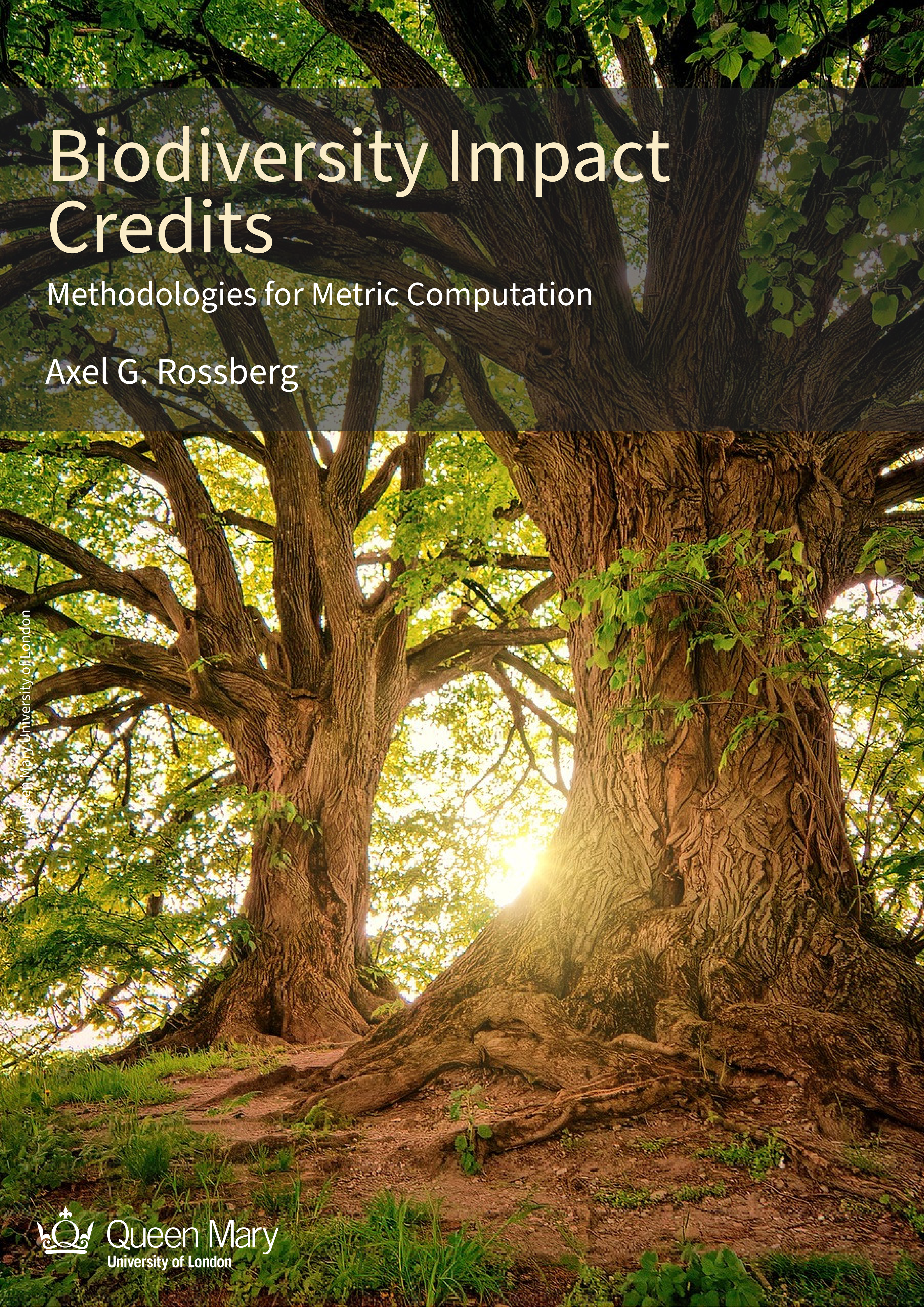
Biodiversity Impact Credits

Methodologies for Metric Computation

Axel G. Rossberg



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Methodologies for Metric Computation

by

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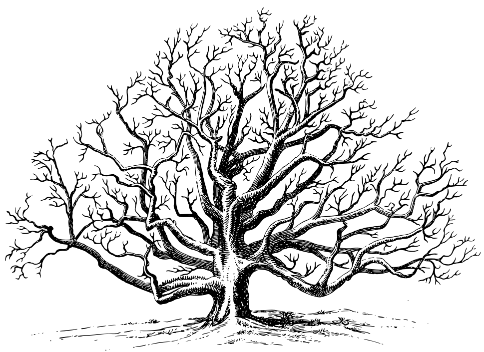

Executive Summary

Biodiversity Impact Credits (BICs) offer a solution for private sector organisations that must account for biodiversity risk, and provide an auditable mechanism linking conservation practitioners with investors seeking conservation outcomes. The metric permits organisations to set themselves achievable, theoretically well-founded science-based targets for global biodiversity conservation.

Similar to CO_2-emission equivalents in the climate context, BICs are not defined by a tool or methodology but through the logic of the underlying science. To compute their BICs, organisations can then choose from a variety of methodologies depending on the organisational and geographic scale considered, the relevant types of impact, affordability considerations, data availability, and the accuracy sought.

This report presents three examples of such methodologies applicable in the context of tree and forest conservation. The first operates at the level of individual tree species, the second is based on the area of natural mixed forest gained or lost in a project, and the last permits measuring the global biodiversity footprint of an organisation or portfolio as resulting from resource use and emissions through supply chains. The brevity of the report reflects the simplicity of the BIC concept and its use.

1
An introduction to Biodiversity Impact Credits

Biodiversity Impact Credits (BICs) quantify the positive and negative effects that interventions in the natural environment have on mean long-term global species extinction risk.[1] The metric thus supports the objective of the 2022 Global Biodiversity Framework[2] "to significantly reduce extinction risk".

The BICs for a single species are given by

$$\mathrm{BIC} = \frac{\Delta N}{N^* + N}, \tag{1.1}$$

where N is the current global population size of the species (i.e., after the intervention has occurred), ΔN is the change in the population of the species that resulted from the intervention, and N^* a regularisation constant capturing the fact that at small population sizes a species can go extinct if, by chance, reproductive success is low over a few generations.[i] Often N^* will be negligibly small compared to N, in which case above formula simplifies to

$$\mathrm{BIC} = \frac{\Delta N}{N}. \tag{1.2}$$

The BICs for a given group of species are given by the sum of the BICs of all species in that group. By the simple fact that population size N enters Eq. (1.2) in the denominator, changes (ΔN) in the populations of species that are close to extinction (have small N) make particularly large contributions to the BICs of a group. BICs therefore inherently focus on species that are close to extinction.

To consistently capture both positive and negative impacts, BICs should be computed for a broad, scientifically established group of species and be reported with reference to this group. Groups of larger-bodied species with longer generation times should be preferred over smaller organisms, since the former are better-studied, tend to be at higher risk and exhibit clearer species delineation. This report, for example, focuses on the computation of BICs for trees.

The additivity of BICs provides flexibility to adjust species groups to meet particular needs. If, for example BICs have been computed for the group of tree species, it might be possible to convert this, if required, into a value for all woody plants by adding estimates of BIC values for shrubs and lianas – since woody plants can be divided into trees, shrubs and lianas.

BICs are measured in units of "species". To see why, note that interventions that single-handedly rebuild the population of a single species to a multiple of its previous size, such that ΔN is just a bit smaller than N, lead to BIC values close to one. BICs can hence intuitively be understood as the number of species whose populations have been rebuilt—even though the deeper scientific rationale is more subtle.

Rather than by appealing to intuition or plausibility considerations, the BIC metric has been derived mathematically from a mathematical model of species extinction risk.[1] As a result, one can show that, when the sum of all BICs of an organisation is positive for a given group of species, this organisation contributes to a reduction of the mean long-term extinction risk of the species in that group—to the extent that the underlying

[i] Precisely, N^* is the population size at which environmental and demographic stochasticity are of equal strength for the given species.

model is valid. This provides BICs with a strong scientific basis and allows organisations to set themselves corresponding science-based targets. In the simplest case the target could be that the organisation's total BICs are positive, as this implies that the organisation contributes to a reduction of mean extinction risk.

In addition, positive BICs imply that the organisation has contributed to increasing the value of the Living Planet Index (LPI) for the group of species considered.[1] The LPI,[3] published bi-annually by the World Wildlife Fund, is the most cited indicator of global biodiversity status and often described as the 'Dow Jones Index of global biodiversity'.

Just as the Dow Jones Index does not explicitly represent interactions between corporations, the complexities of ecosystems and their interactions with society are intentionally not represented by BICs. This does not mean that these should be disregarded. An organisation aiming to meet its BIC target while at the same time benefiting from tangible and intangible ecosystem services or competing with Nature for land and resources is advised to give consideration to such complexities. The better these are understood, the more refined nature-based solutions can be developed that combine cost-efficiency, biodiversity conservation in terms of BICs, and sustainable use. The metric, however, leaves the handling of the uncertainties, risks and opportunities inherent to these dependencies to each organisation rather than prescribing or implying a particular approach.

Similar to the situation with the quantification of climate impact, commonly done in terms of CO_2-emission equivalents, there is a variety of methodologies to estimate BICs depending on the accuracy sought, the organisational and geographic scale considered, the type of impact considered, affordability considerations, and the available data. The metric, thus, is not directly defined by a specific methodology. This provides flexibility to combine, adapt and improve methodologies for particular purposes while at the same time generating metric values in a common, convertible currency with strong scientific support. As a result, however, the present report cannot be a complete guide to the methodology of BIC determination. Rather, it provides a few examples of simple, readily available methods to illustrate the range of conceivable approaches.

Since protection of tree biodiversity is a good example of using BICs, with many shovel-ready investment opportunities,[ii] this report focuses on methods to compute BICs for trees, including tree species close to extinction and afforestation projects. The example methodologies are easily modified or adapted to address other use cases.

Request for comments

Questions and feedback regarding this methodology are welcome at any time.
Please contact the author at: a.rossberg@qmul.ac.uk

[ii] https://www.treeconservationfund.org/

2

Methodology for trees close to extinction

For a tree species close to extinction (e.g. Figure 2.1), the BICs generated by an intervention affecting it can be computed directly from the definition, Eq. (1.1). The BICs corresponding to effects on other species from the efforts to rebuild the population of the endangered species will often be negligibly small, and can then be disregarded. If the global population of a species has predominantly changed as a result of the intervention in question, this formula can be re-written by expressing N as $N_0 + \Delta N$, where N_0 is the population size *before* the intervention occurred:

$$\mathrm{BIC} = \frac{\Delta N}{N^* + N_0 + \Delta N}. \tag{2.1}$$

When evaluating Eq. (2.1), it is important to consider how exactly to quantify population sizes. The method must be consistent across the quantities N, ΔN, N_0 and N^*. Ideally, population size is measured in terms of the total reproductive value of a population.[4,5] However, a direct computation of total reproductive value would require not only knowledge of the reproductive value of each life stage or size class of the tree species but also of the abundances of individuals in all life stages, including juvenile stages. While the former can be obtained from age or stage-structured matrix population models where these are available, the latter may require highly labour-intensive surveys.

The following simpler, approximate approach is therefore proposed. Define N as the number of mature individuals in a population, i.e., those individuals that have reached reproductive age or size (reproductive individuals tend to have similar reproductive values in matrix population models of trees,[6] independent of their age). Seeds, seedling and saplings produced by these mature individuals are not explicitly included but understood to be subsumed in this number. Accordingly, N_0 in Eq. (2.1) above is the number of mature individuals remaining in the wild before the intervention.

Saplings and young trees planted out into a natural forest after being raised *ex situ* are counted by multiplying their numbers with the probability that they reach maturity.[iii] Absent more specific information, this probability can be estimated for an individual i with diameter D_i (measured in cm at $1.3\,\mathrm{m}$ above ground) as

$$p_i = \frac{\exp\left(\lambda D_i^{\mu}\right)}{\exp\left(\lambda D_{\mathrm{mat}}^{\mu}\right)}, \tag{2.2}$$

where D_{mat} is the diameter of the smallest mature trees, $\lambda = 2.93$ and $\mu = 0.208$. This relation is obtained from analyses of demographics in tropical forest plots[7] and turns out to be remarkably robust across plots.[iv] In Eq. (2.1), the total change ΔN in the natural population that resulted from planting out saplings is then estimated as

$$\Delta N = \sum_i p_i, \tag{2.3}$$

summing over all saplings and young trees. For individuals that have reached maturity, $p_i = 1$.

[iii] For immature individuals, reproductive value is proportional to this probability.

[iv] The parameters recommended above are the medians across all plots and survey intervals studied in Ref. 7.

From calculations of demographic stochasticity from matrix population models[6] and of environmental stochasticity from long-term surveys,[8] one can estimate $N^* \approx$ one mature individual. The value of N^* is particularly small for trees because environmental variations can have a strong effect on offspring survival, thus dwarfing the effect of demographic stochasticity. The approximation $N^* = 1$ will often be fully sufficient when evaluating Eq. (2.1) after a population has been rebuilt.

Above considerations permit evaluation of Eq. (2.1) to compute the BICs generated by rebuilding the population of a tree species that is close to extinction. Since the contributions from young, planted trees are captured by their probability to survive to adulthood, high BICs can be achieved in a relatively short time (a few years), e.g. by planting large numbers of saplings in the wild.

Figure 2.1: *Hopea brachyptera*, Critically Endangered. One of the rarest Philippine Dipterocarps, only known from two localities on the Philippines' southern island of Mindanao. Photo: Botanic Gardens Conservation International

3

Methodology for large-scale afforestation and deforestation

For large-scale deforestation or afforestation of natural mixed forest, separate computation of BICs for all affected tree species can be impractical. To handle such cases, which can arise, e.g., in carbon sequestration projects, it is useful to make use of known relations between BICs and other metrics.[1]

Consider first the Biodiversity Stewardship Credit metric, which differs from BICs by replacing in Eq. (1.1) the change ΔN in the population size of a species by the species' local population size n in the area considered. That is, the BSCs for a single species are defined as

$$\text{BSC} = \frac{n}{N^* + N}. \tag{3.1}$$

The BSCs for a group of species are given by the sum of BSCs over all species in the group. This metric is not only useful to quantify contributions of land holders to the maintenance of biodiversity, in many practical cases one can also approximate the BICs resulting from an intervention by the resulting change in BSCs.[1] Dividing BSCs by the size of the area considered, one obtains the BSC density (in units of species/km^2).

A simple area-based method On large spatial scales, BSC density can in turn be approximated by Range-Size Rarity[9] (RSR), a metric defined as the sum of the inverse range sizes of all species (from the group considered) that are present at a given 'location'. A 'location' may be a geographic lattice square or some other more irregularly formed area. For consistency, the 'range size' of a species must be defined as the sum of the areas of the locations in which the species is present.

Over areas that are large compared to the typical range size of a species, average RSR can be approximated by species density, i.e., the number of species contained in the area divided by the size of the area. An implication is that on these large scales it does not matter much whether the ranges of some species are particularly small or not. It does not affect average RSR. Only for the detailed distribution of RSR over the large area this may play a role.

These considerations lead to the following simple formula for estimating the BICs resulting from afforestation or deforestation of natural mixed forest:

$$\text{BIC} = \text{RSR} \times (\text{change in size of forested area}), \tag{3.2}$$

where RSR denotes the typical Range-Size Rarity of trees in forested land in the region in question.

Appendix A provides a table listing recommended values of RSR in forested land by country in the column "Full". Figure 3.1 illustrates these values in a map. The ongoing assessment of all tree species by the International Union for Conservation of Nature (IUCN) will eventually allow determination of RSR at a higher resolution than country scale.

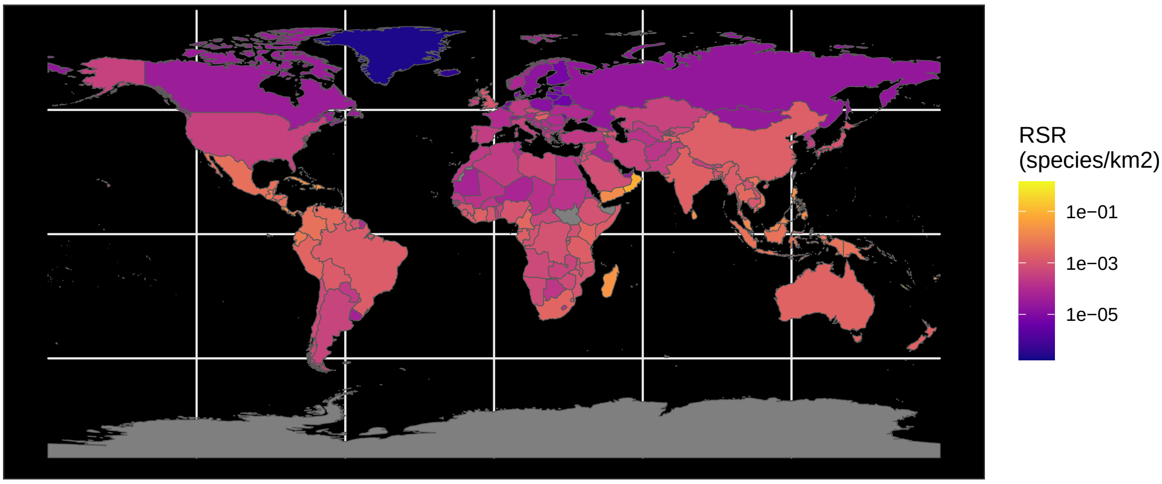

Figure 3.1: Map of mean tree Range-Size Rarity (RSR) by country. Note the logarithmic colour scale. The highest RSR values are found in small island states (Appendix A) and therefore difficult to see on the map.

Combining methods To improve the accuracy of the above method and to better bring out the inherent focus of BICs on species with small global population sizes, it can be advantageous to combine the method using RSR with that for species with low population sizes described in Chapter 2. For consistency, an abundance threshold should then be set from the outset to decide which species to cover by which method. Expertise should also be available to identify and count mature individuals of rare tree species in the affected forest areas.

The table in Appendix A contains in the last two columns modified RSR values where all tree species with less than 50 or less than 250 mature individuals were excluded from the calculation of RSR, based on the IUCN Red List.[10] When, for example, the threshold is set to 50 individuals, total BICs can be estimated using these values as:

$$\begin{aligned}\text{BIC} = &(\text{sum of BICs by Eq. (2.1) for species with } N_0 < 50)\\ &+ \text{RSR}_{\geq 50} \times (\text{change in size of forested area}).\end{aligned} \tag{3.3}$$

This slightly more accurate formula captures the incentive inherent to BICs to enhance the populations of threatened species in afforestation projects.

4

Methodology for organisational footprints

To quantify the overall impact that the operation of an organisation (or a portfolio) has on biodiversity in terms of BICs, the Ecosystem Damage footprint computed using the open-source ReCiPe 2016 methodology[11] or similar approaches can be used.[1] For an accessible illustration of the underlying rationale, see Ref. 12. A simple tool implementing the methodology is available online.[v]

Footprints computed using ReCiPe 2016 have units of species × year. When inputting yearly totals of resource used and/or emissions generated into the algorithms (e.g., emissions per year), then the unit ‘year’ cancels out and the footprint gives a value in units of ‘species’. This value can be used as an estimate of the negative BICs of the footprint of the organisation’s activities. It corresponds to the increase in extinction risk that would result if the organisation would continue operating at the same rate over many years.[1] Thus,

$$\text{BIC} = -(\text{Ecosystem Damage footprint})/\text{year}. \tag{4.1}$$

The range of taxa considered by ReCiPe 2016 is very broad, including insects, plants, arachnids and vertebrates amongst others and covering 1.85×10^6 known species.[13] By comparison, there are only around $58,000$ known tree species. BICs of trees are therefore only one of several components contributing to BIC values obtained using ReCiPe 2016 and so to a reduction in the mean extinction risk for this wider group. Nevertheless, the values are comparable, especially for interventions that primarily increase BICs for trees, as these will nearly inevitably also lead to an increase in BICs over the wider group covered by ReCiPe 2016.

Since trees provide habitat for other species (e.g., insects, birds), some of which are highly specialised to particular host trees, increasing BICs for trees by a given amount is likely to increase BICs for the wider group by a multiple of this. Compensation of biodiversity footprints determined using ReCiPe 2016 with BICs generated by growing trees therefore intrinsically carries a multiplier, similar to multipliers applied in offsetting schemes to guard against empirical and methodological uncertainties.[14] In light of these considerations, biodiversity footprints based on ReCiPe 2016 provide a good yardstick for the amount of BICs an organisation should generate, e.g., by growing trees—alone or in partnership with service providers—to assure it contributes to reducing global species extinction risk.

[v] https://www.bioscope.info/

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A

Table of Range-Size Rarity density estimates

This Appendix provides in Table A.1 mean Range-Size Rarity (RSR) of trees in forested area by country. The column "Full" includes all species in the determination of RSR, the subsequent columns only those species represented by 50 or more mature individuals or 250 or more mature individuals.

The values in Table A.1 were obtained by computing the forested area of each country from the latest values of the country's land area and percentage forest cover published by the World Bank[vi], computing the range of each tree species as the sum of the forested areas of the countries in which it is present, and then calculating tree RSR in the forested area of each country by adding the inverse range sizes of the tree species present in the country. Lists of the countries in which each species is present were obtained from GlobalTreeSearch[15] database[vii] of Botanic Gardens Conservation International (BGCI).

Table A.1: Estimates of mean tree Range-Size Rarity in forested area by country

Country Name	Country Code	Forest Area (km^2)	Forest Proportion (%)	BSC density estimated as RSR (species/km^2) Full	≥50 mature ind.	≥250 mature ind.
Afghanistan	AFG	1.2084E+04	1.8528E+00	1.7658E-04	1.7658E-04	1.7658E-04
Albania	ALB	7.8890E+03	2.8792E+01	1.4895E-04	1.4895E-04	1.4895E-04
Algeria	DZA	1.9490E+04	8.1831E-01	2.5299E-04	2.5299E-04	2.5299E-04
American Samoa	ASM	1.7130E+02	8.5650E+01	3.1983E-02	3.1983E-02	3.1983E-02
Andorra	AND	1.6000E+02	3.4043E+01	9.7182E-06	9.7182E-06	9.7182E-06
Angola	AGO	6.6607E+05	5.3427E+01	5.3587E-04	5.3587E-04	5.3535E-04
Antigua and Barbuda	ATG	8.1200E+01	1.8455E+01	5.9135E-03	5.9135E-03	5.9135E-03
Argentina	ARG	2.8573E+05	1.0441E+01	4.0102E-04	4.0102E-04	4.0102E-04
Armenia	ARM	3.2847E+03	1.1537E+01	4.0565E-03	3.7521E-03	3.7521E-03
Aruba	ABW	4.2000E+00	2.3333E+00	1.3396E-04	1.3396E-04	1.3396E-04
Australia	AUS	1.3401E+06	1.7421E+01	2.2296E-03	2.2244E-03	2.2191E-03
Austria	AUT	3.8992E+04	4.7251E+01	8.9146E-05	7.3940E-05	5.6773E-05
Azerbaijan	AZE	1.1318E+04	1.3694E+01	9.2064E-04	9.2064E-04	9.2064E-04
Bahamas, The	BHS	5.0986E+03	5.0935E+01	3.2431E-03	3.2431E-03	3.2431E-03
Bahrain	BHR	7.0000E+00	8.9172E-01	1.2243E-05	1.2243E-05	1.2243E-05
Bangladesh	BGD	1.8834E+04	1.4469E+01	9.3781E-04	9.3781E-04	9.3781E-04
Barbados	BRB	6.3000E+01	1.4651E+01	1.4030E-02	1.4030E-02	1.4030E-02
Belarus	BLR	8.7676E+04	4.3194E+01	5.3158E-06	5.3158E-06	5.3158E-06
Belgium	BEL	6.8930E+03	2.2764E+01	1.0356E-05	1.0356E-05	1.0356E-05
Belize	BLZ	1.2771E+04	5.5986E+01	2.1720E-03	2.1720E-03	2.1720E-03
Benin	BEN	3.1352E+04	2.7804E+01	3.7180E-04	3.7180E-04	3.7180E-04

Continued on next page

[vi] https://data.worldbank.org

[vii] https://www.bgci.org/resources/bgci-databases/globaltreesearch/

Table A.1: Estimates of mean tree Range-Size Rarity in forested area by country

Country Name	Country Code	Forest Area (km^2)	Forest Proportion (%)	BSC density estimated as RSR (species/km^2) Full	≥50 mature ind.	≥250 mature ind.
Bermuda	BMU	1.0000E+01	1.8519E+01	3.0000E-01	3.0000E-01	3.0000E-01
Bhutan	BTN	2.7251E+04	7.1449E+01	4.8491E-04	4.8491E-04	4.8491E-04
Bolivia	BOL	5.0834E+05	4.6925E+01	1.4630E-03	1.4630E-03	1.4630E-03
Bosnia and Herzegovina	BIH	2.1879E+04	4.2733E+01	1.3954E-04	1.3954E-04	1.3954E-04
Botswana	BWA	1.5255E+05	2.6917E+01	1.9306E-04	1.9306E-04	1.9306E-04
Brazil	BRA	4.9662E+06	5.9417E+01	1.5743E-03	1.5717E-03	1.5701E-03
British Virgin Islands	VGB	3.6200E+01	2.4133E+01	4.5492E-02	4.5492E-02	4.5492E-02
Brunei Darussalam	BRN	3.8000E+03	7.2106E+01	5.8931E-03	5.8871E-03	5.8871E-03
Bulgaria	BGR	3.8930E+04	3.5860E+01	1.2634E-04	1.2634E-04	1.2634E-04
Burkina Faso	BFA	6.2164E+04	2.2721E+01	1.8676E-04	1.8676E-04	1.8676E-04
Burundi	BDI	2.7964E+03	1.0889E+01	1.0751E-03	1.0751E-03	1.0751E-03
Cabo Verde	CPV	4.5720E+02	1.1345E+01	4.3818E-03	4.3818E-03	4.3818E-03
Cambodia	KHM	8.0684E+04	4.5708E+01	1.1973E-03	1.1725E-03	1.1725E-03
Cameroon	CMR	2.0340E+05	4.3030E+01	2.7381E-03	2.6808E-03	2.6336E-03
Canada	CAN	3.4693E+06	3.8696E+01	3.3483E-05	3.3331E-05	3.3331E-05
Cayman Islands	CYM	1.2720E+02	5.3000E+01	2.4998E-02	1.7136E-02	1.7136E-02
Central African Republic	CAF	2.2303E+05	3.5801E+01	4.5701E-04	4.5701E-04	4.5701E-04
Chad	TCD	4.3130E+04	3.4252E+00	1.4206E-04	1.4206E-04	1.4206E-04
Chile	CHL	1.8211E+05	2.4492E+01	5.1976E-04	5.1427E-04	5.1427E-04
China	CHN	2.1998E+06	2.3341E+01	1.7610E-03	1.7492E-03	1.7452E-03
Colombia	COL	5.9142E+05	5.3305E+01	4.5798E-03	4.5713E-03	4.5713E-03
Comoros	COM	3.2920E+02	1.7689E+01	9.3143E-02	9.0105E-02	9.0105E-02
Congo, Dem. Rep.	COD	1.2616E+06	5.5647E+01	8.7653E-04	8.7653E-04	8.7601E-04
Congo, Rep.	COG	2.1946E+05	6.4264E+01	8.2801E-04	8.2801E-04	8.2801E-04
Costa Rica	CRI	3.0349E+04	5.9437E+01	1.7745E-02	1.7712E-02	1.7679E-02
Cote d'Ivoire	CIV	2.8367E+04	8.9205E+00	2.0297E-03	2.0172E-03	2.0172E-03
Croatia	HRV	1.9391E+04	3.4652E+01	1.4981E-04	1.4981E-04	1.4981E-04
Cuba	CUB	3.2420E+04	3.1233E+01	2.4660E-02	2.4629E-02	2.4568E-02
Curacao	CUW	7.0000E-01	1.5766E-01	1.4288E+00	1.4288E+00	1.4288E+00
Cyprus	CYP	1.7253E+03	1.8672E+01	7.9199E-04	7.9199E-04	7.9199E-04
Czechia	CZE	2.6771E+04	3.4678E+01	5.1417E-04	3.4954E-04	2.0013E-04
Denmark	DNK	6.2844E+03	1.5711E+01	9.2410E-06	9.2410E-06	9.2410E-06
Djibouti	DJI	5.8000E+01	2.5022E-01	1.7370E-02	1.7370E-02	1.7370E-02
Dominica	DMA	4.7870E+02	6.3827E+01	6.3219E-02	6.3219E-02	6.3219E-02
Dominican Republic	DOM	2.1441E+04	4.4382E+01	2.2803E-02	2.2676E-02	2.2636E-02
Ecuador	ECU	1.2498E+05	5.0321E+01	6.4706E-03	6.4306E-03	6.4146E-03
Egypt, Arab Rep.	EGY	4.4980E+02	4.5186E-02	1.6318E-04	1.6318E-04	1.6318E-04
El Salvador	SLV	5.8388E+03	2.8180E+01	2.8795E-03	2.8795E-03	2.8795E-03
Equatorial Guinea	GNQ	2.4484E+04	8.7288E+01	1.2410E-03	1.2410E-03	1.2410E-03
Eritrea	ERI	1.0553E+04	8.7182E+00	1.7332E-04	1.7332E-04	1.7332E-04
Estonia	EST	2.4384E+04	5.7039E+01	6.4027E-06	6.4027E-06	6.4027E-06
Eswatini	SWZ	4.9756E+03	2.8928E+01	8.9819E-04	8.9249E-04	8.9249E-04
Ethiopia	ETH	1.7069E+05	1.5124E+01	8.7731E-04	8.5974E-04	8.5388E-04
Faroe Islands	FRO	8.0000E-01	5.8565E-02	2.0329E-07	2.0329E-07	2.0329E-07
Fiji	FJI	1.1400E+04	6.2398E+01	5.4330E-02	5.2839E-02	5.1962E-02
Finland	FIN	2.2409E+05	7.3728E+01	6.7511E-06	6.7511E-06	6.7511E-06
France	FRA	1.7253E+05	3.1509E+01	1.0406E-04	1.0406E-04	9.8267E-05
French Polynesia	PYF	1.4946E+03	4.3060E+01	1.5420E-01	1.5019E-01	1.4952E-01
Gabon	GAB	2.3531E+05	9.1321E+01	1.8669E-03	1.8669E-03	1.8584E-03
Gambia, The	GMB	2.4267E+03	2.3979E+01	9.1928E-05	9.1928E-05	9.1928E-05
Georgia	GEO	2.8224E+04	4.0616E+01	3.0669E-04	3.0669E-04	3.0669E-04
Germany	DEU	1.1419E+05	3.2683E+01	2.3500E-04	1.2115E-04	5.9849E-05
Ghana	GHA	7.9857E+04	3.5097E+01	1.0621E-03	1.0529E-03	1.0529E-03

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Table A.1: Estimates of mean tree Range-Size Rarity in forested area by country

Country Name	Country Code	Forest Area (km^2)	Forest Proportion (%)	BSC density estimated as RSR (species/km^2) Full	≥50 mature ind.	≥250 mature ind.
Gibraltar	GIB	NA	NA	NA	NA	NA
Greece	GRC	3.9018E+04	3.0270E+01	3.0197E-04	3.0197E-04	3.0197E-04
Greenland	GRL	2.2000E+00	5.3600E-04	2.3249E-07	2.3249E-07	2.3249E-07
Grenada	GRD	1.7700E+02	5.2059E+01	2.4538E-02	2.4538E-02	2.4538E-02
Guam	GUM	2.8000E+02	5.1852E+01	4.1702E-02	4.1702E-02	4.1702E-02
Guatemala	GTM	3.5278E+04	3.2921E+01	5.7563E-03	5.6953E-03	5.6655E-03
Guinea	GIN	6.1890E+04	2.5187E+01	9.6714E-04	9.6714E-04	9.6421E-04
Guinea-Bissau	GNB	1.9800E+04	7.0413E+01	2.0706E-04	2.0706E-04	2.0706E-04
Guyana	GUY	1.8415E+05	9.3550E+01	1.7353E-03	1.7351E-03	1.7351E-03
Haiti	HTI	3.4730E+03	1.2602E+01	6.2365E-02	6.0845E-02	6.0229E-02
Honduras	HND	6.3593E+04	5.6835E+01	3.2101E-03	3.1786E-03	3.1786E-03
Hungary	HUN	2.0530E+04	2.2496E+01	1.9469E-03	1.4111E-03	1.2649E-03
Iceland	ISL	5.1350E+02	5.0927E-01	4.0718E-07	4.0718E-07	4.0718E-07
India	IND	7.2160E+05	2.4270E+01	1.9644E-03	1.9394E-03	1.9284E-03
Indonesia	IDN	9.2133E+05	4.9072E+01	4.7971E-03	4.7890E-03	4.7881E-03
Iran, Islamic Rep.	IRN	1.0752E+05	6.6267E+00	3.6520E-04	3.3730E-04	3.3730E-04
Iraq	IRQ	8.2500E+03	1.9004E+00	5.8876E-05	5.8876E-05	5.8876E-05
Ireland	IRL	7.8202E+03	1.1352E+01	3.1381E-04	1.8593E-04	1.8593E-04
Isle of Man	IMN	3.4600E+01	6.0702E+00	1.7160E-07	1.7160E-07	1.7160E-07
Israel	ISR	1.4000E+03	6.4695E+00	2.3449E-03	2.3449E-03	2.3449E-03
Italy	ITA	9.5661E+04	3.2349E+01	3.3231E-04	3.0095E-04	3.0095E-04
Jamaica	JAM	5.9689E+03	5.5114E+01	5.8280E-02	5.6939E-02	5.6939E-02
Japan	JPN	2.4935E+05	6.8409E+01	9.6622E-04	9.5419E-04	9.5419E-04
Jordan	JOR	9.7500E+02	1.0980E+00	6.3933E-04	6.3933E-04	6.3933E-04
Kazakhstan	KAZ	3.4547E+04	1.2797E+00	3.6083E-04	3.3189E-04	3.3189E-04
Kenya	KEN	3.6111E+04	6.3448E+00	2.4360E-03	2.3489E-03	2.2935E-03
Kiribati	KIR	1.1800E+01	1.4568E+00	4.4513E-05	4.4513E-05	4.4513E-05
Korea, Dem. People's Rep.	PRK	6.0301E+04	5.0080E+01	9.1185E-05	9.1185E-05	9.1185E-05
Korea, Rep.	KOR	6.2870E+04	6.4416E+01	2.7697E-04	2.7697E-04	2.7697E-04
Kuwait	KWT	6.2500E+01	3.5073E-01	1.1247E-04	1.1247E-04	1.1247E-04
Kyrgyz Republic	KGZ	1.3154E+04	6.8581E+00	5.3422E-04	5.3422E-04	5.3422E-04
Lao PDR	LAO	1.6596E+05	7.1904E+01	9.2459E-04	9.2184E-04	9.2184E-04
Latvia	LVA	3.4108E+04	5.4809E+01	6.0716E-06	6.0716E-06	6.0716E-06
Lebanon	LBN	1.4333E+03	1.4011E+01	1.0523E-03	1.0523E-03	1.0523E-03
Lesotho	LSO	3.4520E+02	1.1370E+00	1.6748E-04	1.6748E-04	1.6748E-04
Liberia	LBR	7.6174E+04	7.9085E+01	1.4170E-03	1.4006E-03	1.3977E-03
Libya	LBY	2.1700E+03	1.2333E-01	5.1259E-04	5.1259E-04	5.1259E-04
Liechtenstein	LIE	6.7000E+01	4.1875E+01	1.0002E-05	1.0002E-05	1.0002E-05
Lithuania	LTU	2.2010E+04	3.5149E+01	4.0007E-06	4.0007E-06	4.0007E-06
Luxembourg	LUX	8.8700E+02	3.4454E+01	7.2583E-06	7.2583E-06	7.2583E-06
Madagascar	MDG	1.2430E+05	2.1364E+01	2.4539E-02	2.4274E-02	2.4153E-02
Malawi	MWI	2.2417E+04	2.3777E+01	7.5626E-04	7.1165E-04	7.1165E-04
Malaysia	MYS	1.9114E+05	5.8177E+01	1.2120E-02	1.2060E-02	1.2043E-02
Maldives	MDV	8.2000E+00	2.7333E+00	9.4854E-06	9.4854E-06	9.4854E-06
Mali	MLI	1.3296E+05	1.0897E+01	1.6487E-04	1.5735E-04	1.5735E-04
Malta	MLT	4.6000E+00	1.4375E+00	2.2273E-05	2.2273E-05	2.2273E-05
Marshall Islands	MHL	9.4000E+01	5.2222E+01	5.7508E-06	5.7508E-06	5.7508E-06
Mauritania	MRT	3.1280E+03	3.0348E-01	5.9926E-05	5.9926E-05	5.9926E-05
Mauritius	MUS	3.8770E+02	1.9099E+01	5.8044E-01	4.7985E-01	4.7469E-01
Mexico	MEX	6.5692E+05	3.3793E+01	4.2096E-03	4.1824E-03	4.1612E-03
Micronesia, Fed. Sts.	FSM	6.4420E+02	9.2029E+01	9.7800E-02	9.7800E-02	9.7800E-02
Moldova	MDA	3.8650E+03	1.1753E+01	8.5526E-06	8.5526E-06	8.5526E-06
Monaco	MCO	NA	NA	NA	NA	NA
Mongolia	MNG	1.4173E+05	9.0997E+00	2.4387E-05	2.4387E-05	2.4387E-05

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Table A.1: Estimates of mean tree Range-Size Rarity in forested area by country

Country Name	Country Code	Forest Area (km^2)	Forest Proportion (%)	BSC density estimated as RSR (species/km^2) Full	≥50 mature ind.	≥250 mature ind.
Montenegro	MNE	8.2700E+03	6.1487E+01	8.2293E-05	8.2293E-05	8.2293E-05
Morocco	MAR	5.7425E+04	1.2867E+01	2.1837E-04	2.1837E-04	2.1837E-04
Mozambique	MOZ	3.6744E+05	4.6725E+01	9.7952E-04	9.7952E-04	9.7952E-04
Myanmar	MMR	2.8544E+05	4.3734E+01	1.6089E-03	1.5984E-03	1.5984E-03
Namibia	NAM	6.6389E+04	8.0639E+00	5.6424E-04	5.6424E-04	5.4918E-04
Nauru	NRU	NA	NA	NA	NA	NA
Nepal	NPL	5.9620E+04	4.1591E+01	3.2159E-04	3.2159E-04	3.2159E-04
Netherlands	NLD	3.6950E+03	1.0974E+01	6.9392E-06	6.9392E-06	6.9392E-06
New Caledonia	NCL	8.3802E+03	4.5844E+01	1.5324E-01	1.5133E-01	1.5097E-01
New Zealand	NZL	9.8926E+04	3.7570E+01	2.2075E-03	2.1873E-03	2.1570E-03
Nicaragua	NIC	3.4075E+04	2.8316E+01	3.9446E-03	3.9446E-03	3.9446E-03
Niger	NER	1.0797E+04	8.5237E-01	6.7806E-05	6.7806E-05	6.7806E-05
Nigeria	NGA	2.1627E+05	2.3746E+01	1.0118E-03	1.0072E-03	1.0072E-03
Northern Mariana Islands	MNP	2.4360E+02	5.2957E+01	5.0533E-02	5.0533E-02	5.0533E-02
North Macedonia	MKD	1.0015E+04	3.9710E+01	1.1098E-04	1.1098E-04	1.1098E-04
Norway	NOR	1.2180E+05	3.3435E+01	7.3941E-05	7.3941E-05	4.1100E-05
Oman	OMN	2.5000E+01	8.0775E-03	8.1684E-02	8.1684E-02	8.1684E-02
Pakistan	PAK	3.7259E+04	4.8333E+00	3.0881E-04	3.0881E-04	3.0881E-04
Palau	PLW	4.1410E+02	9.0022E+01	1.3165E-01	1.3165E-01	1.3165E-01
Panama	PAN	4.2138E+04	5.6806E+01	1.3657E-02	1.3609E-02	1.3609E-02
Papua New Guinea	PNG	3.5856E+05	7.9176E+01	4.8160E-03	4.8105E-03	4.8105E-03
Paraguay	PRY	1.6102E+05	4.0529E+01	2.2935E-04	2.2935E-04	2.2935E-04
Peru	PER	7.2330E+05	5.6508E+01	2.4750E-03	2.4709E-03	2.4695E-03
Philippines	PHL	7.1886E+04	2.4109E+01	1.7902E-02	1.7846E-02	1.7846E-02
Poland	POL	9.4830E+04	3.0977E+01	1.3700E-05	1.3700E-05	1.3700E-05
Portugal	PRT	3.3120E+04	3.6155E+01	6.4402E-04	6.1383E-04	5.8364E-04
Puerto Rico	PRI	4.9633E+03	5.5956E+01	3.5848E-02	3.2834E-02	3.2431E-02
Qatar	QAT	NA	NA	NA	NA	NA
Romania	ROU	6.9291E+04	3.0116E+01	1.0911E-04	1.0911E-04	1.0911E-04
Russian Federation	RUS	8.1531E+06	4.9784E+01	2.2387E-05	2.2387E-05	2.2387E-05
Rwanda	RWA	2.7600E+03	1.1188E+01	1.1099E-03	1.1099E-03	1.1099E-03
Samoa	WSM	1.6167E+03	5.8155E+01	5.9206E-02	5.8588E-02	5.8588E-02
San Marino	SMR	1.0000E+01	1.6667E+01	2.9871E-07	2.9871E-07	2.9871E-07
Sao Tome and Principe	STP	5.1900E+02	5.4063E+01	7.5302E-02	7.3375E-02	7.3375E-02
Saudi Arabia	SAU	9.7700E+03	4.5448E-01	6.8779E-04	6.8779E-04	6.8779E-04
Senegal	SEN	8.0682E+04	4.1906E+01	2.2173E-04	2.2173E-04	2.0934E-04
Serbia	SRB	2.7227E+04	3.1130E+01	1.2749E-04	1.2749E-04	1.2749E-04
Seychelles	SYC	3.3700E+02	7.3261E+01	1.3220E-01	1.1736E-01	1.1440E-01
Sierra Leone	SLE	2.5349E+04	3.5119E+01	1.0028E-03	1.0028E-03	1.0028E-03
Singapore	SGP	1.5570E+02	2.1685E+01	7.2472E-03	7.2461E-03	7.2461E-03
Sint Maarten (Dutch part)	SXM	3.7000E+00	1.0882E+01	1.5455E-04	1.5455E-04	1.5455E-04
Slovak Republic	SVK	1.9259E+04	4.0056E+01	8.2803E-04	6.7226E-04	3.4355E-04
Slovenia	SVN	1.2378E+04	6.1472E+01	7.0303E-05	7.0303E-05	7.0303E-05
Solomon Islands	SLB	2.5230E+04	9.0138E+01	9.2174E-03	9.2174E-03	9.2174E-03
Somalia	SOM	5.9800E+04	9.5323E+00	1.5521E-03	1.5521E-03	1.5186E-03
South Africa	ZAF	1.7050E+05	1.4055E+01	2.5276E-03	2.5102E-03	2.4985E-03
South Sudan	SSD	7.1570E+04	1.1326E+01	2.8245E-04	2.8245E-04	2.8245E-04
Spain	ESP	1.8572E+05	3.7177E+01	2.8145E-04	2.7606E-04	2.6529E-04
Sri Lanka	LKA	2.1130E+04	3.4158E+01	1.8414E-02	1.7846E-02	1.7752E-02
St. Kitts and Nevis	KNA	1.1000E+02	4.2308E+01	2.2267E-02	2.2267E-02	2.2267E-02
St. Lucia	LCA	2.0770E+02	3.4049E+01	8.5108E-02	8.5108E-02	8.5108E-02
St. Martin (French part)	MAF	1.2400E+01	2.4800E+01	9.7604E-04	9.7604E-04	9.7604E-04

Continued on next page

Table A.1: Estimates of mean tree Range-Size Rarity in forested area by country

Country Name	Country Code	Forest Area (km^2)	Forest Proportion (%)	BSC density estimated as RSR ($species/km^2$) Full	≥50 mature ind.	≥250 mature ind.
St. Vincent and the Grenadines	VCT	2.8540E+02	7.3179E+01	2.5061E-02	2.5061E-02	2.5061E-02
Sudan	SDN	1.8360E+05	9.8285E+00	1.6072E-04	1.6072E-04	1.6072E-04
Suriname	SUR	1.5196E+05	9.7412E+01	9.7688E-04	9.7688E-04	9.7688E-04
Sweden	SWE	2.7980E+05	6.8699E+01	1.8329E-05	1.4755E-05	1.4755E-05
Switzerland	CHE	1.2691E+04	3.2116E+01	3.1469E-05	3.1469E-05	3.1469E-05
Syrian Arab Republic	SYR	5.2208E+03	2.8431E+00	5.2605E-04	5.2605E-04	5.2605E-04
Tajikistan	TJK	4.2380E+03	3.0535E+00	2.0487E-03	2.0487E-03	2.0487E-03
Tanzania	TZA	4.5745E+05	5.1643E+01	1.7256E-03	1.7085E-03	1.7085E-03
Thailand	THA	1.9873E+05	3.8899E+01	3.0221E-03	3.0043E-03	3.0043E-03
Timor-Leste	TLS	9.2110E+03	6.1944E+01	6.6725E-04	6.6725E-04	6.6725E-04
Togo	TGO	1.2093E+04	2.2233E+01	3.2868E-04	3.2868E-04	3.2868E-04
Tonga	TON	8.9500E+01	1.2431E+01	1.4218E-01	1.3101E-01	1.3092E-01
Trinidad and Tobago	TTO	2.2819E+03	4.4481E+01	1.4740E-02	1.4740E-02	1.4740E-02
Tunisia	TUN	7.0273E+03	4.5232E+00	1.1540E-04	1.1540E-04	1.1540E-04
Turkiye	TUR	2.2220E+05	2.8871E+01	2.2604E-04	2.2604E-04	2.2604E-04
Turkmenistan	TKM	4.1270E+04	8.7822E+00	1.5824E-04	1.5824E-04	1.5824E-04
Turks and Caicos Islands	TCA	1.0520E+02	1.1074E+01	1.2047E-03	1.2047E-03	1.2047E-03
Tuvalu	TUV	1.0000E+01	3.3333E+01	4.2135E-05	4.2135E-05	4.2135E-05
Uganda	UGA	2.3379E+04	1.1659E+01	7.7893E-04	7.7893E-04	7.7893E-04
Ukraine	UKR	9.6900E+04	1.6724E+01	1.0196E-04	9.1641E-05	8.1321E-05
United Arab Emirates	ARE	3.1730E+03	4.4678E+00	2.5298E-05	2.5298E-05	2.5298E-05
United Kingdom	GBR	3.1900E+04	1.3186E+01	1.0967E-03	5.9510E-04	2.1892E-04
United States	USA	3.0980E+06	3.3867E+01	3.3720E-04	3.2317E-04	3.2091E-04
Uruguay	URY	2.0310E+04	1.1604E+01	5.1370E-05	5.1370E-05	5.1370E-05
Uzbekistan	UZB	3.6897E+04	8.3732E+00	2.4296E-04	2.4296E-04	2.4296E-04
Vanuatu	VUT	4.4230E+03	3.6284E+01	2.4874E-02	2.4196E-02	2.3970E-02
Venezuela, RB	VEN	4.6231E+05	5.2413E+01	3.3803E-03	3.3736E-03	3.3736E-03
Vietnam	VNM	1.4643E+05	4.6719E+01	4.7120E-03	4.5746E-03	4.5661E-03
Virgin Islands (U.S.)	VIR	1.9910E+02	5.6886E+01	2.0061E-02	1.9867E-02	1.9867E-02
West Bank and Gaza	PSE	1.0140E+02	1.6844E+00	6.3807E-04	6.3807E-04	6.3807E-04
Yemen, Rep.	YEM	5.4900E+03	1.0398E+00	1.6439E-02	1.6439E-02	1.6439E-02
Zambia	ZMB	4.4814E+05	6.0283E+01	3.8909E-04	3.8909E-04	3.8909E-04
Zimbabwe	ZWE	1.7445E+05	4.5094E+01	5.5525E-04	5.5525E-04	5.5525E-04