis, C., Licona, J.C., Lisboa, L.S., Magnusson, W.E., Martínez-Ramos, M., Martínez-Yrizar, A., Martorano, L.G., Maskell, L.C., Mazzei, L., Meave, J.A., Mora, F., Muñoz, R., Nytch, C., Pansonato, M.P., Parr, T.W., Paz, H., Pérez-García, E.A., Rentería, L.Y., Rodríguez-Velazquez, J., Rozendaal, D.M.A., Ruschel, A.R., Sakschewski, B., Salgado-Negret, B., Schietti, J., Simões, M., Sinclair, F.L., Souza, P.F., Souza, F.C., Stropp, J., ter Steege, H., Swenson, N.G., Thonicke, K., Toledo, M., Uriarte, M., van der Hout, P., Walker, P., Zamora, N., Peña Claros, M.: Diversity enhances carbon storage in tropical forests. Global Ecology and Biogeography **24**(11), 1314–1328 (2015)

24. Reckziegel, M., Cheema, M.F., Scheuermann, G., Jänicke, S.: Predominance tag maps. IEEE Transactions on Visualization and Computer Graphics **24**(6), 1893–1904 (2018)
25. Rivers, M.: The global tree assessment - red listing the world's trees. BGJournal **14**, 16–19 (2017)
26. Ruefenacht, B., Finco, M., Nelson, M., Czaplewski, R., Helmer, E., Blackard, J., Holden, G., Lister, A., Salajanu, D., Weyermann, D., Winterberger, K.: Conterminous U.S. and Alaska Forest Type Mapping Using Forest Inventory and Analysis Data. Photogrammetric Engineering & Remote Sensing **74**(11), 1379–1388 (2008)
27. Setturu, B., Ramachandra, T.: Visualization of Landscape Dynamics in National Parks of Central Western Ghats. In: Proceedings of 10th Biennial Lake Conference 2016, pp. 28–31 (2016)
28. Simons, L., He, S., Tittman, P., Amenta, N.: Point-based rendering of forest LiDAR. In: Workshop on Visualisation in Environmental Sciences (EnvirVis), The Eurographics Association, pp. 19–23 (2014)
29. Slocum, T.A., McMaster, R.B., Kessler, F.C., Howard, H.H.: Thematic Cartography and Geovisualization, 3rd, international edn. Prentice Hall Series in Geographic Information Science. Prentice Hall (2009)
30. Ware, C.: Information Visualization: Perception for Design, 3rd edn. Morgan Kaufmann (2004)