11. Land stress: Potential species loss from land use (global; PSSRg)

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11.1. Areas of protection and environmental mechanisms covered

The method is based on the UNEP-SETAC guideline on global land use impact assessment on biodiversity in LCA (Koellner et al. 2013a) concerning the area of protection of ecosystem quality. The approach proposed by Chaudhary et al. 2015 using countryside species-area relationship (SAR) is used for calculating ecoregion specific marginal and average characterization factors (CFs) for biodiversity loss for both land occupation and transformation.

Description of impact pathway

Land use is a main driver of global biodiversity loss (MAS 2005). Within a product's life cycle, the land use impacts can represent a significant portion of their total environmental burden, e.g. for forestry and agriculture based products. Two types of land use interventions are usually considered in life cycle inventories and impact assessments; land transformation (also called land use change) and land occupation (Milà i Canals 2007). During transformation, the land is modified to make it suitable for an intended use, such as deforesting to make space for agriculture. During land occupation, land is used in the intended productive way (e.g. agriculture) and the land cannot develop towards a "natural reference state" (i.e. the regrowth of forest is avoided). The land use impacts result from both land transformation (because the ecosystems characteristics are changed) and land occupation (because ecosystem quality is kept at a different level than its natural state). As biodiversity shows a strong spatial heterogeneity and responds differently to land transformation and occupation in different parts of the world, a regionalized assessment is required (Koellner et al., 2013a).

Modeling the ecosystem quality damage due to land use impact on biodiversity is done in four steps (see Figure 11.1). In the first step *relative* changes in species richness is calculated by comparing the *local* species richness of different land use types with the (semi-)natural regional reference situation (de Baan 2013b, Koellner 2013a). A global literature review was carried out to select studies that report such comparisons. Data from existing databases such as GLOBIO (Alkamade et al. 2010), or the Swiss biodiversity monitoring (BDM 2004) were also imported. Differences across land use types, biogeographic regions (i.e. biomes) and species groups were statistically analyzed. Based on these data, damage scores (so called *local* characterization factors) for six land use types and five taxa in different biomes were calculated.

In the second step, above local CFs are fed into the 'Countryside species area relationship model' to calculate species extinctions due to land use. The model predicts the *absolute* loss of species for each of the five taxa and provides the *regional* characterization factors (CFs) in the unit 'regional species lost per unit of land occupied or transformed' in 804 terrestrial ecoregions.

However, the CFs calculated using SAR treat all species equally, whether the species present in an ecoregion are critically threatened or widely distributed. In the third step, these CFs are weighted with vulnerability scores (Verones et al. 2013) of each species present in a particular region to derive *weighted CFs* in the unit 'global species eq. lost per unit of land occupied or transformed' in 804 terrestrial ecoregions. The CFs calculated in step-2 using SAR and without vulnerability scores are referred to as *unweighted* CFs.

Finally, in step-4, the modelled species lost for each taxon are aggregated using Eq. 1.3 (chapter 1), to derive the ecosystem quality loss in the final endpoint unit- global fraction of potentially disappeared species (PDF). The impact pathway is described in figure 11.1 and equations 11.1 – 11.12. The detailed methodology is explained in Chaudhary et al. 2015.

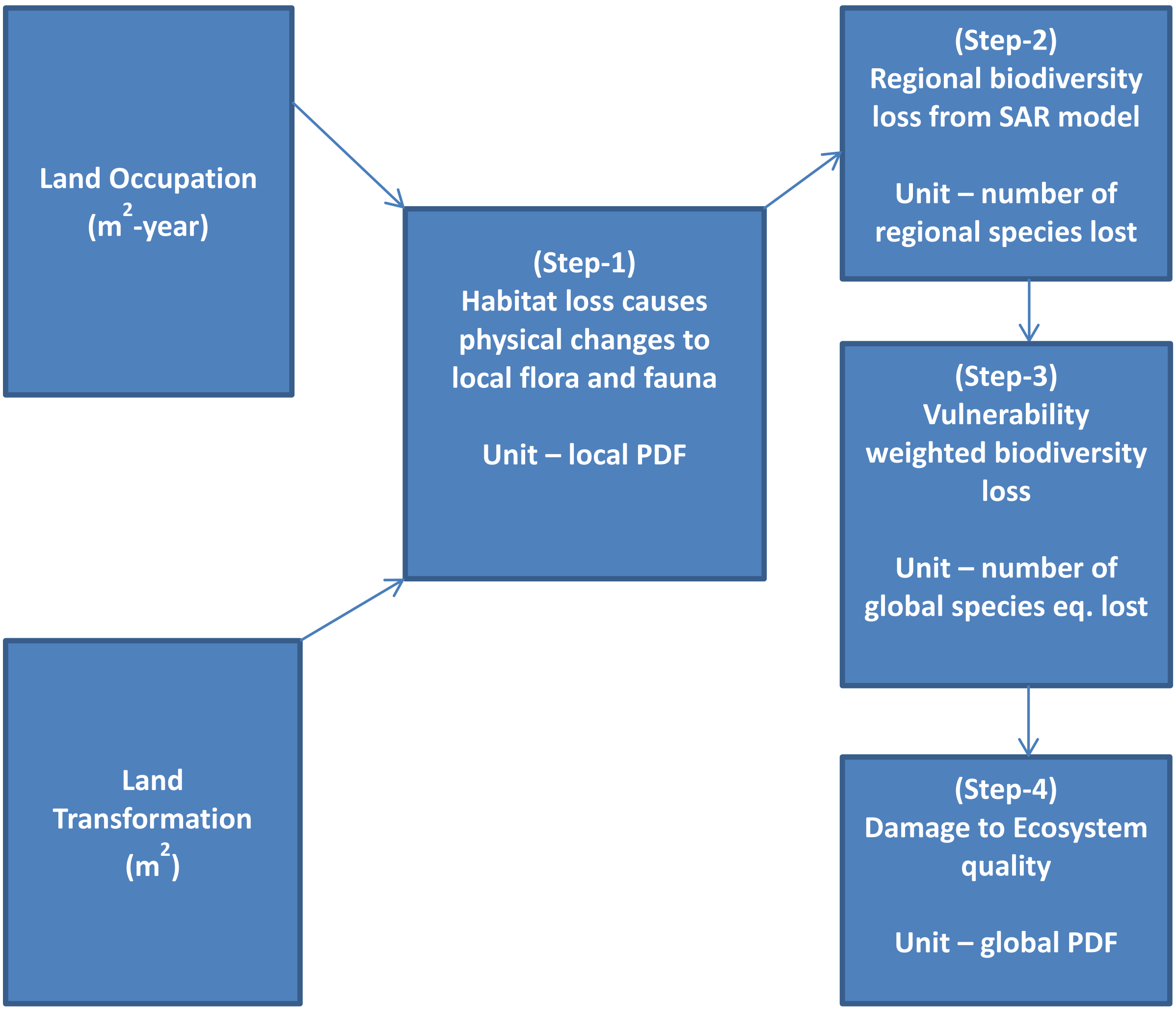

Figure 11.1: Cause-effect chain for ecosystem quality impacts caused by land use and the modeled impact pathway (following ILCD). Land transformation and land occupation causes physical changes to flora and fauna locally, which leads to an altered species composition and species richness on the occupied land itself. If too much suitable habitat is lost, this leads to species extinction on regional or global scales, which in turn negatively affects ecosystem quality. The unit of corresponding biodiversity damage at each step is also shown. PDF is potentially disappeared fraction.

Description of all related impact categories

This impact pathway addresses biodiversity loss and, thus, changes in ecosystem quality.

Methodological choice

Two different sets of CFs are available: (1) marginal CFs, which are typically used in LCA to address impacts of additional land use and (2) average CFs, which are used to assess total impacts of land use within a region.

In ecological and conservation studies, the use of models describing species-area relationships (SARs) is common to predict biodiversity impacts resulting from habitat loss in terrestrial systems (Brook et al 2003). The *classic SAR* model (Arrhenius 1921) is the most commonly used model and defines species richness as a power function, $S = cA^z$, where A is the area, S is the number of species, and c and z are parameters depending on the taxonomic group, region under study, sampling scale and regime (Rosenzweig 1995). This approach of assessing extinction risk is based on the assumption of a binary landscape of either habitat (such as an old-growth forest) or non-habitat (e.g., farmland). In other words, it assumes that the human-dominated areas, such as agriculture and forestry, are totally hostile to biodiversity (Pereira et al. 2012). Therefore, the model has been criticized for overestimation of extinction risk (He & Hubbel 2011). There is a growing recognition that that the human-modified habitats also play an important role in the conservation of biodiversity (Karp et al. 2012). It has been recognized that while some species are highly sensitive to habitat loss and only occur in native habitats, many other species show partial or total tolerance to human-modified habitats, and still other species even benefit from the conditions found in human-modified habitats (Barlow et al. 2007; Proenca et al. 2010).

Alternative models that account for habitat heterogeneity have been proposed to assess patterns of species richness in multi-habitat landscapes. The *matrix SAR* model is one such example where the matrix effects (i.e., the habitat provided by human-modified land) are incorporated into the SAR by calibrating the z value of the power model accounting for taxon-specific sensitivity to each land use type within a heterogeneous landscape (Koh and Gouzoul 2010). However, the matrix SAR model predicts that no species will survive if all *natural* habitat within a region disappears. It predicts very high rates of extinction as the natural undisturbed area within a region tends towards zero. This model outcome is unrealistic for some species which survive in human-modified habitat as well (de Baan 2013b). The *countryside SAR model* has been proposed as an alternative to matrix SAR, recognizing the fact that species adapted to human-modified habitats also survive in the absence of natural habitat (Pereira & Daily 2006). Here, we use the countryside SAR because it is known to outperform both the matrix-calibrated SAR and classic SAR models as shown by Pereira et al. 2014 for projecting tropical bird extinctions.

We first calculate regional CFs using the countryside SAR for five taxa (mammals, birds, reptiles, amphibians, and vascular plants) and six land use types (annual crops, permanent crops, pastures, urban, extensive forestry and intensive forestry). Definitions of each of the land use types are taken from Koellner et al. 2013b. The CFs weighted with vulnerability scores of taxa are then calculated. Ecoregions are used as spatial units because their boundaries approximate the original extent of natural ecosystems before major land use changes and distinct communities of species are known to exist within a given ecoregion (Olson et al 2001).

Spatial detail

The method was applied to 804 ecoregions with varying sizes, resulting in a global coverage. A global average is not considered meaningful but provided for background processes. Country and continental averages are provided based on the share of ecoregions within them.

11.2. Calculation of the characterization factors at endpoint level

Unweighted characterization factors using countryside SAR

The countryside species-area relationship (SAR) model predicts the number of species S_{new} in the remaining habitat area A_{new} as a function of the number of species S_{org} occurring in the original habitat area A_{org} as presented in equation 11.1 (Pereira et al. 2014; Chaudhary et al. 2015; Chaudhary et al. 2016a). The species are classified into species groups sharing similar habitat affinities (h_i) for different habitats in the landscape, given by equation 11.2.

$$\frac{S_{new}}{S_{org}} = \left(\frac{A_{new} + \sum_{i=1}^{n} h_i A_i}{A_{org}}\right)^z$$

Equation 11.1

$$h_i = \left(1 - CF_{loc,i}\right)^{1/z}$$

Equation11.2

Habitat affinities (h_i) are a function of $CF_{loc,i}$ (*local* land occupation characterization factor) which is the relative decrease in species richness (*S*) between a land use type *i* and the regional reference habitat (de Baan et al. 2013a). $CF_{loc,i}$ were available on the resolution of biomes.

The species lost $S_{lost,j,g}$ per taxonomic group *t* due to cumulative land use in an ecoregion *j* is thus given for countryside SAR (equation 11.3) by equation 11.3 (Chaudhary et al.2015):

$$S_{lost,j,t}^{countryside} = S_{org,t,j} - S_{new,t,j} = S_{org,t,j} - S_{org,t,j} * \left(\frac{A_{new,j} + \sum_{i=1}^{n} h_{t,i,j} \cdot A_{i,j}}{A_{org,j}}\right)^{z_j}$$

Equation 11.3

Equation (11.3) calculates the total number of species lost after conversion of the natural habitat to the current land use mix (*average* assessment). This average assessment refers to past conversion of land and not to future conversions, which would be possible as well using the same equations, if the land use of a future point in time is known. In the *marginal* assessment, the impact caused by one additional m^2 of land converted from the current land use mix for the production of a product is calculated. The marginal damage function for the SAR model is given by equation (11.4) as the first derivative of its average damage function by the area lost (de Baan et al. 2013(b)).

$$\frac{dS_{lost,t,j}}{dA_{lost,t,j}} = z_j * \frac{S_{org,t,j}}{A_{org,j}} * \left(\frac{A_{new,j} + \sum_{i=1}^{n} h_{t,i,j} \cdot A_{i,j}}{A_{org,j}}\right)^{z_j - 1}$$

Equation 11.4

This regional damage is then allocated to the different land use types *i* in the ecoregion *j* according to their relative frequency $p_{i,j}$ and the local characterization factor $CF_{loc,t,i,j}$. The allocation factor $a_{i,j}$ for each land use type *i* and ecoregion *j* is given by equation (11.5) (de Baan et al. 2013a):

$$a_{i,j} = \frac{(1 - h_{t,i,j}) * A_{i,j}}{\sum_{i=1}^{n}((1 - h_{t,i,j}) * A_{i,j})}$$

Equation 11.5

Regional characterization factors for occupation of each land use type for the average assessment are calculated by multiplying the species lost per region *j* with the corresponding allocation factor $a_{i,j}$ and dividing this by the area occupied by the land use type, $A_{i,j}$ (equation 11.6) (de Baan et al. 2013(b)). The unit of the CF is *Regional species lost/m^2.*

$$CF_{avg,occ,t,i,j} = \frac{\Delta S_{lost,t,j} * a_{i,j}}{A_{i,j}}$$

Equation 11.6

The regional occupation CFs for *marginal assessment* are calculated using equation 11.7 as a marginal loss of species due to a marginal increase in human used area $\Delta A_{lost,t,j} = 1\ m^2$(de Baan et al. 2013(b)).

$$CF_{marg,occ,t,i,j} = \frac{a_{i,j} * \Delta S_{lost,t,j}}{p_{i,j} * \Delta A_{lost,t,j}}$$

Equation 11.7

For land transformation the regional characterization factors are calculated as a multiplication of $CF_{reg,occ,t,i,j}$ with half the regeneration time (Koellner et al. 2013a, de Baan 2013a), as shown in equation 11.8. The unit is *Regional species lost*years/m²*.

$$CF_{trans,t,i,j} = 0.5 * CF_{occ,t,i,j} * t_{reg,t,i,j}$$

Equation 11.8

To calculate impacts, the $CF_{reg\ ,occ}$ is multiplied by the inventory flow of occupation, that is, the land requirements of a product given in *m²·years*. The $CF_{reg,trans}$ is multiplied by the inventory flow of transformation, that is, the amount of land use change per product in *m²*. The two impacts can be summed up into the total regional biodiversity depletion potential (de Baan et al. 2013a) for each taxonomic group *g* expressed in the unit *Regional species lost*years.*

Vulnerability Scores

The vulnerability of the taxonomic groups was quantified with a vulnerability score (VS) as an indicator for global extinction risk (Chaudhary et al. 2015). The VS is a function of the geographic range (GR) of each species and a threat level (TL). The latter indicates the degree of threats the species is already facing, while the former acts as a proxy for potential susceptibility to new anthropogenic threats. This means that small-ranged and endemic species are considered intrinsically rare.

For each animal species the TL was obtained by linearly rescaling the categories defined by the IUCN Red List of threatened species. It varies from 0.2 to 1 (0.2-least concern, 0.4-near threatened, 0.6-vulnerable, 0-8-endangered, 1- critically endangered). The GR (in km^2) of each species was obtained from maps provided by IUCN and Birdlife international.

From GR and TL, the VS were calculated as global maps for each species *k* in taxon *t*, and each pixel *p* (0.05° × 0.05°) as the area of the respective pixel ($RA_{k,p}$) where species *k* occurs divided by the total GR of the species (the sum of $RA_{k,p}$) and multiplied with TL_k.

The total $VS_{g,p}$ of each animal taxon *t* in a pixel *p* is obtained by summing values for all species *k* of that taxon which occur in pixel *p* and dividing by the number of species of the taxon present in pixel *p* ($n_{g,p}$, eq. 11.9). The numerator of the equation 11.9 without the threat level has also been referred to as “endemic richness” (see Kier & Barthlott 2001 and Kier et al. 2009) or “global biodiversity fraction” (Waldron et al. 2013).

$$VS_{t,p} = \frac{\sum_{k=1}^{m} \frac{TL_k \cdot RA_{k,p}}{\sum_{p=1}^{r} RA_{k,p}}}{n_{t,p}}$$

Equation 11.9

Using ArcGIS 10.2 (ESRI 2013), the individual $VS_{g,p}$ for all the pixels that occur in an ecoregion *j* are used to calculate the $VS_{g,j}$ for that ecoregion for each taxon *g* (eq. 11.10). $n_{g,j}$ in the equation 11.10 is actually the original species richness ($S_{org,g,j}$) from equation 11.3.

$$VS_{t,j} = \frac{\sum_{p=1}^{n}\left(VS_{t,p} \cdot n_{t,p}\right)}{n_{t,j}}$$

Equation 11.10

Vulnerability Scores for plants

Vulnerability score for plants are calculated using the approach by Verones et al. 2015 (in preparation). They used global maps of vascular plant species richness (VPSR; Kreft et al.2007) and species range equivalents (endemic richness, $EVPSR_{bioregion}$ from Kier et al. 2009) per 10,000 km² for 90 biogeographic regions. The vascular plant species richness for each biogeographic region ($VPSR_{bioregion}$) was first calculated. The VS was then calculated from Equation 11.11.

$$VS_{plants,bioregion} = \frac{EVPSR_{bioregion}}{VPSR_{bioregion}}$$

Equation 11.11

VS_{plants} is then implemented to the VPSR map on 30 arc minutes resolution. The fraction in equation 11.11 approximates the expression for calculating VS for animal taxa in equation 11.9 by implicitly assuming that the threat level for all plants is equal to 1. Finally the vulnerability score of plants per ecoregion are calculated in the same way as for animal taxa (eq. 11.10), i.e. the ratio of threatened endemic richness to species richness.

VS-weighted Characterization Factors

The unweighted CFs calculated using SARs (equations 11.6, 11.7 and 11.8) for each taxon *t* per ecoregion *j* and land use type *i* are multiplied by VS of that taxa in that ecoregion (eq. 11.10) to obtain weighted-CFs (equation 11.12) for both land occupation and transformation.

$$CF_{weighted,t,i,j} = CF_{unweighted,t,i,j} \cdot VS_{t,j}$$

Equation 11.12

Using the terminology of Kier et al. 2009, the weighted CFs thus gives an estimate of global threatened endemic richness (of taxa *t*) lost per unit of land use. In Waldron et al. 2013 words, it will be global threatened biodiversity fraction lost per unit of land use for the individual taxa *t*. We denote the units of weighted CFs as – Global species eq. lost/m^2 (for land occupation) and Global species eq. lost*years/m^2 (for land transformation).

Damage to the area of protection ecosystem quality

The damage to ecosystem quality due to a land use type *i* in ecoregion *j* is calculated using equations 11.13 -11.15. The weighted CFs from equation 11.12 for each animal taxa *t* and plants are multiplied by factors W_t and W_{plants} respectively. Global potentially disappeared fraction (PDF_{global}) is then obtained by giving equal weighting to plants and animal taxa (see Chapter 1).

$$W_t = \frac{1}{N \cdot (S_{t,world} \times VS_{t,world})}$$

Equation 11.13

$$W_{plants} = \frac{1}{(S_{t,plants,world} \times VS_{plants,world})}$$

Equation 11.14

$$CF_{weighted,aggregated,i,j} = 0.5 \cdot \left(\sum_{t=1}^{4} CF_{weighted,t,i,j} \cdot W_t \right) + \ 0.5 \cdot \left(CF_{weighted,plants,i,j} \cdot W_{plants} \right)$$

Equation 11.15

Here N = 4 is no. of animal taxa and $S_{t,world}$ is the total global species richness of taxa *t* and is equal to 5,490 for mammals, 10,104 for birds, 9,084 for reptiles, 6,433 for amphibians and 321,212 for plants (WWF Wildfinder 2006).

$VS_{t,world}$ is the world average vulnerability score for taxa *t* calculated from species richness ($S_{org,t,j}$) and vulnerability scores of taxa *g* per ecoregion *j* ($VS_{t,j}$) and divided by their global species richness $S_{t,world}$ (see Chaudhary et al. 2015 – equation S7 of supporting information-1 for more details on calculating taxa-aggregated CFs along with $VS_{t,world}$).

$$VS_{t,world} = \frac{\sum_{j=1}^{804} VS_{g,j} \times S_{org,g,j}}{S_{t,world}}$$

Equation 11.16

$VS_{t,world}$ is equal to 0.44 for mammals, 0.29 for birds, 0.59 for amphibians, 0.46 for reptiles and $VS_{plants,world}$ is equal to 1.0. We denote the unit of these taxa-aggregated CFs as global PDF/m^2 for occupation impacts and global PDF*years/m^2 for transformation impacts.

Taxa-aggregated CFs compatible with other impact categories and for use in full LCA studies

For case studies interested in knowing the biodiversity loss due to land use only, we recommend taxa-aggregated CFs calculated using Eq. 11.15 above.

However, the case studies that apply full LCA of product/processes and are interested in comparing the biodiversity loss due to different drivers or impact categories such as land use, water use, climate change, eutrophication, acidification etc., we recommend using taxa-aggregated CFs calculated using Eq. 11.17 below. In order to make the above taxa-aggregated CFs for land use impacts compatible with other impact categories where so far just the regional species loss is quantified (i.e. without the vulnerability score), we adapted the CFs with a constant *C.* The constant *C* is the median of the ratios of regional and global PDFs across all ecoregions and land-use types calculated using the expression in Eq. 11.15 above. The resulting conversion factor of C = 40 was applied to all CFs. CFs are called global PDF equivalents ($PDF_{global,eq.,i,j}$).

$$CF_{compatible,aggregated,i,j} = \ CF_{weighted,aggregated,i,j} \times \ C$$

Equation 11.17

The CFs provided as Excel and maps on the LC-IMPACT homepage rerfer to the CFs calcualted according to Equation 11.17. If the original global species loss fraction is of interest (Eq. 11.15), the results need to be back-converted by dividing them by the factor of 40.

World-average CFs

In many LCA studies, the geographic location of land use for background processes is unknown. For these cases, world average CFs per land use type *i* and taxa *t* are obtained by weighting the CF of each ecoregion by their global area share (Equation 11.18). Also the CFs for some land use types could not be calculated (denoted by NaN in the excel file) because that land use type didn't exist in the ecoregion. For such cases, the world average CF could be applied (in the maps offered on the Webpage this was not done).

$$CF_{i,t,globalavg} = \sum_{j=1}^{804} CF_{i,t,j} \cdot \frac{A_j}{A_{global}}$$

Equation 11.18

Input Data for Model Parameters

The estimates of model parameters were derived from published empirical data and existing databases. For local characterization factors ($CF_{loc,g,i,j}$), data from global reviews conducted by de Baan et al. 2013b (for all land use types), Elshout et al. 2014 (for agriculture land) and Aronson et al. 2014 (for urban areas) was imported. For z-values (z_j), estimates of Drakare et al. 2006 were used by differentiating between forest, non-forest and island ecoregions. Original species richness ($S_{org,g,j}$) per ecoregion for all taxa were obtained from Olson et al. 2001, Kier et al. 2005 and WWF wildfinder database. Original natural habitat area ($A_{org,j}$), remaining natural habitat area ($A_{new,j}$), and area per land use type for all 804 ecoregions ($A_{i,j}$), were derived from LADA and Anthrome maps (Ellis & Ramankutty 2010). Data for calculating vulnerability scores ($VS_{g,p}$) was imported from IUCN and Birdlife international databases. Finally the regeneration times ($t_{reg,g,i,j}$) calculated by Curran et al. 2014 were used for the calculation of transformation CFs. All the above 8 model parameters were fed into the countryside SAR model to calculate the CFs using equations 11.1 to 11.12 (see Chaudhary et al. 2015 for details).

11.3. Uncertainties

We propagated the parameter uncertainty into the characterization factors using Monte Carlo simulation (1,000 iterations). Triangular probability distribution was assumed for the model parameters - area estimates and z-values per ecoregion. The local CFs were assumed to have non-parametric kernel density and the regeneration times were assumed to follow a lognormal distribution (see de Baan 2013a). Median values along with 95% confidence intervals were calculated for both weighted and unweighted characterization factors for each of the five taxa per land use type and ecoregion. Contribution to variance analysis was carried out to assess the influence of each of the model input parameter on the uncertainty of characterization factors results.

11.4. Value choices

Time horizon

One value choice in the modelling of the land transformation impacts is the time horizon. As explained in the section 1.5 of framework chapter, the further away in time the impact is, the more uncertain its value is, (i.e. lower the level of robustness; see equation 1.4). Biodiversity recovery time (t_{reg}) in a region following the abandonment of human land use ranges from ~80 years to up to ~1200 years depending upon the ecosystem, taxa or the prior land use (Curran et al. 2014). We calculated two sets of transformation CFs. The user can choose between short-term “core” CFs (i.e. those calculated using the 100 year time horizon cut-off, equation 11.19) or CFs “after 100 years” (i.e. after 100 year time horizon). The “core” and “after 100y” CF add up to the total extended transformation CFs (calculated using total recovery times, equation 11.8).

$$CF_{trans,g,i,j} = \begin{cases} 0.5 * CF_{occ,g,i,j} * t_{reg,g,i,j} & \text{for } t_{reg,g,i,j} \leq 100 \\ 100 * CF_{occ,g,i,j} - 0.5 * 100 * \left(\frac{100 * CF_{occ,g,i,j}}{t_{reg,g,i,j}} \right) & \text{for } t_{reg,g,i,j} > 100 \end{cases}$$

Equation 11.19

Level of robustness

The modeling pathway for assessing land use impact on biodiversity relies on ecological models (species area relationship (SAR)) and global datasets and statistical analysis. Therefore, the level of robustness is high for the whole characterization model. As new datasets come along, the estimates of input model parameters can be improved, thereby reducing the uncertainty in the final characterization factors. Further, for the transformation CFs, we provide both the extended CFs and the core CFs (i.e. $t_{reg} \leq 100\ years$). For occupation CFs the time horizon doesn't apply as the impact is typically occurring in less than 100 years.

11.5. Results

The unweighted and weighted characterization factors (CFs) for land occupation and transformation, calculated using both marginal and average approach are presented in Excel files for all 804 ecoregions and 245 countries. In general, the CFs calculated using marginal approach were higher than those with the average approach, but still within the same order of magnitude. Table 11.1 shows the world average CFs calculated using equation 11.18 and average approach.

The CFs for different taxa for most ecoregions were within one order of magnitude across different land use types. The CFs for a particular land use type for a given ecoregion varied by approximately 2 orders of magnitude across five taxa. However, for a given taxa and land use type, the occupation CFs varied by ~5 orders of magnitude across 804 ecoregions. This underscores the importance of regionalized impact assessment within LCA.

Table 11.1: World average endpoint CFs calculated using average approach for land occupation and transformation. Weighted CFs per ecoregion and taxa were first calculated using eq. 11.12. Aggregation across taxa was done using eq. 11.15. CF referring to eq 11.15 are shown in italics, converted CF according to 11.17 in bold. World average values per land use type were finally obtained using eq. 11.18. Mean CFs along with 2.5 & 97.5 percentile values are shown. *

Characterization Factors		Annual crops	Permanent crops	Pasture	Urban	Extensive forestry	Intensive forestry
Occupation (PDF/m^2)	Mean	*$2.1*10^{-15}$* **$8.4*10^{-14}$**	*$1.5*10^{-15}$* **$6.0*10^{-14}$**	*$1.3*10^{-15}$* **$5.2*10^{-14}$**	*$2.4*10^{-15}$* **$9.8*10^{-14}$**	*$3.7*10^{-16}$* **$1.5*10^{-14}$**	*$1.1*10^{-15}$* **$4.3*10^{-14}$**
	2.5%	*$-2.0*10^{-16}$* **$-8.1*10^{-15}$**	*$-6.9*10^{-16}$* **$-2.8*10^{-14}$**	*$-4.9*10^{-16}$* **$-1.9*10^{-14}$**	*$2.7*10^{-17}$* **$1.1*10^{-15}$**	*$-6.3*10^{-16}$* **$-2.5*10^{-14}$**	*$-7.1*10^{-16}$* **$-2.8*10^{-14}$**
	97.5%	*$4.7*10^{-15}$* **$1.9*10^{-13}$**	*$4.9*10^{-15}$* **$2.0*10^{-13}$**	*$4.2*10^{-15}$* **$1.7*10^{-13}$**	*$4.9*10^{-15}$* **$2.0*10^{-13}$**	*$2.8*10^{-15}$* **$1.1*10^{-13}$**	*$4.1*10^{-15}$* **$1.7*10^{-13}$**
Transformation Core (PDF*year /m^2)	Mean	*$1.5 *10^{-13}$* **$6.1*10^{-12}$**	*$1.1*10^{-13}$* **$4.3*10^{-12}$**	*$9.0*10^{-14}$* **$3.6*10^{-12}$**	*$1.7*10^{-13}$* **$6.9*10^{-12}$**	*$2.7*10^{-14}$* **$1.1*10^{-12}$**	*$7.8*10^{-14}$* **$3.1*10^{-12}$**
	2.5%	*$-3.2*10^{-14}$* **$-1.3*10^{-12}$**	*$-8.9*10^{-14}$* **$-3.6*10^{-12}$**	*$-7.8*10^{-14}$* **$-3.1*10^{-12}$**	*$1.7*10^{-15}$* **$6.8*10^{-14}$**	*$-8.9*10^{-14}$* **$-3.6*10^{-12}$**	*$-1.0*10^{-13}$* **$-4.1*10^{-12}$**
	97.5%	*$3.6*10^{-13}$* **$1.4*10^{-11}$**	*$3.6*10^{-13}$* **$1.5*10^{-11}$**	*$3.2*10^{-13}$* **$1.3*10^{-11}$**	*$3.7*10^{-13}$* **$1.5*10^{-11}$**	*$2.1*10^{-13}$* - **$8.6*10^{-12}$**	*$3.1*10^{-13}$* - **$1.2*10^{-11}$**
Transf. Extended (PDF*year /m^2)	Mean	*$2.5 *10^{-13}$* **$1.0*10^{-11}$**	*$1.8*10^{-13}$* **$7.2*10^{-12}$**	*$1.5*10^{-13}$* **$5.8*10^{-12}$**	*$2.9*10^{-13}$* **$1.2*10^{-11}$**	*$4.2*10^{-14}$* **$1.7*10^{-12}$**	*$1.1*10^{-13}$* **$4.6*10^{-12}$**
	2.5%	*$-3.0*10^{-14}$* **$-1.2*10^{-12}$**	*$-8.8*10^{-14}$* **$-3.5*10^{-12}$**	*$-7.7*10^{-14}$* **$-3.1*10^{-12}$**	*$2.8*10^{-15}$* **$1.1*10^{-13}$**	*$-8.9*10^{-14}$* **$-3.6*10^{-12}$**	*$-1.0*10^{-13}$* **$-4.0*10^{-12}$**
	97.5%	*$6.6*10^{-13}$* **$2.6*10^{-11}$**	*$6.7*10^{-13}$* **$2.7*10^{-11}$**	*$5.9*10^{-13}$* **$2.4*10^{-11}$**	*$6.8*10^{-13}$* **$2.7*10^{-11}$**	*$3.9*10^{-13}$* **$1.5*10^{-11}$**	*$5.5*10^{-13}$* **$2.2*10^{-11}$**

***** The complete list of CFs per taxa, per ecoregion and uncertainty ranges are provided in Excel files. Global CFs calculated using the *marginal* approach and compatible CFs along with the transformation CFs with high level of robustness scenario are also provided in online Excel files.

Two sets of CF were calculated: one average (retrospective) and one marginal set of CF. Both sets of CF did not differ much from each other. It would also be possible to calculate average CF comparing the current situation to a potential future situation of land use. However, to do so scenarios of future land conversion would need to be set up, which would be uncertain in itself.

Further, owing to the lack of species richness and geographic range (GR) data in the IUCN database, characterization factors (CFs) for other species groups such as arthropods, fungi or bacteria could not be calculated. Once the above data gaps for these species groups are filled through research efforts, the calculated CFs can be calculated for them.

The input data used to calculate species extinctions through SAR model come with uncertainties and limitations that should be considered when interpreting the results obtained after applying the CFs provided in this study. Although using the latest published data for input parameters, the calculated CFs still have considerable uncertainty and range from positive to negative (Table 11.1). Contribution to variance analysis showed that the model parameter *local* characterization factors ($CF_{loc,g,i,j}$) contributed the most to the variance of both occupation and transformation regional CFs (see Chaudhary et al. 2015 for details). The local CFs were only available at biome level and their values were assumed to be same for all ecoregions within a biome. More global biodiversity monitoring surveys or meta-analysis (e.g. Chaudhary et al. 2016b) comparing species richness in human-modified land with natural/undisturbed land are needed in future to reduce this uncertainty.

Similarly, area parameters also contributed to uncertainty in final CFs. We could only calculate area share of six broad land use types per ecoregion. As more detailed global land use classification maps differentiating between management practices (e.g. organic vs. conventional agriculture, dense vs. vegetated urban etc.) come along, the accuracy of CFs can be improved.

Finally, other aspects of model uncertainty have been addressed in a previous publication such as the comparison between different SAR models, in particular the matrix and countryside SAR (Chaudhary et al. 2015). Alternative models could be included in the future, e.g. considering habitat suitability models (de Baan et al. 2015). However, for the latter, more data is needed before such an approach can be used on a worldwide scale and for taxa other than mammals.

11.6. References

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