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Modelling intact forest landscapes habitats quality at global scales through the use of landscape ecology methods

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Abstract

Modelling intact forest landscapes (IFL) quality as habitats for various species represents a crucial aspect concerning wildlife conservation. Landscape ecology provides a rice pallet of metrics suitable for quantifying complex relationships between landscapes structure and function. Our research aims to conduct an ecological diagnosis of the 2013 non-altered IFL patches as optimal habitats for both edge and interior preferring species by taking into account their spatial adjacency to altered IFL patches by fire related and non-fire related causes between 2003 and 2013 through the use of the Edge Contrast Index Metric and the Core Area Index Metric. Our results evidence that none of the world geographical forest regions suffered potential ecological dysfunctions as habitats for either interior or edge dwelling species. However, the equatorial forest zones of Africa, America and Asia are characterized by alarming low levels of habitat quality which in the future can generate severe malfunctions.

Keywords: *Intact Forest Landscapes, Landscape Ecology, Landscape Function, Landscape Structure, Edge Contrast, Core Area.*

Rezumat. Modelarea calității habitatelor peisajelor forestiere intacte la scară globală folosind metode specifice ecologiei peisajelor

Modelarea calității habitatelor peisajelor forestiere intacte (IFL) pentru diferite specii reprezintă un aspect crucial în privința conservării biodiversității. Ecologia peisajelor permite aplicarea unei game variate de metrici utili în vederea cuantificării relațiilor complexe dintre structura și funcția acestora. Studiul de față are ca scop realizarea unui diagnostic ecologic al parcelelor IFL nealterate din anul 2013 în contextul eficienței funcției acestora de habitate pentru specii ce preferă atât zonele de margine, cât și cele interioare prin intermediul cunatificării influenței parcelelor vecine alterate în perioada 2003-2013 din cauze naturale sau antropice cu ajutorul Indexului Contrastului de Margine și Indexului Suprafeței Centrale. Rezultatele evidențiază faptul că regiunile forestiere globale nu prezintă potențiale disfuncționalități ecologice în contextul furnizării de habitate atât pentru specii interioare, cât și de margine. Totuși, regiunile ecuatoriale din Africa, America și Asia sunt caracterizate de prezența unei calități scăzute a habitatelor, situație ce pe viitor poate genera disfuncționalități severe.

Cuvinte-cheie: *Peisaje Forestiere Intacte, Ecologia Peisajelor, Funcția Peisajelor, Structura Peisajelor, Contrast de Margine, Suprafață Centrală.*

Introduction

Intact forest landscapes (IFL) are composed by a multitude of wild ecosystems which represent crucial habitats for a tremendous variety of species and support complex ecological functions and services vital for human wellbeing (Potapov et al. 2008). Because of these areas immense size and isolation, anthropic disturbances were maintained through history at insignificant levels, favouring their untamed wilderness (Potapov et al. 2008). However, many patches have already been disturbed by human induced fragmentation or alteration and these changes could also affect the ecological functionality of the neighbouring large intact ones. Consequently, between 2000 and 2010 primary forests have massively declined with a staggering annual rate of 0.4% (FAO 2010).

IFL are described as a complex of ecosystems encompassed by a geographical forest zone, characterized by the lack of identifiable anthropic disturbances and an area sufficiently extended and connected for supporting all indigenous wildlife (Potapov et al. 2008). The notion of IFL is not synonymous with primary forest (FAO 2010). Primary forests are included by IFLs together with other primeval rare or scarce vegetated ecosystems, such as grasslands, scrubs, alpine areas or even barren rocky areas (Potapov et al. 2017). IFLs are identifiable by several spatial characteristics, such as a patch surface exceeding 500 km^2, a width of at least 10 km and the lack of areas which in the last 30 to 70 years were highly disturbed by human activities or which contain anthropic infrastructures (Potapov et al. 2008).

The notion of IFL and the criteria of identification were developed by Potapov (2008). Other representative global scale researches focused on identifying undisturbed natural landscapes dynamics under historical anthropic pressure must include several earlier studies based on mathematical models and high levels of subjective speculations (McCloskey & Spalding 1989; Bryant et al. 1997; Sanderson et al. 2002) and also recent assessments established by processing satellite imagery data through the latest available spatial methods (Hansen et al. 2013; Heino et al. 2015; Potapov et al. 2017).

Modelling IFL functionality as habitats for different species is crucial for understanding the spatial distribution of valuable ecological areas for supporting biodiversity located under the threat of various types of degradations, due to anthropic or natural causes. Landscape ecology methods represent an important tool that supports a robust and useful way of quantifying complex ecological aspects regarding IFL through the use of a wide range of landscape metrics. Despite being related with ecology (which studies from a systemically perspective the connections between the earths geospheres), landscape ecology is centred on a couple of distinct essential principles: the geographical extent of ecological processes, the accent on the relation between the natural environment and anthropic activities and the consideration of landscapes as fundamental study units (Botequilha et al. 2006).

There are a great variety of perspectives over the notion of landscape based on the observer ́s qualification and skills. Common ones include the visual elements of the landscape (González Bernáldez 1981) or the cultural perspective, which defines landscapes as a three dimension entity encompassing a material, social and emotional reality (Kosian 2008). Nevertheless, the most widely used remains the perception of landscapes as elements of the land surface, encompassing different natural elements such as mountains, rivers or woods (Wascher 2000). From an ecological perspective a landscape is considered a mixture of different land cover types capable of taking the form of several distinct structural elements such as patches, corridors and matrices (Forman & Godron 1986). A patch is considered a continuous nonlinear surface distinguishable from its neighbourhoods while a corridor represents a unitary linear surface that varies in composition from the rest of the landscape units. A matrix is defined as a continuous area that exceeds the rest of the landscape elements in spatial extension (Forman 1995).

Landscapes are evaluated through the use of landscape metrics at tree well established stages: patch, class and landscape. A class represents a multitude of identical type patches while the totality of classes composing the study area defines a landscape (Botequilha et al. 2006). Landscape metrics primary purpose is the understanding of the relations between landscape structure and function from an ecological relevant perspective (Csorba and Szabo 2012). These metrics were precisely developed for ecological modeling, being proper for quantifying spatial characteristics regarding landscape pattern or arrangement (Botequilha et al. 2006). Landscape metrics were initially computable just for raster data by several software such as Fragstats (McGarigal & Marks 1995) and Idrisi's Patter Module (Eastman 2003). Recent applications allow their calculation for various vector data, notable ones including vLATE (Lang and Tiede 2003), Patch Analyst (Rempel 2010) or Conefor Sensinode (Saura & Torné 2009).

Landscape structure is defined as the ratio between the repartition of energy, matter, life forms and the spatial characteristics of ecosystems. Landscape function indicates three wide aspects: benefits (such as resource supplying, shelter providing or system adjustment), movements (such as of energy, matter, animals or humans) and processes (such as the production of biological material, water filtering or habitat maintenance for various species) (Botequilha et al. 2006). Landscape structure and function relationships are extremely complex and therefore it is difficult to mathematically quantify them in a method that express reality in an ideal manner. Due to this fact, landscape structure indicates only potential landscape ecological or functional aspects and obviously not certain ones.

Landscape patches size and spatial structure influences to a certain level their ecological stability (Botequilha et al. 2006). For example, highly connected and expanded patches containing initial ecosystems indicate greater natural diversity and therefore higher probability of maintaining quality habitats than smaller isolated ones (Dramstad et al. 1996). In a similar manner, patches size and structure dynamics determines the landscape configuration and consequently the length of common edge with adjacent ones. In landscape ecology, the borderlines between landscape patches are named "edge" and influence to a large degree their ecological integrity (Botequilha et al. 2006). Nevertheless, the patches spatial arrangement within the landscape generates different physical characteristics which conversely cause variable ecological processes or flows. As an example, a grassland surrounded by arable land is influenced by longer periods of sun radiation which consequently generates higher values of temperature than one located in the adjacent of a forest (Forman & Godron 1986).

All over the world natural landscapes are facing unprecedented changes generated by the exponential growth of anthropic activities, being constantly transformed into agricultural and artificial landscapes (Kim & Weaver 1994). These changes are spatially manifested in the form of structural modifications such as loss or fragmentation and are usually perceived by natural ecosystems as disturbances being the prime vector for triggering severe ecological dysfunctions. They represent one of the greatest dangers for species habitats at both local and global scales (Sorrell 1998).

Our paper represents one of the first assessments of worldwide IFL's through the use of Landscape Ecology metrics. Based on the stated problems, the aims of the study are:

- to asses a comparative analyses of the potential ecological functionality of non-altered IFL patches as optimal habitats for edge preferring species based on their spatial adjacency to altered IFL patches (by fire and non-fire induced causes);
- to use the same ecological oriented approach by evaluating the patches function as efficient habitats for interior requiring organisms.

Method

The first step of our assessment is represented by the delimitation of the study area. For a more comprehensive perspective, the study was conducted at a global scale. All the IFL patches are located within a forest zone (tree canopy density exceeding 20% in the year 2000) extended over ten geographical regions, therefore resulting in ten geographical forest regions: Africa, Australia and Oceania, temperate South America, tropical South America, temperate North America, boreal North America, temperate Eurasia, boreal Eurasia, West Hemisphere Pacific Islands and Southeast Asia (Potapov et al. 2008). For our study we used all of the ten geographical forest zones except the West Hemisphere Pacific Islands which was excluded based on the fact that it lack's IFL.

The first global IFL database is established on the data available for the year 2000, being prepared in 2005-2006 and updated in 2012. The second global IFL database is centred on the 2013 year data and was performed in 2014-2015. The two databases are based on a common methodology, making in this way possible taking track of the IFL patch losses between 2000 and 2013 and consequently on the ones which remain untouched, spatial information which forms the third database and also the one used for our study, available for free use at www.intactforests.org in the format of shape file vector data (Greenpeace 2017) (figure 1).

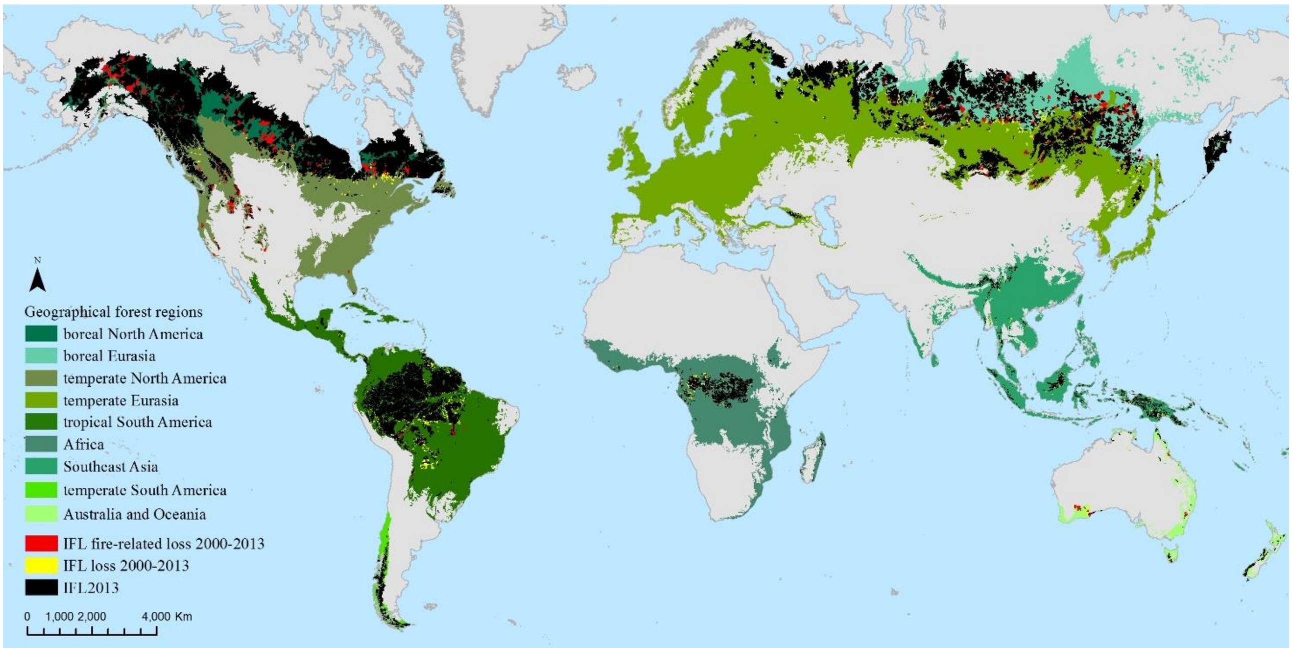

Fig. 1: Map of the study area, with all of the nine geographical forest regions used for the analysis and the IFL dynamics between 2000 and 2012.

An IFL patch loss represents the spatial segregation and therefore functional alteration of an initial IFL patch. Potapov (2017) determined two types of loses, such as forest cutting or replacement by artificial areas (which were considered non-fire generated and are based on anthropic actions) and burned areas distributed in the proximity of intensively administrated infrastructures (which were considered to be induced by natural fires and therefore the assignation of their genesis to anthropic intervention is questionable).

The second step in modelling IFL habitat quality is represented by the third database organization into two new distinct ones which shall be used for our assessment. The first contains the intact IFL in 2013 and the non-fire induced IFL losses between 2000 and 2013. The second encompasses the same intact IFL from 2013 and the fire determined IFL losses between 2000 and 2013. Both databases were converted from vector to raster data, with a cell size of 2 km^2, being proper for large scales models.

The third and final step is represented by the computation of the Edge Contrast Index metric and the Core Area Index metric at a patch and class level through the use of Fragstats software for the non-altered IFL patches from the two new databases (McGarigal et al. 2002).

From an ecological perspective, contrast can be described as the weightiness of dissimilarity between neighbouring patches regarding several ecological functions that are significant to a certain species (McGarigal and Marks 1995). In our case, contrast is expressed as the expected level of disparity between non-altered and altered (by non-fire or fire induced causes) IFL patches concerning the non-altered patches ecological function as habitats for edge preferring species. The degree of contrast characterizing the boundary of an altered and a non-altered IFL patch determines several ecological edge effects, being particularly useful for modelling edge species habitat requirements (Forman and Godron 1986). Therefore, a non-altered IFL patch specie's potential of accessing the resources in the neighbouring altered ones could be embedded by the fact that those patches are affected by human intervention and consequently the resources are weaker. This aspect negatively affects the species possibility of accessing complementary resources (Dunning et al. 1992).

Contrast metrics need the allocation of a matrix of values ranging between 0 and 1 and representing the magnitude of contrast defining common borders (or edges) between altered and non-altered IFL patches. Yet, despite the fact that in this case there is not a solid theoretical support for allocating the selected values, it is still more effective to apply values according to the expert opinion knowledge level of the ecological process under study (McGarigal & Marks 1995). Hence, for our study the employed values were 0 for the adjacencies between patches of the same type or between a patch of any type and the landscape background (suggesting a minimum contrast situation) and 1 for the case of an altered IFL patch adjacent to a non-altered one (indicating a maximum contrast state).

The Edge Contrast Index (abbreviated ECON) quantifies the level of contrast between a patch and its bordering neighbour, equalling the ratio between the sum of the patch of interest perimeter section lengths amplified with their allocated contrast values and the patches total perimeter length, amplified with 100 (McGarigal & Marks 1995; Botequilha et al. 2006). It can be computed at patch or class level through the area weighted mean method:

$$ECON = \frac{\sum_{k-1}^{m}(p_{ijk} * d_{ik})}{p_{ij}}(100)$$

(1)

$$ECON_{AM} = \sum_{j=1}^{n}\left(\left[\frac{\sum_{k=1}^{m'}(p_{ik} * d_{ik})}{p_{ij}}\right]\left[\frac{a_{ij}}{\sum_{j=1}^{n}}\right]\right)(100)$$

$$CON_{AM} = \sum_{j=1}^{n}\left(\left[\frac{\sum_{k=1}^{m'}(p_{ik} * d_{ik})}{p_{ij}}\right]\left[\frac{a_{ij}}{\sum_{j=1}^{n}}\right]\right)(100)$$

$$ECON = \frac{\sum_{k-1}^{m}(p_{ijk} * d_{ik})}{p_{ij}}(100)$$

(2)

Where:

ECON = Edge Contrast Index

$ECON_{AM}$ = Area Weighted Mean Edge Contrast Index

p_{ijk}= lenght (m) of edge of patch ij adjacent to patch type (class) k.

d_{ik}= dissimilarity (edge contrast weight) between patch type i and k.

p_{ij}= lenght (m) of perimeter of patch ij.

Each section composing the non-altered IFL patch perimeter is weighted by the designated contrast value for the shared boundary with an altered IFL patch or background. Hence, for a non-altered IFL patch ECON equals 0 if the patch is entirely bordered by background or by another non-altered patch, suggesting that the patch has no contrast with its neighbourhood. Conversely, ECON equals 100 if the entire non-altered IFL patch is totally surrounded by an altered one.

In landscape ecology, the notion of ”core area” describes the internal area of a patch delimited by an allocated buffer width and similar with the degree of contrast discussed above, it’s ecological relevance it is influenced by the process of edge effect (McGarigal & Marks 1995). Edge effects represent the product of complex interactions between diverse biotic and abiotic components that determine various ecological functions and services in the proximity of patch boundaries compared to patch internal areas (McGarigal & Marks 1995). Therefore, the spatial adjacencies between different patch types favour distinct ecological processes between the edge and the core area regarding the patch of interest and consequently different habitat characteristics, being especially relevant for forest interior preferring organisms (Hansen and di Castri 1992). For example, the boundary area of a non-altered IFL patch adjacent to an altered one might be more exposed to human intervention, aspect which could affect various core area species (given the case of particularly sensitive organisms to human activities). Also, the same edge could generate a barrier which affects the non-altered patch species movements.

Core area metrics also require the conduction of a matrix encompassing the deducted edge depth distances for the adjacencies between altered and non-altered IFL patches. In many situations such as in our case there is a lack of a theoretical basis for specifying any certain edge depth influence and so it must be determined with a high level of subjectivity (McGarigal & Marks 1995). Based on this aspect, for our models we defined an edge depth of 10 km, equalling the minimum width of an IFL patch (Potapov et al. 2012), and representing the influence of an altered patch over a non-altered one. Nevertheless, the effectiveness of the core area metric is crucially influenced by the raster data cell size, patch area and edge depth values applied (McGarigal & Marks 1995). For our study, based on the fact that the landscape resolution is 2 km^2 and the minimum patch dimensions are 500 x 500 km, the 10 km edge influence is suitable for a global scale modelling.

The Core Area Index (abbreviated CAI) is a relative index which computes the percentage of a patch that represents core area, equalling the ration between the patch core area and the total patch area, and amplifying the result with 100. As in the case of the ECON, the CAI is computable at a patch and area weighted mean class level:

$$ECON = \frac{\sum_{k-1}^{m}(p_{ijk} * d_{ik})}{p_{ij}}(100)$$

$$CAI = \frac{{a_{ij}}^{c}}{a_{ij}}(100) \tag{3}$$

$$CAI_{AM} = \sum_{j=1}^{n}\left(\left[\frac{{a_{ij}}^{c}}{a_{ij}}\right]\left[\frac{a_{ij}}{\sum_{j=1}^{n}}\right]\right)(100)$$

$$ECON_{AM} = \sum_{j=1}^{n}\left(\left[\frac{\sum_{k=1}^{m'}(p_{ik} * d_{ik})}{p_{ij}}\right]\left[\frac{a_{ij}}{\sum_{j=1}^{n}}\right]\right)(100)$$

$$CON_{AM} = \sum_{j=1}^{n}\left(\left[\frac{\sum_{k=1}^{m'}(p_{ik} * d_{ik})}{p_{ij}}\right]\left[\frac{a_{ij}}{\sum_{j=1}^{n}}\right]\right)(100)$$

$$ECON = \frac{\sum_{k-1}^{m}(p_{ijk} * d_{ik})}{p_{ij}}(100) \tag{4}$$

Where:

CAI= Core Area Index

CAI_{AM}= Area Weighted Mean Core Area Index

${a_{ij}}^{c}$= core area (m^2) of patch ij based on specified edge depts (m).

a_{ij}= area (m^2) of parch ij.

If a specific patch doesn't possess any core area, CAI equals 0. Conversely, if the patch possesses only core area, then CAI equals 100 (McGarigal and Marks 1995).

Discussion

Initially, the patch level ECON values for the first two maps (which have a possible range of 0 from 100 and are expressed as percent's) were classified into five equal intervals, representing very low (0- 20 %), low (20- 40 %), medium (40- 60 %), high (60-80 %) and very high (80- 100 %) values. Since the last three intervals (medium, high and very high) are spatially represented by small and scarce IFL patches, we merged them into one single interval, which compresses ECON values between 40 to 100 %. Similarly, the patch level CAI values for the first three intervals (representing medium, low and very low values) of the second two maps were also merged into one single interval (comprising values between 0 to 60 %).

The first map quantifies the ECON values for non-altered IFL patches based on their spatial adjacencies with altered ones by human or non-fire related causes (figure 2). Very low ECON values (between 0 and 20 %) are scored by the largest majority of IFL patches. Low ECON values (between 200 and 40 %) are indicated by patches found in eastern Canada, western R. D. Congo, western Brazil, Indonesia, south-east Siberia and north-west Russia. On the other hand, medium and high ECON values (between 40 and 100%) were obtained by remote IFL patches located in tropical South America, temperate North America, Eurasia, Africa, tropical Asia, Australia and especially boreal Eurasia.

Conversely, the second map computes the patch level ECON values for non-altered IFL patches taking into account their common borders with altered ones by natural fires (figure 3). Very low ECON values (between 0 and 20%) characterize almost all the IFL patches composing the nine forest regions of the globe, except several remote ones positioned in central and eastern Alaska or Canada, which returned low values (between 20 and 40%). Also, medium and high ECON values (between 40 and 100%) are modelled by scarce IFL patches located mainly in central-eastern Alaska, USA, central Brazil and eastern Siberia.

The third map shapes the CAI values for non-altered IFL patches regarding their common edge with altered ones by anthropic induced causes (figure

4). Very low, low and medium CAI values (between 0 and 60%) are signed by numerous patches located in North America, South America, Africa, Southeast Asia and Eurasia. High CAI values (between 60 and 80 %) are encompassed by IFL patches situated in the largest part of the Brazilian plateau, Congo river basin, Borneo, Sumatra, eastern Siberia and north-western Russia. Finally, very high CAI values (between 80 and 100 %) were registered by the largest majority of IFL patches.

Finally, the fourth map encompasses the patch level CAI values for non-altered IFL patches concerning their spatial adjacencies with patches altered by fires (figure 5). In this case very low, low and medium CAI values (between 0 and 60%) are registered by scarce IFL patches located in eastern Alaska, north-eastern Montana, central Brazil and eastern Siberia. The rest of the patches returned high and very high CAI values (between 60% and 100%).

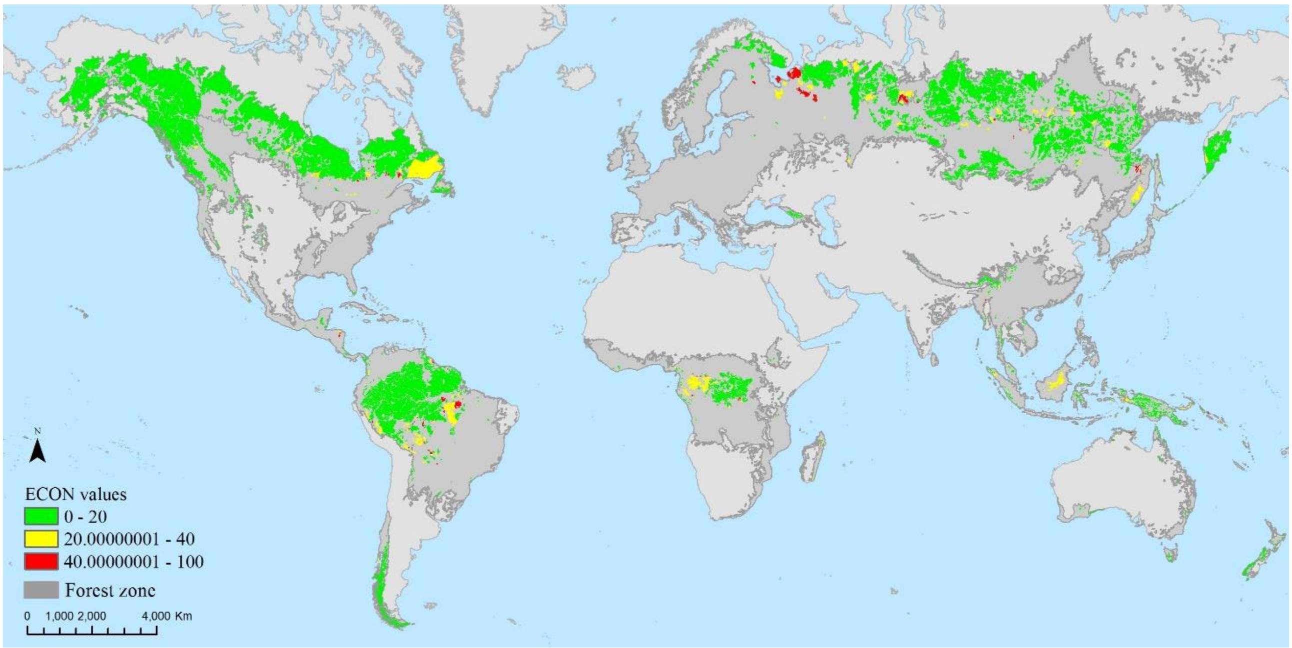

Fig. 2: Patch level ECON values for non-altered IFL patches based on their spatial adjencies with altered ones by non-fire related causes, such as forest clearing induced by human needs for artificial space or agriculture.

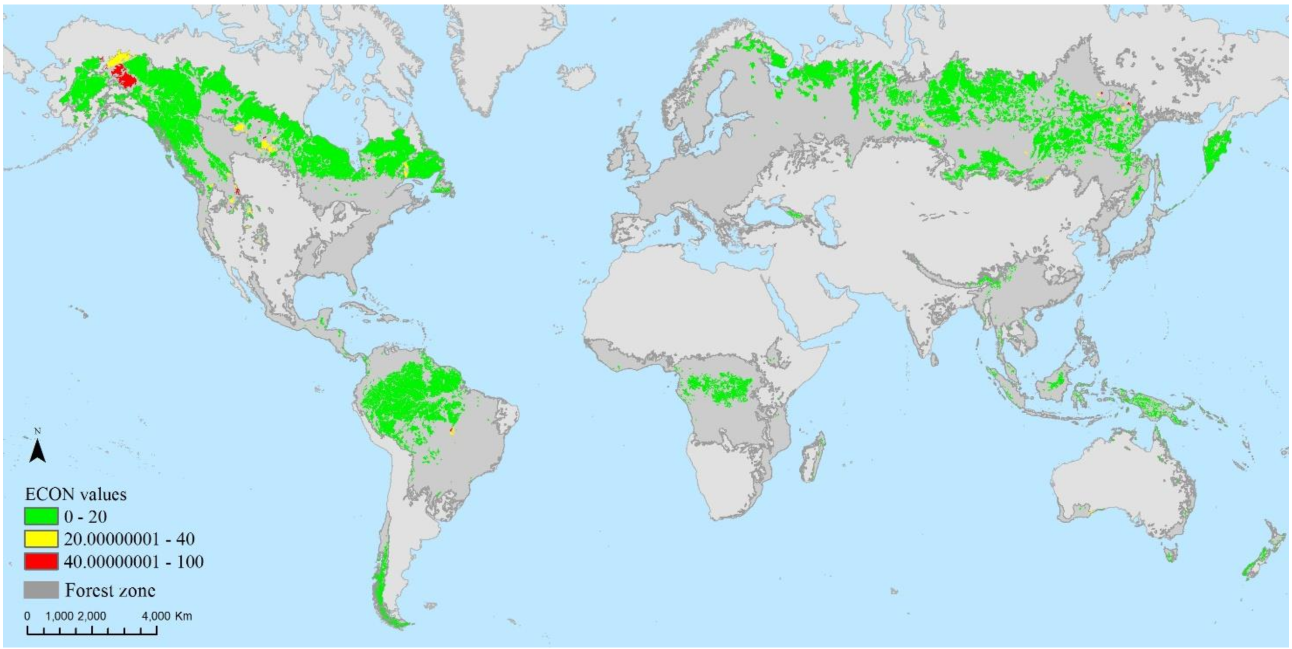

Fig. 3: Patch level ECON values for non-altered IFL patches based on their spatial adjencies with altered ones by fire related causes

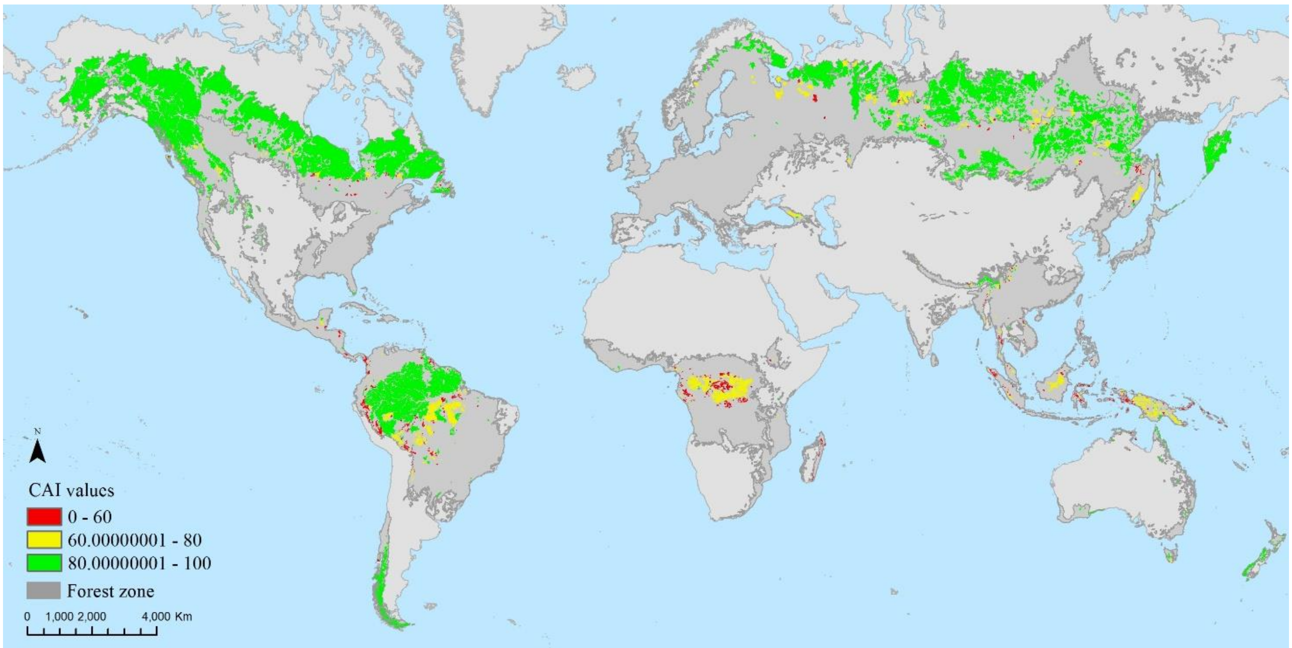

Fig. 4: Patch level CAI values for non-altered IFL patches based on their spatial adjencies with altered ones by non-fire anthropic related causes

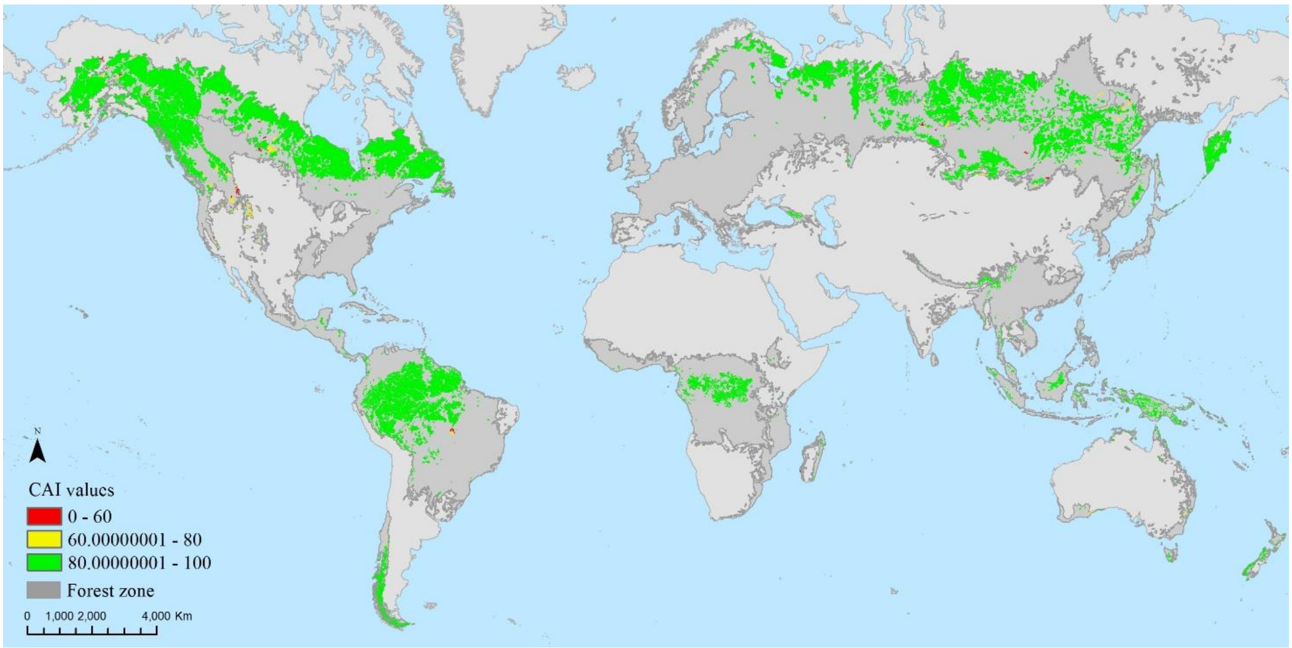

Fig. 5: Patch level CAI values for non-altered IFL patches based on their spatial adjencies with altered ones by fire related causes

For a general perspective, both patch metrics were summed at the class level using the area-weighted mean statistical method, for all of the nine geographical world forest regions. We preferred the patch area weighted mean technique because it offers a more landscape-targeted outlook if compared with the area mean which offers just a patch-oriented viewpoint (McGarigal & Marks 1995). We consider it more relevant for either interior or edge requiring species, based on the fact that the ecological influence of a certain patch over the species it is usually determined by its size. Despite this aspect, if the patch size exceeds the minimum habitat required area of the species in question, it doesn't necessarily guarantee that the patch possesses a healthy ecological functioning. Such information offers just a quantitative viewpoint and not a qualitative one (Csorba and Szabo 2012).

From a landscape ecological perspective, potential ecological dysfunctions could be generated by the amount of common border between altered and non-altered IFL patches. Higher ECON values (> 50 %) suggest a potential malfunction of the IFL patches function as habitat for edge species, based on the fact that the edge shared with a degraded IFL by fire or anthropic causes exceeds half of the perimeter of the non-altered IFL patch (McGarigal & Marks 1995). These aspects could be translated in a high level of vulnerability of the non-altered IFL habitat function to future fire or anthropic degradations. Applying the same logical explanation, lower ECON values (< 50%) suggest a lower level of vulnerability.

On the other hand, lower CAI values (< 50%) indicate a potential dysfunctionality of an non-altered IFL patch habitat quality for interior species, due to the fact that the common edge with a degraded IFL patch generates a buffer area with a size which exceeds half of the total area of the non-altered patch (the remaining less than half of the total area being consider the core area, which is the one typically preferred by such species) (McGarigal & Marks 1995). Consequently, higher CAI values (> 50 %) suggest that the core area exceeds half of the size of the non-altered IFL patch, generating a potential efficient ecological functionality. Therefore, the size, shape and spatial distribution of the intervened patches have the potential to induce severe ecological malfunctions to the non-altered ones, especially affecting their quality as habitats.

Computing the patch area weighted mean ECON values per geographical region based on non-fire or human affected patch adjacencies, our results highlighted the fact that all of the nine regions are characterized by high levels of potential habitat functionality (< 50%). The highest is reached by the temperate southern forests of Oceania and Chile and by the boreal ones of Siberia and Canada (< 3%), followed by the temperate areas of Eurasia and North America (5-10%) and lastly by the tropical regions of South America, Africa and Asia (10-20%). In a similar manner, the patch area weighted mean ECON values regarding adjacencies with fire affected patches also reveal an overall advanced level of habitat quality. The top is reached by the tropical forest of South America, Africa and Asia, and by the temperate southern ones of Chile (< 1%), followed by the temperate zones of Eurasia, North America, Oceania and by the boreal areas of Eurasia (1-5%) and finally by the Canadian taiga (5-10%). Summing the two values, we obtain the patch area weighted mean ECON values per geographical region concerning both types of intervened patch adjacencies. The values highlighted that the temperate southern forests of Oceania and Chile possess the best ecological healthiness (< 5%), followed by the boreal zones of Canada and Russia (5-10%), the temperate areas of North America, Eurasia and the tropical ones from Asia (10-15%) and ultimately by the equatorial regions of Africa and South America (15-20%) (figure 6).

Modelling the patch area weighted mean CAI values per region based on the shared amount of edge between intact patches and human affected ones, our results reflect the fact that all of the nine regions possess a notable level of ecological functionality (over 50 % core area). The only exceptions are represented by Africa and tropical Asia, which scored considerably lower values (between 60 and 65% core area). At the opposite pole, regions such as Oceania, Chile, Siberia and Canada registered considerably higher values (over 90% core area), followed by the temperate forests of Eurasia and North America and by the tropical ones of South America (between 80 and 90%). The patch area weighted mean CAI values centred on the amount of common border between non-altered and altered IFL patches by natural fires points out the highest overall level of habitat quality. Thereby, all the regions encompass core areas summing over 90% of the total patch surface, the largest being modelled for tropical Asia with 100% core area. At the opposite pole, the lowest values characterize temperate Eurasia with 94% core area. Finally, the overall patch area weighted mean ECON values computed at a geographical region level evidences that the temperate southern forests of Oceania and Chile and the boreal ones from North America and Eurasia possess the best habitat functionality (over 90% core area), followed by the temperate areas of Eurasia and the tropical regions of South and Central America (between 70 and 80% core area) and lastly by tropical Africa and Asia (just between 60 and 65% core area) (figure 7).

Various investigations highlighted that increasing population density and worldwide total forest reduction are strongly correlated (Mather 1998; Mather 2000). Furthermore, important areas of both protected forest (3%) and intact forests (1.5%) were lost over the past decade in different regions due to various human induced causes (Heino et al. 2015). Anthropic activities are the main reasons for global IFL reduction between 2000 and 2013 and include the expanse of agriculture and pastures (which are the mains vectors for the IFL losses in tropical America) or logging (which conducted to the largest IFL losses within temperate North America and Eurasia, Africa and Southeast Asia) (Potapov et al. 2017). Also, mining and the expanse of transportation infrastructures are the primary supposed causes for the largest IFL reduction within the southern temperate forests of Chile or Oceania, while fire caused IFL losses are dominant in the boreal regions of Eurasia and North America (Hansen et al. 2015; Potapov et al. 2017). The four models provide evidence that there is an urgent need for a better motorization and conservation of the equatorial and northern temperate non-altered IFL patches, in order to reduce vulnerability to future degradation based on agricultural activities or illegal logging at both regional and national levels (Hunter & Schmiegelow 2010). At a national scale, Brazil stands out as a global model in terms of minimizing deforestation actions, through the use of Landsat data in identifying tendencies in forest reduction over the Amazonian Equatorial forests (Hansen et al. 2015; Instituto Nacional de Pesquisas Especias 2013). At a regional level, the United Nations conducted several initiatives, yet with no success (Hansen et al. 2015).

It is vitally important to maintain as much as possible the high ecological functionality of the immense wild areas located in the boreal forest of North America or Eurasia and in the remote southern temperate forests from Chile or Oceania, areas which probably in the future will remain the last bastions of wilderness. Here, it is recommended that large non-altered forest patches must represent a priority regarding conservation programs. Yet despite the stated aspects, even protected IFL are vulnerable to deforestation actions, especially due to the economic and social underdevelopment of the inhabitants from isolated forested areas (Vanonckelen & van Rompaey 2015). There are studies which prove that the protection of forested areas does not always guarantee a lower rate of forest loss (Heino et.al. 2015). From an overall perspective, our results reflect the fact that in the year 2013 none of the global geographical forest regions non-altered IFL patches is diagnosed as encompassing potential low habitat functionality for interior or edge preferring species, based on the length of shared edge with altered patches between 2000 and 2013. Yet, assessing a comparative analysis, the tropical regions and the northern temperate ones possess overwhelming higher levels of vulnerability than the boreal ones and especially than the southern temperate ones.

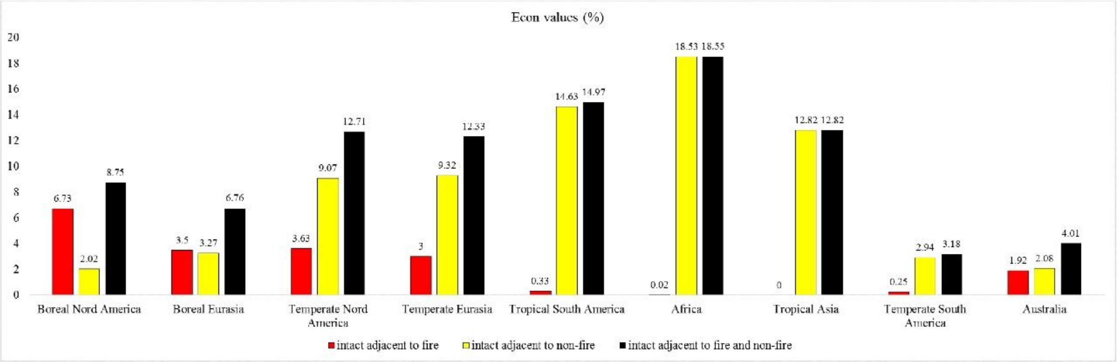

Fig. 6: Patch area weighted mean ECON values per geographical region.

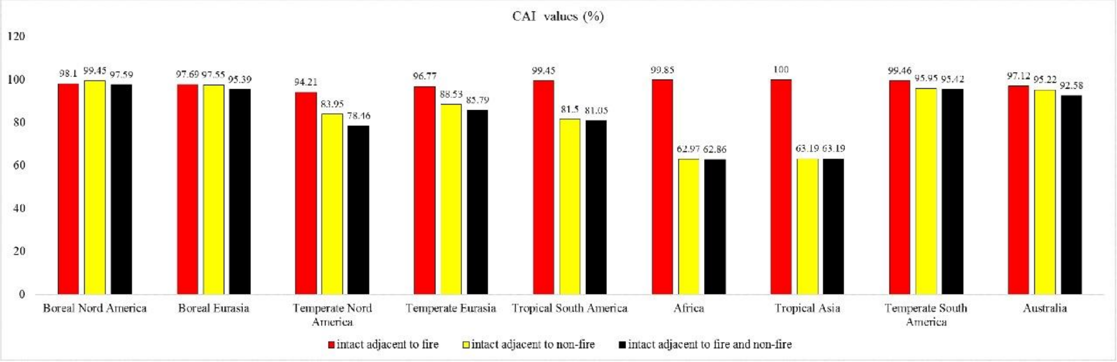

Fig. 7: Patch area weighted mean CAI values per geographical region.

Conclusion

IFL play a vital role in maintaining ecosystems biodiversity by offering favourable habitats for a wide range of species. Despite their isolation and immense size, between 2003 and 2013 numerous IFL patches have already been disturbed by human caused fragmentation or alteration, changes which could consequently affect the ecological integrity of the large neighbouring unaffected ones. The amount of shared edge between altered and non-altered IFL patches represents an essential piece of ecological information suitable for assessing the intact ones functionality as optimal habitats for either interior or edge preferring species. Landscape ecology methods represent an indispensable tool commonly used for modelling landscapes spatial and structural characteristics through the use of a wide range of metrics, measurable at both patch and class level, such as the ECON and the CAI indexes.

Our models highlighted that until 2013 none of the nine world geographical forest regions non-altered IFL patches suffered potential dysfunctions as habitats for both types of species when taking into account the amount of common border with altered IFL patches by fire or non-fire induced causes. The only exception is represented by the equatorial forests of America, Africa and Asia which are characterized by alarming potential future malfunctions.

We therefore strongly recommend attempting actions in two well evidenced directions:

(1) maintaining unaltered at all cost the immense boreal intact forests from North America, Eurasia and of the remote temperate ones from South America and Oceania by expanding the global protected areas network;

(2) implementing rigorous actions for reducing illegal forest exploitation at regional or national scale regarding the higher vulnerable equatorial and northern temperate forests.

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