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Connectivity of Natura 2000 Forest Sites

Executive report

Christine Estreguil

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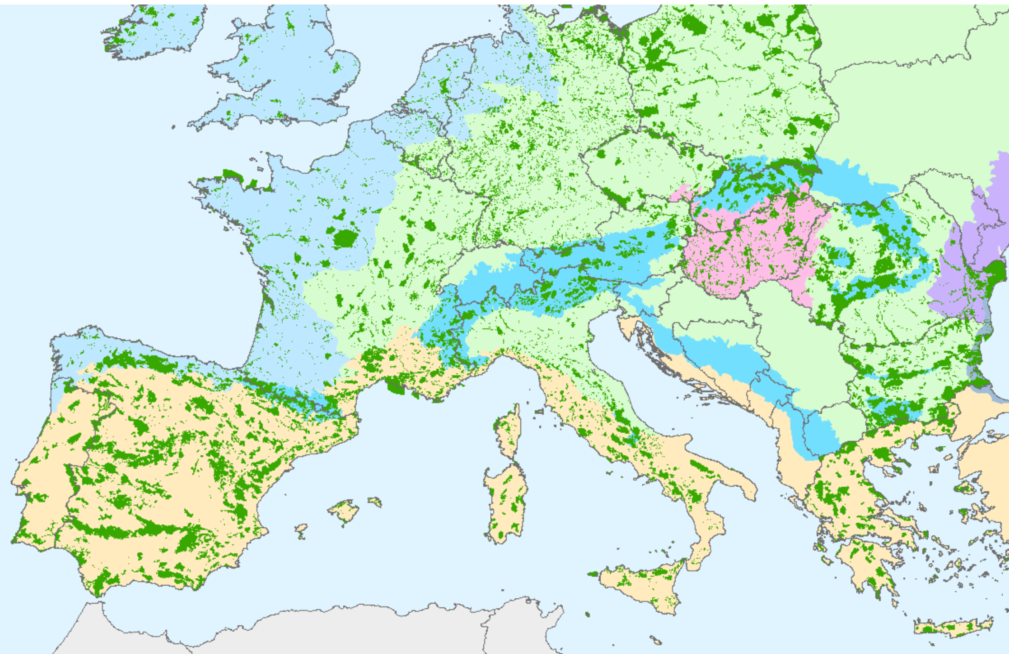

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Connectivity of Natura 2000 forest sites

Executive report

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Abstract

The newly adopted Green Infrastructure Strategy is a key step in implementing targets of the European Biodiversity Strategy to 2020 (EBS). This study responds to policy needs for target 2 on ecosystems conditions and services, target 1 on implementing and enhancing coherence of the Natura 2000 network and sub-target 3b on integrating environmental concerns in forest management. Protected areas such as Natura 2000 sites form the backbone of Green Infrastructure. Their connectivity and integration in the unprotected landscape are essential to enable the movement and dispersal of species, to reduce the fragmentation of habitats and to render ecosystems more healthy and resilient. Connectivity of protected sites depends on the area of site, inter-site distances and landscape suitability (hostile and favourable land uses for species dispersal and movement).

This report describes the JRC integrated model and derived results on the connectivity of Natura 2000 sites (only sites including forest). The model allows a harmonized, easily reproducible and automated EU wide assessment and comparison across countries. The Natura 2000 network is first characterised structurally in terms of simple (physically isolated) and complex sub-nets (spatially connected sites). Natura 2000 shares of complex sub-nets range from 40% in Bulgaria to 5% in Latvia. Second, the functional connectivity of the Natura 2000 subnets is addressed to tackle fragmentation by grey infrastructure including roads and intensive agriculture for species dispersing 500 m in average. A European-wide land use based friction map was created as a proxy of landscape suitability to measure functional (least-cost) distances between sub-nets. Functional connectivity was assessed according to two foci: one focused more on the area of subnets, another one on the inter-site landscape suitability and distances. The site area weighted index values ranges from 15 % (Denmark) to 78% (Malta). Best connected subnets with respect to inter-site landscape and distance were in Bulgaria, Belgium, Portugal, Ireland and Malta. High shares of functionally isolated subnets were in Greece, Denmark and Portugal. Functionally isolated sites and sites of key importance for connectivity were identified for two countries.

The JRC model and derived analysis constitute a potential input to help building a Green Infrastructure in Europe. It allows the connectivity of protected areas to be assessed, isolated areas to be identified. It could guide regional landscape planning of forest conservation and restoration efforts. It could also contribute data and indicators relevant to the Habitat Directive (Article 10), to Rural Development Programmes (CMEF), the Water Framework Directive (NWRMs), and Target 1, 2 and 3 of the EBS.

Contents

1. Connectivity of protected areas in the policy frame

1.1. Background and rationale

In Europe, natural/semi-natural lands are increasingly eroded and fragmented by the continued expansion of grey infrastructure (urbanization, transport infrastructure, industrialization) and of the slow but continued intensification of land management (unsustainable agriculture and forestry). To remedy these changes hindering bio-diversity, protected areas provide one opportunity to achieve the conservation *in situ* of targeted valuable habitats and species. The Natura 2000 (N2K) network of protected sites, with approximately 26.000 sites covering 1,000,000 km^2, *i.e.* 18% of the territory of the European Union across 27 Member states forms the centre piece of the European Union nature and biodiversity policy (Evans, 2012). It was established under the Habitats Directive (92/43/EEC). To be effective, biodiversity conservation must go beyond protected area boundaries and incorporate the spatial scale of ecological processes, the impact of human activities outside protected areas and the contribution of human-dominated un-protected landscapes to conservation (Vimal *et al.*, 2012). There is the need to acknowledge nature as a system rather than individual parts. The establishment of N2K network (*i.e.* the sum of the individual sites) should be distinguished from the establishment of the overall ecological coherence of the network. Article 10 of the Habitats Directive and Article 3 of the Birds Directive (09/147/EC) specifically include establishing the necessary functional connections inside and outside the designated sites. Only this way, the N2K network could form 'a coherent ecological network' of sites for the conservation of natural habitats and species of Community Interest.

Maintaining or strengthening the ecological coherence of protected area networks would primarily be implemented through providing connectivity (Bennett and Mulongoy, 2006). The connectivity of protected areas and their integration in the wider landscape should be considered as key elements in addition to site coverage and representativeness by eco-region, and to management, governance and financing issues (Aichi target 11 of the Convention for Biodiversity, European Biodiversity Strategy to 2020 (EC, 2011)). Furthermore, Green infrastructure (GI) has been introduced as one essential tool to tackle biodiversity threats resulting from habitat loss and fragmentation, and land use changes. The newly adopted Green Infrastructure Strategy (EC, 2013) is a key step in implementing the following targets of the European Biodiversity Strategy to 2020: target 2 on ecosystems conditions and services, target 1 on implementing and enhancing coherence of the N2K network and sub-target 3b on integrating environmental concerns in forest management. Protected areas, such as N2K sites, form the backbone of GI. One key- principle of GI is on increasing the spatial and functional connectivity between natural and semi-natural – protected and un-protected – areas, paying attention that land management delivers multifunctional benefits such as maintaining and improving ecological functions. Spatial planning is also mentioned to guide development away from sensitive areas and promote the restoration and enhancement of ecosystems and connections between natural areas.

In forestry, sustainable forest management practices integrate more and more biodiversity aspects such as deadwood, monitoring of threatened species, use of natural regeneration and mixed tree species stands (FOREST EUROPE *et al.*, 2011). However, they rarely apply a landscape approach for the strategic planning of afforestation-reforestation measures. Fragmentation, land uses changes at forest edges and changes in connectivity of forest fragments affect ecological processes such as gene flow, pollination, wildlife dispersal, and by doing so, affect habitat provision services. Forest patterns have also a role to play for disturbance and climate regulation services as for example, in modulating pest propagation or in species ranges expansion under climate change (Gil-Tena *et al.*, 2013).

In protected areas, forest communities are often close to natural forests such as old-growth forest, uneven-aged stands with multiple tree species and high amount of deadwood; they provide habitats for forest dwelling animals, plants and fungi species. To be resilient, such forests require a degree of connectivity that does not seem to be available in the intensively harvested forest landscapes of today. Harvested forests have younger, even-aged stands of single tree species which consequently have fewer deadwoods and where deciduous trees are more rarely used. Lack of connectivity can produce not yet visible extinction debts. In many cases there may still be time to hamper such extinctions through landscape restoration and better planning of the production landscape in-between protected areas (Bergsten *et al.*, 2013). To integrate biodiversity conservation in the management of N2K forest spaces, Velasquez *et al.* (2010) proposed an environmental diagnosis based on vital functions (floristic richness, forest structure, habitat area and recovery capacity) and the fragility of the space (fire and erosion hazards, fragility of vegetation). The connectivity of protected areas could represent an additional criterion to complement this diagnosis and to further generate management areas and prioritise actions.

The JRC develops research on integrated modelling to improve the European-wide assessment and reporting on fragmentation and connectivity; this topic is addressed at ecosystem level (forest) and at the level of protected areas. The activity responds to policy needs of implementing targets 1, 2 and 3b of the European Biodiversity Strategy to 2020 (EC, 2011). This study builds upon a set of indices from previous forest application (Estreguil *et al.*, 2012) and develops them further to assess European-wide, the connectivity of N2K sites (including forest) in a harmonized way across Member States. Since no single map of GI exists, this study illustrates one possible way to integrate the concern of connectivity of protected areas in the mapping exercise of GI.

1.2. Definitions and measures

Assessing the ecological connectivity of protected area networks is not straightforward due the current lack of detailed knowledge of the ecological requirements of many species and habitats (Opermanis *et al.*, 2012). The challenges further increase with the scale of the concept, on providing a vision of a series of functionally inter-connected landscape elements and on transforming this vision into reality on the ground.

In ecology, connectivity has two components: the physical links between elements of the spatial structure of a landscape (*i.e.* 'connectedness') and the functional connectivity, depending on species and research opportunities. The later has been measured as the distance between sites, structure and composition of landscape, dispersal success between sites and search time travelling from one to another site. Connectivity is thus a combined product of structural and functional connectivity, *i.e.* the effect of physical landscape structure and the actual species use of the landscape (Tischendorf and Fahrig, 2000ab). When applied to protected areas, measures should not necessarily be to link individual patches with physical structures (such as corridors of similar habitat), but to ensure the existence of required functional connections between sites (*e.g.* inter-site distances or/and landscape permeability).

Functional connectivity between protected areas like N2K sites can be measured by the dispersal success of species listed in Annexes of the EU Habitats Directive based on the presence of same species on paired sites. Such approach was applied in Opermanis *et al.* (2012) to address the trans-boundary connectivity of the N2K network on the basis of the presence of 192 reptile, amphibian, invertebrate and plant species from Annex II. Data on dispersal successes of species are not systematic and are often insufficient to allow a European-wide study for forest habitats and species. In alternative, 'structural' connectivity measures like sites' connectedness are more easily implementable. Such measures are however considered too simple because they solely refer to Euclidian distances between sites and a neutral landscape; they do not account for different dispersal capacities of species depending on distances and landscape suitability in between sites. Connectedness is generally assumed to be a key factor contributing to connectivity; landscape connectedness and biological connectivity are often, but not systematically, correlated (Campagne *et al.*, 2009) as recently shown between paired N2K sites (Opermanis *et al.*, 2012).

JRC developed an easily repeatable and automated model to assess the connectivity of protected areas in broad structural and functional terms (Table 1). The model is a compromise between a pure functional biological model and the commonly and traditionally used connectedness measure (*e.g.* Opermanis *et al.*, 2012).

2. Databases and models

To measure the connectivity of protected sites, the JRC integrated model requires three data inputs: (1) the protected area network layer, (2) a land use/cover layer 'translated' into hostile and favourable land use/cover for species dispersal and movement, (3) a arbitrarily fixed average dispersal distance of species in a landscape of medium suitability.

Figure 1. Natura 2000 sites network with forest spaces

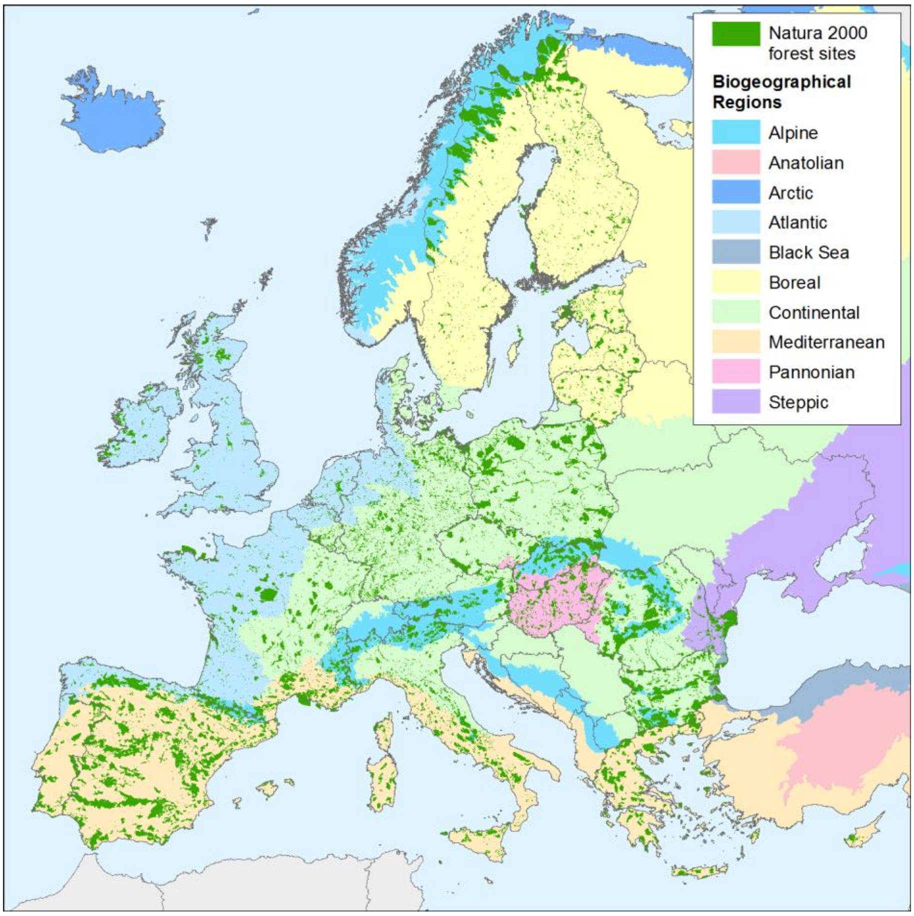
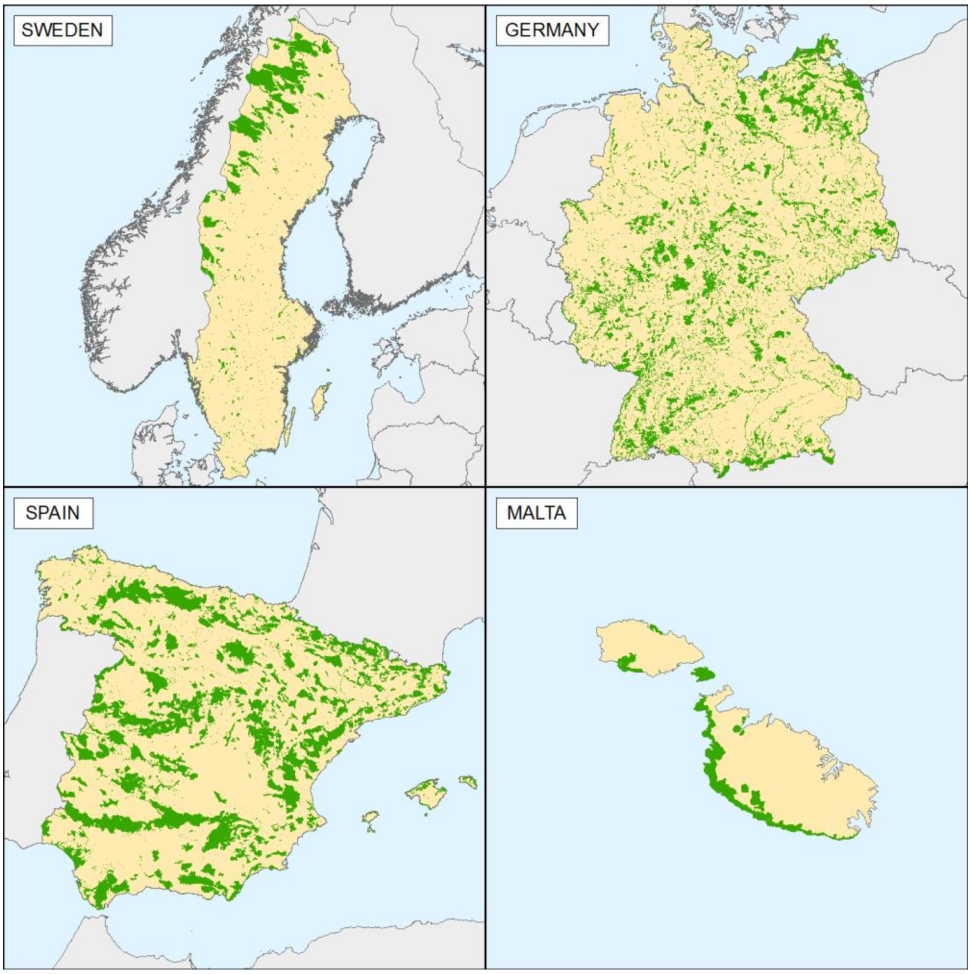


Figure 1 illustrates the European-wide distribution of the network of N2K sites where the presence of forest is declared within the N2K Site Standard Form[1]. The classes of forest cover are: N16 "Broad-leaved deciduous woodland", N17 "Coniferous woodland", N18

[1] Natura 2000 dataset, temporal coverage 2011: http://www.eea.europa.eu/data-and-maps/data/ds_resolveuid/60860bd4-28d6-44aa-93c7-d9354a8205e3

"Evergreen woodland", N19 "Mixed woodland". Circa 80% of the N2K sites include forest. Differences among countries in terms of sizes and number of sites, their distribution as well as distances between sites are obvious as shown in Figure 2.

Figure 2. Country differences in the Natura 2000 network. In Sweden (top left) sites are sparsely distributed in a wide country; in Germany (top right) sites are numerous and of a small size; in Spain (bottom left) sites are large and closer one another; in Malta (bottom right) sites are few but closely located in a small country.

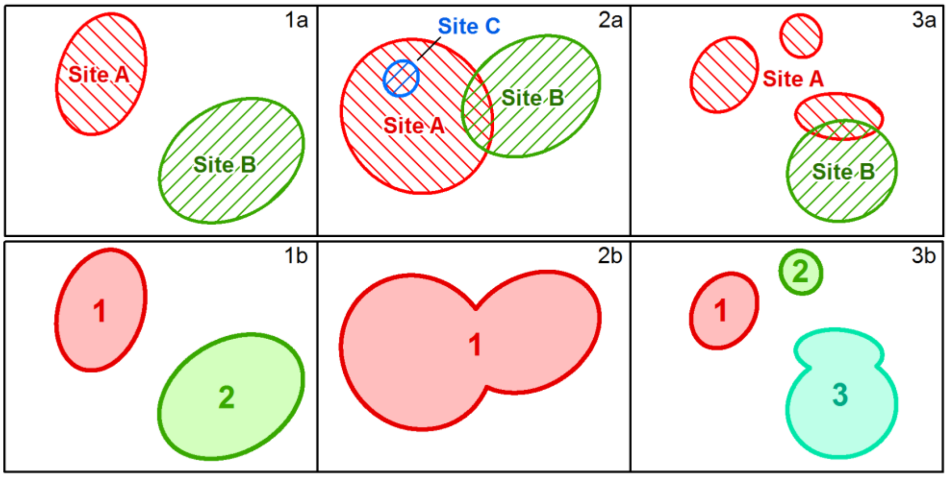


For further input into the model, all vector polygons representing the extracted site areas had been converted in a raster file (100 m spatial resolution) in order to generate sub-network (subnet) components which were formed by one or more N2K sites in case of overlap (sites physically connected) (Figure 3).

The second data input into the JRC model was the European-wide land use based friction map. It was created as a proxy of landscape resistance to measure functional (least-cost) distance between sites. Landscape resistance and suitability for species movement and dispersal is species specific. For this analysis, hostile land uses for the dispersal of animals and plants were based on the threats and disturbances they often represent for biodiversity, such as land uses derived from urbanization, industrialization, intensive agriculture and road infrastructure. The Corine Land Cover (CLC) map of year 2006[2] was reclassified into three land cover classes (artificial, intensive agriculture, natural) to form the main layer for the friction map.

[2] The Corine Land Cover (CLC) map of year 2006 version 16 was downloaded from the European Environment Agency web site, available at 100 m raster resolution with 44 land cover/use classes (Inspire grid compliant) and reclassified into three friction classes. http://www.eea.europa.eu/data-and-maps/data/ds_resolveuid/ef13cef8-2ef5-49ae-9545-9042457ce4c6

Figure 3. Three examples of distribution of Natura 2000 sites and rasterization into subnets for subsequent analyses: (upper figures 'a') polygons representing the site boundaries; (lower figures 'b') conversion into raster subnets. In examples 2 and 3 the number of sites doesn't correspond to the number of subnets.



Since roads represent barriers to most natural wildlife movements, the CLC map was further enriched by the fine resolution European-wide main road network (highways, motorways, national roads) available from the Open Street Map (OSM) web site (Haklay *et al.*, 2008; Bennett, 2010; www.openstreetmap.org) (Figure 4). The OSM layer has the advantage to localize features like bridges, viaducts, tunnels and eco-bridges, which are points facilitating species movements. They were accounted in final road paths. "Movement resistance" (or friction) values were assigned to every land use by using a logarithmic friction scale from 1 to 1,000 per distance unit (1 m): 10 for natural and semi-natural land cover, 100 for 'more intensive' agricultural lands, 500 for national roads and the highest 1,000 values for artificial surfaces (urban, highways and motorways). The movement cost inside all protected areas was set as equal to 1. "NoData" value (no movement) was given to water bodies.

Figure 4. Preparation of land use based friction map: (left) Corine Land Cover 2006 layer, (centre) Open Street Map layer showing a tunnel further accounted into the final friction map (right).

The JRC model requires two entry parameters, a specific average species dispersal distance and a landscape of medium suitability for species dispersal. A 500 m distance was taken as the average dispersal capability of 'connectivity sensitive' forest dwelling species. As suggested by Opermanis *et al.* (2012), a distance limitation to a maximum of 1 km between sites in a pair seems fair to study connectivity of trans-border protected sites as it reflects well the possibilities of most *taxa* to travel between sites given their maximum dispersal capacities. Vittoz and Engler (2007) estimated upper limits of the distances within which 50% and 99% of the seeds of a plant population are dispersed for seven dispersal modes. Distances related to trees were 500 m up to 1.5 km in most cases of animal vectors (zoochory) and 40 m up to 150 m in case of anemochory and small mammals. Moreover, the probability of species dispersal in between a pair of protected sites depends on the presence of hostile land uses between the sites. The functional analysis applies a probabilistic model of connectivity where the probability of dispersal decreases as an exponential function of the effective distance and the landscape resistance. 50% probability of dispersal was set at 500 m distance in a landscape of medium resistance (set at 100)[3]. For example, there is the same 50% of probability that species disperse 500 m in agricultural lands, or 5 km in natural/semi-natural lands or 50 m in artificial lands.

Figure 5. Structural connectivity analysis of a complex and a simple subnet: (top-left) subset of seven N2K sites; (top-right) binary masking of N2K sites into two subnets; (bottom-left) morphological analysis by GUIDOS MSPA; (bottom-right) complex subnet classified into 6 nodes and 4 links.

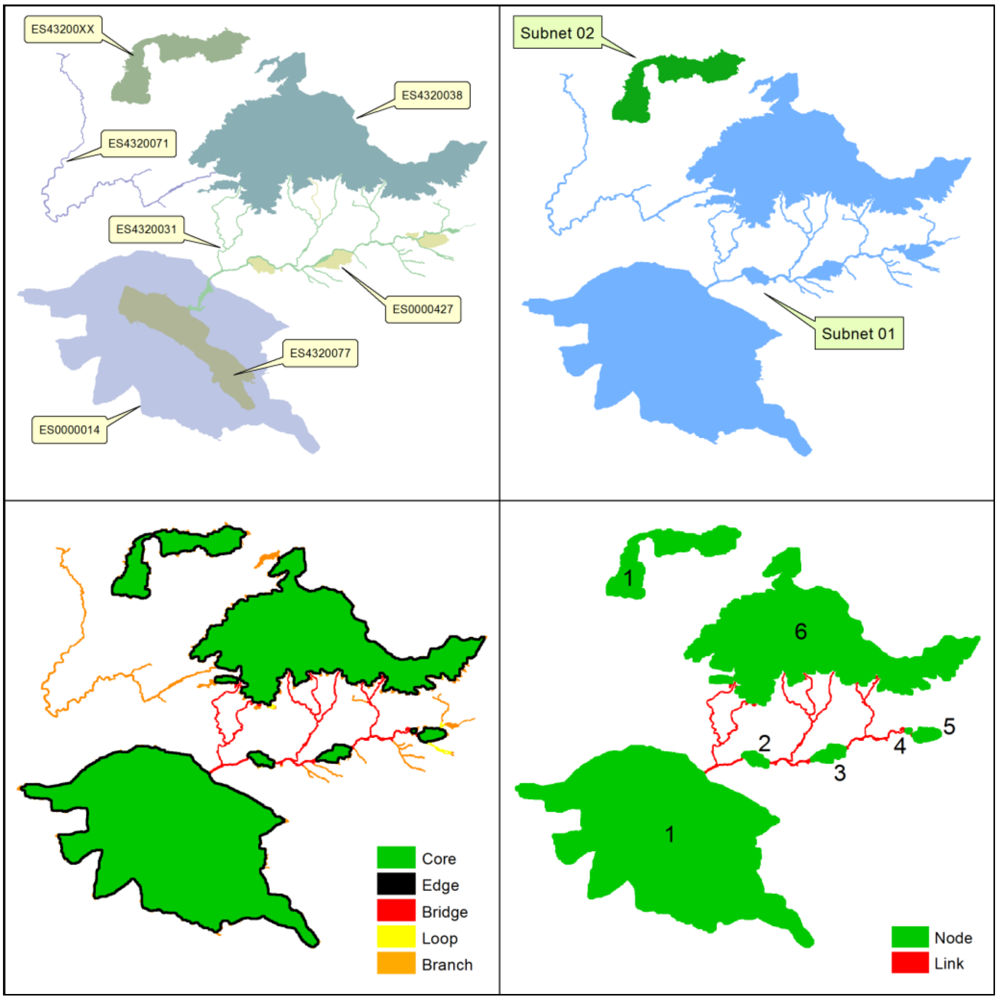


Table 1 provides the outcome of the JRC integrated model based on indices that were computed and organized into three main families:

- First, general background information on the N2K sites network was provided on the land proportion of the N2K sites, the median size and the maximum size of subnets and the inter-site landscape composition in terms of natural/semi-natural, 'more intensive' agriculture and artificial surfaces.

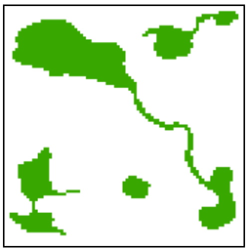
[3] The cost distance matching the 50% probability was 50,000, which corresponds to the average dispersal distance (500 m) multiplied by the average friction per distance unit (100). A cost limit was set to 250,000 to avoid heavy computation of cost paths between distant subnets, which are already connected through other subnets between them. A cost of 250,000 is equivalent to 2.5 km in agricultural lands, 25 km in natural/semi-natural lands and 250 m in artificial lands.

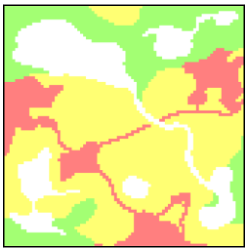
- Second, the structural connectivity of the N2K sites network was obtained from the Morphological Spatial Pattern Application of the GUIDOS[4] free-download software (Soille and Vogt, 2009) of the N2K sites network binary layer. The network was characterised structurally in terms of simple (physically isolated) and complex subnets (spatially connected sites made of protected nodes and links) (Figure 5).

- Third, functional connectivity was measured with a network based habitat availability model. The functional distance between sites was computed from the land use based friction map with the "least cost path" method, which provided the cheapest friction path from site to site through the landscape. Functional subnets were defined as those from which at least, one least cost path was found to another subnet. The average of all non-null probabilities of dispersal between each pair of subnets ('active connectivity mean' index) was computed to translate how strong the probability of dispersal is. Functionally isolated subnets were those from which no least cost paths were found and the N2K share in isolated subnets was quantified. Functional connectivity indices were selected from the simplified power weighted probability of dispersal function introduced in Estreguil *et al.* (2012). They were obtained from the Conefor[5] free open source software (Saura and Torné, 2009) on the basis of the area of each site, their topology and inter-site effective (least cost) distances for a given species dispersal ability (arbitrarily fixed as 500 m in a landscape of medium resistance (100)). The two functional indices were: the site area weighted Root Probability of Connectivity (RPC) and the un-weighted Root Average Probability of Connectivity (RAPC).

[4] forest.jrc.ec.europa.eu/download/software/guidos
[5] www.conefor.org

Table 1. Three families of standardised indices.





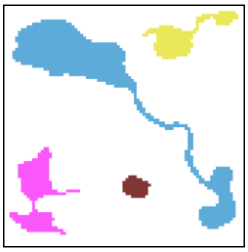
NATURA 2000 SITES AND THE LANDSCAPE IN BETWEEN SITES

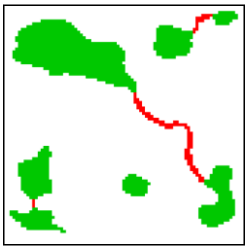
A Natura 2000 site (green shade in upper figure) may be one single designated site, or corresponds to a group of sub-sites under the same site identifier. The landscape in the wider country side (*i.e.* outside Natura 2000 sites) is described into four friction classes depending on land uses: *Natural–semi-natural (incl. forest)*, *Agricultural, Artificial incl. large roads lands* (respectively pale green, yellow and salmon shades in lower figure).

Indices:

- Land proportion of Natura 2000 sites (incl. forest) per country.
- Inter-site landscape composition: land share of artificial land, agricultural land and natural/semi-natural land per country and in EU.

Why? Protected forest land in Natura 2000 sites offers spaces where attention should be paid on maintaining (or restoring) favourable conservation status of forest habitats and forest dwelling species. Intensive land uses such as artificial and agricultural lands, by contrast to natural/semi-natural lands, likely makes it difficult for forest-dwelling animals and plants to move or disperse their seeds in between N2000 protected sites. The predominance of intensive land uses is a factor which affects the ecological coherence of the protected N2000 network.





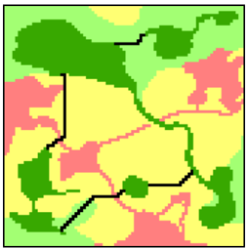
STRUCTURAL CONNECTIVITY OF NATURA 2000 SITES

The structural connectivity of the Natura 2000 sites' network is described in terms of sub-nets according to morphological shapes. Sub-nets are categorised as *complex sub-nets* when they are made of *nodes* (site wider than 200 m, minimum area 90 ha; bright green shade in lower figure) which are physically connected with *links* (e.g. linear site less than 200 m wide ; red shade in lower figure). Alternatively, they are categorised as *simple subnets* (one single node) when they are physically isolated from other sites in the non-protected landscape.

Indices:

- Number of subnets, subnets median size, subnet maximum size
- Share of Natura 2000 sites in simple and complex subnets.

Why? Subnets include protected forest spaces which provide the best conditions for forest habitats and species conservation. Complex subnets offer inter-connected and protected spaces for dispersal. Links are likely more exposed to the penetration of invasive species due to their shape and size than nodes. Still, they offer key connecting or stepping stones features for the dispersal of forest species. Simple subnets, particularly when their size is small, may be considered for physical connection to others subnets by landscape planners and conservationist to enhance the whole structural connectivity of the N2000 network.



FUNCTIONAL CONNECTIVITY OF NATURA 2000 SITES

The probability of functional connectivity of Natura 2000 network depends on the size, number and arrangement of Natura 2000 subnets, the inter-subnet functional distance and the landscape suitability in between subnets (proxy of resistance to the dispersal of animals and plants). The model applied a 500m species dispersal ability in a landscape of medium resistance (100). The presence of 'least cost' paths (black lines in figure) connecting subnets makes the subnets functionally connected.

Indices:

- Site area weighted functional connectivity of Natura 2000 sites: the RPC index varies with site number and area, inter-site distance, and landscape resistance. The area of each site has a significant weight in the calculation.
- Un-weighted functional connectivity of Natura 2000 sites: the RAPC index is similar to the RPC index, but the area of each site has no influence in the calculation, thus given more importance to the distance and landscape suitability in between sites.
- Active connectivity mean (only functionally connected subnets): the index provides the mean of all non-null probabilities of connectivity, translating how 'strong' functional paths are when they exist.
- Natura 2000 sites share into isolated subnets (with null probabilities of connectivity)
- Localized key sites in providing connectivity and isolated subnets in Natura2000 network

Why? The lack of functional connectivity reduces the capability of organisms to move in between protected sites and can interfere with pollination, seed dispersal, wildlife migration and breeding. The Green Infrastructure debate includes mitigating sites' isolation to make ecosystem more resilient. This may be obtained by decreasing landscape resistance and/or distances in between sites and/or creating new protected sites where needed.

3. Connectivity analysis of Natura 2000 network

3.1. Structural connectivity

Table 2 provides the shares of N2K sites including forest spaces distributed as simple subnets (single node/site physically isolated) and as complex subnets (physically inter-connected sites as nodes and links) per country and for the whole of Europe. As expected, we observe in all countries high shares of *simple subnets*. The level of intra-connectivity of subnets depends on how large the areas of subnets are. Countries show differences in shares of complex subnets ranging from Bulgaria with nearly 40% share down to 5% in Latvia. The N2K network in Latvia is structurally less connected than in Bulgaria. This is due to lower share of complex subnets and also to smaller sizes of subnets. Additional information available in Figure 5 tells that Latvia has more subnets but their sizes are smaller than in Bulgaria (smaller median size).

Country	Simple subnet	Complex subnet
BG	60.4%	39.6%
CY	75.0%	25.0%
LU	76.0%	24.0%
BE	76.8%	23.2%
DK	76.9%	23.1%
ES	77.8%	22.2%
RO	77.9%	22.1%
AT	80.4%	19.6%
HU	80.4%	19.6%

Country	Simple subnet	Complex subnet
NL	80.4%	19.6%
IE	80.6%	19.4%
UK	82.7%	17.3%
DE	82.9%	17.1%
LT	83.4%	16.6%
CZ	84.5%	15.5%
PL	84.7%	15.3%
PT	85.5%	14.5%
EUR	**85.9%**	**14.1%**

Country	Simple subnet	Complex subnet
IT	87.1%	12.9%
FR	87.2%	12.8%
MT	88.9%	11.1%
GR	90.3%	9.7%
SK	90.4%	9.6%
EE	90.9%	9.1%
FI	93.1%	6.9%
SE	93.8%	6.2%
LV	94.9%	5.1%

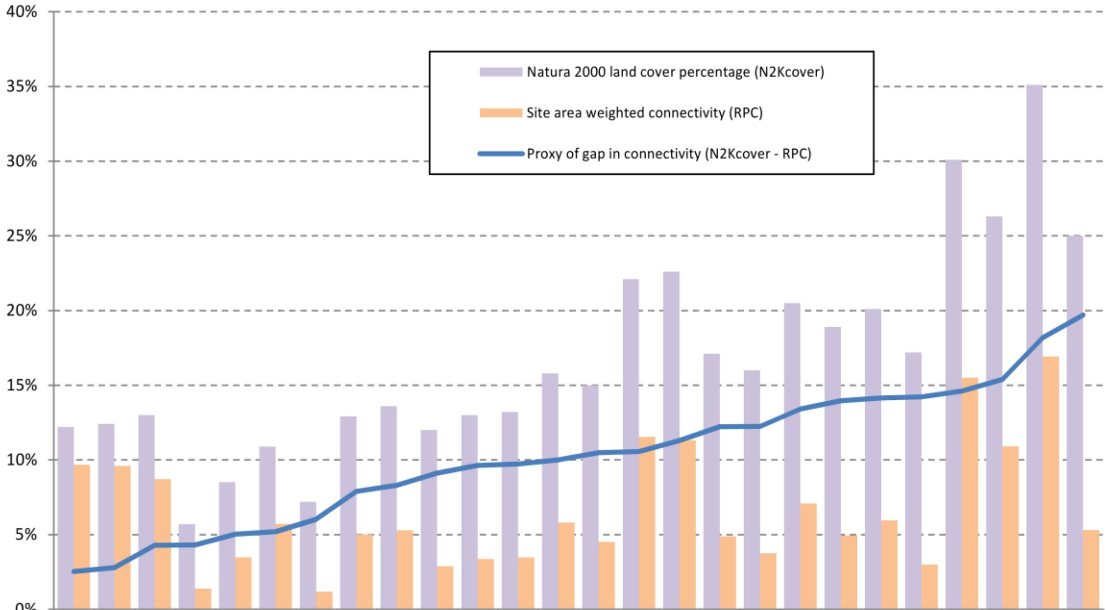
Table 2. Shares of Natura 2000 sites including forest spaces as simple subnets (single node/site) and as complex subnets (nodes and links) per country.

3.2. Functional connectivity

Figure 6 provides the country-based results on the functional connectivity of the N2K network with emphasis on the site sizes (site area weighted connectivity index value - RPC). To ease interpretation, the chart includes the N2K land cover area shares per country, as well as a proxy of the gap in connectivity and a table which provides the number of subnets, the subnet median size and the subnet maximum size. The difference between the N2K land cover percentage and the RPC index value translates the gap in connectivity, in absolute value. It represents a proxy of the effort to be made in each country to reach an area equivalent maximally connected network (N2K distributed as a single subnet). Countries are ranked per increasing absolute gap in connectivity.

We can notice that large median sizes of subnets (Greece) or high number of subnets (Germany, France and Sweden) or the presence of very large subnets (Poland, Finland, Sweden, and France) are not obviously associated with high functional connectivity of the N2K network.
Each country has specific subnets area and distribution and inter-site landscape suitability. Countries with lowest connectivity gaps towards a maximally connected network are Malta, Cyprus, and Ireland, while highest gaps are found for Spain, Bulgaria and Greece. Lithuania, France, Austria and the Czech Republic show similar gaps. Countries with similar N2K land cover percentage also show different connectivity gaps (for example, Italy and Portugal).

Figure 6. National profile of functional connectivity of the Natura 2000 sites including forest. Focus is on site-area weighted analysis of connectivity



	MT	CY	IE	UK	NL	SE	DK	FI	BE	LV	LT	FR	AT	CZ	LU	RO	PT	DE	PL	EE	HU	IT	SK	ES	BG	GR
Number of subnet.	9	44	284	1090	184	3088	178	2952	1036	296	312	3965	297	665	79	371	69	6931	854	699	611	1230	207	849	131	227
Subnet. median size (km^2)	0.9	1.1	0.8	0.9	3.1	0.6	5.1	0.7	0.9	2.7	2.1	0.5	1.4	0.8	0.5	6.5	4.9	0.8	2.6	1.3	2.5	5.1	1.2	5.0	12.6	30.9
Subnet. max size (km^2)	30	635	2624	2704	1012	15908	223	7557	385	936	948	5412	2813	2196	88	18649	1842	4398	9729	729	2632	2238	6837	25191	10656	2930

In Figure 7, functional connectivity is again reported with emphasis on site sizes but is presented to allow a comparison of the connectivity status of the N2K network among countries (ratio of RPC to the N2K land cover percentage). Countries with well-connected networks are Romania, Slovakia, Luxembourg, Sweden, Ireland, Cyprus and Malta. Countries with least connected networks are Denmark, Italy, and Greece.

Figure 7. Country-based status in connectivity (RPC/N2Kcover)

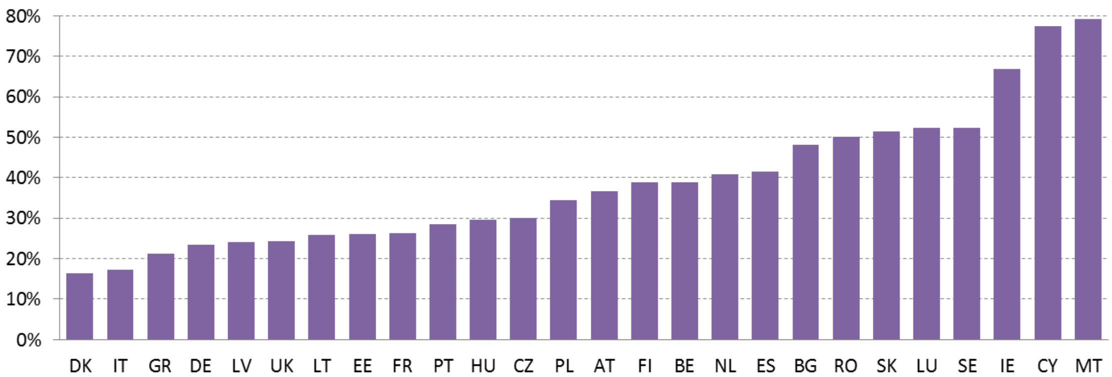
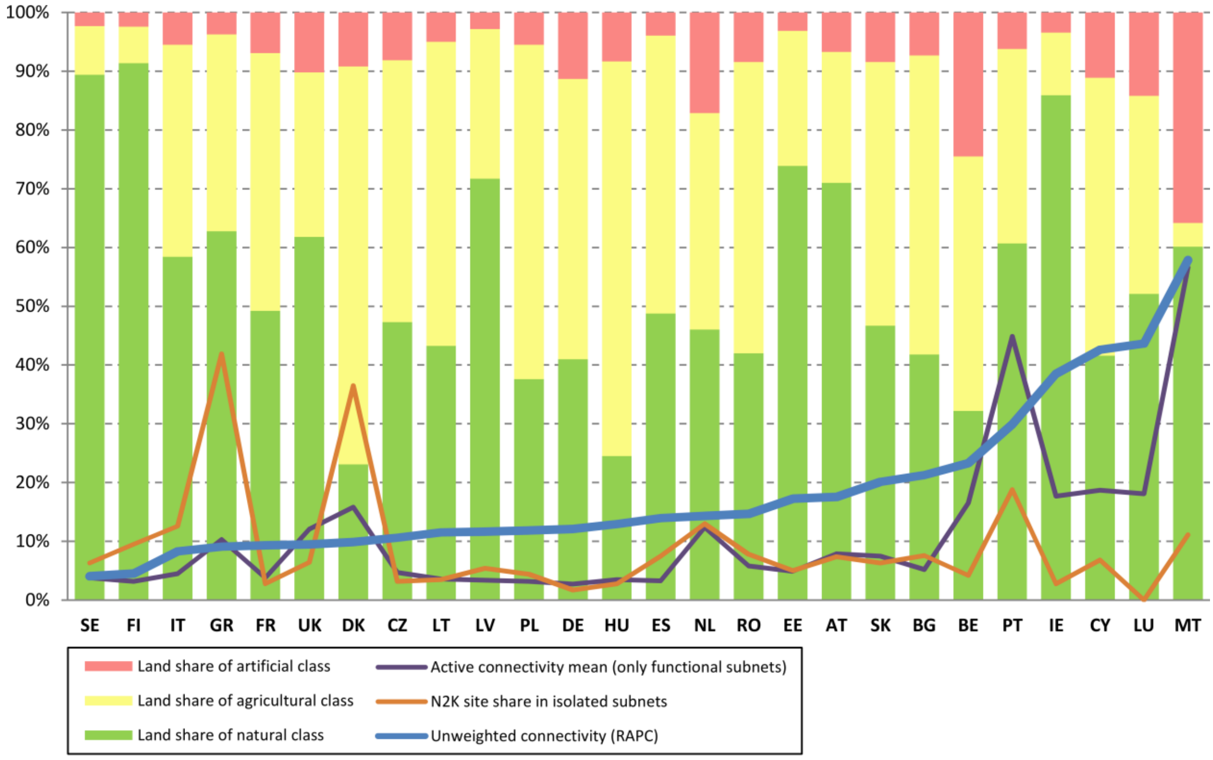


Figure 8 provides the functional connectivity of N2K sites, now from the point of view of inter-site distances and inter-site landscape resistance along least cost paths connecting sites (un-weighted connectivity index RAPC). All sites are considered equal in area. Countries are ranked per increasing RAPC index value. Countries with well-connected networks are Bulgaria, Slovakia, Belgium, Portugal, Ireland, Cyprus, Luxembourg and Malta.

The chart also provides the landscape composition in between N2K sites in terms of land cover shares in artificial, agricultural and natural lands per country. The country-wide landscape composition does not necessarily explain the functional connectivity of the N2K network. For example, countries dominated by natural lands like Sweden and Finland have a favourable landscape but do not show high connectivity values due to too

large distances between sites (figure 2). Also, countries with high country-wide shares of artificial lands like Malta, Belgium, and Netherlands do not have low connectivity index values due to the distribution of sites and the existence of functional paths in between.
Figure 8 also includes the active connectivity mean (only functionally connected subnets) as well as the N2K subnet shares in isolated subnets. The highest shares of isolated subnets are found in Greece (effect of sea isolating islands), Denmark and to a less degree in Portugal and the Netherlands. When only considering functionally connected sites, Portugal shows the second highest active connectivity mean which translates suitable inter-site distances and landscape along least cost paths (with respect to 500 m dispersal distance and landscape friction values as given in section 2). Malta is a small island with few but closely located sites, and as a result shows the highest active connectivity mean.

Figure 8. National profile of functional connectivity of the Natura 2000 sites including forest. Focus is on unweighted analysis of connectivity, and the landscape composition between sites. (in Europe, shares of natural, agricultural and artificial lands are respectively 56.2%, 37.4% and 6.4%)



4. Model application for prioritization in landscape restoration and planning

4.1. Key protected sites providing connectivity and gaps

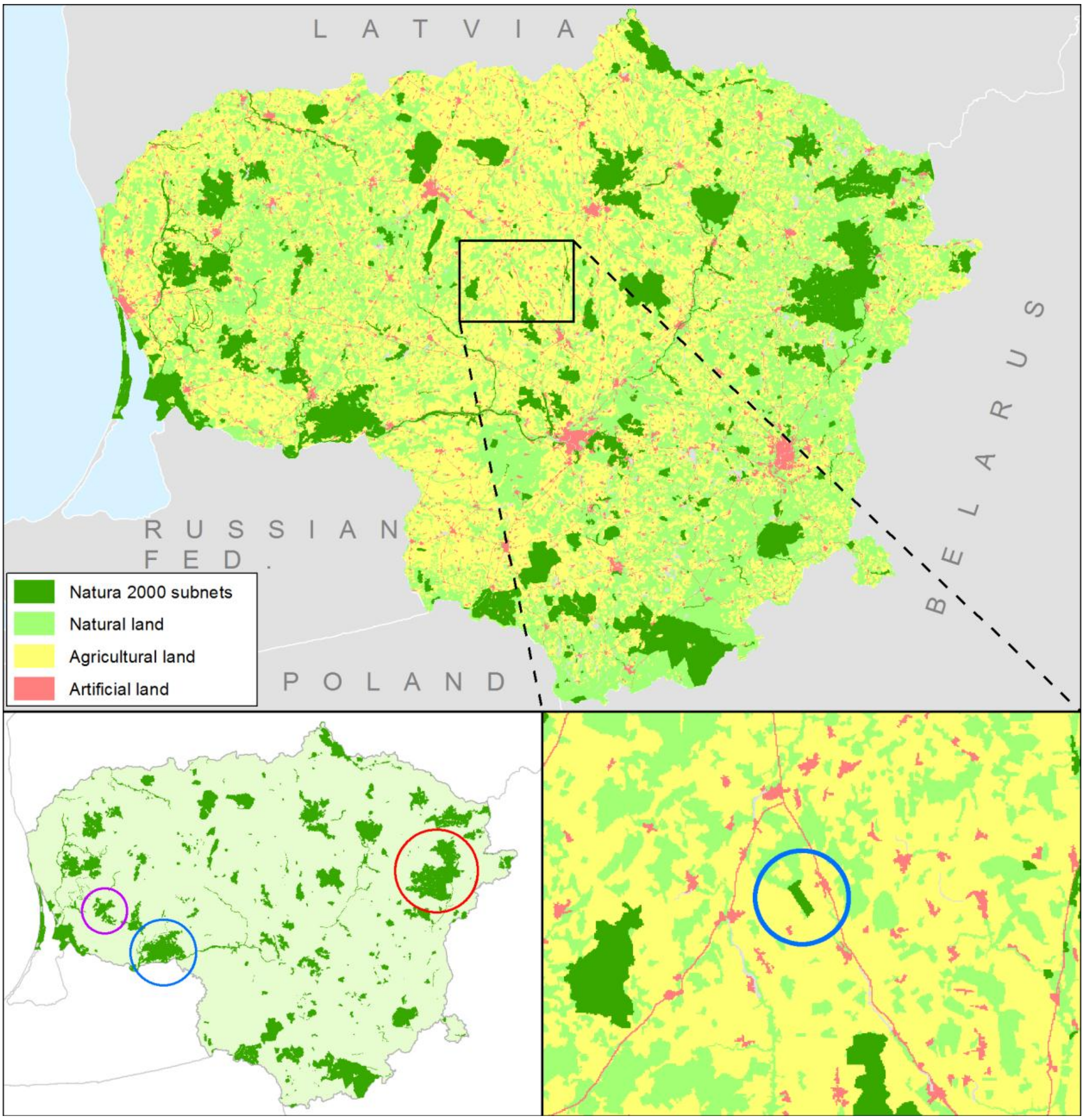
Lithuania was chosen as a case study to illustrate the identification of key subnets providing connectivity in the N2K network (sites including forest). Gaps in connectivity are also identified by the presence of isolated subnets. The list of the first most important subnets and isolated ones are provided below and located in figure 9:

- Subnet 85 (Figure 9, bottom left, red circle) was identified by calculating the difference in connectivity with and without this subnet (dRPC and dRAPC); it includes 12 sites, the largest: LTIGN0018 "Aukstaitijos Nacionalinis Parkas" and LTMOL0010

"Labanoro Regioninis Parkas", with habitats of European interest 9010 "Western Taïga", 9050 "Fennoscandian herb-rich forests with *Picea abies*" and 9020 "Fennoscandian deciduous swamp woods".

- Subnet 185 (Figure 9, bottom left, blue circle) was identified by calculating the difference in connectivity with and without this subnet, its key role resulted to be a connector with other subnets (dRAPCconnector); it includes 27 sites, the largest LTJUR0008 "Karsuvos Giria" and LTTAU0006 "Viesviles Aukstupio Pelkynas" with habitats of European interest same as above.

Figure 9. (top) the Natura 2000 network and friction map in Lithuania; (bottom left) three key subnets providing functional connectivity; (bottom right) isolated subnet.



- Subnet 155 (Figure 9, bottom left, purple circle) was identified by calculating the difference in connectivity with and without the subnet, its key role resulted to be a connector with other subnets (dRAPCconnector); it includes 2 sites, LTSLUB004 "Vainuto Miskai" and LTSIL0005 "Zaliosios Miskas", presence of forest but no habitats of European interest listed.

- Subnet 128 (Figure 9, bottom right), which includes the site LTRAD0002 "Strazdyne", was found isolated. This site has habitats of interest 9020 "Fennoscandian hemiboreal natural old broad-leaved deciduous forests" and 91E0 "Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior*", it is an important botanical reserve surrounded by agriculture and spruce plantations.

4.2. Impact of roads on isolation and change in connectivity

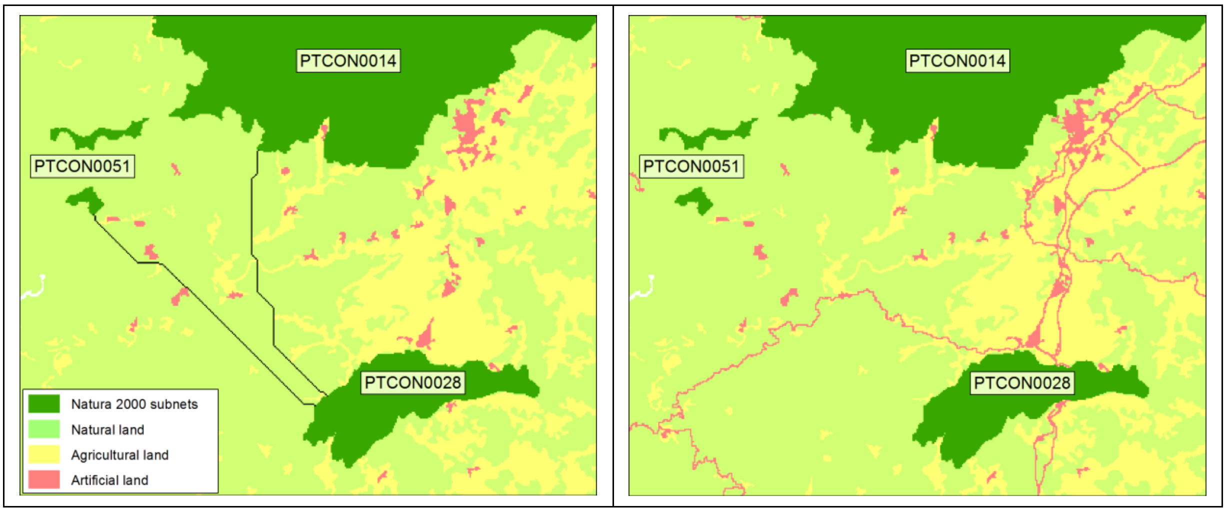
Portugal was chosen to address the impact of roads on the connectivity of N2K sites and to demonstrate how changes could be reported using the current model.
For year 2006, Table 3 illustrates the significant impact that roads (increase of 2% land share) had in reducing functional connectivity for both indices, the area weighted index (RPC) and the un-weighted index (RAPC) more sensitive to landscape resistance and distance. The impact of roads was also significant in increasing the number of isolated subnets.

INDEX	CLC 2006 with OSM roads	CLC 2006 without OSM roads	CLC 1990 without OSM roads
RPC	4.88%	5.11%	5.12%
RAPC	29.92%	30.21%	30.47%
Isolated subnet	18.8%	11.6%	10.1%
Land share of artificial class	6.2%	4.2%	2.3%
Land share of agriculture class	33.1%	34.1%	36.1%
Land share of natural class	60.7%	61.7%	61.5%

Table 3. Impact of roads and changes in connectivity of the Natura 2000 network

Figure 10 shows the isolated subnet (site PTCON0028 "Gardunha") where main habitats of interest listed are 4030 "European dry heaths" and 9230 "Galicio-Portuguese oak woods".

Figure 10. Three Natura 2000 sites located in Castelo Branco District in Portugal: (left) the site 'PTCON0028' has functional paths to nearest sites (black line) when the friction map has no roads while (right) it is isolated when roads are mapped.



The 1990-2006 change results that are given in Table 3 must be taken only for demonstration purposes of the model. For the landscape resistance, the friction map was solely based from the CLC layers of years 2006 and 1990. In 1990, the OSM road network was not available. Also, the N2K network did not exist in 1990. We applied the consolidated version (European Environment Agency, 2011) as for year 2006. With no road layers available, a rather stable connectivity of the N2K network and a minor increase of isolated networks were found between 1990 and 2006. Changes of landscape resistance involved mainly changes in artificial (urban) lands and agriculture and probably did not affect significantly least cost paths between N2K sites.

5. Conclusions

This report described the JRC integrated model and derived country based results on the connectivity of Natura 2000 sites (only sites including forest). The model allows a harmonized, easily reproducible and automated EU wide assessment and comparison across countries. The model integrates both structural and functional principles; it represents a compromise between a biological model based on dispersal success of species for which data are scarce and the commonly used but too simple connectedness measure based on Euclidian distance and neutral landscape.

The Natura 2000 network was first characterised structurally in terms of simple (physically isolated) and complex subnets (spatially connected sites). Second, the functional connectivity of the Natura 2000 subnets was presented per country with two different foci: one addressed connectivity with emphasis on the area of site, while the other one gave more emphasis on inter-site distance and landscape suitability. Shares of functionally isolated subnets were also given per country. The geo-location of functionally isolated sites and sites of key importance for connectivity were demonstrated for two countries. Entry parameters into the JRC model were the average dispersal distance of species and the choices of suitable and hostile land uses for species dispersal. In this analysis, grey infrastructure (artificial lands and roads), followed by intensive agriculture were considered the most hostile land uses for species dispersing 500 m in average. Natural/semi-natural lands were considered suitable regardless they were open lands or offering shelter for species (like woodlands). They could be adapted to (forest) users' needs and priorities. This analysis could be one input on if and where to take conservation and restoration efforts among and in between Natura 2000 sites in order to enhance the connectivity of designated areas and of ecosystems in the biodiversity context.

The JRC model and derived analysis constitute a potential input to help building a Green Infrastructure in Europe. It allows the connectivity of protected areas to be assessed and isolated areas to be identified. It could guide regional landscape planning of forest conservation and restoration efforts. It could also contribute data and indicators relevant to the Habitat Directive (Article 10), to Rural Development Programmes (CMEF), the Water Framework Directive (NWRMs), and Target 1, 2 and 3 of the EBS.

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Abstract

The newly adopted Green Infrastructure Strategy is a key step in implementing targets of the European Biodiversity Strategy to 2020 (EBS). This study responds to policy needs for target 2 on ecosystems conditions and services, target 1 on implementing and enhancing coherence of the Natura 2000 network and sub-target 3b on integrating environmental concerns in forest management. Protected areas such as Natura 2000 sites form the backbone of Green Infrastructure. Their connectivity and integration in the unprotected landscape are essential to enable the movement and dispersal of species, to reduce the fragmentation of habitats and to render ecosystems more healthy and resilient. Connectivity of protected sites depends on the area of site, inter-site distances and landscape suitability (hostile and favourable land uses for species dispersal and movement).

This report describes the JRC integrated model and derived results on the connectivity of Natura 2000 sites (only sites including forest). The model allows a harmonized, easily reproducible and automated EU wide assessment and comparison across countries. The Natura 2000 network is first characterised structurally in terms of simple (physically isolated) and complex sub-nets (spatially connected sites). Natura 2000 shares of complex sub-nets range from 40% in Bulgaria to 5% in Latvia. Second, the functional connectivity of the Natura 2000 subnets is addressed to tackle fragmentation by grey infrastructure including roads and intensive agriculture for species dispersing 500 m in average. A European-wide land use based friction map was created as a proxy of landscape suitability to measure functional (least-cost) distances between sub-nets. Functional connectivity was assessed according to two foci: one focused more on the area of subnets, another one on the inter-site landscape suitability and distances. The site area weighted index values ranges from 15 % (Denmark) to 78% (Malta). Best connected subnets with respect to inter-site landscape and distance were in Bulgaria, Belgium, Portugal, Ireland and Malta. High shares of functionally isolated subnets were in Greece, Denmark and Portugal. Functionally isolated sites and sites of key importance for connectivity were identified for two countries.

The JRC model and derived analysis constitute a potential input to help building a Green Infrastructure in Europe. It allows the connectivity of protected areas to be assessed, isolated areas to be identified. It could guide regional landscape planning of forest conservation and restoration efforts. It could also contribute data and indicators relevant to the Habitat Directive (Article 10), to Rural Development Programmes (CMEF), the Water Framework Directive (NWRMs), and Target 1, 2 and 3 of the EBS.

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