Landscape Fragmentation in Iceland

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60 ECTS thesis submitted in partial fulfilment of a
Magister Scientiarum degree in Geography

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Abstract

Landscape fragmentation measurements provide baseline data of direct human influence on landscape and habitat systems through land use. In 2011, the European Environment Agency, the EEA and the Swiss Federal Office for the Environment or FOEN created a comprehensive report on the status of landscape fragmentation in 28 European countries, excluding Iceland. This thesis builds on EEA and FOEN methodology in order to create comparable data for Iceland. The Icelandic data set had to be adjusted to the European format to ensure that the results could be compared. The calculations were obtained using GIS software technology, where five types of reporting units were used with six different fragmentation geometries. Three of the six fragmentation geometries were created considering local environmental factors, amending the constraining factors used in the European research. The results indicate that landscape fragmentation in Iceland is low. By revealing the baseline data now, one can account for fragmentation in future infrastructure development planning through monitoring. This can be achieved on a country level e.g. by implementing the base line indicators as one of the factors considered in the newly proposed country planning policy. The effects of fragmentation to ecosystems accrue in a gradual manner. Addressing the issue beforehand can limit costly mitigation measures in the future and furthermore strengthen Iceland’s ability to provide various landscape habitats to the country´s particular flora and fauna.

Útdráttur

Sundrun landslagsheilda er það þegar stórum landslagssvæðum er skipt upp í minni og einangraðari svæði (EEA & FOEN, 2011). Helstu áhrifaþættir eru mannlegir þættir eins borgvæðing sem og línulegir þættir eins og lestarteinar og vegir. Sundrun landslags hefur margvísleg áhrif á búsvæða lífvera, þar sem þau bæði skerðast en einnig breytast að innri gerð. Umhverfisstofnun Evrópu og Umhverfisstofnun Sviss reiknuðu megindlega hver sundrun landslagsheilda væri innan 28 landa í Evrópu (EEA & FOEN, 2011) og var Ísland ekki haft með í þeim útreikningi. Markmið þessarar ritgerðar er að skapa samanburðarhæfar niðurstöður við Evrópsku rannsóknina en jafnframt að skapa heilstæð grunnlínugögn sem gætu nýst innanlands t.d. sem umhverfisþáttur í umhverfismati áætlana eða sem sambærilegur þáttur í umhverfisvöktun skipulagsyfirvalda tengdu nýju landsskipulagi. Mæld sundrun var reiknuð með hjálp landfræðilegra upplýsingakerfa, þar sem sex frábrugðnar formgerðir sundrunar voru metnar með tilliti til fimm samanburðaeininga. Niðurstöðurnar benda til minni sundrunar en víðast hvar í Evrópu. Þó bendir ýmislegt til þess að ástæða sé til þess að vakta áframhaldandi þróun. Áhrifum sundrunar hefur verið lýst sem stigmagnandi vandamáli í Evrópu, þar sem brugðist var við of seint og nú er unnið að því að auka tengingu svæða með dýrum mótvægisaðgerðum. Þar er vandmálið að stórum hluta tengt landspendýrum. Hér á landi hafa áhrif sundrunar búsvæða á tegundahópa ekki verið könnuð. Með því að vakta sundrun landslags við gætum við gætt að því; að á meðan við byggjum upp innviði samfélagsins röskum við ekki samheldni landslagsheilda með sama hætti og á meginlandi Evrópu.

I would like to dedicate this thesis to my grandfathers.
Who both had rich interest in the natural processes
that govern the Earth.

Jónas Jakobsson
through his work in meteorology

&

Guttormur Sigbjarnarsson
through his work in geology

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1 Introduction

Landscape Fragmentation is an important factor which has influenced change to natural habitats and can lead to decline in biodiversity over time. It has been defined as “the result of transforming large habitat patches into smaller, more isolated fragments of habitat” (EEA & FOEN, 2011, p. 9). Hence, fragmentation is looked at from its geometric characteristics where the causes of fragmentation have been identified as firstly linear elements such as roads, railways, rivers, irrigation ditches and fences and secondly spatial elements such as urban areas, water bodies, reservoirs, and inhabitable areas such as glaciers or very steep mountainous land areas.

Human influence on landscape has steadily increased with time. While improving infrastructure and concurrently increasing harvesting of resources, the disturbance to original flora and fauna has increased day by day (EEA & FOEN, 2011). With increased population and improved technology infrastructure becomes more concentrated and therefore denser. This modifies natural habitat areas more than meets the eye at first glance. Fragmenting elements hinder the movement of species around the landscape. This results in reduced connectivity between areas which leads to both the reduction of living space and the increased isolation of individuals. Additionally, it affects the balance of the ecosystem, edge dwelling species can gain an advantage over centre dwelling species or species more vulnerable to noise or human interactions. Therefore, as time passes the habitat transforms and vulnerable species either move from the area or gradually disappear.

Landscape fragmentation is wide ranging and complex with variant effects to different species. It is also problematic because the effects are both gradual and cumulative. Indications to these effects have not gone unnoticed. This has led to increased environmental awareness with improvements in legislation and environmental monitoring and planning (Tillmann, 2005). Environmental monitoring has changed considerably in recent years with increased access to information, research literature and geographic data. This has led researchers to look at effects on a broader geographical scale therewith, introducing numerous quantitative and qualitative indicators (Uuemaa, Mander, & Marja, 2013).

Landscape fragmentation processes have been discussed and analysed using several methods. Most methods create an indicator of a sort that values ecological homogeneity and can be used to evaluate changes, compare areas and pinpoint vulnerable sites. Current indicators have improved and are now more in tune with the ecological processes at hand (see Chapter 2.1). It is imperative to understand the benefits and disadvantages of using indicators:

> “Indicators are measurements that convey information about more than just themselves. They provide means for quantifying and simplifying information on complex issues. They are purpose-dependent, almost always open to various interpretations, and never tell the whole story. Indicators are needed because assessing and monitoring everything is impossible and because what is known needs to be conveyed to non-experts in policy relevant form” (Kapos, Lysenko, & Lesslie, 2000, p. 8).

Geographic information systems GIS provide a simple and a useful tool to implement environmental indicators into planning and environmental monitoring. The system's benefits are that they can quickly assess large geospatial areas using multiple indicating factors simultaneously (Uuemaa, Mander, & Marja, 2013). This helps in the creation of baseline data for comparison, prediction or review of either individual- or multiple projects concurrently.

In 2011 the European Environment Agency (EEA) and the Swiss federal office for the Environment (FOEN) measured quantitatively landscape fragmentation for 28 countries in Europe, excluding Iceland (EEA & FOEN, 2011). The results revealed that fragmentation varied from high values in Western and Central Europe to low values in large parts of Scandinavia. The EEA & FOEN report (hereinafter referred to as the European research) was meant to provide a basis for management action. Accordingly, by identifying vulnerable areas the results offers data for prioritising future development plans or restoration practices (EEA & FOEN, 2011).

Due to increased environmental awareness in Iceland, erosion and wetland degradation have received warranted attention (Sigbjarnarson, 1969; Aradóttir, Arnalds, & Archer, 1992; Þórhallsdóttir, 1998; Arnalds, et al., 2001; Garðarsson, et al., 2006). Both have had a negative impact to flora and fauna gaining the attention of the public as well as legislative authorities. This has resulted in the improvement- and the adaptation of further legislation, concurrently motivating governmental agencies, institutions and NGO´s in forming restoration plans and practices (Aradóttir & Halldórsson, 2011; Aradóttir, Pétursdóttir, Halldórsson, Svavarsdóttir, & Arnalds, 2013). Ecosystems, habitats and habitat types have gained increased juridical status with the adaptation of a new Law on environmental protection. The statute additionally recognises the perceived qualities of landscape therewith strengthening the definition of landscape (Waage, 2013; Law on environmental protection, No. 60/2013).

In terms of planning and land use, Environmental impact assessment (EIA) and Strategic environmental assessments (SEA) have been implemented into Icelandic planning practices. Therewith, environmental concerns are valued for either each project at hand or for proposed changes in public planning. However, these useful practises however only address environmental concerns on the scale of each project, and cumulative effects of all projects or plans are overlooked. Currently a country planning policy is being developed by the Icelandic national planning agency (Icelandic National Planning Agency, 2014). The planning policy itself has been subject to undergo a SEA and planning authorities have presented a description or scoping report, calling for comments from stakeholders and the general public.

Fragmentation of Icelandic landscape has been discussed by Þórhallsdóttir (2002) and analysed by Wald (2012) in her master's thesis, where she looked at land-use development since 1900 in South-West Iceland. She outlined the transforming stages of land use with a schematic representation where land is transformed first by mechanization, then urbanization, then industrialization and finally intensification, all at the cost of wetlands degradation (Wald, 2012, p. 61). One factor in Wald's analysis was landscape fragmentation where she measures the number of patches and average patch size, for the years 1950, 1980 and 2010. These factors can serve to enrich the understanding of trends in development but are inadequate for comparison as they do not capture all fragmentation phases (Jaeger, 2000). This was pointed out by Wald where she suggested effective mesh size for comparison research (Wald, 2012, p. 41). Presently neither a regional baseline dataset exists nor a database that addresses the topic countrywide which would be usable in planning, environmental monitoring and historical development research.

First aim of the thesis is to measure landscape fragmentation in Iceland countrywide and to create a baseline dataset for the current degree of fragmentation. The second aim is to make the results comparable to the 28 countries valued in the European research made in 2011.

The research questions were as follows:

- First, what is the current degree of landscape fragmentation in Iceland?
- Second, how fragmented is Iceland when compared to other European countries?

Two additional research questions were added during the course of the research.

- When looking at anthropological and environmental fragmentation of landscape, what natural constraint boundaries are applicable to fulfil the first aim of the research?
- Is the created baseline data applicable for planning and/or monitoring in Iceland?

The structure of the thesis is as follows:

Chapter 2 presents a discussion on the theory the thesis builds on: Firstly, the indicator used to value fragmentation (2.1). Secondly, the ecological effects of fragmentation (2.2). Thirdly, the study area Iceland is briefly described (2.3) including subchapters on its flora fauna, habitat types and land use (2.3.1 - 2.3.4). Fourthly, a discussion on Iceland's legislation regarding, landscape, ecological habitats and the wilderness concept (2.4.1 - 2.4.3) and finally the newly proposed country planning policy is discussed (2.4.4).

Chapter 3 presents the methods used to calculate the fragmentation. Firstly, the fragmenting elements which were selected (3.1 - 3.1.3). Secondly the reporting units used (3.2). Thirdly the fragmentation geometries used (3.3). Fourthly, the six constraints considered and finally, a chapter on how the fragmentation was measured using geographical information system software (3.4).

Chapter 4 presents the results. Firstly, results on the European fragmentation geometries (4.1). Secondly, results on the Icelandic fragmentation geometries (4.2). Finally, results are compared to the European Research's findings (4.3).

Chapter 5 presents discussions on the presented results

Chapter 6 presents the final conclusions.

Appendix A presents influential factors in classifying the local road network, before measuring the fragmentation.

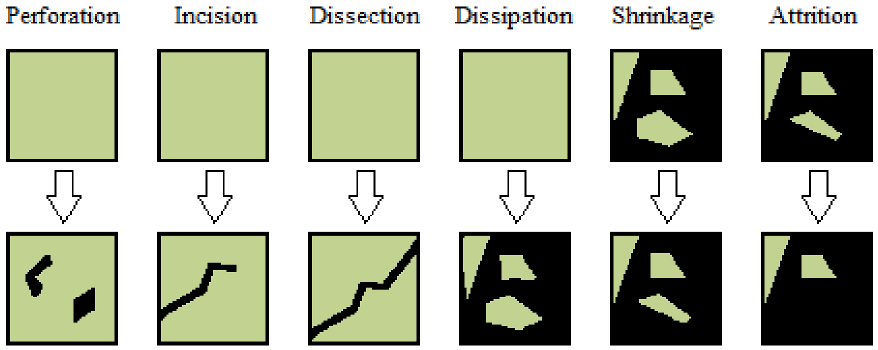
Appendix B presents the transparency sheets used to overlay the grid based results in the printed version of the thesis.

2 Theory

2.1 The Fragmentation Indicator

The fragmentation indicator used to measure the level of landscape fragmentation in the European research is actually a measure of landscape connectivity. It has been named Effective Mesh Size (M_{eff}). The indicator was introduced by Jaeger (2000) and later improved by Moser, Jaeger, Tappeiner, Tasser, & Eiselt, (2007) (see further discussion below). In short, it evaluates the possible connectivity between areas, meaning it values the odds of one point (individual) selected randomly in an area being able to connect to another random point (another individual) without being blocked by a fragmenting element (Jaeger, 2000).

Landscape fragmentation by linear or spatial elements has been studied from its geometric characteristics where its spatial processes have been geographically analysed. Forman (1995a) compiled a dozen of the general principles of regional ecology and listed their spatial representations. He identified five processes on fragmentation (1995b, p. 407) which Jaeger (2000) adopted and modified to better account for their mathematical characteristics. Jaeger categorized them as six different phases shown in Figure 2.1, where the changes from the upper examples to the lower identify the effects caused to the spatial pattern.



(Source: Jaeger, 2000; Forman, 1995b)

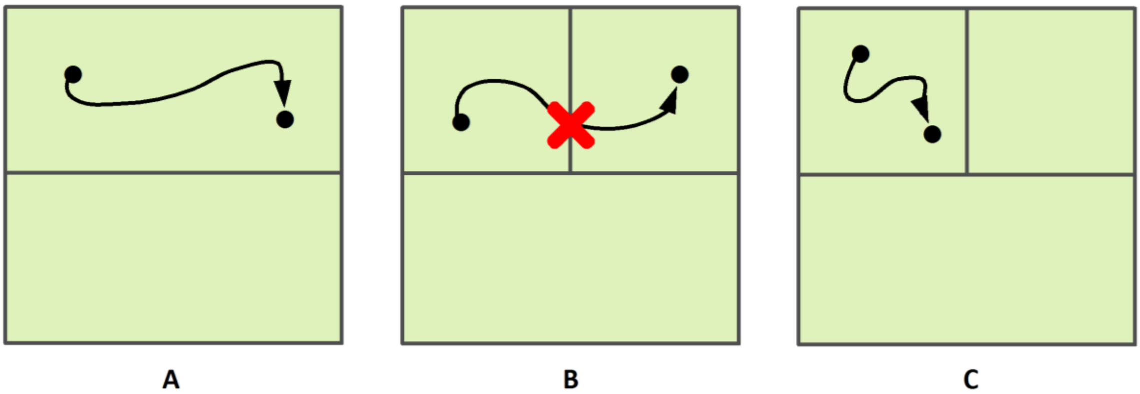
Figure 2.1 Geometric characteristics of fragmentation

Subsequently Jaeger (2000) created three different indicators (measures) and compared their mathematical properties to five commonly used indicators at that time. First, he compared how the different indicators responded to the six different characteristics of fragmentation. Secondly, he valued the indicators based on a set suitability criteria where mathematical simplicity and intuitive interpretation were among favoured qualities. As a result it was determined that Effective Mesh Size was best fitted to solve the set criterions. Its value decreases in reaction to all the fragmentation phases apart from incision where it showed no effect. In regards to the suitability criteria it was considered as satisfying with respect to mathematical simplicity and intuitive interpretation but perhaps its best quality was that it was area-proportionately additive. This means that it "characterizes the fragmentation of a region independently of its size and can be calculated for the combination of two or more regions" (Jaeger, 2000, p. 120).

As mentioned, Effective Mesh Size is a measure of landscape connectivity and is based on the probability that two points in the same area can meet without a fragmenting element blocking their path. It is described by (1) $\mathrm{M_{eff}}$ Cut.

$$\mathrm{M_{eff}\ Cut} = \left(\left(\frac{A_1}{A_{total}}\right)^2 + \left(\frac{A_2}{A_{total}}\right)^2 + \left(\frac{A_3}{A_{total}}\right)^2 + \cdots + \left(\frac{A_n}{A_{total}}\right)^2\right) \cdot A_{total} = \frac{1}{A_{total}} \sum_{i=1}^{n} A_i^2, \tag{1}$$

where n equals number of patches, A_1 to A_n represent the patch sizes and A_{total} represents the total area. This has been visually illustrated by Jaeger in the European research (Figure 2.2) wherein A, the odds of two randomly chosen points to connect are valued. When new fragmenting elements are added (B) the two points become disconnected. This means that the odds of finding a point in the represented area decreases (C) (EEA & FOEN, 2011, p. 22).



(Source: EEA & FOEN, 2011, p. 22)

Figure 2.2 Basic illustration of Effective Mesh Size

One problem with $\mathrm{M_{eff}}$ Cut (1) has been recognized. It reveals itself when different regions or areas are compared, for example municipalities. The reporting unit boundaries then act as fragmenting elements as illustrated in Figure 2.3.

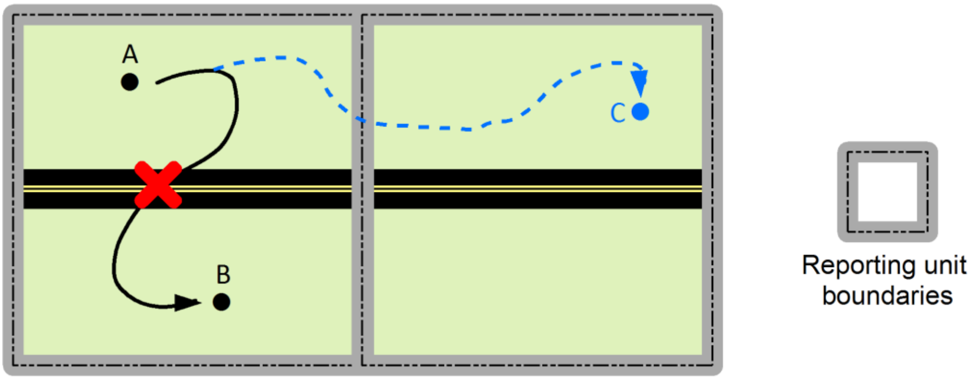


Figure 2.3 The boundary problem

Consequently, even though there is no fragmenting element in between points A and C the calculated odds value the same as between point A and B. Because the reporting unit boundaries are not always fragmenting factors and sometimes are only used as comparison areas, the use of M_{eff} Cut (1) becomes problematic.

Moser, Jaeger, Tappeiner, Tasser, & Eiselt (2007) adjusted the (1) to account for this boundary problem and introduced (2), a formula that accounts for cross boundary connections the M_{eff} CBC:

$$\begin{aligned} \mathrm{M_{eff}\ CBC} &= \frac{1}{\mathrm{A_{total}}}\left(\mathrm{A_1}\cdot \mathrm{A_1^{cmpl}} + \mathrm{A_2}\cdot \mathrm{A_2^{cmpl}} + \cdots + \mathrm{A_n}\cdot \mathrm{A}_n^{\mathrm{cmpl}}\right) \\ &= \frac{1}{\mathrm{A_{total}}}\sum_{i=1}^{n} \mathrm{A}_i \cdot \mathrm{A}_i^{\mathrm{cmpl}}, \end{aligned} \tag{2}$$

where n equals number of patches, A_1 to A_n represent the patch sizes inside the planning unit, A_1^{cmpl} to A_n^{cmpl} represent the total patch size and A_{total} represents the total area of all patches. M_{eff} CBC (2) retains the qualities of being area-proportionately additive while offering a new approach in comparing areas (Moser, Jaeger, Tappeiner, Tasser, & Eiselt, 2007).

Because M_{eff} is a measure of landscape connectivity it has to be transformed to show landscape fragmentation which was done in the European research by using

$$\mathrm{S_{eff}} = \frac{1}{\mathrm{M_{eff}}}, \tag{3}$$

referred to as Effective mesh density or S_{eff}. In the European research the results were reported as the Effective mesh density per 1000 km^2 which is the chosen method of this this thesis where the reported values S_{eff} CBC are valued accordingly.

2.2 Effects of fragmentation

How and to what degree fragmentation influences biodiversity has been discussed thoroughly in the field of landscape ecology. The effects on ecosystems are diverse (Saunders, Hobbs, & Margules, 1991). The effects on species richness can be insidious (With, 1997 in Ewers & Didham, 2006) and complex (see below). The effects on habitats can affect one species differently than another. Hence, the species mosaic as a whole must be considered in tune with the landscape type of each study area (Andrén, 1994). It is also important to bear in mind that fragmentation is not a “catchall phrase” of all human negative impacts on nature (Fahrig, 2003, p. 509) although many negative factors can be related to it.

Landscape fragmentation is one factor directly related to the enhancement of infrastructure, and has been shown to be one of the factors leading to the decline in biodiversity and species richness (Fahrig & Rytwinski, 2009). Urbanization of Europe was a gradual process and is currently on going (Antrop, 2004). Urbanized areas affect biodiversity, species richness and species population of the overlaid area by reason of cumulative habitat degradation and proliferation due to infrastructure in surrounding regions. It has been shown to affect vegetation structure and alter animal communities (Sauvajot, Buechner, Kamradt, & Schonewald, 1998). Another research finds that population density has direct effect on biodiversity and species richness (Luck, Ricketts, Daily, & Imhoff, 2004).

Roads and railways both have a substantial effect on wildlife population (Fahrig & Rytwinski, 2009; Jaeger, et al., 2005). Jaeger et al. (2005) outline four ways in which roads and traffic impact wildlife ecosystems based on numerous sources. These are; habitat loss, traffic mortality, population subdivision and inaccessibility due to barrier effects. The barrier effects impacts are both due to animal behavioural avoidance and actual fences (Jaeger & Fahrig, 2004). Edge effects of human disturbance around roads are greater than in settlement areas, they were estimated around 400 to 600 m by Sauvajot, Buechner, Kamradt & Schonewald (1998). Jaeger et al. (2005), by creating an interactive model, conclude that predicted traffic volumes have more effect on species population than road size. Furthermore, they analysed road avoidance factors where species populations with high noise and high surface avoidance where most vulnerable to roads.

Fahrig and Rytwinski (2009) collected and synthesized 79 studies where the effects of roads where analysed on 131 different species. Their findings included that the negative factors of roads outnumbered the positive ones by a factor of five. They also created a flowchart to better determine which species are more likely to experience negative, neutral or positive effects by roads. EEA & FOEN have identified 39 consequences of linear infrastructure on the environment and various ecosystem services (2011, p. 11).

Major rivers and water bodies were the natural elements chosen as barriers in the European research. Both are waters which have the possibility to keep boats afloat and consequently, could act as obstructing barrier for many terrestrial animals (EEA & FOEN, 2011).These natural elements can be influenced by infrastructure e.g. by harnessing hydrological power; the effects can be cumulate with construction of dams and the creation of reservoirs that alter the water flow. It should be noted that major rivers and water bodies differ from roads in the manner that even though they act as barriers they do not influence other affiliated factors (like traffic mortality). Anyhow, they can enhance the fragmentation of the land surface areas especially in combination with anthropological effects.

In Iceland the effects of climate, cultivation and soil erosion have in many ways had an impact on the original flora and related ecosystems (Aradóttir, Arnalds, & Archer, 1992; Arnalds, et al., 2001; Þórhallsdóttir, 2002). Natural processes that serve to fragment landscape, like both wind and water erosion have escalated due to human influences. Furthermore, Saunder, Hobbs & Margules (1991) reveal that fragmentation due to human influence can serve to increase exposure to both wind and water erosion.

Constraining elements are chosen in the European research to remove mountainous land areas using both elevation and temperature thresholds (see chapters 3.4.1 and 3.4.2 for more detailed description). This was done to remove mountainous areas considered not suitable for settlement. EEA & FOEN (2011) note, that for some regions the impact of mountainous land areas is so important that it is not meaningful to compare the level of landscape fragmentation without accounting for lakes and mountains (EEA & FOEN, 2011, p. 26).

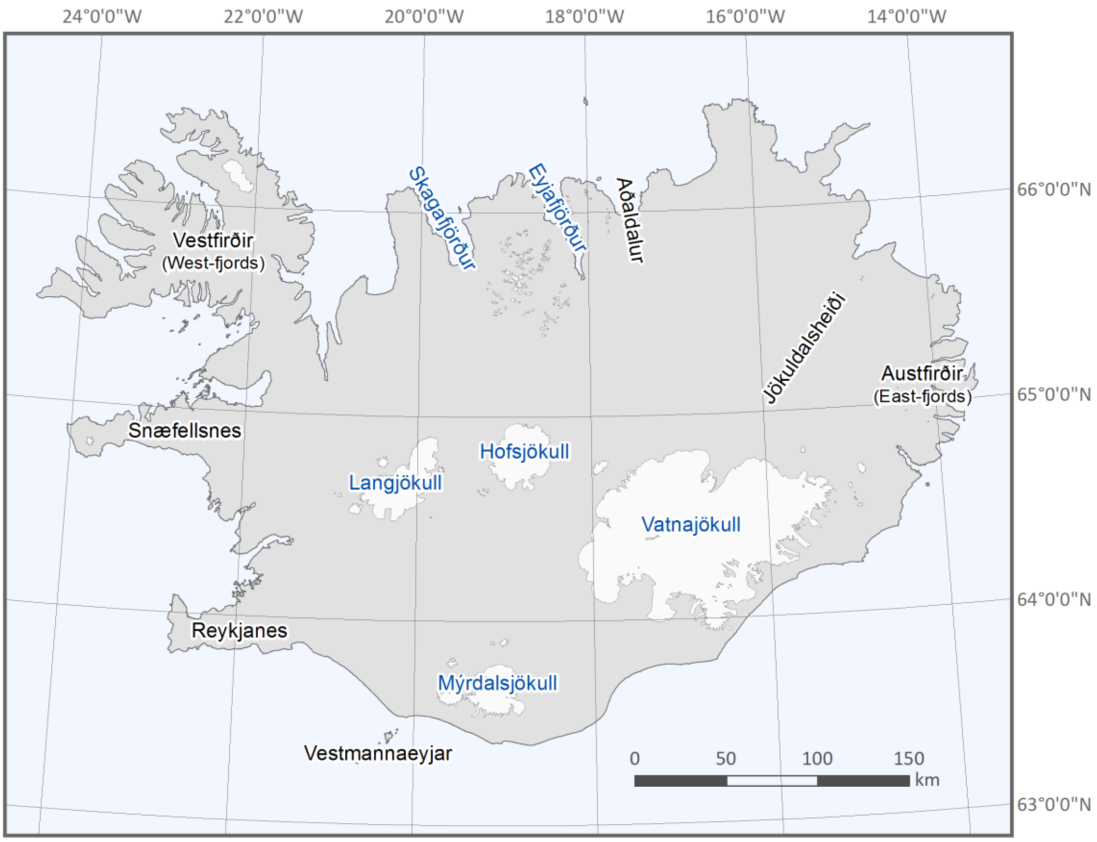
Change in surface temperature close to fragmenting barriers can also alter previous conditions (Saunders, Hobbs, & Margules, 1991). Temperature influences growth (Bergþórsson, 1996), and threshold temperatures can limit growth and can serve as an indicator to which species have viable growth possibilities. Alternating the surface can then provide one species with advantage over another or exclude both species from the edge of the barrier (Sunders, Hobbs & Margules, 1991). Moreover fragmentation can influence changes to solar radiation to the ground surface. Where the same barrier can both increase solar radiation to fragmented path edges, and shadow effect on the other side. This is more prominent where low solar angles exist yet varies between different habitat types. Hence, inside forest land areas different reactions to the same influence are expected (Sunders, Hobbs & Margules, 1991, 20). Removal of vegetation by barriers can also provide space for invasive species (Sunders, Hobbs & Margules, 1991).

Linking landscape- or habitat fragmentation research directly to species richness has returned mixed results, showing a decrease, no change or even an increase with increased fragmentation (Fahrig, 2003; Debinski & Holt, 2000). Therefore it is crucial to recognize the limits of approximations (Fahrig, 2003). The results tended to vary between different factors; by species, the scale of the research and the timeline considered (Debinski & Holt, 2000). Species also showed different responses to the fragmenting area, distance to edge, shape complexity, isolation and matrix contrast (Fahrig, 2003). This again was divergent between different traits of species depending on their rank in the food chain (Ewers & Didham, 2006). Ewers & Didham (2006) conclude that all the contradictory findings cannot solely be explained by different scales or methods and add that the findings can “either obscure or enhance the detection of fragmenting effects” (Ewers & Didham, 2006, p. 127).

Therefore when quantifying natural processes in the method, it is important that both the scale and analyses are relevant to the ecological processes studied (Li & Wu, 2004). Landscape fragmentation has been measured using various methods which have often led to incomparable results. It could be stated that this has not dissuaded researchers rather this has motivated them to improve the evaluation process as previously discussed in Chapter 2.1.

2.3 Study area (Iceland)

Iceland is an island positioned on the North Atlantic ridge in the North Atlantic Ocean. Its total land area is about 103 450 km^2 if smaller islands are included (CLC, 2006) where about 10 900 km^2 are glaciers or surface ice or about 10.5 % of the total area. Iceland's land-surface is mountainous (Einarsson, 1984) although the highest mountain in Iceland is only 2 110 m above sea level. The climate in Iceland is complex and has been described as maritime climate with cool summers and mild winters, where southern and western Iceland are temperate while the northern part and the highlands are snowy (Einarsson, 1984). Weather in Iceland can be harsh (Ólafsson, Furger, & Brümmer, 2007) with a high temperature flux regularly around the freezing point (Arnalds, 2011) and frequent exposure to strong winds largely form cyclonic storms which frequently form just south of Iceland (Nawri, Petersen, Björnsson, & Jónasson, 2013). Figure 2.4 shows the study area with chosen labels mentioned in this research.



(Data source: National Land Survey of Iceland, 2011a)

Figure 2.4 Study area

2.3.1 Flora

Species richness of Icelandic vascular plants is low or less than 500 (Kristinsson, 2008). However, moss and lichen vegetation is higher in species richness and covers more than 3000 km^2 (Arnalds, 2011) List of floral species in Iceland is available online and is regularly updated (Kristinsson, n.d.). Changes to the natural flora due to human settlement are acknowledged and is discussed further in chapter 2.3.4.

Vegetation mapping in Iceland started in 1955 and is currently a work in progress. It started with small scale mapping; 1:36.000, 1:40.000 and 1:25.000 see (Guðjónsson, Egilsson, & Skarphéðinsson, 2005) and (Guðjónsson, 2010). Since then about two thirds of the country have been mapped on a small scale (Guðjónsson, 2010). Additionally a large scale 1:500.000 simplified overview was presented of the whole country (Guðjónsson & Gíslason, 1998). Other mapping projects connected to vegetation are forest mapping; Forests in Iceland have been mapped by Traustason and Snorrason (2008) and adjusted to the CORINE classification scheme. The results were that forests covered 1569 km^2 or about 1,5% of Iceland's land surface, natural forests covered 1155 km^2 (Traustason & Snorrason, 2008). Historical development research on forests areas have also been revived for small study areas (Sigurmundsson, Þorbjarnarson, Gísladóttir, & Óskarsson, 2012).

2.3.2 Fauna

Icelandic fauna is marked by the isolation of the country. Icelandic land mammals are few and were all, except for one brought here by settlers, purposefully or unknowingly (Hersteinsson, 2004). The one exception is the artic fox (*Alopex lagopus)* which migrated to the county with surface ice and got isolated after the Little Ice Age (the sixteenth to the nineteenth century) (Mellows, et al., 2012). Imported farm animals were at first; sheep, goats, pigs, cattle and horses. Hidden passengers were the house mouse, wood mouse, brown rat and black rat. Later cats and dogs were imported as well (Hersteinsson, 2004). The American mink was imported in 1931 and escaped captivity the following year. In 1975 the mink could be found all around Iceland (Skírnisson, 1993).

Reindeers were brought to Iceland on four occasions for farming purposes in 1771, 1777, 1784 and 1787 and were positioned in different locations around Iceland. The first two packs died, and only few of the reindeers from the third pack managed to survive and join the fourth pack, which still roams free in the east of Iceland (Þórisson, 2004). All reindeers in Iceland have roamed free since they first arrived and presently, their population size is controlled with managed hunting practices (East Iceland Natural History Institute, 2008). Rabbits are perhaps the most recent land mammal inhabitants (Hersteinsson, 2004).

Icelandic bird life is diverse, where 94 wild bird species have been recorded to lay eggs in Iceland, thereof 75 birds nest every year and 60 of which were recorded before 1800 (Petersen, 1998). In total, 349 bird species have been accurately sighted, encompassing migratory birds, vagrant birds, winter dwellers and hatchers (Petersen, 1998). Iceland offers birds distinctive living conditions to birds, whereas there are few forests, numerous wetland areas, and the human impact on many areas is still comparatively low (Petersen, 1998).

Small species (here referring to insects and other small species which are not mammals) in Iceland have been studied on a long term basis. In a bibliographical article from 1990, there are 458 references to articles which relate to the topic (see Ólafsson, 1990) of which 52 articles are related to the ecological fauna. Small species are one of the factors considered in the ecological mapping of Iceland (see next chapter 2.2.3).

2.3.3 Habitat types

Icelandic ecosystems are currently being mapped by the Icelandic institute of natural history, mapping and categorizing habitat types for the first time. Published results for habitat type categorizations in eight sites in the highlands can be found in Magnússon, et al., 2009. The categorization is mostly based on vegetation, other taxa likely to dwell within each habitat type are also described such as, birds, mammals and small species. At present 24 habitat types have been categorized and divided into five main categories. The authors conclude that extensive groundwork has been formed, and that the results of the classification will provide a basis for extensive mapping in the highlands, especially in the volcanic zones (Magnússon, et al., 2009). As of yet, four areas 400 km^2 each, the maps are available online presented in the scale of 1:50 000 (Icelandic Institute of Natural History, 2012).

2.3.4 Land use

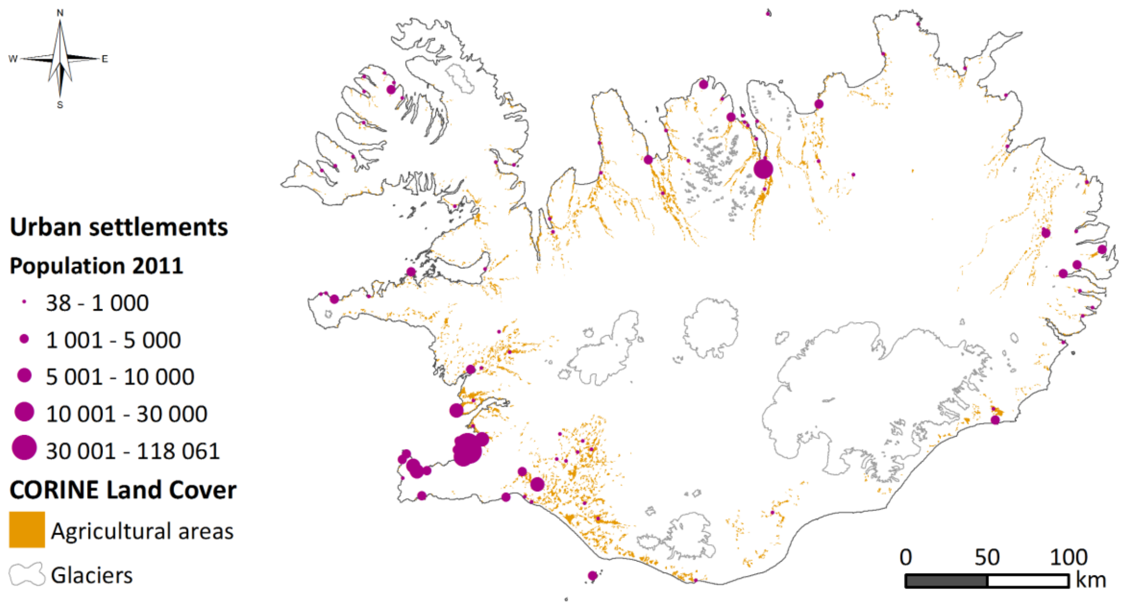
The effects of historical changes to the natural environment since settlement have been grave and anthropological factors have influenced degradation to the original landscape habitats. Two phases have been identified; the former one is what could be called the deforestation phase and the latter being the wetland irrigation phase (Þórhallsdóttir, 2002).

Immediately after settlement; settlers started to cultivate and to a large extent clear away contemporaneous birch forests (Haraldsdóttir, 1995) followed by excessive grazing (Aradóttir, Arnalds, & Archer, 1992). These factors combined degraded the natural fauna so that it became less resilient to soil erosion processes (Sigbjarnarson, 1969; 1994; Arnalds, et al., 2001). Harsh climate and volcanic events hastened this development. Iceland is now gravely affected by erosion, it is estimated that 42% of the country can be categorised as a desert and other large areas are gradually degrading (Arnalds, 2011). The the wetland irrigation phase has also threatened habitats, where wetland cultivation or wetland irrigation increased substantially after 1940. It is estimated that over 4000 km^2, have been drained (Óskarsson, 1998 in Garðarsson, et al., 2006 p. 7). Currently, the agricultural richest areas contain only 9-18% of the original wetlands.

After settlement the environmental conditions in Iceland were at times harsh and people struggled. The mechanism of agriculture similar to Europe increased the cultivation of land areas which was, followed by improvements in agriculture. This provided new opportunities for society to evolve; the food surplus allowed changes to norms and what followed were reforms along with improvements to infrastructure and later resulting in urbanization (Valsson, 2003). In Iceland this reform happened later than in Europe (Antrop, 2004) and provided much needed improvements to quality of life with increased food stability and sustainability. Land use changes have been listed by Snæbjörnsson, et al. (2010) in regards to agriculture, and Valsson (2003) in regards to urban development. Current land use was reviewed recently concerning greenhouse emissions (Hallsdóttir, Harðardóttir, Guðmundsson, Snorrason, & Þórsson, 2010).

The CORINE Land Cover (CLC) is a European cooperative project where land surface cover is classified into predefined classes (EEA, 1994).The National Land

Survey of Iceland joined the project in 2007. Subsequently, the methodology was localized and the Icelandic environment was classified for the years 2000 and 2006 providing countrywide comparable data on land use followed by a report on the work which included analysis of land cover changes between the two classifications (Árnason & Matthíasson, 2009). One main objective of the CLC is to have comparative data across all of Europe where statistical information meet's a set standard and can consequently be compared cross countries or between different time periods (EEA, 1994). The data has a fixed reference scale at 1:100 000 and the minimum mapping unit is 0.25 km^2. Current land use can be visualised using the CORINE land cover database. In figure 2.5 the CLC agricultural areas are shown in relation to urban settlements.



(Data Source: National Land Survey of Iceland, 2011a; Árnason & Matthíasson, 2009)

Figure 2.5 Urban settlements and agricultural areas.

Fragmenting factors in Iceland are not different from internationally assessed factors. That is to say factors including urban areas, linear infrastructure such as roads and environmental factors water streams and water bodies. The data used to analyse these factors is described in Methods (see Chapter 3.1) they are divergent, based on which fragmenting geometry is used (see Chapter 3.3).

Agriculture is one factor that has also been assessed internationally as a fragmenting element e.g. by Girvetz, Thorne, Berry, & Jaeger (2008). Agriculture assessment was omitted from this thesis as it did not suit comparison to the European research. Datasets however are available on the topic, e.g. the network of irrigation ditches has been estimated and mapped (Gísladóttir, Guðmundsson, & Áskelsdóttir, 2010; Gísladóttir, Guðmundsson, & Áskelsdóttir, 2009) along with farmstead land areas (Gísladóttir, Grétarsson, Metúsalemsson, Traustason, & Arnalds, 2006) and surface field areas (Hallsdóttir, Harðardóttir, Guðmundsson, Snorrason, & Þórsson, 2010).

Natural constraint boundaries are used to emphasize the combination effects of natural and anthropogenic fragmentation (Girvetz, Thorne, Berry, & Jaeger, 2008) or to consolidate large areas in order to adequately compare their levels of fragmentation (EEA & FOEN, 2011). When choosing constraining factors, there are two key points which should be observed: Firstly, they must be distinguished accordance to ecologically relevant factors (Li & Wu, 2004); secondly, there must be room for alternative interpretation i.e. by showing results hierarchically using different fragmentation geometries, where environmental constraints are not considered and where they are considered (Jaeger, et al., 2008; Girvetz, Thorne, Berry, & Jaeger, 2008). This provides planning authorities, researchers and the general public better oversight. The description on which fragmenting elements were chosen along with chosen constraint boundaries are described in Methods (see chapters 3.1 and 3.4).

2.4 Legislation and Planning

Landscape fragmentation touches on two topics within Icelandic legislation. First, it is connected to the concept of landscape, how it is perceived and how it has been defined by legislative authorities. The second topic is that of the preservation of ecological habitats. Both topics are important and have changed considerably in recent years. Moreover, wilderness is another concept that has been implemented into Icelandic laws. Wilderness is discussed in chapter 2.4.3 for the sake of clarity and distinction from the Landscape fragmentation concept. As mentioned in the introduction a country planning policy is being developed by the Icelandic national planning agency. It presents new opportunities in country wide environmental monitoring in substantiating existing laws and contracts as will be discussed below.

2.4.1 Landscape

Landscape definitions vary between legislations, if one looks up landscape ("landslag" in Icelandic) in the national law database on the webpage of the Icelandic parliament ten results are presented (see table 2.1). Landscape is not defined in all statutes although there is a noticeable difference between older and newer adaptations. In earlier legislation (and the Law on chemicals, No. 61/2013) landscape is not defined specifically but it is however considered as part of the environment which is defined as:

> "Synonym for humans, animals, plants and other biota, soil, geological formations, water, air, climate and **landscape**, community, health, culture and cultural preservatives, employment and material wealth" (Law on environmental impact assessment No. 105/2006) [translated by the author].

Waage (2013) studied the concept of landscape in detail and reviewed the development of landscape definitions in Icelandic legislation. Three subsequent phases can be extracted from her discussion; first when the concept was introduced in environmental protection it had connotations of perceived aesthetics. The second phase led to the removal of perceived qualities thus, only physical attributes remained. In the third and most recent phase, the new Law on environmental protection No. 60/2013 saw the implementation of the definition of landscape as defined in the European Landscape Convention which Iceland signed the 29th of June, 2012 (see table 2.1).

Law on planning (No. 123/2010) was influenced by the landscape convention (Waage, 2013). During the perpetration stage, the human perception of landscape was removed and landscape was defined from its topography and place in the natural or anthropological environment (see table 2.1). This was criticized in a report made for the Icelandic Ministry for the Environment (2011) in preparation for the new Law on environmental protection. The authors hold that the definition is "too substantial and therefore hardly applicable" (Icelandic Ministry for the Environment, 2011, p. 173) [translated by the author].

The method used in this research to measure fragmentation quantitatively according to ecological indicators does not include human perception on the fragmented landscape, nor was that intended. One can however acknowledge the importance of such research. Fragmentation does affect people's perception of landscape as discussed by Di Giulio, Holderegger, & Tobias (2009), where they point out that there are currently no solutions available which address both the ecological issue and the human perspective issue simultaneously. This new approach has sparked the interest of researchers (see e.g. Llausàs & Nogué, 2012).

Table 2.1 Icelandic laws containing Landscape in their texts.

Law	No/Year	Definitions of Landscape*
Law on environmental protection (Lög um náttúruvernd)	No. 44/1999	Not defined. However, it is mentioned in the first paragraph of article 53 that one explanatory precondition for forming a National Park is to have unique landscape properties.
Law on fire safety (Lög um brunavarnir)	No. 75/2000	Not defined. However, listed as part of the environment by definition.
Law on environmental impact assessment (Lög um mat á umhverfisáhrifum)	No. 106/2000	Not defined. However, listed as part of the environment by definition.
Law on protection against oceanic and costal pollution. (Lög um varnir gegn mengun hafs og stranda)	No. 33/2004	Not defined. However, listed as part of the environment by definition.
Law on protection of lake Mývatn and Laxá river in Suður-Þingeyjarsýsla. (Lög um verndun Mývatns og Laxár í Suður-Þingeyjarsýslu)	No. 97/2004	Not defined. However, it is mentioned in Art. 3, second paragraph that one needs to apply for a permit/consent to the Icelandic National Planning Agency for any project that can affect landscape.
Law on strategic environmental assessment (Lög um umhverfismat áætlana)	No. 105/2006	Not defined. However, mentioned in Art. 10 b section 7, as one environmental factor which should be considered; "impacts to areas or **landscape** which are recognised to have protection status locally or internationally".
Law on Vatnajökull national park (Lög um Vatnajökulsþjóðgarð)	No. 60/2007	Not defined. However, it is mentioned in article 2, first paragraph, that one of the aims for forming the National Park was to protect its landscape.
Law on planning (Skipulagslög)	No. 123/2010	Defined as: "Landscape means an area which has appearance and character due to natural and/or anthropological factors. Landscape therefore takes into account the daily environment, environment under protection values and environment which has been degraded. Landscape includes e.g. urban areas, rural areas, remnants, rivers, lakes and maritime waters."
Law on environmental protection† (Lög um náttúruvernd)	No. 60/2013	Defined as: "Landscape means an area, as perceived by people whose character is the result of the action and interaction of natural and or human factors."‡
Law on chemicals (Efnalög)	No. 61/2013	Not defined. However, listed as part of the environment by definition.

*Most citation to laws where translated by Author unless marked
†Became effective 1st of April 2014.
‡The official translation of the European Landscape Convention (2000).

2.4.2 Ecological habitats

Habitats ("búsvæði" in Icelandic) are mentioned in eight laws according to the national law database on the webpage of the Icelandic parliament. Table 2.2 lists these legislations and describes how habitats are defined in these different statutes.

Table 2.2 Icelandic laws containing Habitat in their texts.

Law	No/Year	Definitions of Habitat*
Law on the protection, conservation and hunting of wild birds and wild mammals. (Lög um vernd, friðun og veiðar á villtum fuglum og villtum spendýrum)	No. 64/1994	Habitats are defined as; areas which wild animals use for self-sustainability and stopovers, e.g. nesting sites and feeding grounds, or as a travel path. "(1st article, after amendment in 2004) Habitats are also mentioned further see discussion
Law on environmental protection (Lög um náttúruvernd)	No. 44/1999	Habitats are defined as: "Site or area where species can sustain themselves" (after amendment in 2007), also mentioned further see discussion.
Law on Þingvellir national park. (Lög um þjóðgarðinn á Þingvöllum)	No. 47/2004	Not defined. However in accordance to article 4, first paragraph, The biota of lake Þingvallavatn shall be conserved in order to protect its habitats.
Law on protecting lake Þingvallavatn and its water catchment area. (Lög um verndun Þingvallavatns og vatnasviðs þess)	No. 85/2005	Not defined. However in accordance to article 4, the biota of lake Þingvallavatn shall be conserved in order to protect its habitats.
Law on environmental responsibility (Lög um umhverfisábyrgð)	No. 55/2012	Habitats are defined as: "Site or area where species can sustain themselves" also mentioned further see discussion
Law on environmental protection† (Lög um náttúruvernd)	No. 60/2013	Habitats are defined as: "Site or area where species can sustain itself" also mentioned further see discussion
Law on chemicals (Efnalög)	No. 61/2013	Not defined, however is a part of the definition of nature conservation areas (article 24 a): "**Habitats**, habitat types and ecosystems which are protected in accordance to Law on Environmental Protection"
Presidential verdict on division of governmental matters between ministries in the government offices of Iceland. (Forsetaúrskurður um skiptingu stjórnarmálefna milli ráðuneyta í Stjórnarráði Íslands).	No. 71/2013	Not defined, however "biological diversity e.g. protection of ecosystems, **habitats**, species and genetic materials…" is listed as the first agenda under nature conservation which falls under the Ministry for the environment and natural resources (article 6, 1st paragraph 2a)

*Citations to laws where translated by the author
†Become effective 1st of April 2014.

The protection of habitats is an important factor in Icelandic legislation. Preservation of ecological habitats falls under the ministry for the environment and natural resources (Presidential verdict on division of governmental matters between ministries in the Government offices of Iceland, No 71/2013). The legislation provides clear goals towards preservation, protection and even restoration. The oldest legislation mentioned (table 2.2) or, the Law on the protection, conservation and hunting of wild birds and wild mammals (No. 64/1994), stipulates in Art. 6 that “one should approach habitats cautiously and with consideration and avoid unnecessary disturbance”.

In the older Law on Environmental protection (No. 44/1999) habitats are defined (see table 2.1) and mentioned in regards to two main topics. The first topic concerns protected remnant areas (“náttúruminjar” in Icelandic) where the minister can select an area (recommended by the Environment Agency of Iceland or The Icelandic Institute of Natural History) for nature conservation and protection. There are five categories of protected remnant areas which are; National Parks (“þjóðgarðar” in Icelandic); nature protection areas (“friðlönd” in Icelandic); nature monuments (“náttúruvætti” in Icelandic); recreational protection sites (“fólkvangar” in Icelandic); and finally a category for biota, their habitats, habitat types and ecosystems (Icelandic Ministry for the Environment, 2011, p. 164). The second topic concerns the Nature conservation plan, which like the name suggests is a plan for nature conservation made for the Minister every 5 years (Article 65 in Law on Environmental protection, No. 44/1999). The plan should present “clear information on natural remnant areas, nature protection areas and biota, habitats, habitat types and ecosystems which provide cause for conservation” (Article 65, paragraph 1 of Law on environmental protection, No. 44/1999) [translated by the author].

In the older Law on environmental protection the protection of habitats was nearly conditioned on being listed as protected remnant area in one of the five categorizations previous paragraph. The environmental agency holds a list of protected remnants (“náttúruminjaskrá” in Icelandic). In it, habitat types, ecosystems or natural habitat areas gain increased legal protection. Currently, only three habitat areas have directly been classified as remnant areas (Environment Agency of Iceland, n.d.). However notably the biota of other remnant areas have been influential (or a key factor) in the provided description of other remnant areas without mentioning habitats directly.

In a preparation report for the new legislation on environmental protection the importance of habitats and their monitoring is mentioned on numerous locations (Icelandic Ministry for the Environment, 2011). Regarding land use the report takes a commendable stance on conservation measures;

> “Due to large presumable changes in cultivation and increasing conflict of interest it is important to ensure that the effects to natural habitats are not overlooked and this shall be given more thought on a municipal scale; to protect the mosaic structure of habitats which is sufficient for the needs of birds, plants and other biota depending on the situation” (Icelandic Ministry for the Environment, 2011, p. 62) [translated by the author].

By the adaptation of the new law on environmental protection (No. 60/2013) habitats get a more realistic representation. This is largely due to structural changes in the law where conservation goals are specified in line with the aims of the law. For instance, art. 2 specified preservation goals for habitats types, ecosystems and species are listed. The main goal of the law is to conserve biological diversity, explicated further: “To provide protection for domestic species so they can sustain themselves in their natural habitats” (Art. 2 1st Paragraph C in Law on environmental protection, No. 60/2013). Hence, the desirability of preserving the sustainability of domestic species is generally acknowledged. Further protection status is dependant to more specific classifications.

Wetland areas larger than 1000 m^2, salt marshes, intertidal flats and natural birch forests obtained special protection, as they shall not be disturbed unless a grave motive exists and no other options are available (Art. 57 in Law on environmental protection No. 60/2013). The heightened legal status of protected habitats is also listed along with more information on responses or resolutions to conflicts (Art. 59 and Art. 60). Specific habitat areas can be selected for conservation corresponding to the older law, where protected remnant areas were defined. Protected areas are categorised in a similar manner. Moreover, additional categories have been added. The category which specifically mentions habitats is Nature protection area, where certain areas can be selected for preservation (Art. 49 Law on environmental protection, No. 60/2013).

Ecological restoration has received valid attention in Iceland and numerous restoration projects have been formed, implemented and reported. Aradóttir & Halldórsson (2011) presented a report on this subject where they the viewed causes, legislation and history of ecological restoration which was followed by an overview listing of 70 relevant restoration projects. The historical motives for restoration over the last decade were listed by Aradóttir, Pétursdóttir, Halldórsson, Svavarsdóttir, & Arnalds, (2013) they found that soil erosion and the protection of soils and vegetation were the strongest drivers for restoration and later socioeconomic drivers connected to forest cultivation. The authors criticized the outdated policy framework which they claimed provides little incentive for restoration and in some cases favoured reversed incentives for negative effects.

In a recent Law on environmental responsibility No. 55/2012 habitats are defined (see table 2.2). The protection status of habitats is emphasised by referring to the law on environmental protection (part b of article 6 (22)). In article 7 on the assessment of damage to protected species and environmentally protected areas the first paragraph states:

> “Impacts of environmental damages in accordance to the 1st paragraph, article 3 shall be assessed, considering in parallel; the protection status of the species or area before the damage was made; service to species or area as well as the ability for species or area for natural renewability. Data on measurable factors shall be used to ascertain if substantial harmful changes to former status are certain e.g. data on… the capability for species, their habitat or habitat type to restore in a short period of time a status equal or better than former state” (Article 7, Law on Environmental responsibility No. 55/2012) [translated by author].

2.4.3 Wilderness

Wilderness is a concept that was adopted to the U.S. Wilderness Act of 1964. Its purpose was to "…secure for the American people of present and future generations the benefits of an enduring resource of wilderness…" (In Sec. 2a of the U.S. Wilderness Act, 1964). The concept itself was defined in Sec 2c as: "Recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain" (U.S. Wilderness Act, 1964). Additionally, it is further defined as:

> "an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) has outstanding opportunities for solitude or a primitive and unconfined type of recreation; (3) has at least five thousand acres [$\approx$20.23 km^2] of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition; and (4) may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value" (Sec. 2c U.S. Wilderness Act, 1964).

The wilderness concept has since then been used in e.g. The World Conservation Union (IUCN) Framework for Protected Areas, there defined as:

''A large area of unmodified or slightly modified land and or sea, retaining its natural character and influence, which is protected and managed so as to preserve its natural condition'' (The World Conservation Union, 1994 in Mittermeier et al., 2003).

In Iceland wilderness ("óbyggt víðerni" in Icelandic) is defined in the new Law on Environmental protection No. 60/2013 as

> "An area in the wilderness, generally at least 25 km^2 in size and at least of a 5 km distance from manmade constructions and other technical landmarks, e.g. transmission lines, power plants, reservoirs and built up roads".

In article 3 of the same law, the conservation goals are stated. One contributing factor is to guard the remaining wilderness areas. Wilderness areas can also be defined as conservation areas according to article 46.

In Iceland the human perception of wilderness areas has been empirically valued with regards to tourism in the central highlands of Iceland (Sæþórsdóttir, 2012). From Sæþórsdóttir's (2012) results it can be derived that the qualities of wilderness give largely positive experiences to the beholder, which is an important resource for the tourist industry. The wilderness areas are however fragile and careful planning and site management is needed in order to sustain undamaged wilderness areas. Ólafsdóttir and Runnström (2011) have mapped wilderness areas in Iceland from a more perspective point of view where they used view-shed analysis, to calculate which areas in Iceland are without visual view of manmade constructions and other technical landmarks. Their result showed that 33% of the total country area fits their definition.

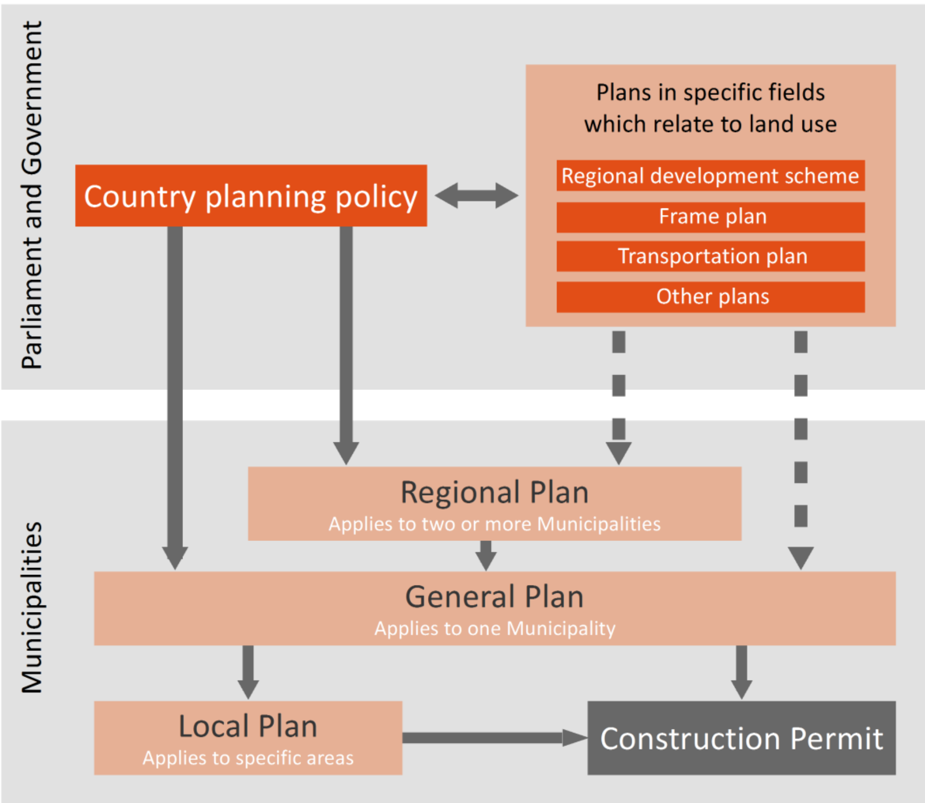
The wilderness concept refers more to the ability for humans to experience untouched nature (Sæþórsdóttir, 2012). Therefore, wilderness areas are preserved as undisturbed by human infrastructure. Landscape fragmentation is however more focused on the ecological effects to the landscape caused by both anthropological and or natural factors. Wilderness areas would theoretically measure low in fragmentation. However, this author feels that the two concepts should be valued and viewed independently. Ideally this would be conducted by combining the two in more complex environmental models or as separate baseline indicators in large scale planning practises.

2.4.4 Country planning policy

Planning offers a unique tool for nature conservation, monitoring and planning. Authorities in Iceland have presented numerous useful practices and guidelines to limit the effects of projects and settlement plans on e.g. biodiversity. Examples of these guidelines are environmental impact assessment (EIA) and strategic environmental assessments (SEA). Both of which have been implemented into Icelandic laws and regulations (Law on environmental impact assessment, No. 106/2000; Law on strategic environmental assessment, No. 105/2006).

Icelandic planning structure is changing as the country planning policy sets the foundation for other planning stages (Figure 2.6) wherein the country planning policy:

> "…combines public plans concerning, transportation, regional matters, nature conservation, energy usage and other fields which concern land use and it is arranged in consideration of the planning of land use guided by sustainable development" (Art. 10 2nd paragraph in Law on planning, No. 123/2010). [translated by the author].



(Source: Icelandic National Planning Agency, 2014, 2)

Figure 2.6 Country planning structure

The Icelandic National Planning Agency has publicized a description of the country planning policy of 2015-2026 (Icelandic National Planning Agency, 2014). The country planning policy addresses issues based on topics presented by the Minister for the environment and natural resources. In the published description these are: Planning for the (central) highland of Iceland; settlement patterns and the dispersal of settlements; planning of oceanic and coastal regions and finally planning of rural land use (Icelandic National Planning Agency, 2014).

All the topics presented could benefit from good environmental indicators. The proposal for the country planning policy is based on strategic environmental assessment (Icelandic National Planning Agency, 2014) meaning that, environmental effects of strategic actions are valued. This involves identifying environmental concerns where environmental base line indicators are presented and any individual policy/plan/project is analysed to conclude how it will influence selected factors (here reference scale is important). Finally after the policy/plan/project is implemented a monitoring process takes over where changes to the baseline are measured and compared to expected results in accordance to a previously defined timeline.

When preserving the landscape of the central highlands, landscape identities (not fragmented landscape), wilderness and soil as according to the agreement of the European Landscape Convention shall be considered. One factor in viewing settlement patterns and the dispersal of settlements is to put forward planning guidelines regarding e.g. land use and transportation. More diverse cultivation or usage of oceanic and coastal regions can cause a conflict of interests between stakeholders where ecological preservation of natural resources is considered of high value. Regarding land use in rural areas, the progression of agriculture and changes in cultivation practices have put increased pressure on ecosystems and it is therefore important that the country planning policy provides good guidelines to promote sustainable land use.

A timeline for the evaluation process has been presented, where baseline indicators are listed, options are valued and environmental impacts estimated. Descriptions of four categories have been presented, each with a list of the major plans involved as well, base line indicators and the environmental guidelines which are to be considered (Icelandic National Planning Agency, 2014).

Habitats, habitat types and ecosystems are not listed with the presented base line indicators. Perhaps this is due to the fact that no national database exists on this specific topic. Many factors indirectly related to the preservation of habitats are included as baseline indicators. These are i.a.: Settlement Patterns (density, urban sprawl, road networks), land classification, soil erosion and land restoration areas, natural forests, water quality, environmentally protected areas, wilderness areas, wetland areas, agricultural land use, transportation infrastructure and traffic. All of the above have geographical data available on their status.

3 Methods

The methodology used to measure the fragmentation of Icelandic landscape was based on the European assessment report of landscape fragmentation in Europe (EEA & FOEN, 2011). Figure 3.1 provides a simplified overview of the structure of the assessment. It outlines the main factors that had to be considered before the actual calculation was derived.

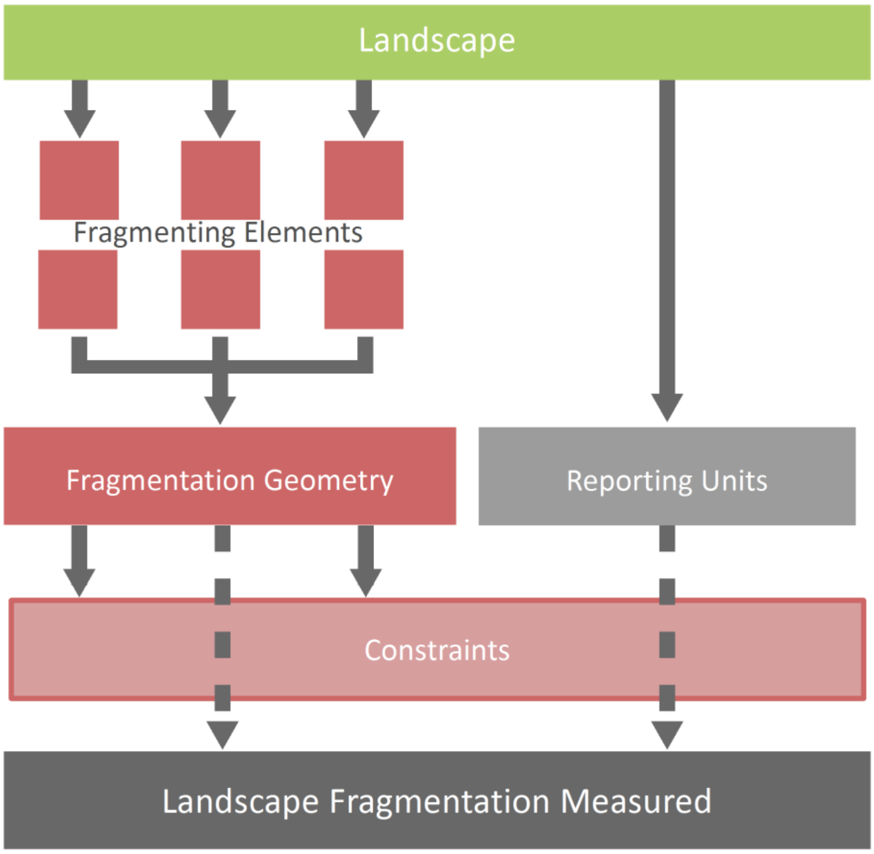


Figure 3.1 Simplified structure of assessment

The landscape fragmentation indicator rests on selecting spatial variables from the landscape which are the rooting causes of the fragmentation. These causes are henceforward referred to as fragmenting elements (Chapter 3.1), and are represented by either linear vector datasets or spatial vector datasets. The fragmenting elements are classed as different fragmentation geometries depending on what factors are chosen as variables (Chapter 3.3).

The reporting units represent comparative areas and can therefore be: administrative boundaries such as municipalities; natural boundaries such as water catchment areas or other predetermined artificial boundaries like a 1 km^2 grid (Chapter 3.2).

Constraints are contemplated areas which are deliberately excluded from the computation, by reason of two factors. Firstly, to account for indirect natural barriers such as climate or steep elevation surfaces and secondly to normalise the comparative area, conditioned to large scale analysis of sometimes dissimilar landscape identities (Chapter 3.4). The constraints are also like the fragmenting elements dependant on which fragmentation geometry is selected.

The fragmentation geometry is the foundation on which the calculation is built upon. Six fragmentation geometries were used in this thesis maintaining three identical to the European research and adding three new fragmentation geometries which were created (Chapter 3.3).

Numerous adjustments were made to the fragmenting elements. This included adapting local data to fit the same structure as set by the European research and excluding irrelevant factors not found in Iceland (chapter 3.1). The reporting units from the European research were used, along with two more local comparison units (chapter 3.2). Perhaps the most problematic factor in the data preparation work were the constraint boundaries, set by the European research. This was due to the fact that they excluded over 80% of the country’s land surface which in turn meant that the first aim of the research would not be fulfilled unless amended. This led to the creation of three new constraining boundaries, for both local representation and as alternatives in comparison with the European results (chapter 3.4).

The final calculations were derived using Geographical Information Systems or GIS making use of many of the numerous spatial calculating functions available. A predefined ArcGIS tool made by Girvetz (2011) helped in this effort (see chapter 3.5).

3.1 Fragmenting Elements

This chapter provides an overview of the different datasets used as fragmenting elements for the model calculations and explains how each dataset was transformed. The fragmenting elements and criterions are listed in table 3.1. These are mostly the same factors used in the European report (EEA & FOEN, 2011, p. 28). Six elements were selected from the CORINE land cover database (chapter 3.1.1.), data on the Icelandic road network was categorized to fit the functional road class format wherein the first four classes where used as fragmenting factors (chapter 3.1.2). Seven major rivers with water catchment areas greater than 3000 km^2 were also used as fragmenting elements (chapter 3.1.3). Choosing to select the same CLC fragmenting elements as in the European research, adjusting the local road network data to correspond to the European research as well as using same criterions in selection of fragmenting rivers makes all the input data comparable with those used in the European research.

Table 3.1 Fragmenting elements

Dataset	**Year**	**Fragmenting elements**
Corine Land Cover (CLC)	2006	1.1: Continuous urban fabric*, discontinuous urban fabric 1.2: Industrial and commercial units, road and rail networks* and associated land, port areas and airports 1.3: Mineral extraction sites, dump sites, and construction sites 1.4.1: Green urban areas 1.4.2: Sport and leisure facilities (only included as a barrier if they were completely surrounded by the previous classes) 4.2.2: Salines* 5.1.2: Water bodies
TeleAtlas Multinet® † National Land Survey of Iceland & The Icelandic Road Administration	2009 2011	Class 00 'Motorways' (buffer 2 × 15 m)* Class 01 'Major roads' (buffer 2 × 10 m) Class 02 'Other major roads' (buffer 2 × 7.5 m) Class 03 'Secondary roads' (buffer 2 × 5 m) Class 04 'Local connecting roads' (buffer 2 × 2.5 m) Railroads (buffer 2 × 2 m)*
CCM2: Catchment Characterisation and Modelling version 2.1	2007	Rivers with catchment areas greater than 3 000 km^2

(Source: The table is based on table 2.2 in EEA & FOEN, 2011 p. 28).

*These factors do not exist in Iceland
† TeleAtlas Multinet® road data was not available for Iceland (see chapter 3.1.2).

3.1.1 CORINE Land Cover

The hierarchical structure of the CLC data is useful to identify fragmenting elements from the environment. In the European report on landscape fragmentation 7 factors were chosen with three factors on a second level in the hierarchical structure and four on the third level (EEA & FOEN, 2011). The factors come from three first level classes; artificial surfaces, wetlands and water. The Icelandic data differs, hence some classes do not exist in Iceland and other classes are too small to reach the minimum mapping unit (Árnason & Matthíasson, 2009). For instance, the fragmenting factor continuous urban fabric is left out. The CLC data which differs in this way is marked with a star (*) in table 3.1.

In Iceland the CLC fragmenting factors are 1360 and they cover about 1619 km^2 (Figure 3.2). The most significant fragmenting factors there are water bodies and the rest are artificial surfaces.

(Data Source: Árnason & Matthíasson, 2009).

Figure 3.2 Fragmenting elements: CORINE

3.1.2 Road network

The EEA & FOEN (2011) use data from the TeleAtlas® Multinet® to acquire information about linear fragmenting elements. TeleAtlas® Multinet® (Now TomTom Multinet) is a vector dataset available throughout Europe, excluding Iceland. It is a road network database which is maintained according to ISO/TS 16949 standard (TeleAtlas, 2008) and the database was purchased by the European Commission in 2009 (European Commission, 2009). The Multinet network data is categorized on the bases of road functional importance (TeleAtlas, 2010) and is divided into classes named Functional Road Classes (here after; FRC). FRC orders roads into 9 classes of which only five are considered as fragmenting factors (see table 3.1). Road functional importance looks at what role the road plays for the average user. It is defined by which roads are more important or less important to the transportation network in total. This can be very useful when comparing different areas on a global scale with ranged difference in both usage and design.

Because the TeleAtlas® Multinet® road network data is not available for Iceland, road data from the IS X 1.2 digital database (National Land Survey of Iceland, 2011a) was manually reclassified to fit a similar structure. The IS X database is an "online version" of the IS 50v database, developed by the National Land Survey of Iceland. The IS 50v is a vector database with eight different datasets including a transportation layer. The project to build up this database started in 1998 (Þorbergsdóttir, 2004) and is an ongoing project. The version used here was IS 50v 3.1 where the online version is named IS X 1.2. The online version includes a transportation vector dataset which is designed for publication. It differs from the original because it excludes roads that are to be closed for traffic due to the requests of: The Environment Agency of Iceland; the Soil Conservation Service of Iceland and in accordance to the conservation program of Vatnajökull National Park (National Land Survey of Iceland, 2011b). This dataset is from the year 2011 and was chosen in regards to the comparison with EEA & FOEN (2011).

The transportation dataset from the IS50v database was built in cooperation with to Icelandic Road Administration (National Land Survey of Iceland, 2011b). In the IS50v-X digital database two different classifications of roads exists as attributes. First there is a road category based on Icelandic legislation. The Icelandic Road Administration works in accordance to Icelandic Law on roads (No. 80/2007). In this legislation, roads are divided into four categories; national roads, municipal roads, private roads and finally public routes the national roads category has four subcategories which are defined in the law and the category of public routes encompasses hiking paths, cycling paths, horse trails, etc. Because road category classification is mostly based on the legal status of roads, this also determines who is the keeper of the road and therefore in charge of obligatory maintenance.

The Second classification is road structural type. This classification is also originated from the Icelandic Road Administration where roads have been evaluated according to their design structure (Icelandic Road Administration, 2010). The structure design of roads is determined by a traffic capacity assessment for the 20 years following the roads construction. It is a good indicator on how much traffic can be expected and serves as a direct reference to the roads geometric design and profile.

In an effort to classify the roads based on their functional importance these two classification schemes were combined to form 31 independent classes, where each class consisted of both the category (legal status) and the structural design. Road category was important in looking at what role the road had in the transportation network. The roads structure type was important to see the approximated usage and which roads are bigger or smaller in design. Consequently, both aforementioned categorizations were useful in evaluating function. Each of the 31 classes were independently valued and then re-categorized to fit the FRC format. In Table 3.2 the classes are listed with their road category and structure type along with their Estimated Functional Road Class (FRC_E).

Table 3.2 Estimated Functional Road Classes

	Icelandic Road administration		Estimated Functional Road Classes	
Nr.	Road category	Structure type	FRC_E	Name
1	Primary roads	A	**1**	Major Roads
2	Primary roads	B	**2**	Other Major Roads
3	Primary roads	C	**2**	Other Major Roads
4	Local access roads	C	**3**	Secondary Roads
5	Local access roads	D	**3**	Secondary Roads
6	Secondary roads	C	**3**	Secondary Roads
7	Public Roads	A	**4**	Local Connecting Roads
8	Public Roads	B	**5**	Local Roads of High
9	Highland roads	C	**6**	Local Roads
10	Highland roads	D	**6**	Local Roads
11	Highland roads	F1	**6**	Local Roads
12	Primary highland roads	C	**6**	Local Roads of High
13	Primary highland roads	F1	**6**	Local Roads of High
14	Secondary roads	D	**6**	Local Roads
15	Primary roads	D	**7**	Local Roads of Minor
16	Private Roads	C	**7**	Local Roads of Minor
17	Private Roads	D	**7**	Local Roads of Minor
18	Private Roads	F1	**7**	Local Roads of Minor
19	Private Roads	F2	**7**	Local Roads of Minor
20	Private Roads	F3	**7**	Local Roads of Minor
21	Private Roads	Not defined *	**7**	Local Roads of Minor
22	Public Roads	C	**7**	Local Roads of Minor
23	Public Roads	D	**7**	Local Roads of Minor
24	Highland roads	F2	**8**	Other Roads
25	Highland roads	F3	**8**	Other Roads
26	Primary highland roads	F2	**8**	Other Roads
27	Public Roads	F1	**8**	Other Roads
28	Public Roads	F2	**8**	Other Roads
29	Public Roads	F3	**8**	Other Roads
30	Public Roads	Not defined *	**8**	Other Roads
31	Secondary roads	F1	**8**	Other Roads

(Data source: National Land Survey of Iceland, 2011a.)

* Data was missing from attributes for road structure type therefore two more classes were created, where the value <NULL>, was counted as a separate class value.

FRC_E values 1-4 were considered to be fragmenting factors and in preparation for the model calculations a polygon buffer layer was created around each of those and their sizes were kept identical to the European research. Major roads got a buffer of 2 × 10 m, Other major roads got a buffer of 2 × 7.5 m, secondary roads got a buffer of 2 × 5 m and local connecting roads got a buffer of 2 × 2.5 m. Appendix A contains the definitions for each road category and structure type along with explanatory figures for each of the 31 classes and a description on how each class was valued individually in accordance to the FRC classification scheme.

No road was classified as a motorway. TeleAtlas® Multinet® define FRC 0 as "all roads that are officially assigned as motorways" (Tele Atlas, 2010, 47). However, in Iceland only one road can possibly fit this definition. It is the primary road Reyjanesbraut (road nr. 41) which provides a connection from Keflavik International Airport with the capital area (Currently the only international airport in Iceland). Reykjanesbraut is the longest 2 × 2 road in Iceland and it‘s construction was finished in 2008 (Icelandic Road Adminstration, 2008). In the CORINE land cover project for 2006, the buffer zone for Reykjanesbraut is extended to reach 100m and was considered as motorway. (Árnason & Matthíasson, 2009, p. 44). However in this estimation of fragmentation, Reykjanesbraut was not differently valued from other roads with the same road category and structure type (here Primary roads and Structure type A). Nevertheless, this had no influence on the final result. Because the CORINE buffer of 100m overlays the 30m buffer set by the FRC_E value 1.

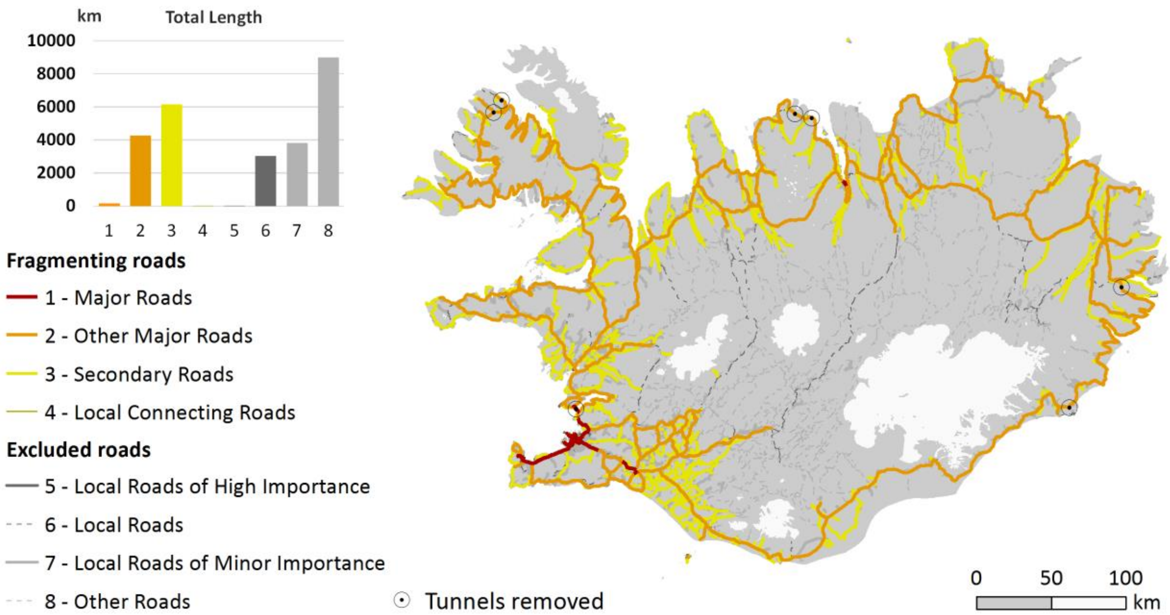
Tunnels longer than 1km where not considered as fragmenting factors, and were removed manually from the road network after the roads were classified. This was done in accordance to European research because the landscape above the tunnels is unaffected by the infrastructure bellow (EEA & FOEN, 2011). In total, seven tunnels were removed ranging from 1.300 m to 11.000 m see table 3.4. The longest tunnels Héðinsfjarðagöng and the tunnel through Breiðdals- and Botnsheiði are divided in to parts which are also listed in table 3.3.

Table 3.3 Tunnels in Iceland longer than 1 km.

Name of tunnel	**Length**
Héðinsfjarðargöng	11 000 m
(Ólafsfjarðarleggur)	7 100 m
(Siglufjarðarleggur)	3 900 m
Breiðadals- og Botnsheiði	9 160 m
(Breiðdalsleggur)	4 150 m
(Botndalsleggur)	2 907 m
(Tungudalsleggur)	2 103 m
Fáskrúðsfjarðargöng	5 900 m
Hvalfjörður	5 770 m
Bolungarvíkurgöng	5 400 m
Ólafsfjarðarmúli	3 400 m
Almannaskarð	1 300 m

Source: Icelandic Road Administration (2012).

In Figure 3.3 the geographical distribution of the FRC_E data is shown. The length of the first four FRC_E are about 40% of the total length of the road vector layer, FRC_E values 5, 6, 7 and 8 were not considered to be fragmenting elements. The total length of each fragmenting factor is graphed to emphasize that very few roads are valued FRC_E 4 and 5. Tunnels that were removed before the calculations are marked with dots.



(Data source: National Land Survey of Iceland, 2011a)

Figure 3.3 Fragmenting elements: Roads

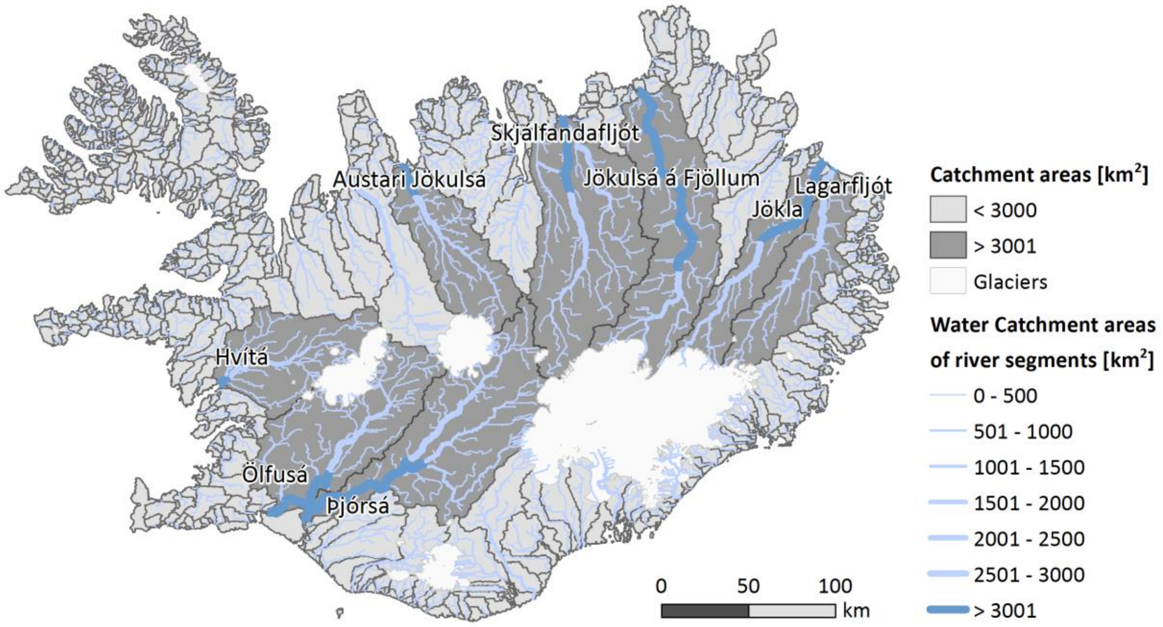
3.1.3 Water catchment areas

In the European research, rivers with water catchment areas greater than 3000 km^2 were included as fragmenting factors in assessing fragmentation of non-mountainous land areas (EEA & FOEN, 2011). The reason given was that these rivers have the possibility to keep boats afloat and therefore also act as an obstructing barrier for many terrestrial animals. The data used to define these rivers came from the CCM River and Catchment Database (Vogt, et al., 2007) which was also utilised for this research.

In order to identify which rivers in Iceland have water catchment areas greater than 3000 km^2, the defined attributes of the CCM database of both the water catchment areas and river segments where joined together based on ID's given in the database. At that point each river segment had a joint catchment area in km^2. The attribute table was then extracted and analysed. It is therefore defined for each river segment which segment it connects to (attribute field "NEXTDOWN"). Using this information, the catchment areas for each river segment were added to the next one connected to it. If more than one were connected to the next one, they were summarized and this was repeated (in loop) 37 times to get the total water catchment areas for each river segment. These attributes were subsequently joined in the GIS to the CCM river segments and those rivers with more than 3000 km^2 where extracted and buffered 2*10m before being added to the landscape fragmentation calculations.

The CCM database accuracy for Iceland is low or 30arc seconds, and surface lines are displayed where water might flow through sub surface channels (Vogt, et al., 2007). The Icelandic Met office in cooperation with the Environment Agency of Iceland are working on a hydrological database for Iceland where similar calculations could be used to extract the water catchment areas for each river segments (Björnsson, Egilson, & Sverrisson, 2013). Such a database would include not only surface water but also groundwater flow. The Met office database was not used here to maintain comparability to the European research. Nonetheless, the planned database will be much more accurate than the CCM and would be ideal to identify natural fragmenting elements in future research.

Figure 3.4 shows the catchment areas for each river segment and highlight parts of rivers which have bigger water catchment areas than 3000 km^2. These belong to eight different rivers and are labelled in the figure.



(Data Source: Vogt, et al., 2007, National Land Survey of Iceland, 2011a).

Figure 3.4 Fragmenting elements: Major Rivers

3.2 Reporting units

Reporting units selected as comparison areas were five in total. Two of which were used for comparison to the European report result findings, two additional reporting units were added intended for local comparison, and the last one was a 1km^2 grid of the total land surface area, which was also used as measurement unit in the European research (EEA & FOEN, 2011).

The first reporting unit is on a country scale wherein the country is measured as a whole area and the coastline boundaries set in the CLC project were used as reference (Árnason & Matthíasson, 2009). The CLC coastline includes the largest islands surrounding the country. This practice differs from the European research where all islands were excluded from the measurements. The reasoning behind for including the islands was primarily due to the fact that some of them possess towns or settlements and one municipality consists only of islands.

The second reporting unit, is based on NUTS 3, regions. NUTS is an abbreviation which stands for “nomenclature of territorial units for statistics”. NUTS are statistical comparison areas used within the European Union as well as countries of the European Free Trade Association, EFTA by agreement (Eurostat, 2008). NUTS are organized in a hierarchical order where each country is divided into NUTS 1 regions that contain NUTS 2 that then contain the NUTS 3 regions (Eurostat, 2007). The regions do not cross boundaries internally but NUTS 1, 2 and 3 can be the same in all comparative areas. Provided that the areas do not reach the population thresholds given (Table 3.4).

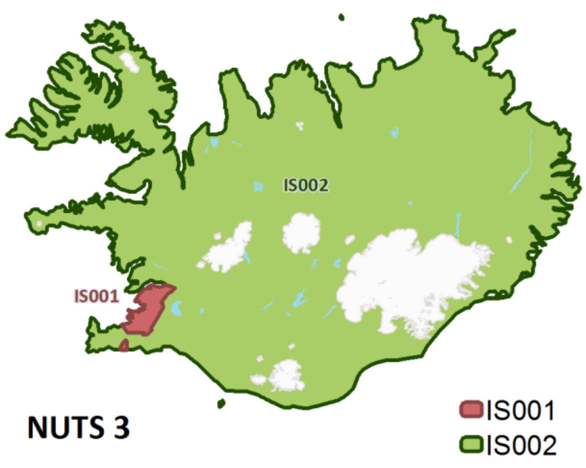
Table 3.4 NUTS population thresholds

Level	Minimum population	Maximum population
NUTS 1	3 000 000	7 000 000
NUTS 2	800 000	3 000 000
NUTS 3	150 000	800 000

(Source: Eurostat, 2007, 10)

All NUTS regions are chosen based on certain principles but for practical reasons can align with other institutional divisions used (Eurostat, 2007). They are chosen based on homogeneity of the area, whether it is on socio economic bases, historical bases or based on geographical factors, such as the same types of altitude or soil types (Eurostat, 2007).

Iceland, by agreement, created NUTS areas in 2006 which were accepted by Eurostat in 2008 (Harðarson & Sindradóttir, 2012). All of Iceland is represented in the first two NUTS areas (NUTS 1 and NUTS 2) but on the third level (NUTS 3) the country is divided in two areas; the capital area and the countryside which refers to; all areas outside the capital area (Harðarson & Sindradóttir, 2012). Figure 3.5 shows the classified NUTS 3 regions which were used as the second reporting unit.



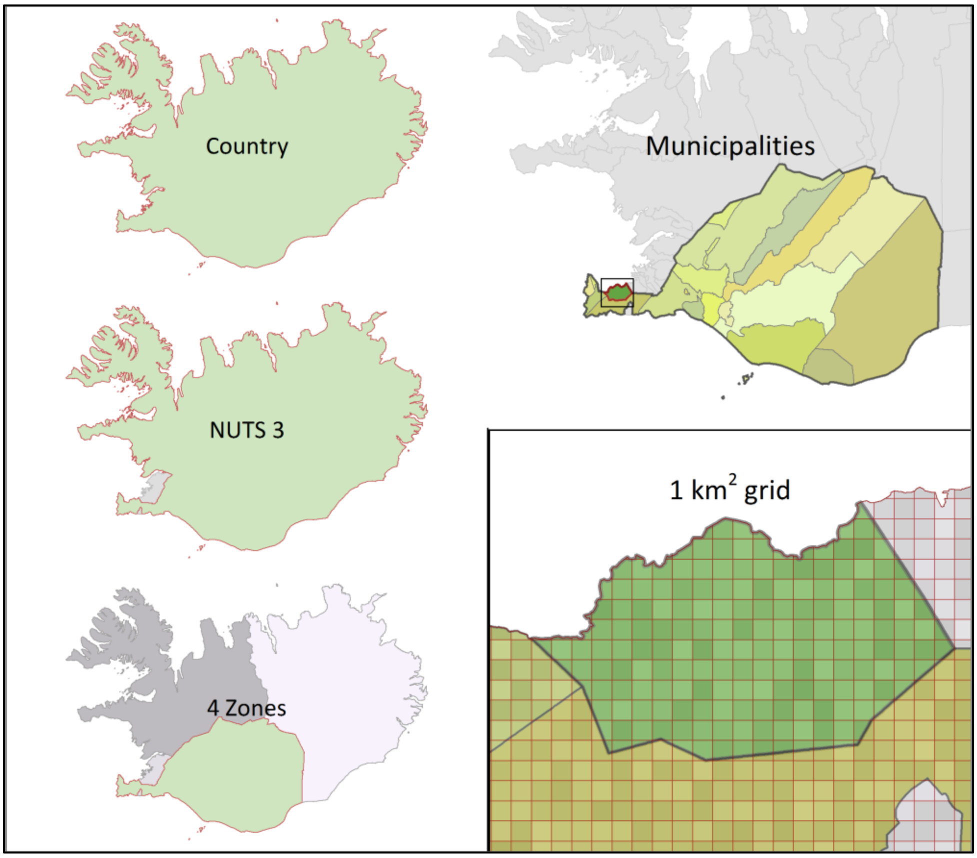
(Data source: National Land Survey of Iceland, 2011a)

Figure 3.5 NUTS 3 comparison areas in Iceland

The third reporting unit divides the country in to four zones. These zones are one of three proposals made, to correlate local statistical boundaries to the NUTS region boundaries (Harðarson & Sindradóttir, 2012). Three solutions were presented and discussed in a memorandum from Statistics Iceland however a final decision had not been made on which of the three proposals where to be used.

The fourth reporting unit is Icelandic municipalities. They are 76 in total, variant in shapes and sizes. Their boundaries correlate between the four zones used, which correlate with the NUTS regions which correlate to the country as a whole. This provides a good hierarchical overview of the scale of fragmentation on different levels (see Figure 3.6).

The fifth reporting unit is a 1 km^2 grid. In the European research, EEA & FOEN (2011) used the Land and Ecosystem Account database LEAC, developed by the EEA (Gómez & Páramo, 2005). The grid is accessible online from the EEA webpage (EEA, 2011). As the database includes Iceland it was decided to use it in this thesis when measuring fragmentation for the European Fragmentation Geometries. Another 1 km^2 grid developed by LISA, an organization of Geographical Information in Iceland in cooperation with the National Land Survey of Iceland (LISA & National Land Survey of Iceland, 2006), was also used but only with fragmentation geometries which included locally adjusted fragmentation constraints (see next chapter).



(Data source: National Land Survey of Iceland, 2011a; Árnason & Matthíasson, 2009; LISA & National Land Survey of Iceland, 2006)

Figure 3.6 Reporting unit hierarchy

3.3 Fragmentation Geometries

Fragmentation geometries (FG) determine which fragmenting elements are used as factors in the calculations. Providing alternatives to the input data, planning authorities receive a broader databank to value the information presented (Girvetz, Thorne, Berry, & Jaeger, 2008). FGs are a set of man-made or environmental factors which are considered to fragment the landscape. The European research (EEA & FOEN, 2011) used three types of fragmentation geometries and they are as follows: The first is FG-A1 which represents major anthropogenic fragmentation; second; FG-A2 stands for major and medium anthropogenic fragmentation and third, is FG-B2 which stands for Fragmentation of non-mountainous land areas. The first two (FG-A1 and FG-A2) only assessed fragmentation based on anthropological elements while the third (FG-B2) considered also natural factors such as rivers and water bodies. The study area for FG-B2 was normalized for international comparison using constraints (see next Chapter 3.4).

Landscape fragmentation was measured after the three previously mentioned FG and furthermore three additional FG where added. These where named Iceland fragmentation geometries one to three (FG-ICE 1-3). They were kept the same as FG-B2 regarding the selection of fragmenting elements. However, the main difference was in the selection of environmental constraints, meaning that the constraints set to remove mountainous land differed greatly. FG-ICE 1 stands for fragmentation of non-glacial land areas, FG-ICE 2 stands for fragmentation of non-barren areas and FG-ICE 3 stands for fragmentation of plausible grass growth areas. Table 3.5 provides an overview of all fragmentation geometries used in this research. The next chapter outlines the selection of constraining factors.

Table 3.5 Fragmentation Geometry

Fragmentation geometry	**Barriers used**		
	Man-made barriers* Artificial surfaces and roads	**Natural barriers** Lakes and major rivers.	**Constraints** Mountains, glaciers or low growth areas
FG-A1	Of roads, only major roads (class 1) are considered	Not considered	No constraint
FG-A2	Of roads, major roads, other major roads, secondary roads and local connecting roads (class 1-4) are considered	Not considered	No constraint
FG-B2	Of roads, major roads, other major roads, secondary roads and local connecting roads (class 1-4) are considered	Considered	Constraint set by a 9,5°C isoline using July mean temperature values 1950-2000
FG-ICE 1	Same as FG – B2	Considered	Glaciers used as constraint
FG-ICE 2	Same as FG – B2	Considered	Thermal bliss value of 25,5 was used as an isoline constraint†
FG-ICE 4	Same as FG – B2	Considered	Thermal bliss value of 32 was used as an isoline constraint†

* No motorways exist in Iceland, see discussion in chapter (3.1.2).

† Thermal bliss is a value introduced by Bergþórsson (1996) (see chapter 3.4.2).

3.4 Constraints

Constraints are predefined areas which limit the calculation area. They are excluded from the selected reporting units and the selected FGs before the fragmentation is measured. Areal constraints are used to account for indirect natural barriers to landscape connectivity such as high mountainous areas with high elevation and, steep slopes which are mostly impassable for land surface species. Another indirect natural barrier is the local climate as it concerns influence on applicable living conditions. One beneficial influence of using the environmental constraints was that it normalised the European comparative area (EEA & FOEN, 2011). It excluded large areas where landscape fragmentation was low but poor living conditions existed thus giving a more consistent data for comparison.

The European research (EEA & FOEN, 2011) took in account noticeable difference in elevation and climate across Europe, they produced three constraints to account for this, two for elevation and one to account for local climate (1-3 in table 3.6).

Table 3.6 Constraints

	Criterions	Datasets	Year
Elevation	1. Elevation is higher than 2 500 m* 2. Elevation is higher than 1 500 m and the slope is steeper than 2 °	Nordregio[†] EU-DEM GTOPO30 IS-DEM	2004 2004 2007 2012
Climate	3. Mean July temperature > 9.5 °C (1950–2000) 4. Glaciers (CLC class 3.3.5) 5. Thermal bliss value of 25,5[‡] 6. Thermal bliss value of 32,0[‡]	WorldClim Corine Land Cover Halldór Björnsson et al.	2005 2006 2007

* No surface is higher than 2500 m in Iceland
[†] The Nordregio data set was not used in this thesis
[‡] Thermal bliss is a value introduced by Bergþórsson (1996) see discussion below.

During the first calculations it became clear that the third criterion set for climate excluded over 80% of Iceland’s land surface areas which in turn meant that the first aim of the research would not be fulfilled unless amended. On account of this a third research question was added to the thesis which in turn meant exploring other viable constraint boundaries for the climate which would be ecologically valid. It was decided to add three different constraints for comparison (4-6 in table 3.6).

3.4.1 Elevation

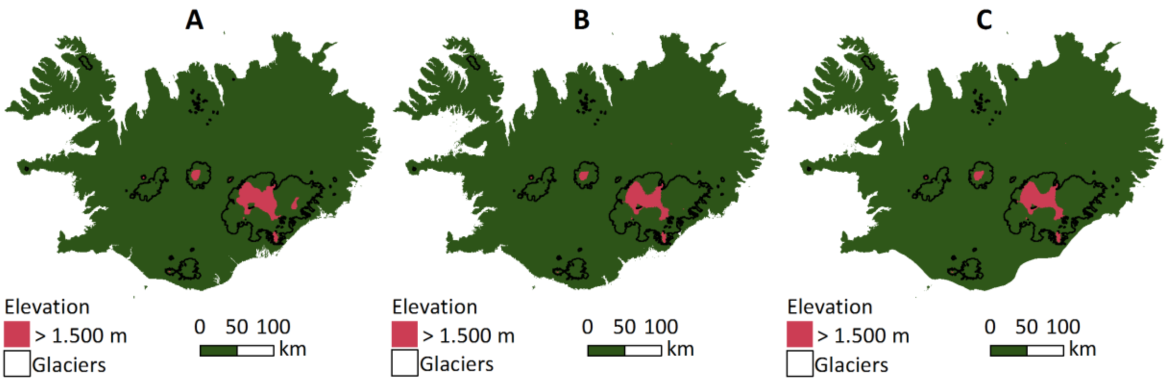
The two elevation criterions introduced in the European research were duly considered. There all surface areas above 2500 m were removed following the first criterion and all surfaces higher than 1500 m with a slope steeper than 2° following the second criterion. In Iceland the highest mountain is “Hvannadalshnjúkur” which is 2110 meters above sea level. Therefore, the first European criterion was irrelevant to this thesis. However, three digital elevation model datasets DEM where used to map areas over 1500m.

The first DEM used was a created by the U.S. Geological Survey USGS in 2007. It was named the GTOPO30 DEM. It is a global dataset with a 30-arc-second resolution (Verdin, et al., 2007; USGS, 2007). This dataset was created to help estimate global risk areas of landslides following large earthquakes (Verdin, et al., 2007). This DEM is older and less accurate than the other data sets used, but its purpose and development was motivational for other global elevation datasets.

The second DEM used comes from a project called the GMES RDA project or Global Monitoring for Environment and Security, Reference Data Access (Center for Strategy Evaluation Services, 2013; EEA, 2013). It is a project within the European Earth Monitoring Programme that was established by the GMES Regulation (EU) No 911/20109 (Center for Strategy Evaluation Services, 2013). The DEM used from this project, was given the name EU-DEM and is here after referred to by that name. The EU-DEM is one of two datasets that were created because they were given a priority status in the GMES project preparatory action (Center for Strategy Evaluation Services, 2013). The EU-DEM was used in Nordregio's analysis of mountain areas in EU member states, and neigbouring countries (Nordregio, 2004). The Nordregio also used data from the USGS in their analysis or the USGS GTOPO30 DEM (Nordregio, 2004). Nordregio classified mountain areas so that they could be used for the purpose of statistical analysis. One of the factors classified were all areas with a base height between 1500-2499m and 2° slope within 3km radius of this base height (Nordregio, 2004). The Nordregio data was used by the EEA &FOEN (2011) as the second criterion.

The third DEM used in this thesis was a newly developed DEM from the National Land Survey of Iceland named "Landshæðakerfi Íslands" which can be translated to "Iceland elevation model" but is here after called IS-DEM (National Land Survey of Iceland, 2011a). The creation of this DEM was one of the biggest geodesy projects the National Land Survey of Iceland has implemented and a description on its the development can be found in the technical report by Valsson (2012).

In figure 3.7 all areas above 1500m are highlighted each with a different dataset. A displays the results of the GTOPO30 DEM and B the EU-DEM whilst finally C shows the IS-DEM. Even though there is some difference in the measured area above 1500m almost all of these areas are on glaciers in Iceland. Therefore these data sets were not analysed in concern to slope like the Nordregio (2004) research. Another reason was that all these areas fall out of the research boundaries set by climate constraints (see next chapter 3.4.2).



(*Data source:* **A**: *USGS 2007b,* **B:** *EEA, 2013,* **C:** *National Land Survey of Iceland 2011a*)

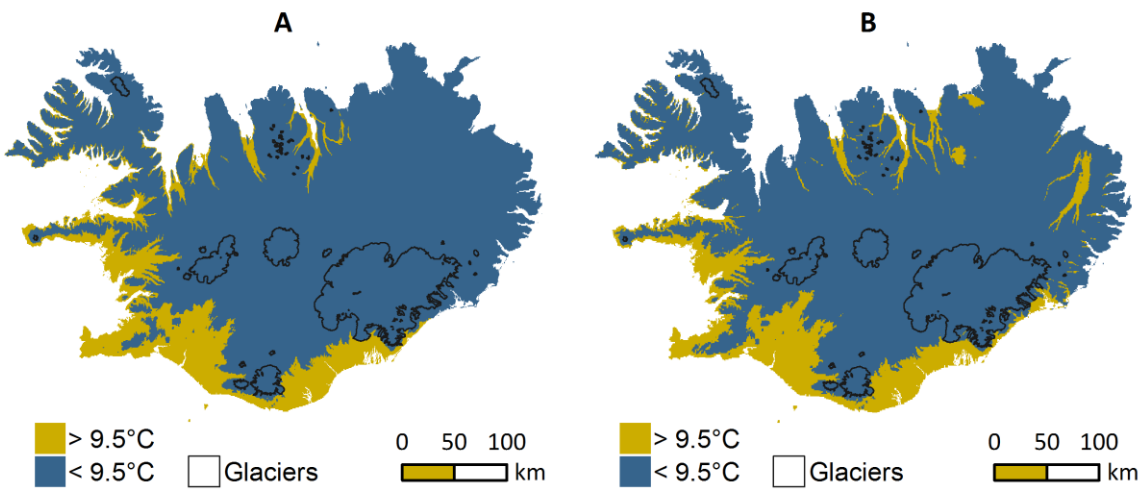
Figure 3.7 Elevation criterions considered

3.4.2 Climate

July mean temperature, from 1950-2000 was set as a constraining factor in the European research (EEA & FOEN, 2011) (Factor 3 in table 3.6). Meaning, if the temperature was lower than the isoline of 9.5 °C the results for these areas were removed from the total are of comparison. This was done to remove lover elevation areas which were considered, not suitable for settlement. Reasons being, that these areas have low primary production, few towns, roads or buildings, mostly because of the short growing season, existence of glaciers and lack of forests (EEA & FOEN, 2011).

The European research (EEA & FOEN, 2011) used data from WorldClim which is a global dataset with a spatial resolution of 30 arc seconds (1-km) spatial resolution (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005). When published it improved greatly the accessibility to global weather data, and today it is widely used for analysis. The mean temperature data is interpolated from numerous weather stations and as pointed out by the authors the quality depends on the quality and density of weather observation stations (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005).

For Iceland the 9.5° C isoline was computed from the WorldClim data. From that point it became clear that the third constraint excluded most of the eastern lowland settlements and settlements in the east-fjords, and the north eastern coastline (Figure 3.8 A). Individual weather stations were compared to the WorldClim data, which showed mixed results. Therefore it was decided to add a newer and more accurate mean temperature data set for comparison.



(*Data source:* **A**: *Hijmans, et al. 2005,* **B:** *Björnsson et al. 2007.*)

Figure 3.8 Mean July temperature 1950-2000 (A) and 1961-1990 (B).

Björnsson, Jónsson, Gylfadóttir and Ólason (2007) from the Icelandic Metrological Office made a local mean temperature dataset for Iceland for a different time period or 1961-1990. The weather station network is denser and more accurate as it used data from 84 individual weather stations, 8 stations within 50 km of the next station and 23 within 100 km (Björnsson, Jónsson, Gylfadóttir, & Ólason, 2007). This dataset was compared to the WorldClim data in regards to the 9.5 °C threshold (Figure 3.8 B). The biggest difference is in the eastern part of Iceland where Björnsson et al. data includes higher values. Another noteworthy difference is in the north-west where the WorldClim data includes higher values.

This meant that just changing the temperature dataset would not serve the purpose of evaluating fragmentation around all settled areas in Iceland and in turn meant choosing which areas were more suited for evaluation (A or B in Figure 3.7) which, was considered unacceptable. Consequently, developing a new approach was necessary for local analysis. Therefore, it was decided to change the isoline variable when fragmentation vas measured on a local scale, but to keep it for the European comparison, using the WorldClim data as reference (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005). The author argues however that using the 9.5° C threshold temperature is questionable, especially in regards to ecological consistency because it lacks rational explanation why this temperature was chosen over another in the European research.

Three new constraints were created and referred to as fourth, fifth and sixth constraint boundaries (4-6 in Table 3.6). The fourth excludes only glaciers where all other land areas where considered. Hence, it was decided to use the polygon vector data from the CLC class 3.3.5: Glaciers and perpetual snow. Using glaciers directly as barrier is interesting due to two reasons. Firstly, glaciers are truly a barrier for almost all species and secondly as suggested by (Magnúsdóttir, Þórhallsdóttir, & Svavarsdóttir, 2014) when glaciers decline due to changes in climate new habitat areas appear, and vegetation seams to inhabit these areas in a relatively quickly.

The fifth and sixth constraint barriers are based on a value created by Páll Bergþórsson. (Bergþórsson, 1996) has studied the relations between temperature and vegetation growth. He points out that using threshold temperature is only useful, in comparison, when the study area is small and is within a limited climatic area. For a more regional approach he introduces a new special index he names “thermal bliss” (“hitasæld” translated by the author). Wherein, vegetation growth (V) is connected to mean temperature data using (4); (Bergþórsson, 1996, 144).

$$\mathrm{V_m} = \mathrm{T_m}/(1 - \mathrm{T_m}/30\,), \tag{4}$$

where $\mathrm{V_m}$ quantifies growth in unidentified units and T_m is the mean temperature of month m. The growth represents the possibilities of growth if other cultivation conditions are met such as appropriate moisture levels, sunshine levels, and appropriate soil types. The thermal bliss (H) is then measured from (5) or the total sum of growth over a one year period where measured growth is above 0 in value

$$\mathrm{H} = \sum_{m=1}^{12} \mathrm{V_m}. \tag{5}$$

Here, Bergþórsson (1996) creates an indicator of thermal production of a given place. This method was used with the mean temperature values computed by Björnsson et al. (2007) to calculate the average thermal bliss for Iceland 1960-1990. This was done in ArcGIS using several spatial analyst functions (Figure 3.6). Monthly growth was first calculated for each month, then all twelve months were summarized using raster calculator again to produce the average thermal bliss value. In figure 3.9 the blue parallelograms represent raster images, the purple trapezium represent the constant 0 which controls the Greater than function. The yellow boxes represent ArcGIS functions used for calculation.

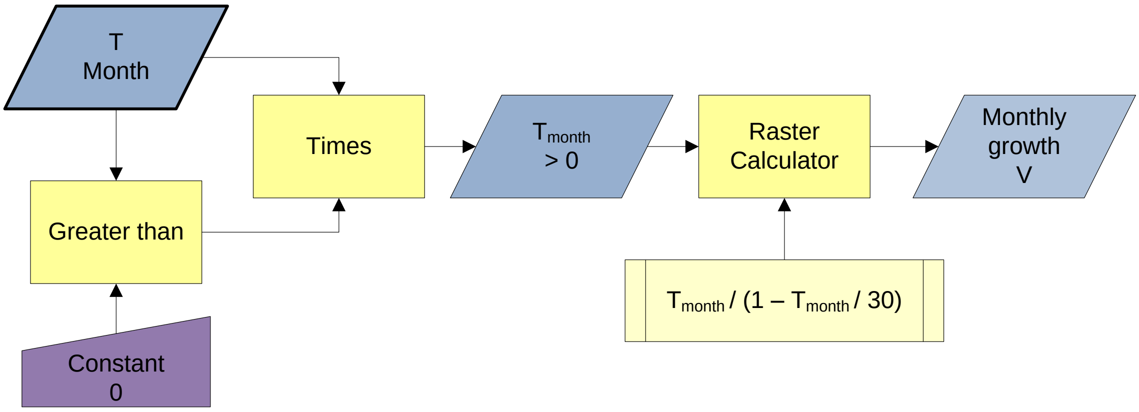
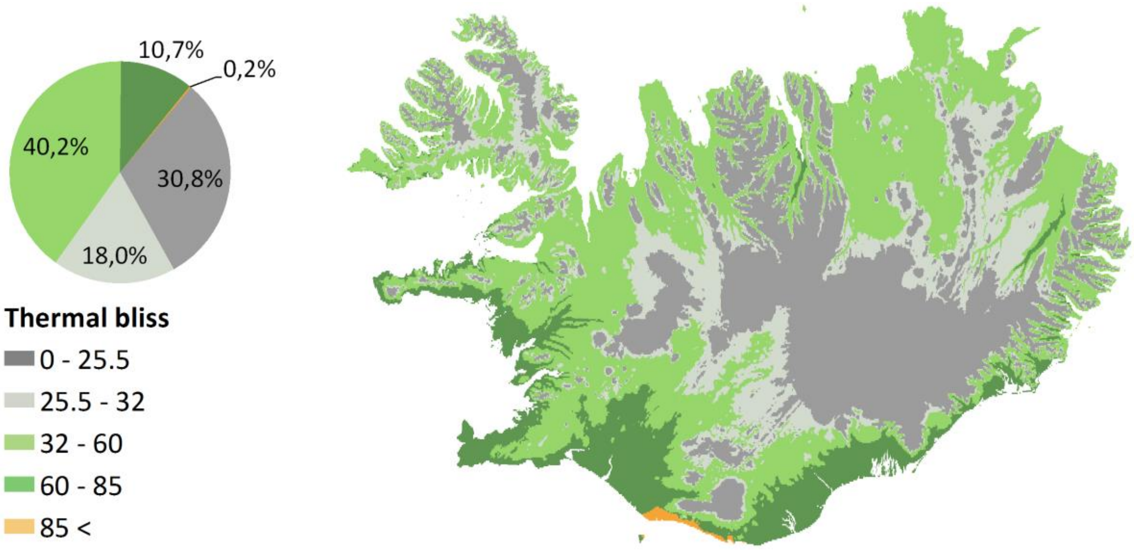


Figure 3.9 Calculating monthly growth using ArcGIS spatial analyst functions.

Figure 3.10 displays the calculated mean thermal bliss for 1961-1990. In Bergþórsson (1996, 144-145) article he mentions several types of vegetation and at which values they can grow, these values are listed in Table 3.7 for comparison.



(*Data source: Björnsson et al. 2007.*)

Figure 3.10 Average thermal bliss in Iceland 1961-1990, selected values are shown.

Table 3.7 Selected thermal bliss values described.

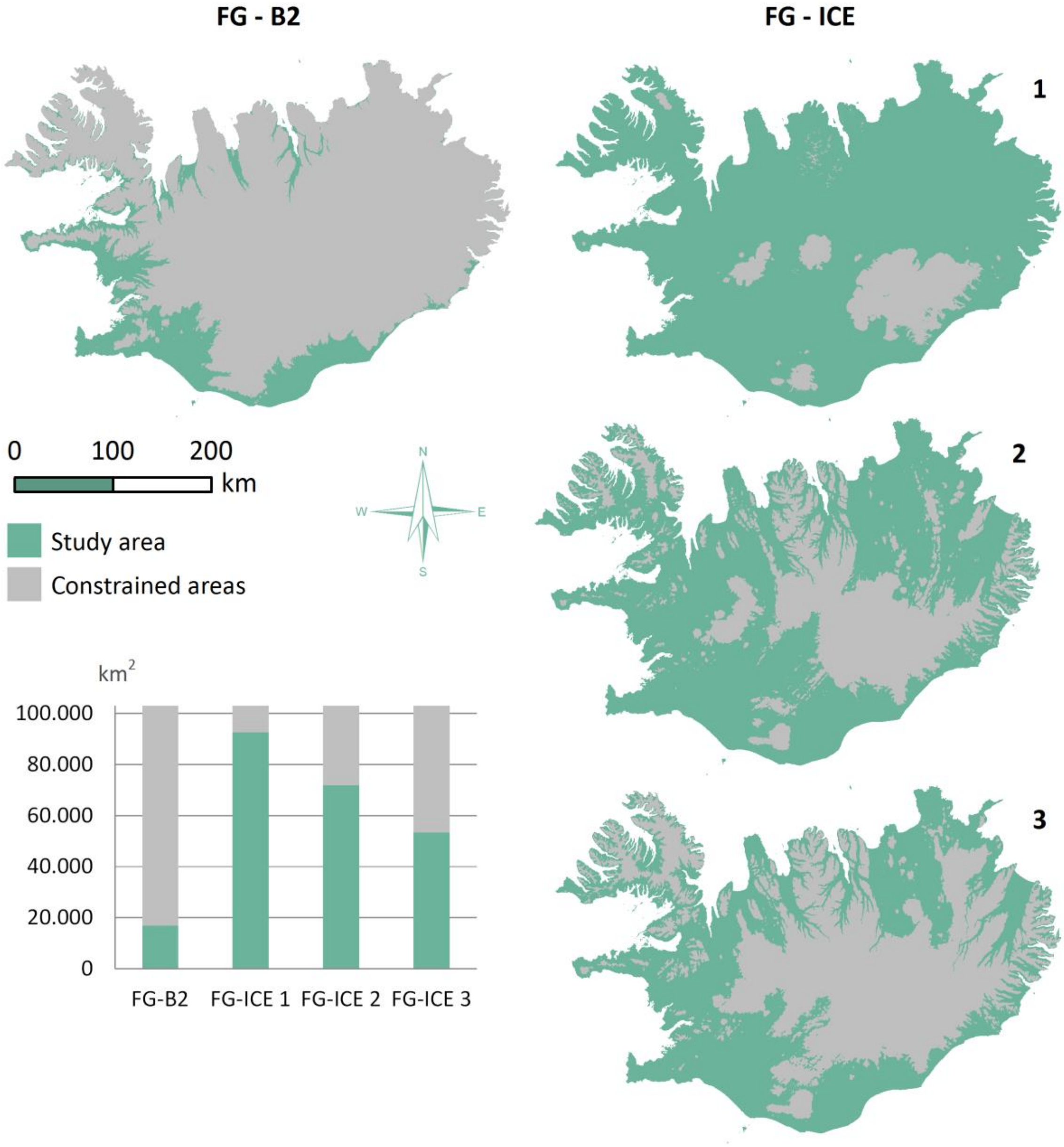
Thermal bliss value	**Description**
Under 25	Moss and/or lichen vegetation can grow
Just over 25	Grass can grow
32	Grass grows
60	Birch grows
90	Barley can grow

Source: Bergþórsson, 1996, 144-145.

It is best to note here that Figure 3.10 does not show the current vegetation in Iceland and it is only a generalization. The author argues however that this is the more realistic approach, because it takes into account the possibility of vegetation growth during the whole year and is not restricted to the warmest month. This is very important in Nordic latitudes. Temperature is one of key factors for vegetation growth in Iceland but many other factors are not considered here such as appropriate moisture levels, sunshine levels and soil properties (Bergþórsson, 1996). Grazing from farm animals (mostly sheep's) volcanic ash fall, floods, followed by soil erosion have also had a big impact on vegetation (Sigbjarnarson, 1969; 1994). These factors are not considered by the thermal bliss value.

The fifth constraint selected was based on using the thermal bliss value of 25.5 as isoline. Meaning, that all areas with a thermal bliss value lower than 25.5 where removed. Therefore, all plausible barren areas were removed, while maintaining areas where lichen vegetation grows and conditions for limited grass growth are plausible. The sixth constraint was based on the thermal bliss value of 32 as isoline. Here all low growth areas are excluded while maintaining the areas where grass plausibly grows if other environmental preconditions are met.

Figure 3.11 displays all the constraint criterions used in this thesis, where each constraint is labelled with the fragmentation geometry which is appointed to it. Where the measured area is given a green colour and the constrained areas are coloured in grey. The total land surface area of each constraint is graphed in km^2 for comparison. As mentioned FG-B2 stands for "Fragmentation of non-mountainous land areas" and can also be called the European comparative area, FG-ICE 1 stands for fragmentation of non-glacial land areas, FG-ICE 2 stands for fragmentation of non-barren areas and finally FG-ICE 3 stands for fragmentation of plausible grass growth areas.



(Data source: Hijmans, et al. 2005; Björnsson et al. 2007; Árnason & Matthíasson, 2009)

Figure 3.11 Constraint boundaries set by different fragmentation geometries

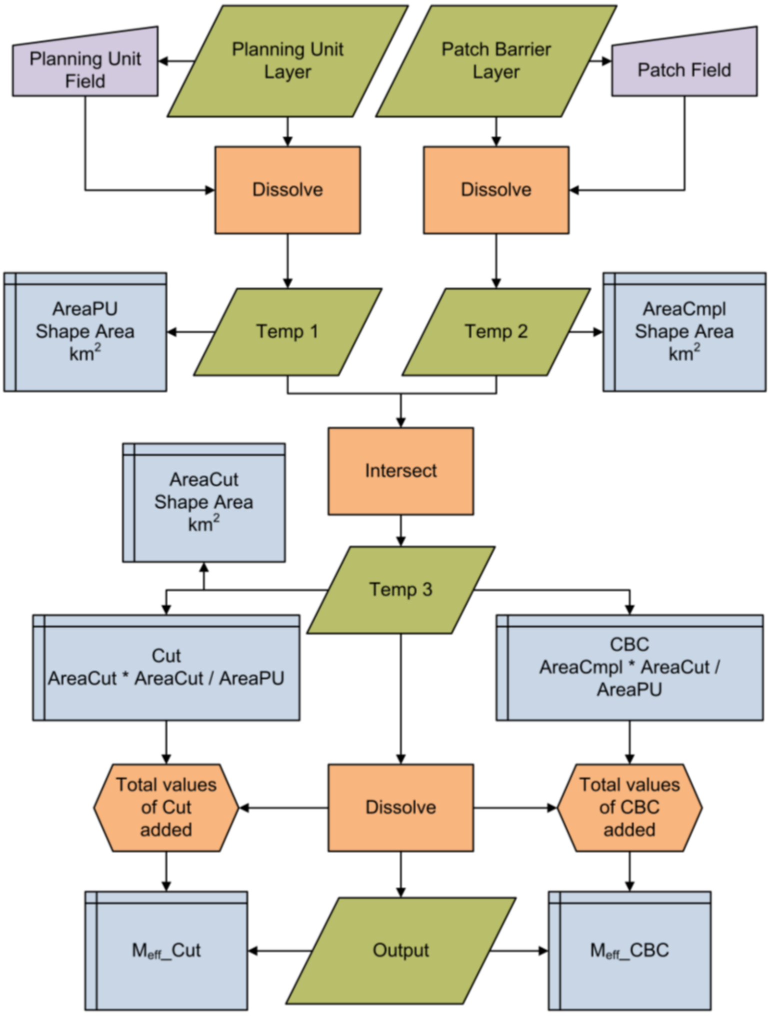
3.5 Calculating the fragmentation

Girvetz, Thorne, Berry, & Jaeger, (2008) created a GIS tool that can be directly used to measure landscape connectivity and therefore fragmentation. The tool was first written in visual basic 6.0 (Girvetz, 2008), but the version used in this thesis for the calculations was the Meff Calculator 10 beta is written as Python script which can be added to a predefined Arc tool and is intended for use with the GIS software ArcGIS 10 (Girvetz, 2011). The tool has been used in two publications; Girvetz, Jaeger & Thorne (2007) and Girvetz, Thorne, Berry & Jaeger (2008).

By analysing the Python script and the different functions used, a simple diagram can be made to explain its function (Figure 3.12). The tool gathers spatial calculating functions from within the ArcGIS to calculate the landscape connectivity. The input layers are two polygon vector datasets with predetermined attributes. First is the planning unit layer which sets the comparison scale and is determined by the selected reporting unit. Second is the patch/barrier layer, which is determined by the selected fragmentation geometry.

Before adding both some adjustments were made. For the reporting unit the constrained areas where removed based on the FGs used. For the patch barrier layer all linear fragmenting elements where buffered using set distances listed in table 3.1 transforming them to spatial fragmenting elements. The spatial elements were again determined by the selected FG and combined using ArcGIS spatial union, where overlaying spatial factors are fitted together. Thereafter previously used constraints were used to remove unwanted areas of the patch barrier layer before the calculation.

The M_{eff} calculator (Figure 3.11) first dissolves the input layers based on the set attribute field. To dissolve is to aggregate or combine the multiple polygons which have the same attributes in common (ESRI, 2012). This creates two temporary output layers where it is possible to firstly, analyse the size of the research area and secondly, the size of the fragmenting area in km^2. Thereafter by using the intersect function, the two dissolved input layers, which overlap geographically are extracted to a third temporary layer and the size of the overlapping is calculated. These three calculated areas are then used to calculate both the M_{eff} Cut using (1) and the M_{eff} CBC using (2). After this the third temporary layer (intersected layer) is dissolved using the original planning unit attributes. The total values for the M_{eff} Cut and M_{eff} CBC are added to the layer attributes, which then have the correct comparison scale. The tool ends on deleting the two first temporary files and finally extracting the third one as output. In figure 3.2 the green parallelograms represent vector polygon layers, the purple trapezium represent the attribute layer which controls the dissolve function and is selected beforehand. The orange boxes represent ArcGIS functions used for calculation. The orange hexagons represent a statistical function optional to the dissolve function, where the total values of specified fields are added to the output. The blue boxes represent calculated attributes of the vector layers.



(Data source: Girvetz, 2011)

Figure 3.12 M_{eff} calculator

The tool calculates landscape connectivity using both M_{eff} Cut (1) and the M_{eff} CBC (2). Only the M_{eff} CBC values where used in this thesis and as was done in the European Research (EEA & FOEN, 2011) the calculated values were transformed to show Effective Mesh Density or S_{eff} using (3). The end results are shown as S_{eff} per 1000 km^2.

4 Results

This chapter displays the results of the calculation on landscape fragmentation in Iceland. Results are divided into 3 subchapters. In the first subchapter (Chapter 4.1) the landscape fragmentation was calculated using the same fragmentation geometries and same reporting units set by the European research. The results indicate that landscape fragmentation is very low for the FG-A1 and low for the FG-A2. The FG-B2 however shows that fragmentation is higher.

The second subchapter (Chapter 4.2) shows the measured landscape fragmentation baseline for local use and comparison. Therewith three new fragmentation geometries created. These are the FG-ICE 1, FG-ICE 2 and FG-ICE 3, and their creation was to a great extent based on the European fragmentation geometries, but their main difference is in the natural constraints barriers which were chosen in order to value fragmentation on a more detailed level. Two additional reporting units were also added. They were selected for inland comparison and are connected to the administrative boundaries, first as four zones that can be thought of as the next step down from the NUTS 3 classification and secondly the difference between municipalities was analysed. The results indicate that landscape fragmentation is low when FG-ICE 1, 2, and 3 are used.

In the third subchapter (Chapter 4.3) the results are compared to 28 other European countries based on two types of reporting units. The country as a whole and the NUTS statistical areas from the 30 countries are compared to Iceland in regards to ranking. The comparison shows that Iceland is either the fifth least fragmented country in Europe (FG-B2) or the least fragmented (FG-ICE 1, 2 and 3).

4.1 European fragmentation geometries

The following chapter reveals the results on fragmentation in Iceland based on three fragmentation geometries, FG-A1, FG-A2 and FG-B2. The results are categorized depending on the reporting unit beginning with the; country unit (total value). The country in total measures low in fragmentation and major and medium anthropogenic fragmentation is very low. However, fragmentation of non-mountainous land areas is higher. In table 4.1, the values for landscape fragmentation and landscape connectivity are shown. S_{eff} values represent the number of meshes per 1000 km^2. M_{eff} values show the effective mesh size.

Table 4.1 Landscape fragmentation in Iceland: Country (total value).

	FG-A1	**FG-A2**	**FG-B2**
M_{eff} CBC	102 356	35 581	718
S_{eff} CBC	0.00977	0.0281	1.39

The second reporting unit is the NUTS 3 regions. The measured landscape connectivity and fragmentation for the regions are shown in table 4.2. Fragmentation in both the capital area and the countryside are low when major and medium anthropogenic fragmentation is measured. Fragmentation of non-mountainous land areas is higher in the capital area but the countryside measures lower than Country total value as indicated above.

Table 4.2 Landscape fragmentation in Iceland: NUTS 3

	Capital area			Countryside		
	FG-A1	FG-A2	FG-B2	FG-A1	FG-A2	FG-B2
M_{eff} CBC	88 985	7 556	150	102 494	35 870	744
S_{eff} CBC	0.0112	0.132	6.67	0.00976	0.0279	1.34

The third reporting unit is the 1 km^2 grid. Each square km^2 (not excluded by constraints) was measured. The value for each square is listed as an attribute in a geographic database and can be projected as image. In figures 4.2, 4.3 and 4.4 the results of landscape fragmentation on a grid basis are shown as well as indicating fragmentation (firstly FG-A1, secondly FG-A2 and thirdly FG-B2). Outlines of the grid are removed from the figures but fragmenting factors are shown on transparency-sheets overlaying the figures to provide a better overview of which factors are influential (see Appendix B for reference). The S_{eff} values are classified before the projection and an overview of how many grid squares fall in each category are shown in figure 4.1.

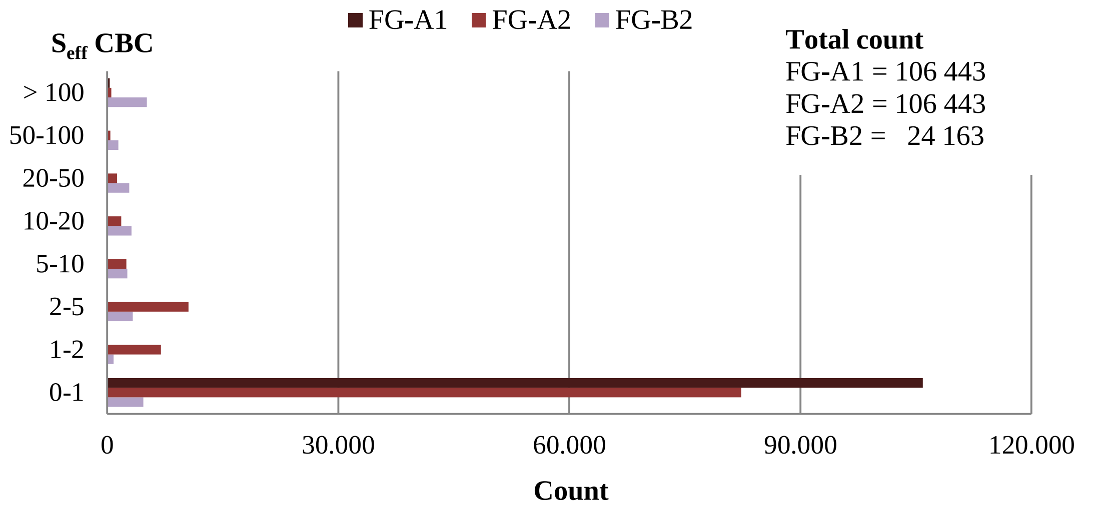


Figure 4.1 Data overview: Results FG-A1, FG-A2 and FG-B2.

Major anthropogenic fragmentation is very low, 99% of the assessed area values between 0 and 1 and only 0.3% value greater than 100. Those areas are islands, and areas in and around the capital area. Medium anthropogenic fragmentation is also low. There 77% of the country values between 0 and 1, mostly in the highlands, the south, south-east and the West-fjords in the northwest. Medium fragmentation areas are close to settlements and or cultivated agricultural areas. High fragmentation tends to be close to the coastline. Fragmentation of non-mountainous land areas is more equally divided between set categories where 19% of the assessed area values between 0 and 1. Larger areas value in the highest category (> 100) or 21%. The lowest fragmentation levels are in the south-south-east and on the Southern side of the Snæfellsnes peninsula in the west of the country. The highest values (excluding islands) are in the north in Eyjafjörður and in Aðaldalur east of Eyjafjörður. Very high fragmentation values are also recorded where areas very close to the coastline become isolated because of set constraints.

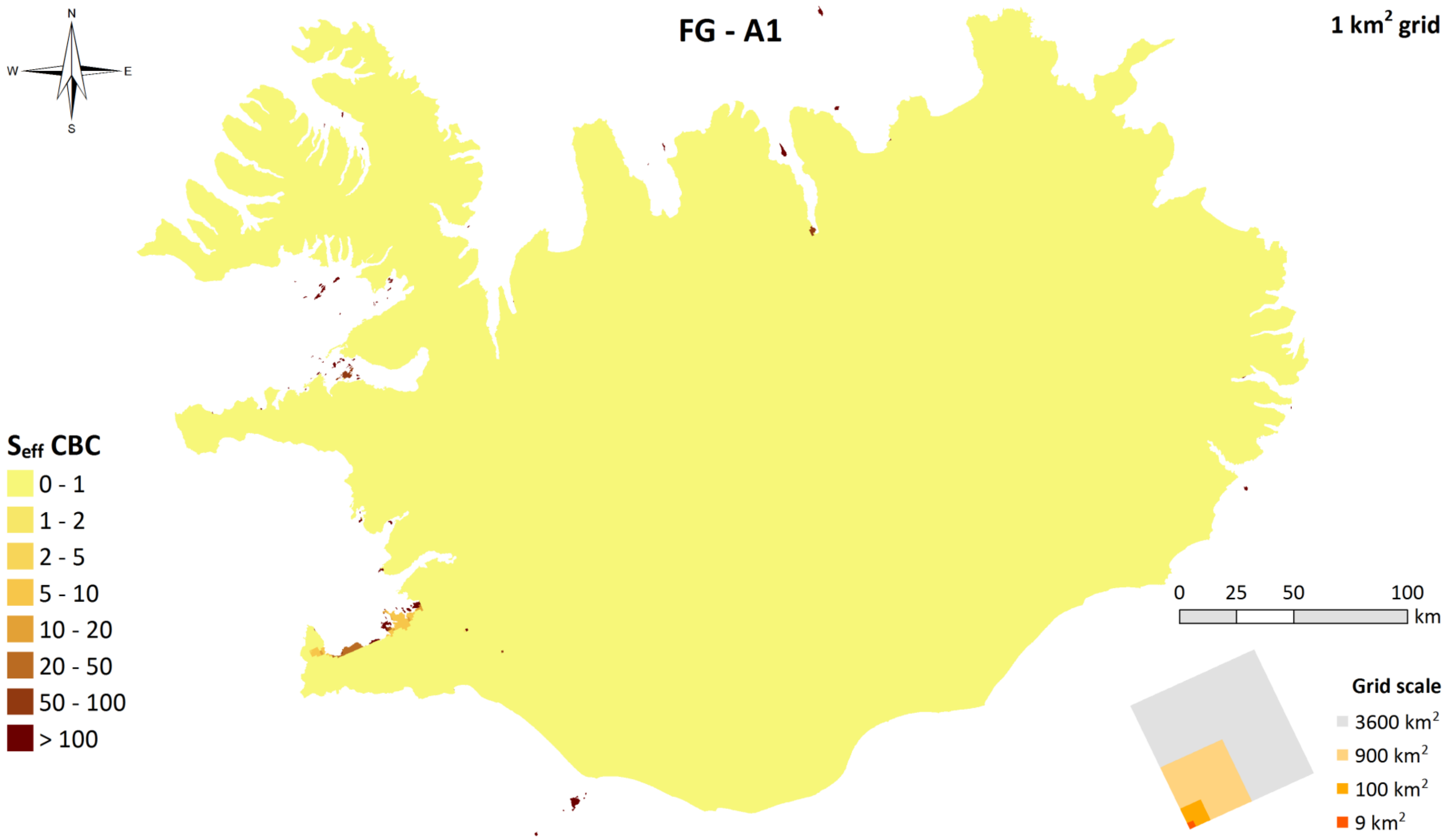


Figure 4.2 Major anthropogenic fragmentation FG A1: 1 km^2 grid results. *Seff CBC represents effective mesh density per 1000 km^2.*

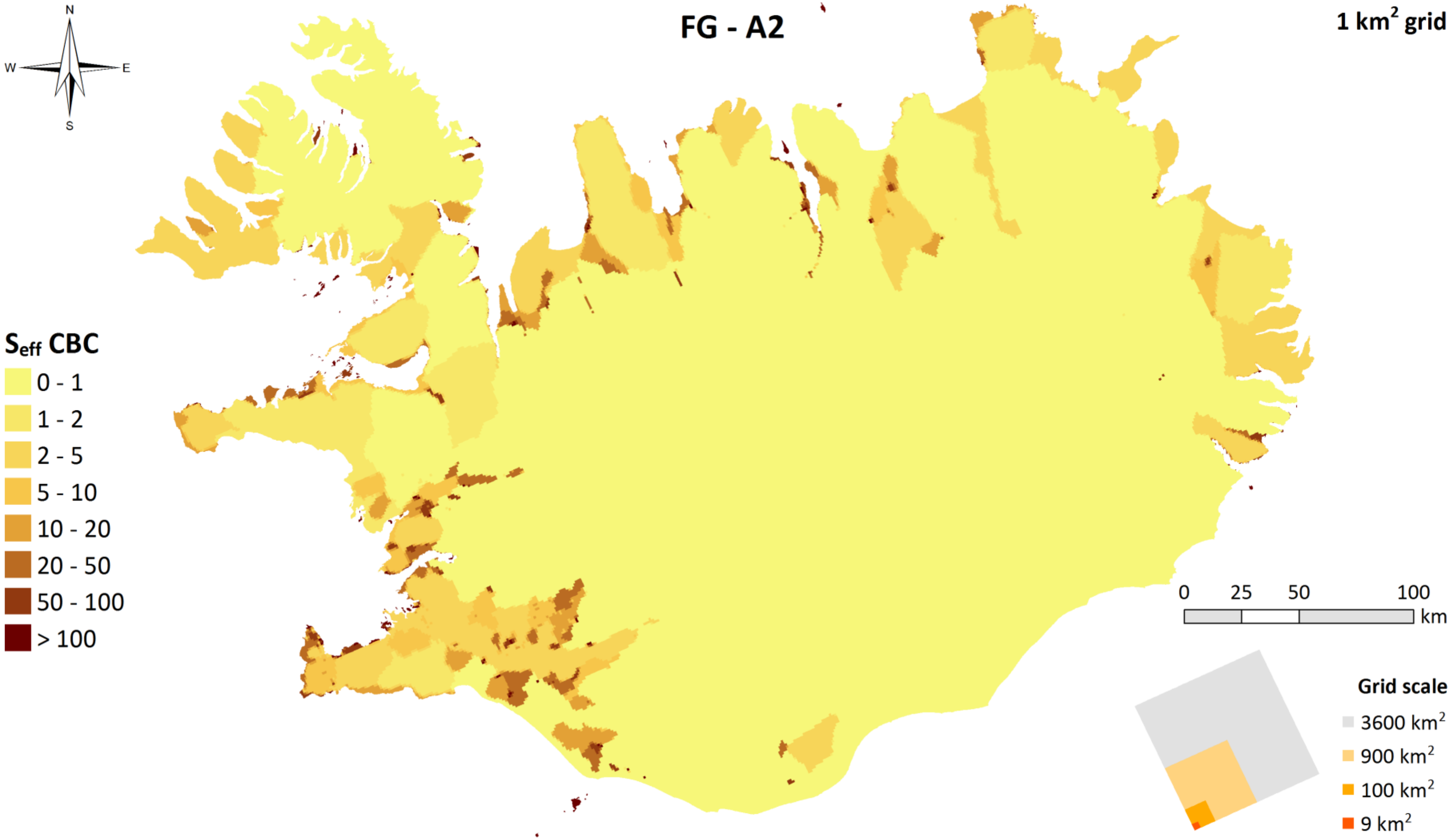


Figure 4.3 Medium anthropogenic fragmentation FG A2: 1 km² grid results.

Seff CBC represents effective mesh density per 1000 km²

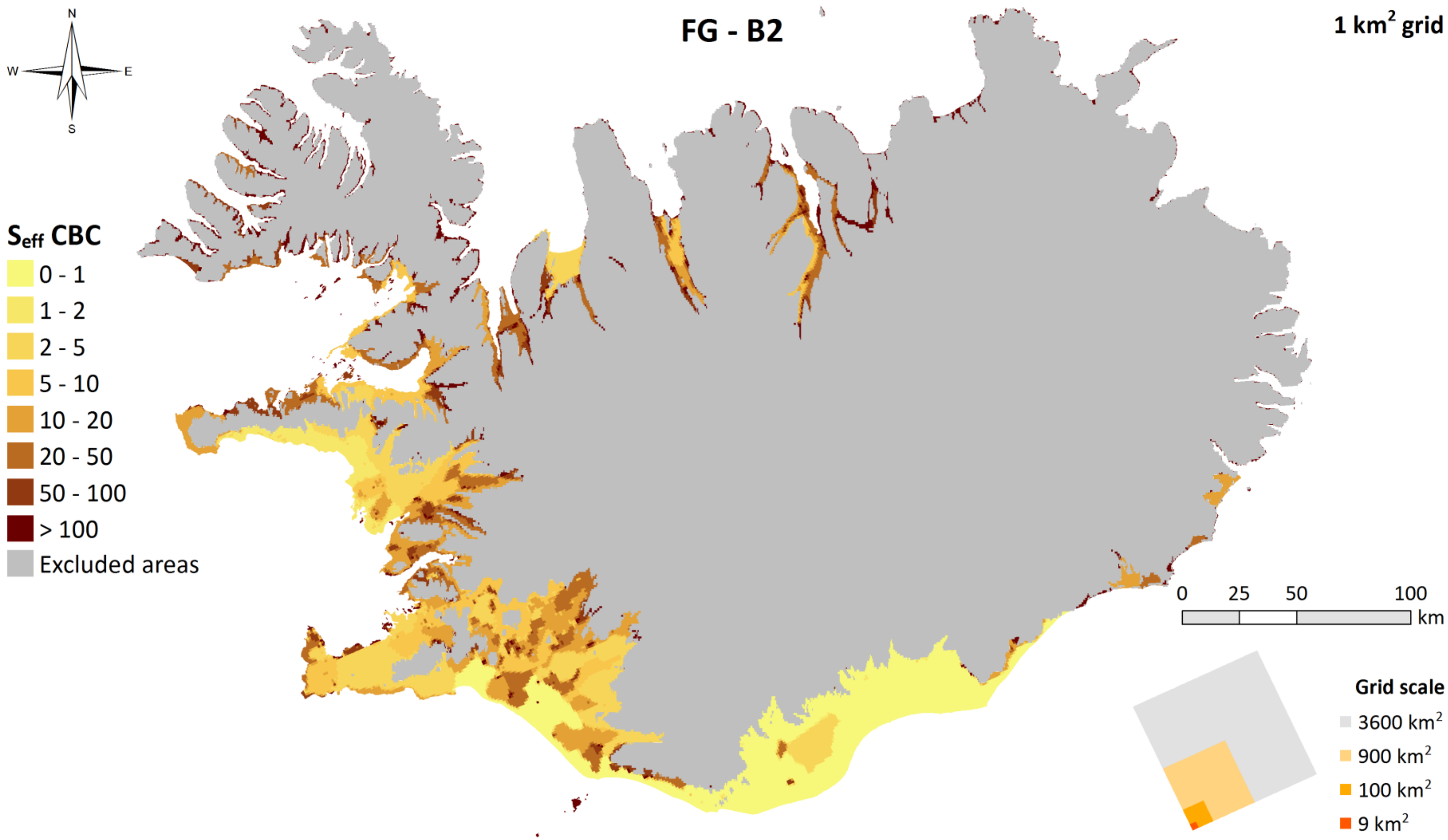


Figure 4.4 Fragmentation of non-mountainous land areas FG B2: 1 km² grid results. *Seff CBC represents effective mesh density per 1000 km².*

4.2 Icelandic fragmentation geometries

The following chapter reveals the results on fragmentation in Iceland based on the Icelandic fragmentation geometries, FG-ICE 1, FG-ICE 2 and FG-ICE 3. Again the results are categorized after the reporting units starting at the country category (total value). Country in total measures very low for all three geometries. In table 4.3 the values for landscape fragmentation and landscape connectivity are shown. S_{eff} values represent the number of meshes per 1000 km^2. M_{eff} values show the effective mesh size.

Table 4.3 Landscape fragmentation in Iceland: Country (total value).

	FG-ICE 1	FG-ICE 2	FG-ICE 3
M_{eff} CBC	26 268	17 729	6 582
S_{eff} CBC	0.0381	0.0564	0.152

The second reporting unit shown is the NUTS 3 regions. The measured landscape connectivity and fragmentation for the regions are shown in table 4.4. Fragmentation in both the capital area and the countryside are very low for all three geometries.

Table 4.4 Landscape fragmentation in Iceland: NUTS 3

	Capital area			Countryside		
	FG-ICE 1	FG-ICE 2	FG-ICE 3	FG-ICE 1	FG-ICE 2	FG-ICE 3
M_{eff} CBC	6 125	4 375	2 193	26 501	17 921	6 665
S_{eff} CBC	0.163	0.228	0.456	0.0377	0.0558	0.150

The calculations for the Icelandic fragmentation geometries on a 1 km^2 grid bases is shown in figures 4.5, 4.6 and 4.7. Just as in the European geometries the outlines of the grid are removed from the figures but fragmenting factors are shown on transparency-sheets overlaying the figures to provide an overview of which fragmenting factors are influential. For data overview on how many squares fall into set categories see figure 4.8.

The results show that landscape fragmentation of non-glacial land areas is broadly very low. There 74% of the country values between 0 and 1: The highlands, the south, south-east and the West-fjords value low. Medium fragmentation areas are close to settlements and or cultivated agricultural areas. High fragmentation is measured closer to the coastline, on islands, and Nunataks.

Fragmentation of non-barren areas is also very low or 67% of the area values between 0 and 1. Fragmentation is higher closer to settlements, near the capital area on the south-south western lowlands. In the north; low or medium fragmentation follows the coastline with high peaks around settled areas. Both the East and West –fjords show an increase in fragmentation due to natural barriers.

Fragmentation on plausible grass growth areas measures higher but still is still low with 50% of the country valued between 0 and 1. The largest increase in fragmentation is in the West and East- fjords, along with a, considerable increase in the eastern heath areas. High fragmentation is also measured just west of Vatnajökull glacier and north of Mýrdalsjökull glacier.

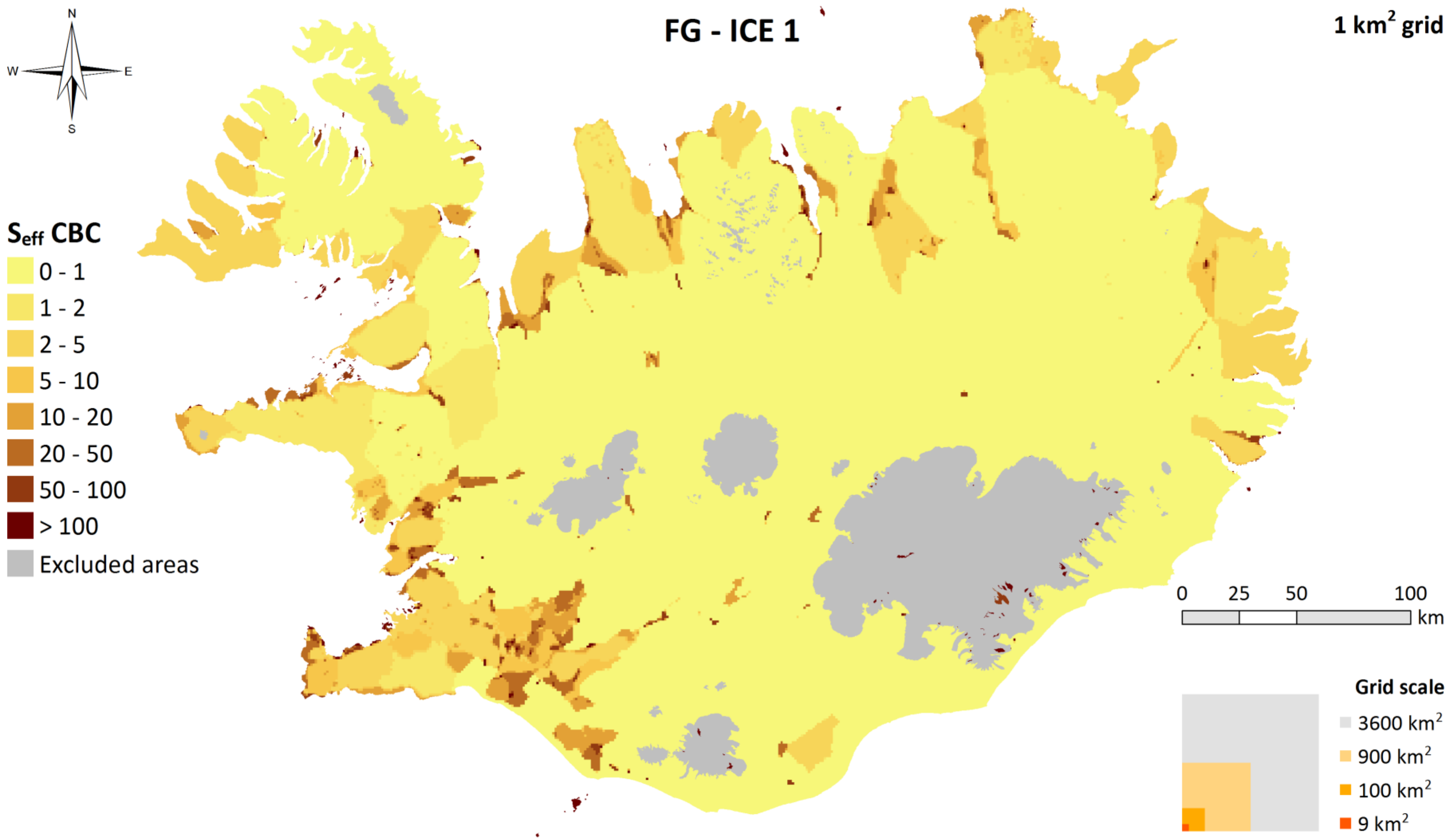


Figure 4.5 Fragmentation of non-glacial areas FG-ICE 1: 1 km² results.

Seff CBC represents effective mesh density per 1000 km².

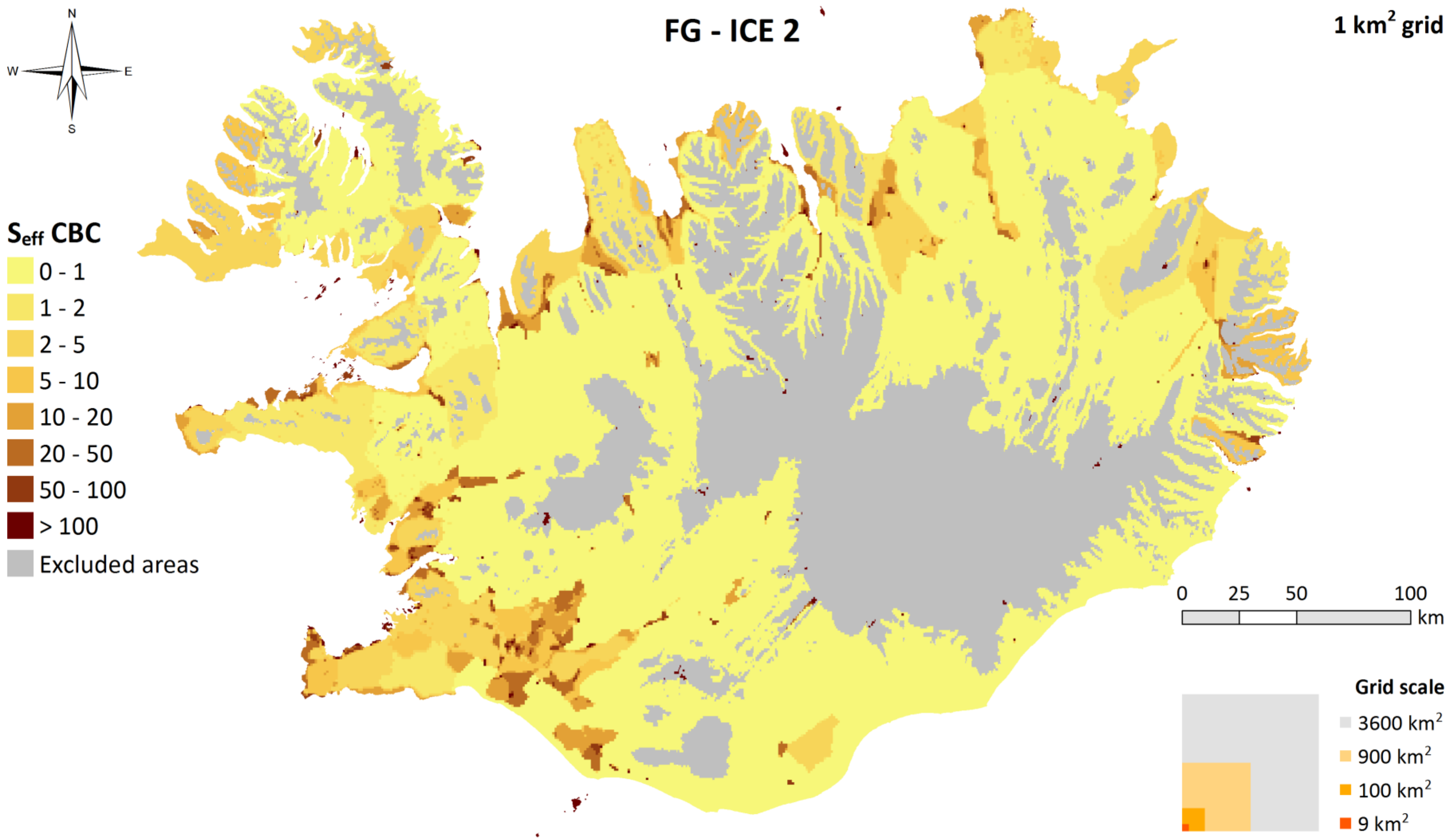


Figure 4.6 Fragmentation of non-barren land areas FG-ICE 2: 1 km² grid results.

Seff CBC represents effective mesh density per 1000 km².

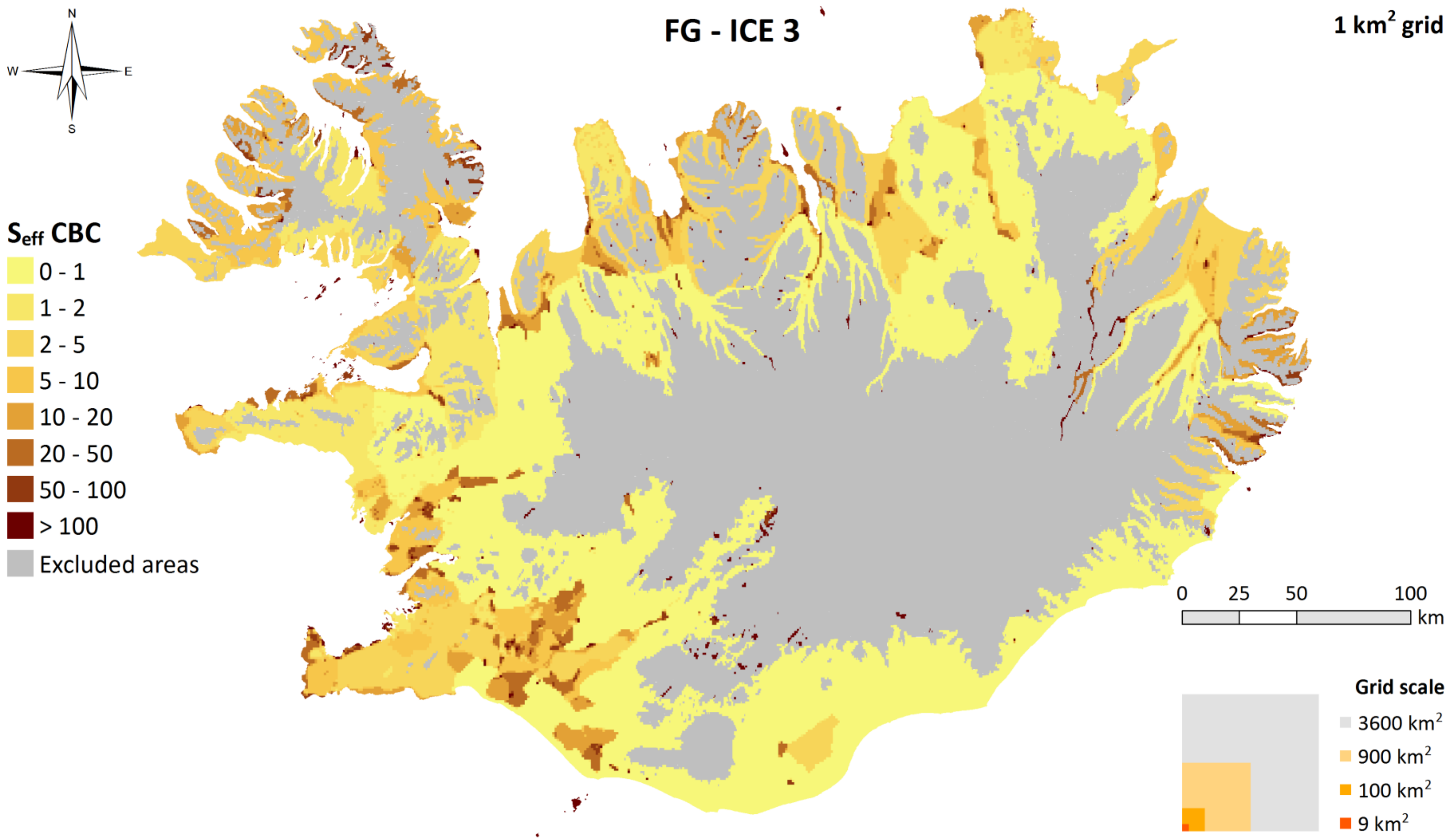


Figure 4.7 Fragmentation of plausible grass growth areas FG-ICE 3: 1 km^2 grid results. *Seff CBC represents effective mesh density per 1000 km^2.*

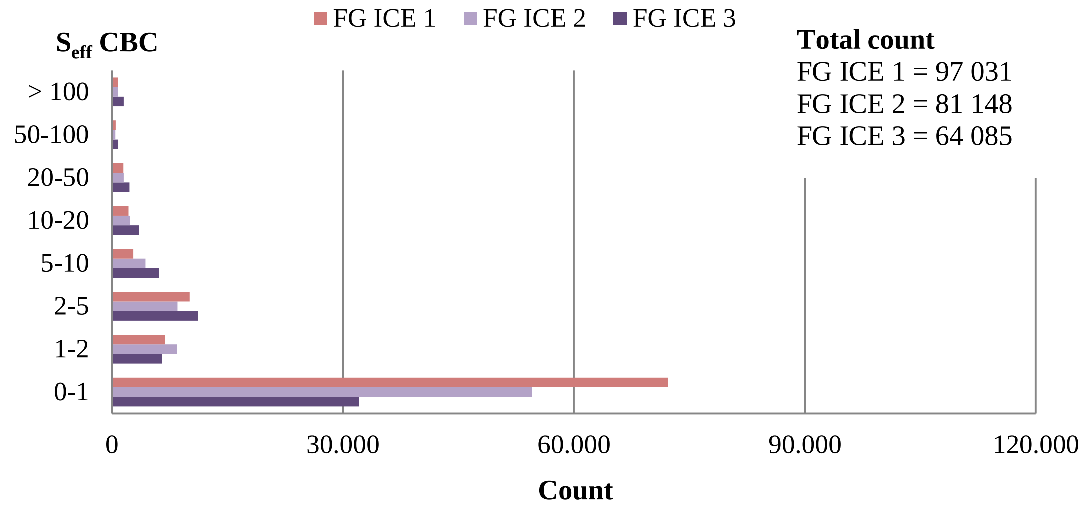
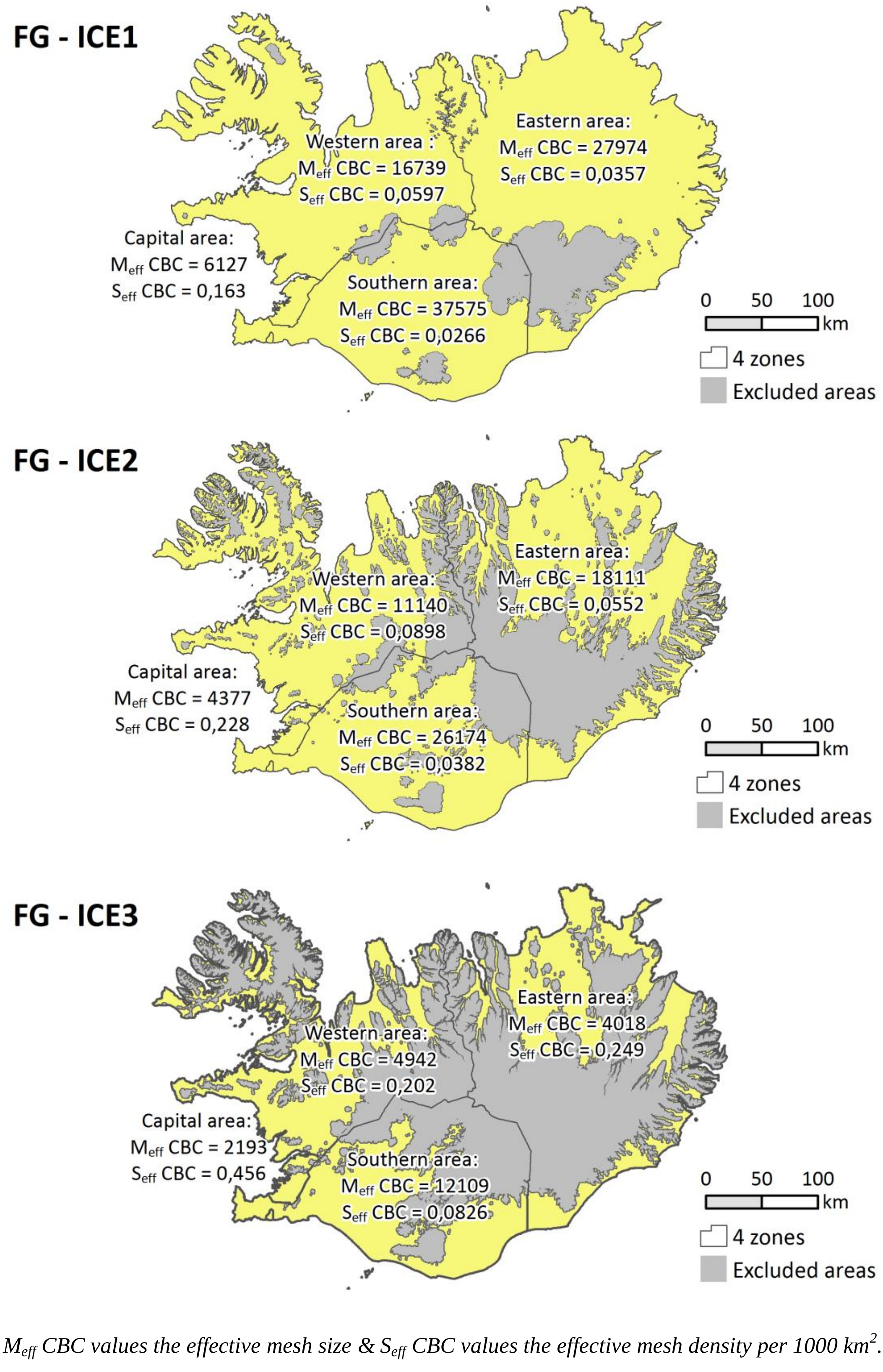


Figure 4.8 Data overview: Results FG ICE 1, FG ICE 2 and FG ICE 3.

Results for the fourth reporting unit are shown in figure 4.9. There the country is divided into four zones. The results on fragmentation of these areas show that all the zones measure low or below 1 mesh per 1000km^2. Fragmentation in the capital was higher than in other zones. The western area is more fragmented than the eastern area when non-glacial land areas and non-barren areas are measured. However, this turns around when plausible grass growth areas are measured. The southern area had the smallest fragmentation levels for all three fragmentation geometries.

The fifth reporting unit measures landscape fragmentation for the 74 different municipalities in Iceland. Figure 4.10 provides an overview of the results while table 4.5 lists the results for each municipality. Many municipalities value low in fragmentation or between 0-1. Their count is 47 in total when non-glacial land areas are measured, 40 when non-barren areas are measured and 29 when plausible grass growth areas are measured.

Highest values of fragmentation for all fragmentation geometries are measured in Vestmannaeyjabær, located on the islands south of Iceland. Stykkishómsbær, located north on the Snæfellsnes peninsula in the west of Iceland, is the second most fragmented when non-glacial land areas and non-barren areas are measured. However, Árneshreppur located on the north-eastern Westfjords, when plausible grass growth areas are measured. The third most fragmented municipality when non-glacial land areas and non-barren areas are measured is the municipality Garður (Sveitarfélagið Garður) located on the Reykjanes peninsula. However, when plausible grass growth areas are measured Kaldrananeshreppur south of Árneshreppur is valued as third most fragmented. In figure 4.10 Stykkishómsbær and Vestmanneyjabær municipalities are magnified from FG-ICE 1, the Reykjanes peninsula is magnified from FG-ICE 2 and Árneshreppur and Kaldrananeshreppur are magnified from FG-ICE 3.



M_{eff} CBC values the effective mesh size & S_{eff} CBC values the effective mesh density per 1000 km^2.

Figure 4.9 Landscape fragmentation results for four zones based on the three Icelandic fragmentation geometries.

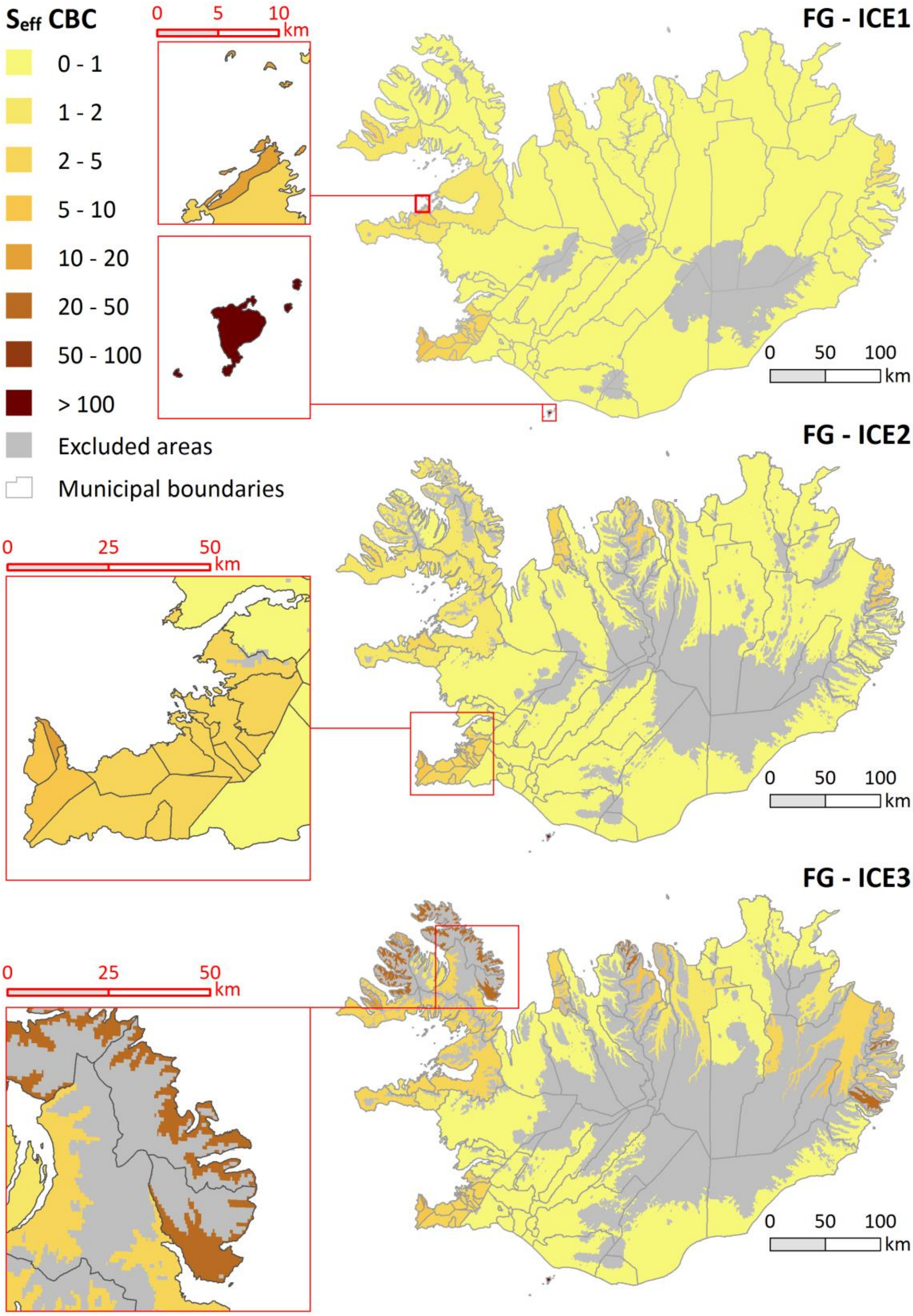


Figure 4.10 Landscape fragmentation of municipal areas in Iceland. Based on the three Icelandic fragmentation geometries, areas of interest are magnified.

Table 4.5 Landscape fragmentation in Iceland: 74 municipalities

		FG -ICE 1		FG -ICE 2		FG -ICE 3	
	Municipality	**M_{eff} CBC**	**S_{eff} CBC**	**M_{eff} CBC**	**S_{eff} CBC**	**M_{eff} CBC**	**S_{eff} CBC**
Capital area	Garðabær*	254	3.94	254	3.94	255	3.93
	Hafnarfjarðarkaupstaður	280	3.57	280	3.57	283	3.53
	Kjósarhreppur	21 695	0.0461	14 795	0.0676	6 828	0.146
	Kópavogsbær	315	3.17	315	3.17	319	3.13
	Mosfellsbær	241	4.15	237	4.21	237	4.22
	Reykjavíkurborg	254	3.94	225	4.44	219	4.58
	Seltjarnarneskaupstaður	303	3.30	303	3.30	341	2.93
Western area	Akrahreppur	29 519	0.0339	5 515	0.181	1 938	0.516
	Akraneskaupstaður	230	4.35	230	4.36	252	3.98
	Árneshreppur	2 574	0.389	942	1.06	38.5	26.0
	Blönduósbær	599	1.67	291	3.43	146	6.86
	Bolungarvíkurkaupstaður	2 546	0.393	1 411	0.709	59.7	16.8
	Borgarbyggð	23 611	0.0424	15 158	0.0660	6 247	0.160
	Dalabyggð	858	1.17	679	1.47	457	2.19
	Eyja- og Miklaholtshreppur	734	1.36	675	1.48	596	1.68
	Grundarfjarðarbær	674	1.48	619	1.62	559	1.79
	Helgafellssveit	468	2.14	439	2.28	393	2.55
	Húnavatnshreppur	40 100	0.0249	22 481	0.0445	5 369	0.186
	Húnaþing vestra	28 447	0.0352	19 160	0.0522	7.324	0.137
	Hvalfjarðarsveit	13 930	0.0718	9 742	0.103	4 518	0.221
	Ísafjarðarbær	2 099	0.476	632	1.58	43.5	23.0
	Kaldrananeshreppur	2 259	0.443	739	1.35	39.7	25.2
	Reykhólahreppur	1 418	0.705	947	1.06	339	2.95
	Skagabyggð	610	1.64	499	2.00	394	2.54
	Skorradalshreppur	29 306	0.0341	21 190	0.0472	10 454	0.0957
	Snæfellsbær	570	1.75	502	1.99	424	2.36
	Strandabyggð	1 921	0.521	975	1.03	274	3.65
	Stykkishólmsbær	51.0	19.6	50.4	19.8	138	7.25
	Súðavíkurhreppur	2 442	0.409	1 475	0.678	521	1.92
	Sveitarfélagið Skagafjörður	20 455	0.0489	6 249	0.160	1 593	0.628
	Sveitarfélagið Skagaströnd	599	1.67	541	1.85	385	2.60
	Tálknafjarðarhreppur	271	3.69	222	4.50	88.5	11.3
	Vesturbyggð	764	1.31	591	1.69	276	3.63

* Álftanes was merged with Garðabær on 1st of January 2013.

Area	Municipality	FG -ICE 1 M_{eff} CBC	FG -ICE 1 S_{eff} CBC	FG -ICE 2 M_{eff} CBC	FG -ICE 2 S_{eff} CBC	FG -ICE 3 M_{eff} CBC	FG -ICE 3 S_{eff} CBC
Southern area	Ásahreppur	41 452	0.0241	19 470	0.0514	3 541	0.282
	Bláskógabyggð	32 037	0.0312	19 973	0.0501	7 333	0.136
	Flóahreppur	5 918	0.169	4 295	0.233	2 217	0.451
	Grindavíkurbær	329	3.04	329	3.04	321	3.11
	Grímsnes- og Grafningshreppur	10 650	0.0939	5 345	0.187	2 138	0.468
	Hrunamannahreppur	42 458	0.0236	24 859	0.0402	9 181	0.109
	Hveragerðisbær	6 100	0.164	4 476	0.223	2 412	0.415
	Mýrdalshreppur	36 156	0.0277	26 801	0.0373	12 709	0.0787
	Rangárþing eystra	33 106	0.0302	22 454	0.0445	10 350	0.0966
	Rangárþing ytra	38 029	0.0263	23 055	0.0434	7 527	0.133
	Reykjanesbær	172	5.82	172	5.82	179	5.59
	Sandgerðisbær	129	7.73	129	7.74	143	6.99
	Skaftárhreppur	33 365	0.0300	22 168	0.0451	8 867	0.113
	Skeiða- og Gnúpverjahreppur	37 133	0.0269	23 786	0.0420	6 448	0.155
	Sveitarfélagið Árborg	22 428	0.0446	16 220	0.0617	8 273	0.121
	Sveitarfélagið Garður	69.3	14.4	69.3	14.4	76.5	13.1
	Sveitarfélagið Vogar	285	3.51	285	3.51	286	3.50
	Sveitarfélagið Ölfus	5 783	0.173	4 267	0.234	2 307	0.433
	Vestmanneyjabær	5.01	199	5.01	199	5.01	199
Eastern area	Akureyrarkaupstaður	35 058	0.0285	12 123	0.0825	976	1.02
	Borgarfjarðarhreppur	933	1.07	477	2.09	140	7.14
	Breiðdalshreppur	25 618	0.0390	9 279	0.108	42.9	23.3
	Dalvíkurbyggð	2 314	0.432	469	2.13	110	9.13
	Djúpavogshreppur	42 235	0.0237	17 614	0.0568	1 904	0.525
	Eyjafjarðarsveit	46 609	0.0215	8 977	0.111	693	1.44
	Fjallabyggð	972	1.03	221	4.52	43.5	23.0
	Fjarðarbyggð	19 755	0.0506	8 653	0.116	201	4.98
	Fljótsdalshérað	28 622	0.0349	14 375	0.0696	338	2.96
	Fljótsdalshreppur	38 194	0.0262	15 190	0.0658	136	7.38
	Grýtubakkahreppur	1 341	0.746	603	1.66	196	5.10
	Hörgársveit	16 923	0.0591	5 598	0.179	491	2.04
	Langanesbyggð	3 300	0.303	2 685	0.372	1 107	0.903
	Norðurþing	3 365	0.297	2 451	0.408	1 176	0.850
	Seyðisfjarðarkaupstaður	547	1.83	151	6.64	45.6	21.9
	Skútustaðahreppur	33 880	0.0295	16 922	0.0591	1 264	0.791
	Svalbarðshreppur	4 024	0.249	3 246	0.308	1 455	0.687
	Svalbarðsstrandarhreppur	42 755	0.0234	30 888	0.0324	2 300	0.435
	Sveitarfélagið Hornafjörður	24 522	0.0408	16 795	0.0595	7 467	0.134
	Tjörneshreppur	1 641	0.609	1 392	0.718	1 071	0.934
	Vopnafjarðarhreppur	3 247	0.308	2 136	0.468	601	1.67
	Þingeyjasveit	30 163	0.0332	6 939	0.144	512	1.95

4.3 Comparison to Europe

Fragmentation of 28 European countries where measured in 2011 (EEA & FOEN, 2011). The value of fragmentation was compared to the European research based on two reporting units first on a country level and secondly on the NUTS 3 level. The comparison data was extracted from Annex 1 in the European research (EEA & FOEN, 2011, pp. 77-85).

Because the constraint boundaries set by the FG-B2 or fragmentation of non-mountainous land areas this excludes 84% of the country's land surface including many small settlements and habitable areas. The fragmentation geometries FG-ICE 1. 2 and 3 are also compared to the European FG-B2 values. The same fragmenting factors are considered but different constraint boundaries are the limit for the study area boundaries.

Comparison of the results above with the European results reveals that fragmentation of Iceland is low on a European level. but high compared to Scandinavia (see table 4.7). Here Iceland is the fifth least fragmented country in Europe. This is when FG-B2 values are considered. If FG-ICE 1. 2 or 3 are compared in the same manner the results differ and Iceland becomes the least fragmented country in Europe.

Icelandic NUTS 3 areas where compared to the European NUTS X regions from 30 individual countries. Table 4.6 provides an overview of the ranking where 1 equals the most fragmented area. NUTS X is a combination of NUTS 2 and NUTS 3 regions. When FG-B2 is used for comparison. Iceland as a whole (IS: NUTS 1 and 2) ranks nr 523 of the most fragmented NUTS areas. When the NUTS 3 areas are compared; the capital area (IS001) ranks nr. 426 of the 583 (this includes Iceland's NUTS 3 areas) and the Countryside (IS002) ranks 527. If the FG-ICE values are compared Iceland as a whole ranks very low or as the least fragmented area. If the country is divided into NUTS 3 areas FG-ICE 1 and 2 share the bottom place with the Norwegian region of Finnmark (NO073) at the bottom where the capital area is more fragmented and the country side is less fragmented than Finnmark. For FG-ICE 3 the capital area ranks between the Norwegian region Hordaland (NO051) and the Romanian region Harghita (RO074). The countryside ranks bellow Finnmark.

Table 4.6 Iceland NUTS 3 areas ranked with NUTS-X areas of 30 European countries.

Fragmentation geometry	**Country**	**NUTS area**	**Name of region**	**M_{eff} CBC**	**S_{eff} CBC**	**Rank**
FG-B2	Iceland	(IS)	Iceland	717.79	1.39	**523**
FG-B2	Iceland	(IS001)	Capital area (IS)	149.93	6.67	**426**
FG-B2	Iceland	(IS002)	Countryside (IS)	744.00	1.34	**527 ***
FG-ICE 1	Iceland	(IS)	Iceland	26 268.20	0.04	**582**
FG-ICE 1	Iceland	(IS001)	Capital area (IS)	6 125.35	0.16	**581**
FG-ICE 1	Iceland	(IS002)	Countryside (IS)	26 501.11	0.04	**583 ***
FG-ICE 2	Iceland	(IS)	Iceland	17 728.59	0.06	**582**
FG-ICE 2	Iceland	(IS001)	Capital area (IS)	4 375.28	0.23	**581**
FG-ICE 2	Iceland	(IS002)	Countryside (IS)	17 921.32	0.06	**583 ***
FG ICE 3	Iceland	(IS)	Iceland	6 582.30	0.15	**582**
FG-ICE 3	Iceland	(IS001)	Capital area (IS)	2 192.53	0.46	**565**
FG-ICE 3	Iceland	(IS002)	Countryside (IS)	6 665.12	0.15	**583 ***

* When capital area above is included in the ranking.

Table 4.7 Country (total value) compared to 30 other European countries

	FG-B2			FG-B2 Iceland as ICE 1	FG-B2 Iceland as ICE 2	FG-B2 Iceland as ICE 3
	M_{eff} CBC	**S_{eff} CBC**		**S_{eff} CBC**	**S_{eff} CBC**	**S_{eff} CBC**
Luxembourg	7.40	135.17	Luxembourg	135.17	135.17	135.17
Belgium	9.51	105.11	Belgium	105.11	105.11	105.11
Malta	10.20	98.04	Malta	98.04	98.04	98.04
Netherlands	16.36	61.12	Netherlands	61.12	61.12	61.12
San Marino†	22.75	43.96	San Marino†	43.96	43.96	43.96
Germany	23.46	42.63	Germany	42.63	42.63	42.63
France	33.84	29.55	France	29.55	29.55	29.55
Czech Republic	44.16	22.64	Czech Republic	22.64	22.64	22.64
Poland	57.63	17.35	Poland	17.35	17.35	17.35
Denmark	62.95	15.89	Denmark	15.89	15.89	15.89
Lithuania	75.62	13.22	Lithuania	13.22	13.22	13.22
Switzerland	76.59	13.06	Switzerland	13.06	13.06	13.06
Slovenia	100.85	9.92	Slovenia	9.92	9.92	9.92
Hungary	106.84	9.36	Hungary	9.36	9.36	9.36
Estonia	108.36	9.23	Estonia	9.23	9.23	9.23
Portugal	108.57	9.21	Portugal	9.21	9.21	9.21
Italy	111.73	8.95	Italy	8.95	8.95	8.95
Latvia	112.93	8.86	Latvia	8.86	8.86	8.86
Austria	161.31	6.20	Austria	6.20	6.20	6.20
Ireland	170.41	5.87	Ireland	5.87	5.87	5.87
Spain	181.22	5.52	Spain	5.52	5.52	5.52
Liechtenstein	197.73	5.06	Liechtenstein	5.06	5.06	5.06
Slovakia	209.92	4.76	Slovakia	4.76	4.76	4.76
Bulgaria	246.83	4.05	Bulgaria	4.05	4.05	4.05
United Kingdom	265.16	3.77	United Kingdom	3.77	3.77	3.77
Greece	308.22	3.24	Greece	3.24	3.24	3.24
Iceland	**717.79**	**1.39**	Finland	0.69	0.69	0.69
Finland	1 443.39	0.69	Romania	0.60	0.60	0.60
Romania	1 655.72	0.60	Sweden	0.60	0.60	0.60
Sweden	1 673.51	0.60	Norway	0.40	0.40	0.40
Norway	2 525.04	0.40	**Iceland***	**0.04**	**0.06**	**0.15**

* Same fragmenting factors used with different constraint boundaries.
† Value for San Marino was taken from the NUTS-X units.

(Data Source: EEA & FOEN 2011 p. 77).

5 Discussions

The results revealed that landscape fragmentation in Iceland is very low when measured on a county scale and on the NUTS 3 scale. In direct comparison to the European Research it showed that Iceland is the fifth least fragmented country using the European climate constraints and the NUTS 3 areas also valued low in comparison with the capital area being more fragmented than the country-side. When the country is divided into four zones the capital area is the most fragmented of the four. The results on a municipal level varied greatly where the most fragmented municipality was Vestmannaeyjabær the area of which consists of a cluster of islands south of the country. This is not surprising because the surrounding ocean acts as fragmenting barrier and the settlement covers a sizable part of the largest island.

The measured level of fragmentation on the municipal level varied considerably depending on the excluded constraint barriers. An example of this is the municipality Eyjafjarðarsveit which was the least fragmented municipality when fragmentation of non-glacial land areas were measured (FG-ICE1). However as the measured area decreased so did its ranking among other municipalities. Ranking as the 51st most fragmented municipality when fragmentation of non-barren areas (FG-ICE2) where measured and it ranked as the 44th most fragmented when plausible grass growth areas (FG-ICE3) were measured. In figure 5.1 the variability is shown using the grid based results as a reference. The figure demonstrates the changes in the measured area dependant on the fragmentation geometry used. There it is evident that the main difference is due to different approaches in the selection of natural constraining barriers.

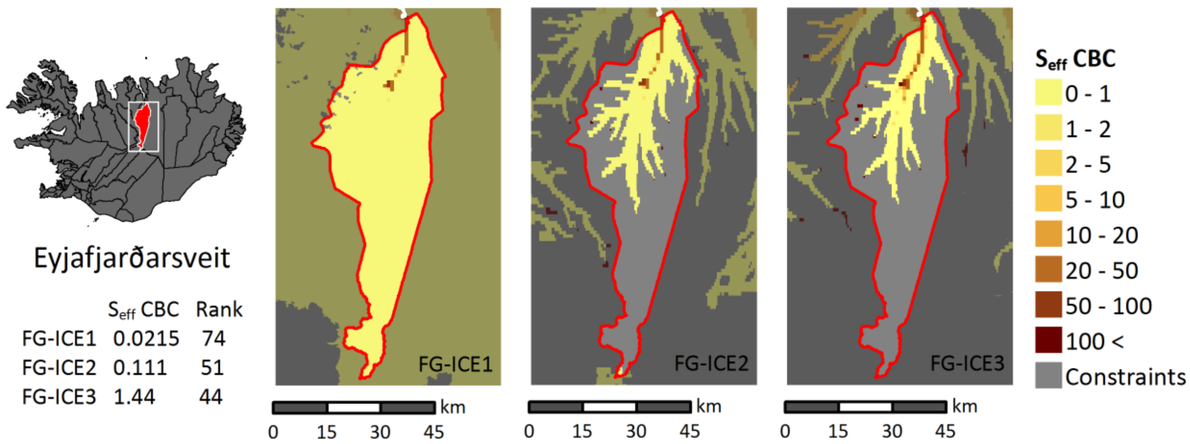


Figure 5.1 Results for Eyjafjarðarsveit

Consequently, the selection of environmental constraints is very influential and must be carefully considered when analysing the results. Hence as presented in figure 4.10 uninhabited fjords in the West-fjords become the most fragmented municipal areas when plausible grass growth areas (FG-ICE3) are measured. The measured fragmentation there is irrelevant to both major and medium anthropological effects, as is shown in figures 4.2 and 4.3 where only man-made fragmenting elements are considered. The natural barriers however exist and can limit species movement to and from these areas. The reviewer of the results must therefore be aware of what factors are influential in each calculation.

The 1 km^2 grid results provide the most detailed analysis for visual and statistical comparison. The grid dataset for each calculation was very large and therefore in reviewing the data it is most effective to provide to quickly indicate where the most fragmented areas can be found. The European fragmentation geometries (FG-A1, FG-A2 and FG-B2) are levelled in a hierarchical order in relation to the selection of fragmenting elements (EEA & FOEN, 2011). This means that, FG-A2 builds upon FG-A1 and so on. However, all the Icelandic fragmentation geometries (FG-ICE 1-3) contain the same fragmenting elements (same as FG-B2) and the only difference is in the selection of constraint boundaries. As mentioned, providing alternatives in presented results helps the reviewer to gain a broader perspective (Girvetz, Thorne, Berry, & Jaeger, 2008) and increases the practicality as it becomes more formable to variant usage. All the fragmentation geometries give a distinct view on fragmentation as discussed in the following dialog.

Major anthropological fragmentation FG-A1 is very low in Iceland this shows clearly in figure 4.2 where almost all the country is with S_{eff} CBC lover than 1. The highest measured values are on the islands surrounding the country mostly due oceanic barriers. Other high fragmentation areas are on the Reykjanes peninsula south west of the capital, where the 100m buffer set by the CLC artificial surfaces around the biggest 2 by 2 road in Iceland is influential. Fragmentation is also higher around the capital itself which is not surprising being the most densely populated area in Iceland.

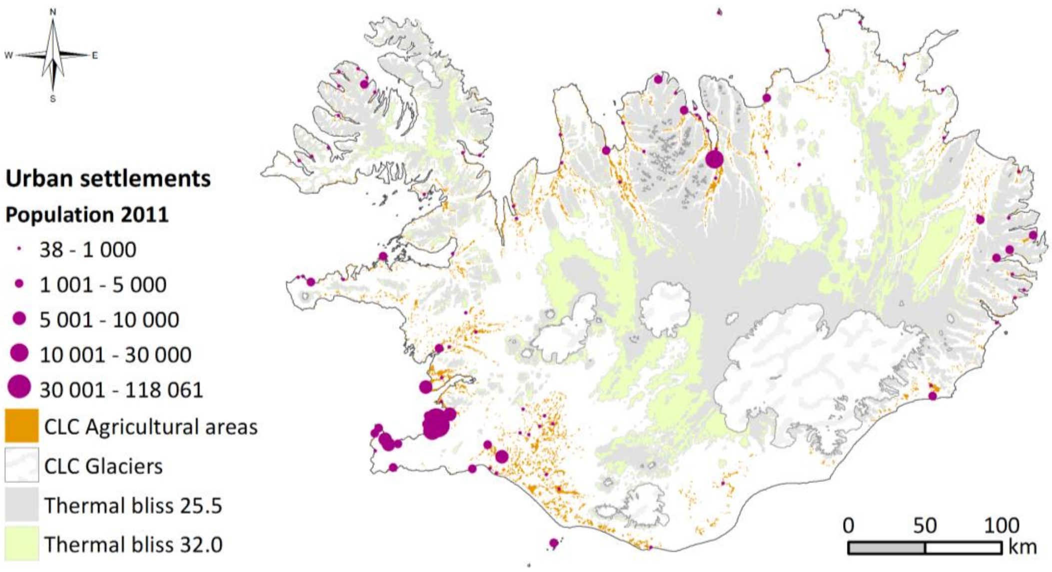
Medium anthropological fragmentation FG-A2 measures low for inland areas as all fragmenting infrastructure considered lays relatively close to the coastlines (Figure 4.3). Low fragmentation was measured around the south east shore, where few settlements exist. High fragmentation was measured close urban settlements, especially if the settlement was close to the coastline. One can see that natural barriers have influenced the settlement pattern greatly, which is reflected in the measurements even though natural barriers are not considered as fragmenting factors when using the FG-A2.

Fragmentation of non-mountainous land areas FG-B2 shows higher levels of fragmentation in both the western and northern part of Iceland (Figure 4.4). Higher levels of fragmentation are close to settlements and in the agriculturally rich areas. This can be seen if the results are compared to agriculture documented by the CLC database (Figure 2.5). The effects of the European constraint barrier are high and have influenced the total values for both the country as whole and the NUTS 3 regions.

The reasoning behind using corresponding methods to the European research (EEA & FOEN, 2011) in this thesis was that by using comparable input data and consistent fragmentation geometries the results could be used hand in hand. In order to achieve this, numerous adjustments had to be made to the input data, and existing datasets were classified to fit same structure used in the European Research. The presented results for FG-A1, FG-A2, and FG-B2 serve this purpose. However one should note that islands where included in this thesis' measurements which was not done in the European research.

Northern parts of Europe differ from the central parts of Europe regarding climate and therefore using constraints to normalize the comparison in the European research was reasonable. However the author feels that better reasoning was needed when the July mean temperature value of 9.5° C from 1950-2000 was chosen as constraint isoline. For the sake of maintaining the comparability with the European research this constraint barrier was nonetheless used here as well for the FG-B2. The threshold temperature constraint boundary however excludes 83% of the total country area including numerous settlements in the northern and eastern parts of Iceland. Adding on to the methodology seemed appropriate to provide more wide ranging local data. Consequently the, European research climate constraint was maintained whilst providing three new constraints alternatives. This strengthened the results, especially in regards to local assessment where all settled areas could be analysed with natural barriers.

The three new indicators which were created provide three new viewpoints to monitor future changes in fragmentation. In figure 5.2 the three new environmental constrain barriers are overlaid by urban settlements and agricultural areas. It becomes clear that natural barriers have also influenced people´s selection of settlements and their adaptation of arable land areas as is suggested by the FG-A2 results.



(Data Source: National Land Survey of Iceland, 2011a; Árnason & Matthíasson, 2009; Björnsson et al. 2007)

Figure 5.2 FG-ICE constraints compared to the pattern of human settlement.

Using the glaciers directly as constraint (FG-ICE1) was interesting for the reason that due to changes in climate glaciers are decreasing in size therewith, creating new habitats where they once lay (Magnúsdóttir, Þórhallsdóttir, & Svavarsdóttir, 2014). The results for fragmentation of non-glacial areas FG-ICE 1 showed that fragmentation measured highest on close urban settlements and agriculturally rich areas (Figure 4.5).

Thermal bliss, values the possibility of vegetation growth during the whole year (Bergþórsson, 1994). It is based on mean temperature values similar to the European climate constraint however it takes in account the whole year as a growth period contrary to just the warmest month. The chosen thermal bliss values 25.5 and 32 where selected to indicate, non-barren areas (FG-ICE2), and plausible grass growth areas (FG-ICE3). The results showed that the fragmentation values increase as natural barriers are given more weight, in the measurements of non-barren land areas FG-ICE 2 (Figure 4.6) and furthermore when plausible grass growth areas FG-ICE 3 were measured (Figure 4.7).

Fragmentation was analysed using hierarchically structured reporting units. This provides the option of reviewing the data on different scales simultaneously. As an example of this practice, the fragmentation of non-glacial areas is shown for the municipality Vogar (Figure 5.3). There, all the reporting units connected to Vogar are shown in one figure which then uses the fragmentation geometry of non-glacial areas FG-ICE.

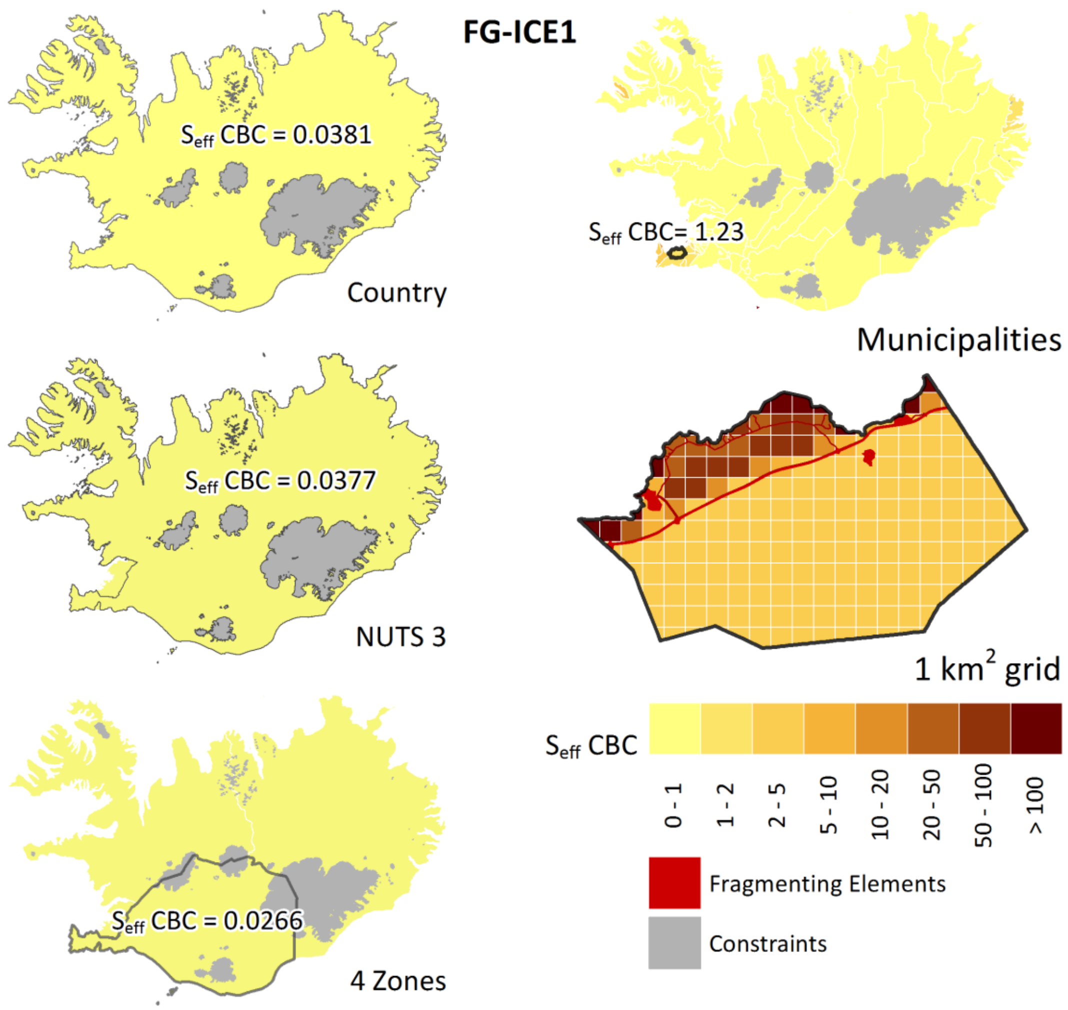


Figure 5.3 Municipality of Vogar is presented using the hierarchically structured data.

Recent changes in Icelandic legislation due to amendments of older laws and adaptation of new laws have given habitats increased recognition. After the implementation of the new Law on environmental protection (60/2013) the focus is more wide-ranging as large wetland areas and natural birch forest have gained important protection status. This happened after the ministry for the Environment had recommended the protection of habitats in relation to land use (Icelandic Ministry for the Environment, 2011). Legislation regarding the concept "landscape" has also changed both in regards to protection but also in terms of how the landscape is perceived (Waage, 2013). The perceived landscape has also been implemented into Environmental legislation through the concept of Wilderness which is purely a human based approach to landscape.

In the law on Environmental responsibility No. 55/2012 it is stated that in order to measure impacts of environmental damages, measurable factors are needed. Correspondingly in environmental assessment, quantifying indices based on topographic representation of set indicators is favoured. Consequently quantitative base line data or ground truth data sets the foundation for future comparison and geographic datasets are regularly used as reference. In the selection of baseline indicators for the SEA of the proposed Country planning policy, this has been the case, where the vast majority of selected baseline indicators have available datasets represented by geographic information (see Icelandic National Planning Agency, 2014 p. 7-8). Nonetheless, habitats, habitat types or ecosystems are not listed with the presented base line indicators, although it should be noted that some factors connect directly to the preservation of habitats here referred to as the three categories; "soil erosion and land restoration," "natural forests" and "wetlands".

Perhaps the most practical reason why habitats are not selected as a reference can be related to the fact that currently no country wide database exists on the current habitat types in Iceland and until now neither did a database on the wholeness of habitat land areas. Regarding habitat types this will change because habitat types are currently being mapped by the Icelandic Institute of Natural History (Magnússon, et al., 2009) where the groundwork has been established for the highlands and the country as a whole is proposed as the end product.

Ideally the country planning policy will provide the most advantageous way of monitoring human influences which lead to the fragmentation of the environment. Firstly, because it views the whole country and therefore is able to assess country wide trends in land use. Secondly, because it provides the foundation for all planning practices, and therefore has the ability to advise local planning authorities to adjust their plans to follow set environmental goals. Thirdly, it will be updated on regular basis, meaning that it will monitor the selected environmental baselines which consequently will highlight threats or unwanted changes.

Even though comparatively, to most of the European countries, the fragmentation of the habitats of Iceland measure low, the rapid expansion of infrastructure during the last decade (Wald, 2013) gives cause for concern. It follows the European development where fragmentation has increased day by day and which has led researchers and governmental bodies to view the problem on a continental scale (EEA & FOEN, 2011). Indeed, effects of fragmentation to ecosystems in Europe have been shown to be cumulative and moderate until a certain threshold is reached, with variant effects to different species and taxa.

The fact that Icelandic habitats areas and human settlement areas are both constricted by climate, soil erosions and volcanic events means that the total level of fragmentation measures higher in agriculturally cultivated areas and close to urban settlements. In order to maintain sustainable relations with the local biota, monitoring infrastructure changes is advisable. By creating the first baseline dataset on the level of fragmentation in Iceland this author hopes it can be put to use by planning authorities in country-wide environmental monitoring through the country planning policy or other monitoring programmes.

Ground level research is needed on the effects of fragmentation on the Icelandic biota. The ongoing programme to map the habitat types in Iceland is the first step towards a fuller understanding of Icelandic ecosystems. One can theorise that larger ecological monitoring programmes could be formed from those results, whilst simultaneously using fragmentation along with other influential environmental factors to indicate or predict future risk factors.

6 Conclusions

Landscape fragmentation in Iceland was measured using Effective Mesh Size (Jaeger, 2000) which accounted for cross boundary connections between reporting units (Moser, Jaeger, Tappeiner, Tasser, & Eiselt, 2007). The calculations were done using GIS software and a predefined tool (Girvetz, 2011) helped with the analysis. The calculation took in account six different fragmentation geometries, three were adapted from the EEA and FOEN (2011) report on fragmentation of Europe along with three additional fragmentation geometries which were created to account for different environmental barriers. Numerous datasets where adjusted before the calculation, most extensively of which was that of the local dataset on roads (National Land Survey of Iceland, 2011a) which had to be reclassified to fit the European comparison. The results were presented using hierarchically structured reporting units which gave values for; the country as a whole area; for the NUTS 3 statistical areas, 4 Zones, Municipalities, and finally as a 1 km^2 grid.

Generally landscape fragmentation in Iceland is low, however numerous areas with high fragmentation where reported. These were areas close to settlements or agricultural zones, and also in settled fjords and islands. This was the case with all the measured fragmentation geometries. Nonetheless fragmentation increased when more environmental constraints where considered.

Fragmentation measures are relatively low compared to most countries in Europe or the fifth least fragmented country, trailing Finland, Romania, Sweden and Norway. This was when the European fragmentation geometry “Fragmentation of non-mountainous land areas FG-B2” was compared to the European result values (EEA & FOEN, 2011). The environmental constraints used in this fragmentation geometry to account for different climate across Europe and to normalize the comparative data, exclude over 80% of Iceland’s land surface, including urban settlements and agricultural areas.

By adding on to the European research methods and creating three new environmental constraints barriers more divergent results could be presented, expanding the possibilities for further usage of the data for future comparisons or monitoring practices. The first barrier excludes glaciers using the CLC 2006 database (Árnason & Matthíasson, 2009) while the second and third barriers exlude areas based on calculated thermal bliss values (Bergþórsson, 1993) where thermal bliss is an indicator of thermal production of a given place.

The measured results provide baseline information on the current status of fragmentation in Iceland applicable for environmental monitoring, either in relation to planning practices through Strategic Environmental Assessment or in other comprehensive environmental prediction models. In Europe the disturbance caused by fragmentation to natural habitats is alarming to both flora and fauna alike. The lack of overview delayed mitigation, while the problem increased day by day. By providing baseline data now it is the author’s hope that it will help to monitor future changes and address them in their early stages. That in turn can hinder the same effects from happening in Iceland thus limiting costly mitigation measures in the future. Not to mention that it can, continue to provide various landscape habitats to the particular flora and fauna Iceland hosts.

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Appendix A

Functional Road Classes are categorized into 8 classes (Tele Atlas, 2010), five of which are considered fragmenting elements in the European Research (EEA & FOEN, 2011). For the reason that TeleAtlas® Multinet® (now TomTom Multinet) road network data was not available for Iceland, road data from the IS50v digital database (National Land Survey of Iceland, 2011a) was manually reclassified to fit a similar structure. This was done using two attributes appointed to the IS50v road data, first the road structural type and secondly road category (see Chapter 3.1.2).

A simplified description on the road structural types is illustrated bellow but for more detailed description see (The Icelandic Road Administration, 2010 p. 5).

A	Four or six lane road separated from opposite traffic.
B	Two or four lane road separated by at least a 2 m barrier between opposite traffic lanes.
C	Two lane road
D	One lane road
F1-F3	Usually narrow gravel roads which are maintained seasonally. The numbering represents the roads quality where 1 is better than 2.

The classification of road category is mostly based on the roads legal status. The different categories where described in English in a booklet which is published every year on the Road system (The Icelandic Road Administration, 2012 p. 2-5).

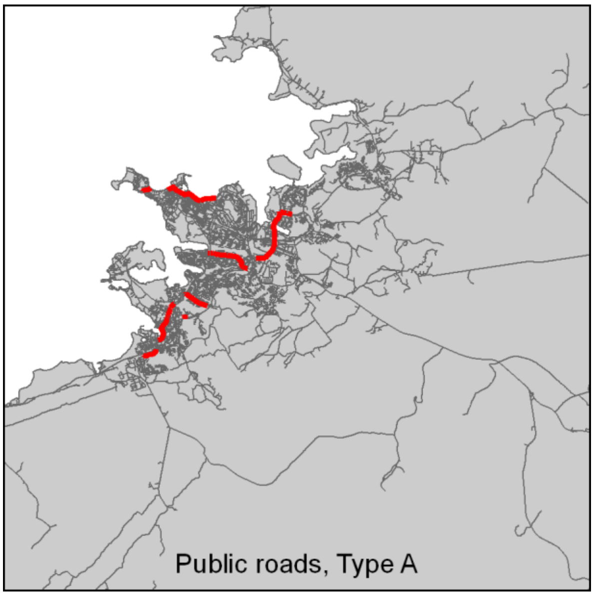
Primary roads	"Primary roads are a part of the basic transport system and connect the country's urban areas. These, in turn, are connected to villages with a population of 100 inhabitants or more. Roads with substantial traffic connecting municipalities in the metropolitan area are also primary roads. In cases where a primary road ends in a municipality, it stretches as far as the first intersection with a street that belongs to the municipality. In some cases, a primary road connects an airport or a harbour, that is important for cargo transport or tourism".
Secondary roads	"Secondary roads are roads outside populated areas that connect primary roads or highland roads to a primary road. They can also be roads connecting a village with less than 100 inhabitants to the primary road system or roads to airports and harbours, which are important to cargo transport and tourism, as well as roads to ferry harbours, national parks and their interiors, and popular tourist destinations in rural areas".
Local access roads	"Local access roads are roads to places such as farms, factories, churches, public schools and other public places located outside populated areas. They are officially planned and listed in the Road Register. A road can also qualify as a local access road if it connects a group of 30 summerhouses or more to a primary or a secondary road".

Primary highland roads	**“**A part of Iceland’s basic transport system runs through its highlands. Because of the nature of these roads, however, services are limited and they are closed in the winter. Highland roads are usually narrow gravel roads or tracks and most rivers are unbridged**”**.
Highland roads	**“**These are state roads that do not belong to any of the road categories listed above. This category covers roads across mountains and moors. These roads are usually with seasonal traffic and limited services. Highland roads are usually narrow gravel roads or tracks and most rivers are unbridged**”**.
Private roads	**“**The owners of … private roads are the keepers of these roads**”**.
Public roads	**“**Public roads are owned by public authorities and can be used freely by the general public**”**.

The Multinet network data is categorized on the bases of road functional importance and is divided into ten classes named Functional Road Classes (Tele Atlas, 2010 p. 47). Their description was given as follows:

FRC 0	Motorways	Removed from the online version
FRC 1	Major Roads	
FRC 2	Other Major Roads	
FRC 3	Secondary Roads	
FRC 4	Local Connecting Roads	
FRC 5	Local Roads	
FRC 6	Local Roads	
FRC 7	Local Roads of Minor Importance	
FRC 8	Other Roads	

In the following pages the 31 individual classes which were formed by combining road structural type and road category are described. This includes the factors which where influential in the decision on which estimated functional road was attributed to it, along with explanatory figures and the given FRC_E value.



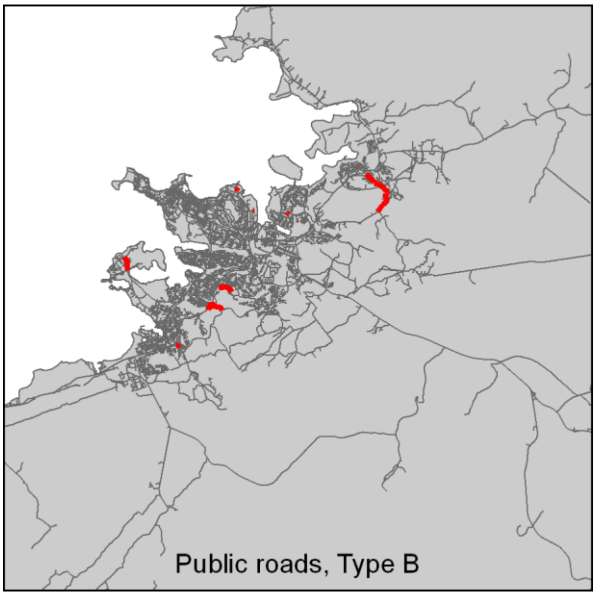
Public roads | Type A

Public roads are roads within urban areas that are owned by local municipalities; they are not state roads accordance with Article 8, in law no. 80/2007.

Type A contains divided roads with at least four lanes. Usually a central reservation is placed between the lanes.
$ÁDU_h$ > 10.000 cars

These roads are one of the main connections and they make different parts of the settlement accessible.

FRC = 4



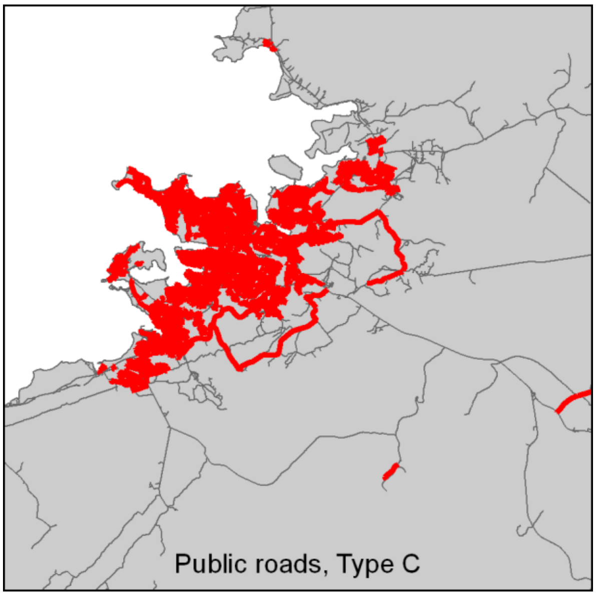
Public roads | Type B

Public roads are roads within urban areas that are owned by local municipalities; they are not state roads in accordance with Article 8, in law no. 80/2007.

Type B contains two or four lane roads. They have a central reservation at least 2 meters wide to hinder cars from going in the opposite direction.
$ÁDU_h$ between 3500 - 10.000 cars

These roads are the main connections within a settlement

FRC = 5



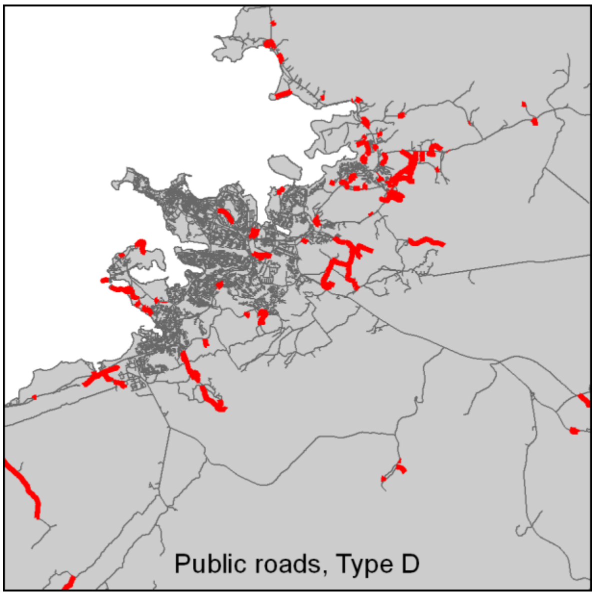
Public roads | Type C

Public roads are roads within urban areas that are owned by local municipalities; they are not state roads accordance with Article 8, in law no. 80/2007.

Type C contains two lane roads.

These roads are used to travel between different parts of the settlement area

FRC = 6



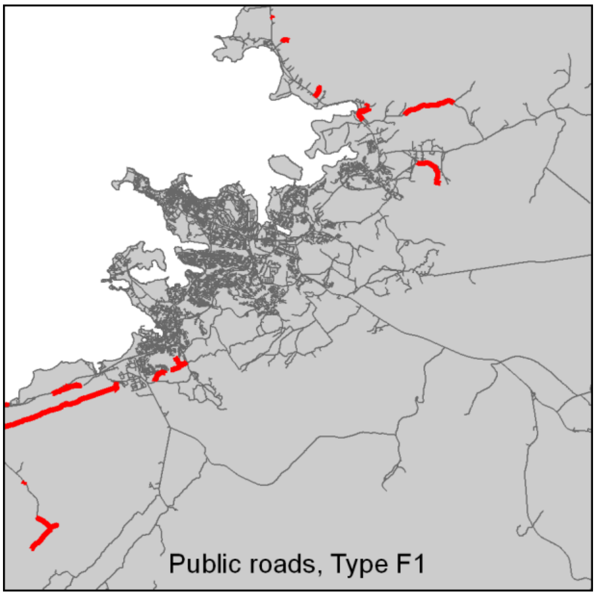
Public roads | Type D

Public roads are roads within urban areas that are owned by local municipalities; they are not state roads in accordance with Article 8, in law no. 80/2007.

Type D contains one lane roads.

Mostly rural roads that have a minor connecting importance. These also include dead end roads and roads inside the living area.

FRC = 7



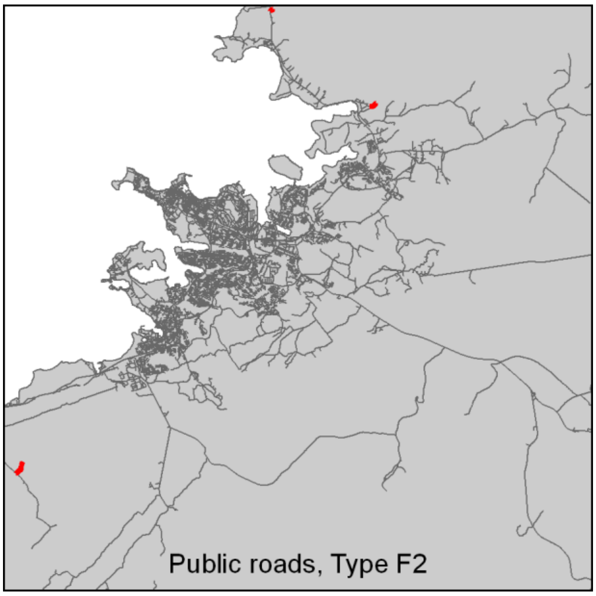
Public roads | Type F1

Public roads are roads within urban areas that are owned by local municipalities; they are not state roads in accordance with Article 8, in law no. 80/2007.

Type F usually contains gravel roads or tracks, which are sometimes cleared of snow but can have unbridged rivers. 1, 2, 3, are an assessment on quality.

For crossing a Jeep is usually needed, at least for F2 & F3

FRC = 8



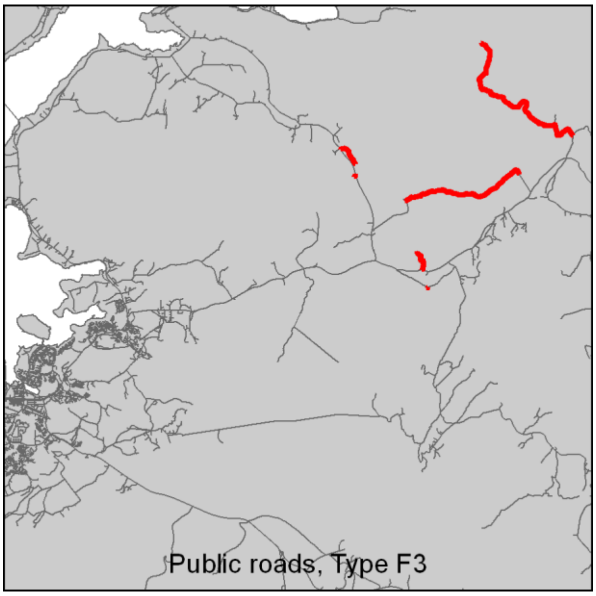
Public roads | Type F2

Public roads are roads within urban areas that are owned by local municipalities; they are not state roads accordance with Article 8, in law no. 80/2007.

Type F usually contains gravel roads or tracks, which are sometimes cleared of snow but can have unbridged rivers. 1, 2, 3, are an assessment on quality.

A jeep is usually needed, at least for F2 & F3

FRC = 8



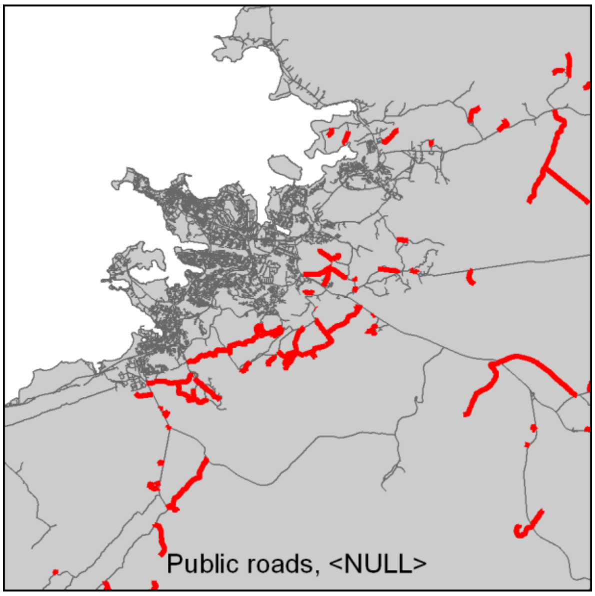
Public roads | Type F3

Public roads are roads within urban areas that are owned by local municipalities; they are not state roads in accordance with Article 8, in law no. 80/2007.

Type F usually contains gravel roads or tracks, which are sometimes cleared of snow but can have unbridged rivers. 1, 2, 3, are an assessment on quality.

A jeep is usually needed, at least for F2 & F3

FRC = 8



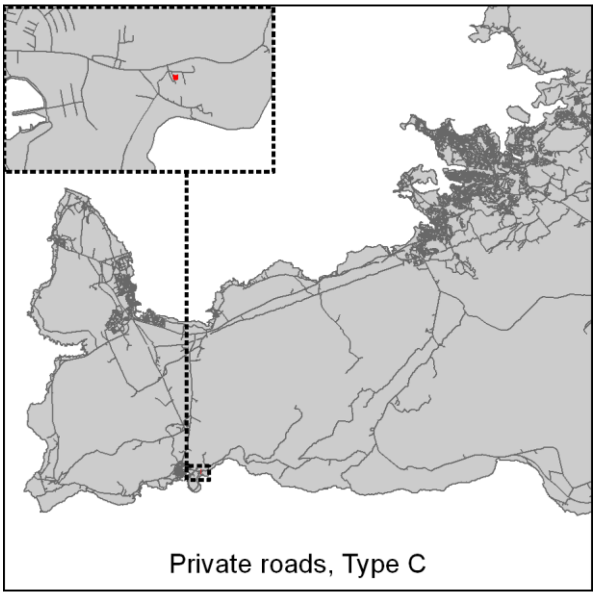
Public roads | <NULL>

Public roads are roads within urban areas that are owned by local municipalities; they are not state roads in accordance with Article 8, in laws no. 80/2007.

No structure type was listed

Mostly rural roads that have a minor connecting importance.

FRC = 8



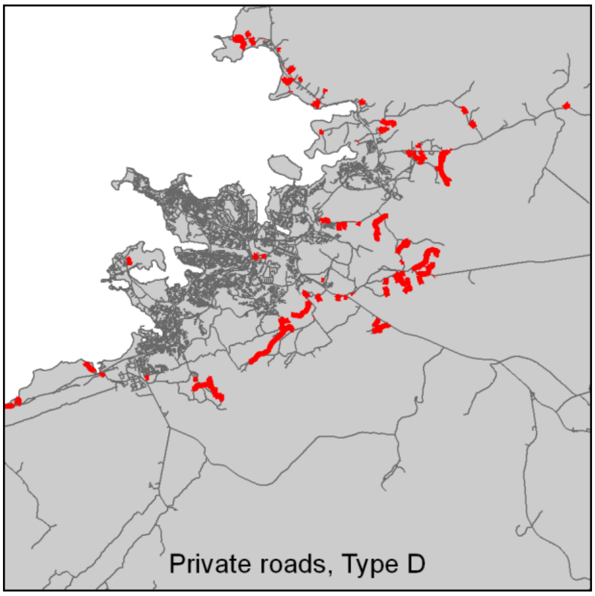
Private roads | Type C

Owners of private roads are the keepers of them, they do not belong to the State or the Municipalities, the owner of the road is in charge of maintenance of the road

Type C contains two lane roads.

Private roads with structure type C are only 16 in total for the whole data set and their placement has only a destination function.

FRC = 7



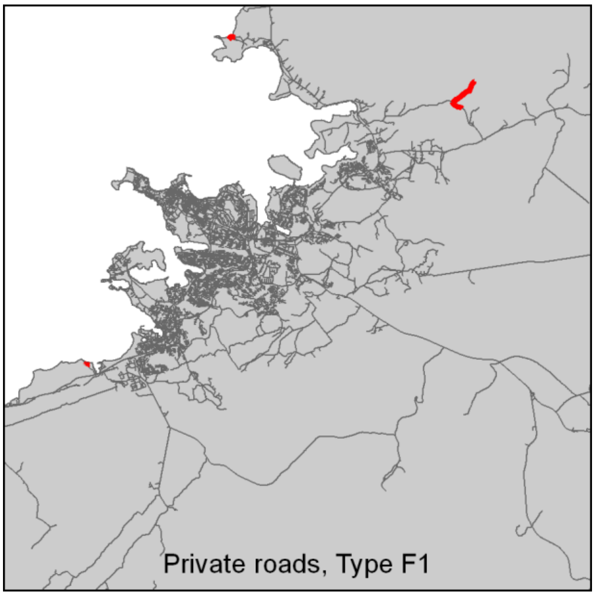
Private roads | Type D

Owners of private roads are the keepers of them, they do not belong to the State or the Municipalities, the owner of the road is in charge of maintenance of the road

Type D contains one lane roads.

Mostly rural roads that have a minor connecting importance. Also dead end roads and roads inside the living area.

FRC = 7



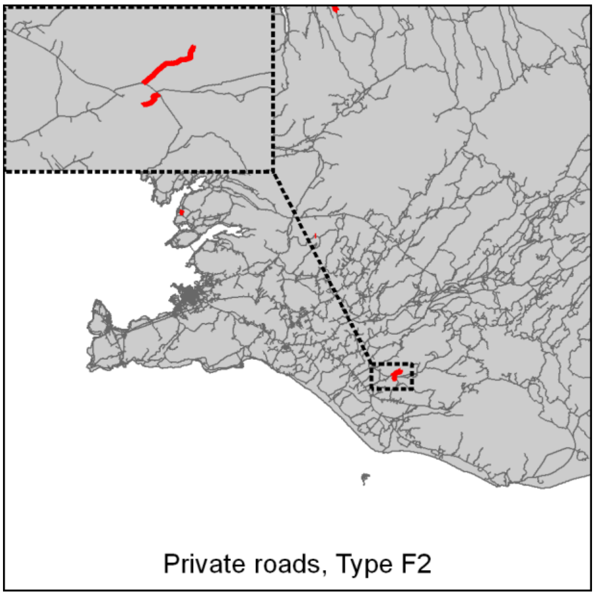
Private roads | Type F1

Owners of private roads are the keepers of them, they do not belong to the State nor the Municipalities, the owner of the road is in charge of maintenance of the road

Type F usually contains gravel roads or tracks, which are sometimes cleared of snow but can have unbridged rivers. 1, 2, 3, are an assessment on quality.

Roads with only a destination function. A jeep is usually needed, at least for F2 & F3.

FRC = 7



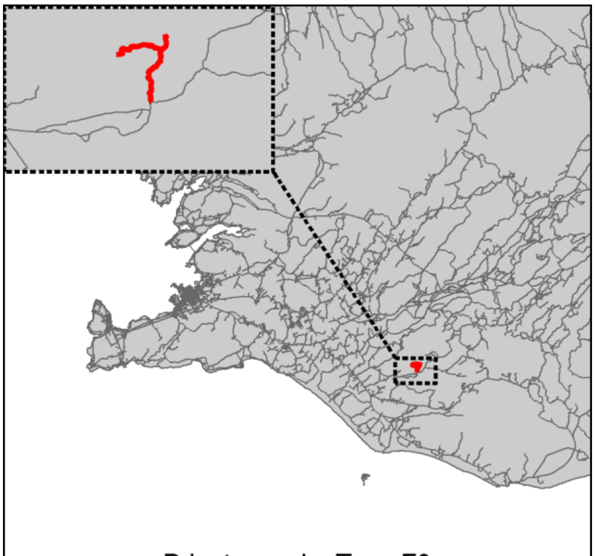
Private roads | Type F2

Owners of private roads are the keepers of them, they do not belong to the State or the Municipalities, the owner of the road is in charge of maintenance of the road.

Type F usually contains gravel roads or tracks, which are sometimes cleared of snow but can have unbridged rivers. 1, 2, 3, are an assessment on quality.

Roads with only a destination function. A jeep is usually needed, at least for F2 & F3.

FRC = 7



Private roads, Type F3

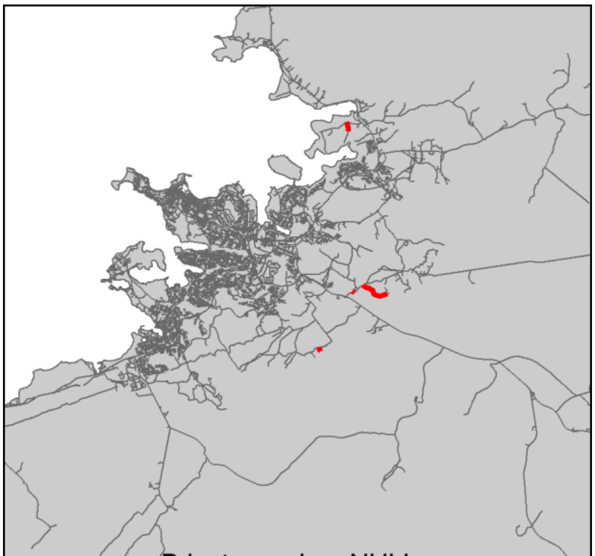
Private roads | Type F3

Owners of private roads are the keepers of them, they do not belong to the State or the Municipalities, the owner of the road is in charge of maintenance of the road.

Type F usually contains gravel roads or tracks, which are sometimes cleared of snow but can have unbridged rivers. 1, 2, 3, are an assessment on quality.

Roads with only a destination function.
Jeep is usually needed, at least for F2 & F3.

FRC = 7



Private roads, <NULL>

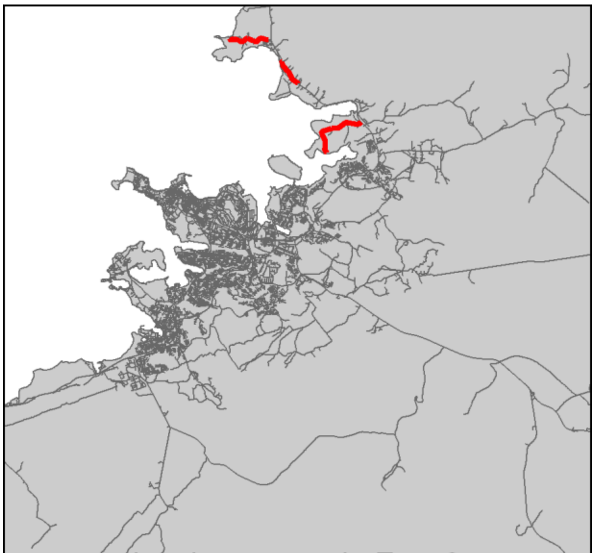
Private roads | <NULL>

Owners of private roads are the keepers of them, they do not belong to the State or the Municipalities, the owner of the road is in charge of maintenance of the road.

No structure type was listed.

Roads with only a destination function.
Mostly rural roads that have a minor connecting importance.

FRC = 7



Local access roads, Type C

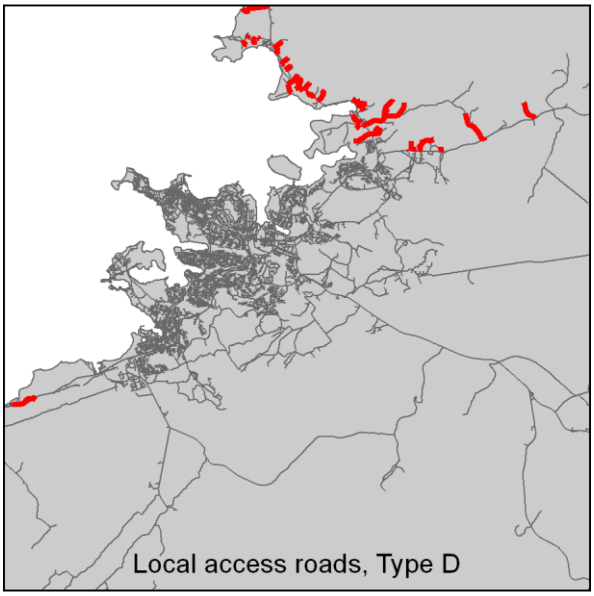
Local access roads | Type C

Local access roads are roads to places such as farms, factories, churches, public schools and other public places located outside populated areas. They are officially planned and listed in the Road Register. A road can also qualify as a local access road if it connects a group of 30 summer houses or more to a primary or a secondary road.

Type C contains two lane roads.

Roads which are used to travel between different parts of a region.

FRC = 3



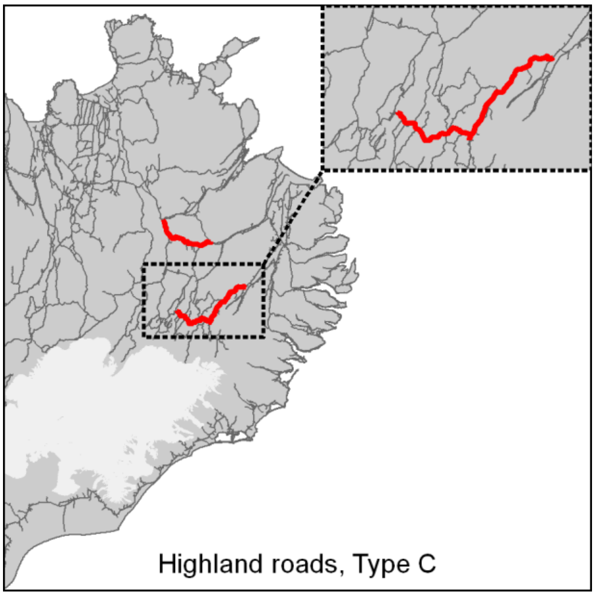
Local access roads | Type D

Local access roads are roads to places such as farms, factories, churches, public schools and other public places located outside populated areas. They are officially planned and listed in the Road Register. A road can also qualify as a local access road if it connects a group of 30 summer houses or more to a primary or a secondary road.

Type D contains one lane roads.

Roads which are used to travel between different parts of a region.

FRC = 3



Highland roads | Type C

Highland roads lay across mountains and moors. These roads are usually with seasonal traffic and limited services.

Type C contains two lane roads.

Roads which have minor connecting importance in a rural area.

FRC = 6

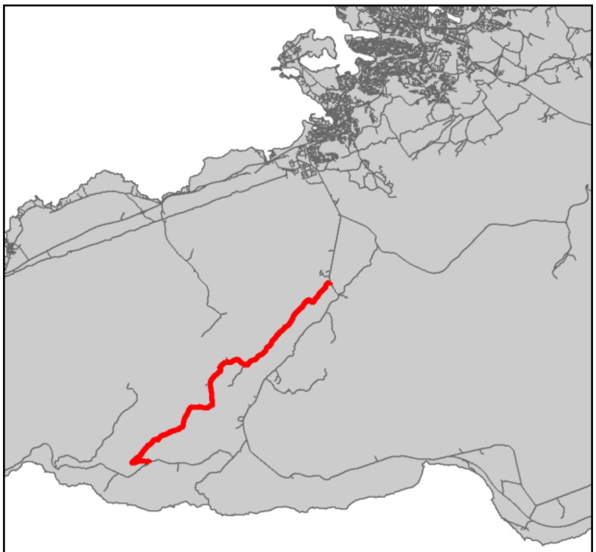
Highland roads | Type D

Highland roads lay across mountains and moors. These roads are usually with seasonal traffic and limited services.

Type D contains one lane roads.

Roads which have minor connecting importance in a rural area.

FRC = 6



Highland roads, Type F1

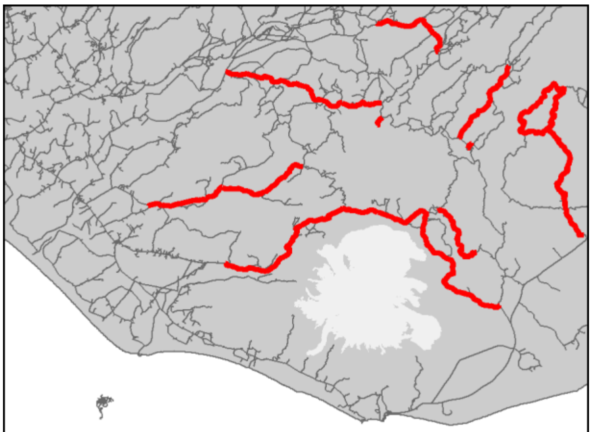
Highland roads | Type F1

Highland roads lay across mountains and moors. These roads are usually with seasonal traffic and limited services.

Type F usually contains gravel roads or tracks, which are sometimes cleared of snow but can have unbridged rivers. 1, 2, 3, are an assessment on quality.

Roads which have minor connecting importance in a rural area.

FRC = 6



Highland roads, Type F2

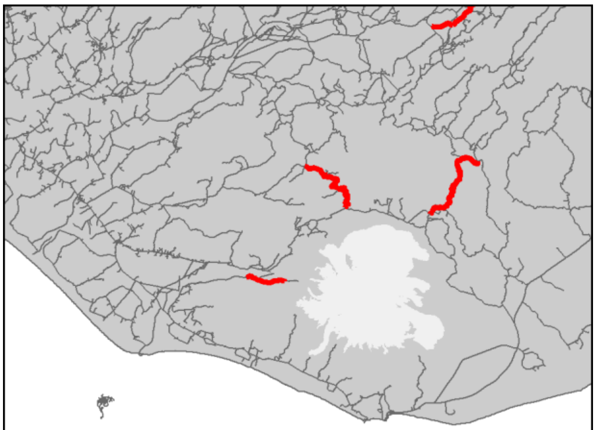
Highland roads | Type F2

Highland roads lay across mountains and moors. These roads are usually with seasonal traffic and limited services.

Type F usually contains gravel roads or tracks, which are sometimes cleared of snow but can have unbridged rivers. 1, 2, 3, are an assessment on quality.

Roads which are less important for a navigation system. A jeep is usually needed, at least for F2 & F3.

FRC = 8



Highland roads, Type F3

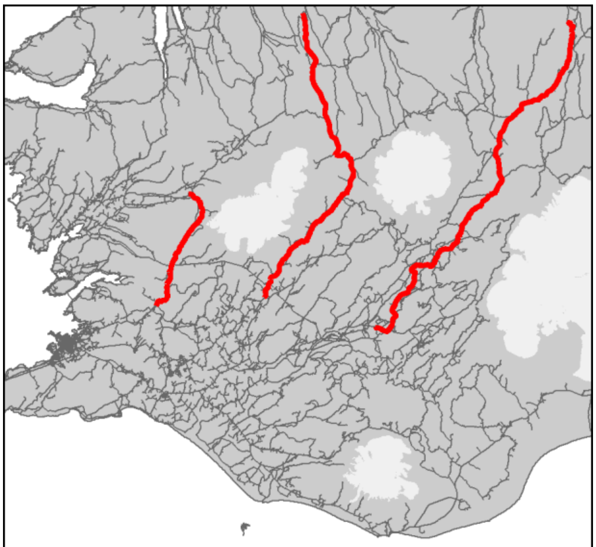
Highland roads | Type F3

Highland roads lay across mountains and moors. These roads are usually with seasonal traffic and limited services.

Type F usually contains gravel roads or tracks, which are sometimes cleared of snow but can have unbridged rivers. 1, 2, 3, are an assessment on quality.

Roads which are less important for a navigation system. Jeep is usually needed, at least for F2 & F3.

FRC = 8



Primary highland roads, Type C

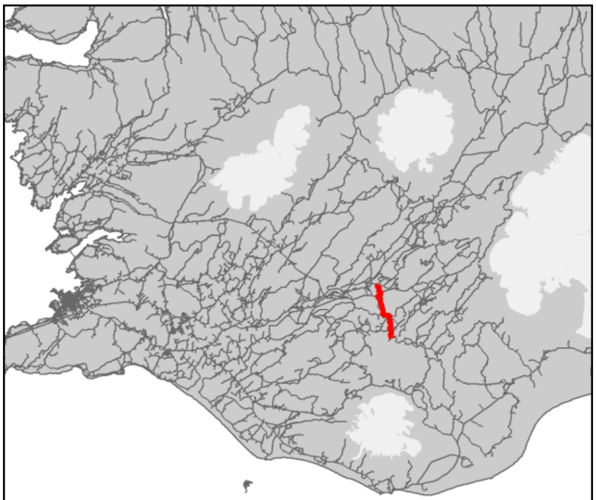
Primary Highland roads | Type C

Primary Highland roads are state owned and lay across mountains and moors. These roads are usually with seasonal traffic and seasonal services regarding maintenance.

Type C contains two lane roads.

Roads which have minor connecting importance in a rural area

FRC = 6



Primary highland roads, Type F1

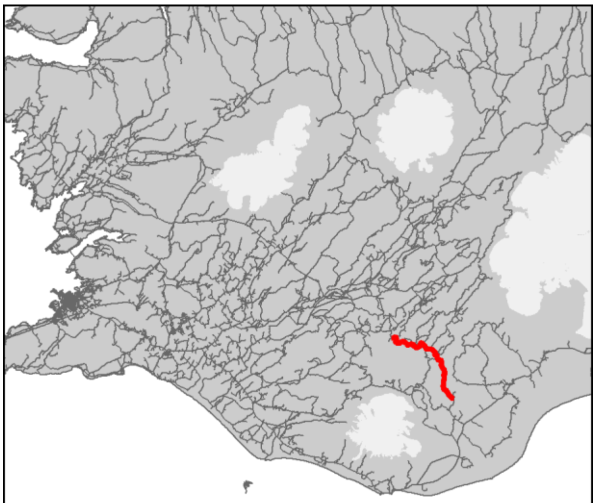
Primary Highland roads | Type F1

Primary Highland roads are state owned and lay across mountains and moors. These roads are usually with seasonal traffic and seasonal services regarding maintenance.

Type F usually contains gravel roads or tracks, which are sometimes cleared of snow but can have unbridged rivers. 1, 2, 3, are an assessment on quality.

Roads which have minor connecting importance in a rural area.

FRC = 6



Primary highland roads, Type F2

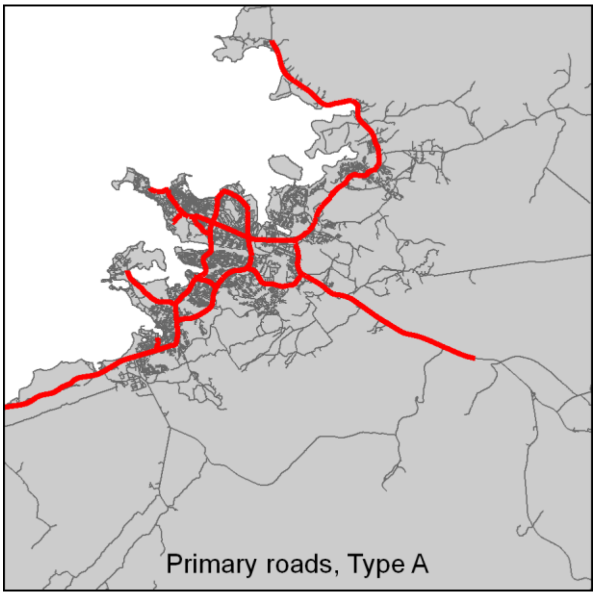
Primary Highland roads | Type F2

Primary Highland roads are state owned and lay across mountains and moors. These roads are usually with seasonal traffic and seasonal services regarding maintenance.

Type F usually contains gravel roads or tracks, which are sometimes cleared of snow but can have unbridged rivers. 1, 2, 3, are an assessment on quality.

Roads which have minor connecting importance in a rural area. A jeep is usually needed, at least for F2 & F3.

FRC = 8



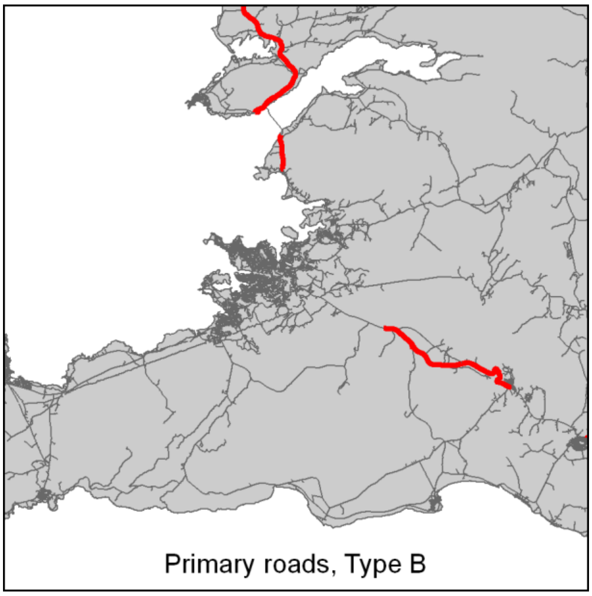
Primary roads | Type A

Primary roads are a part of the basic transport system and connect the country's urban areas. These, in turn, are connected to villages with a population of 100 inhabitants or more. Roads with substantial traffic connecting municipalities in the metropolitan area are also primary roads.

Type A contains divided roads with at least four lanes. Usually a central reservation is placed between the lanes.
$ÁDU_h$ > 10.000 cars

Roads of high importance in national traffic and transport.

FRC = 1



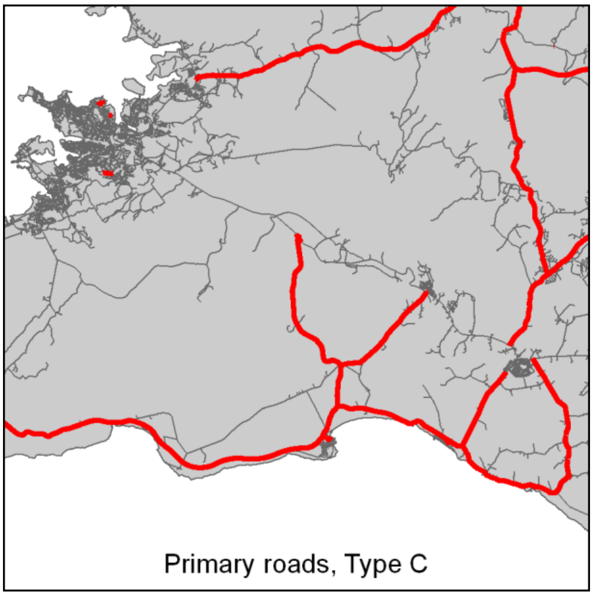
Primary roads | Type B

Primary roads are a part of the basic transport system and connect the country's urban areas. These, in turn, are connected to villages with a population of 100 inhabitants or more. Roads with substantial traffic connecting municipalities in the metropolitan area are also primary roads.

Type B contains two or four lane roads. They have a central reservation of at least 2 meters wide to hinder cars from going in the opposite direction. $ÁDU_h$ between 3500 - 10.000 cars

Roads used to travel between different neighbouring regions.

FRC = 2



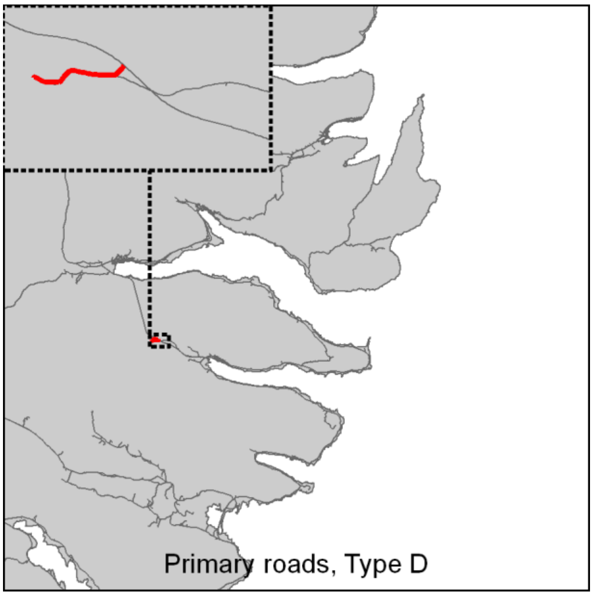
Primary roads | Type C

Primary roads are a part of the basic transport system and connect the country's urban areas. These, in turn, are connected to villages with a population of 100 inhabitants or more. Roads with substantial traffic connecting municipalities in the metropolitan area are also primary roads.

Type C contains two lane roads.

Roads used to travel between different neighbouring regions.

FRC = 2



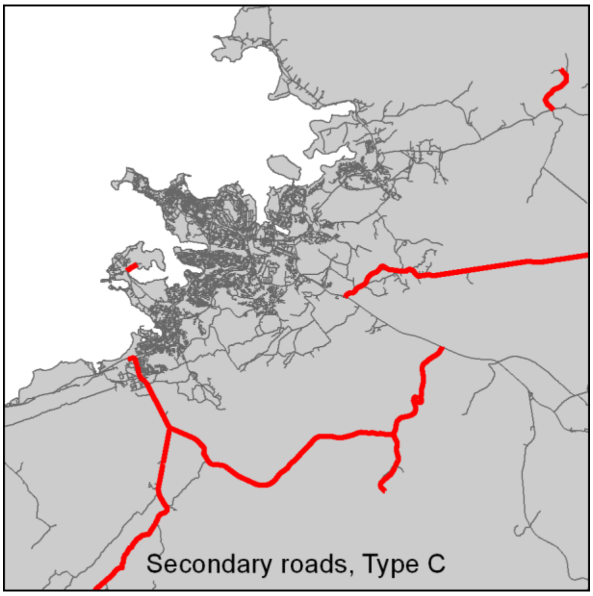
Primary roads | Type D

Primary roads are a part of the basic transport system and connect the country's urban areas. These, in turn, are connected to villages with a population of 100 inhabitants or more. Roads with substantial traffic connecting municipalities in the metropolitan area are also primary roads.

Type D contains one lane roads.

Primary Roads with structure type D are only 3 in total for the whole data set. Their placement only has a destination function.

FRC = 7



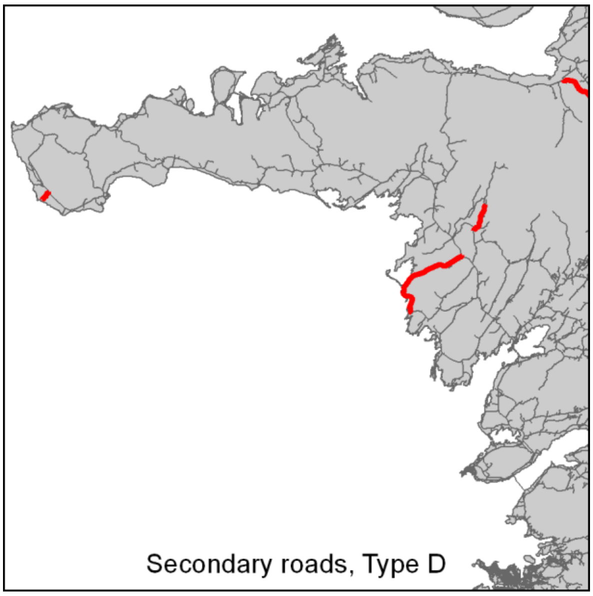
Secondary roads | Type C

Secondary roads are roads outside populated areas that connect primary roads or highland roads to a primary road. They can also be roads connecting a village with less than 100 inhabitants to the primary road system but also roads to airports and harbours.

Type C contains two lane roads.

Roads used to travel between different parts of the same region.

FRC = 3



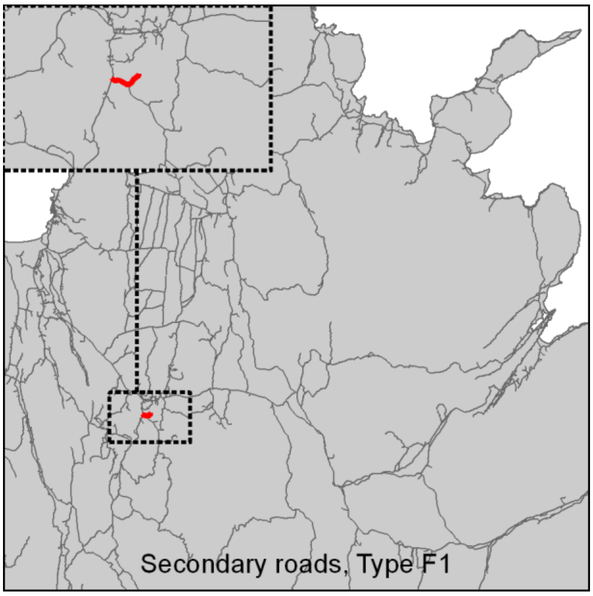
Secondary roads | Type D

Secondary roads are roads outside populated areas that connect primary roads or highland roads to a primary road. They can also be roads connecting a village with less than 100 inhabitants to the primary road system but also roads to airports and harbours.

Type D contains one lane roads.

Roads used to travel between different parts of the same region.

FRC = 3



Secondary roads | Type F1

Secondary roads are roads outside populated areas that connect primary roads or highland roads to a primary road. They can also be roads connecting a village with less than 100 inhabitants to the primary road system but also roads to airports and harbours.

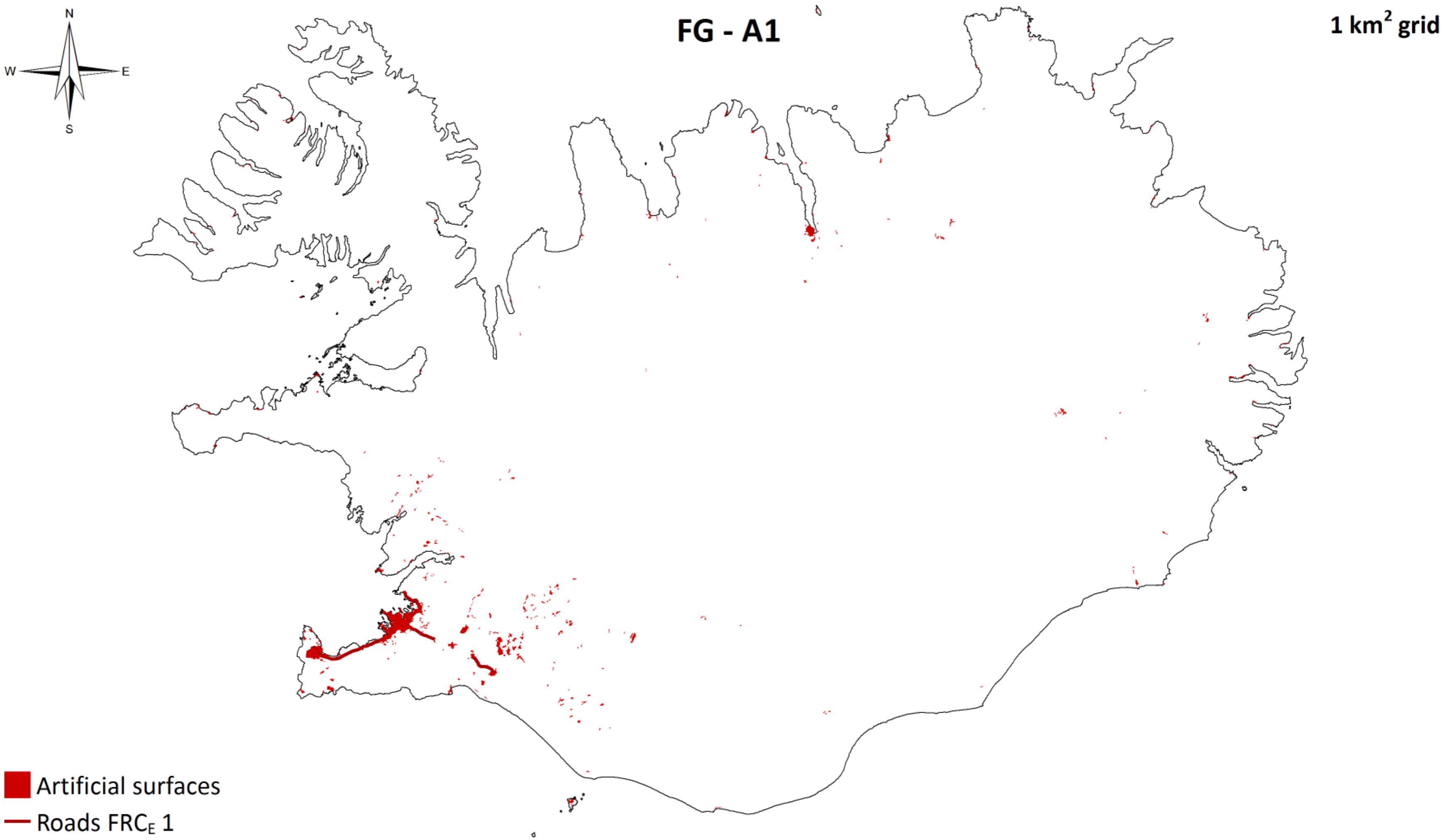
Type F contains usually gravel roads or tracks, which are sometimes cleared of snow but can have unbridged rivers. 1, 2, 3, are an assessment on quality.

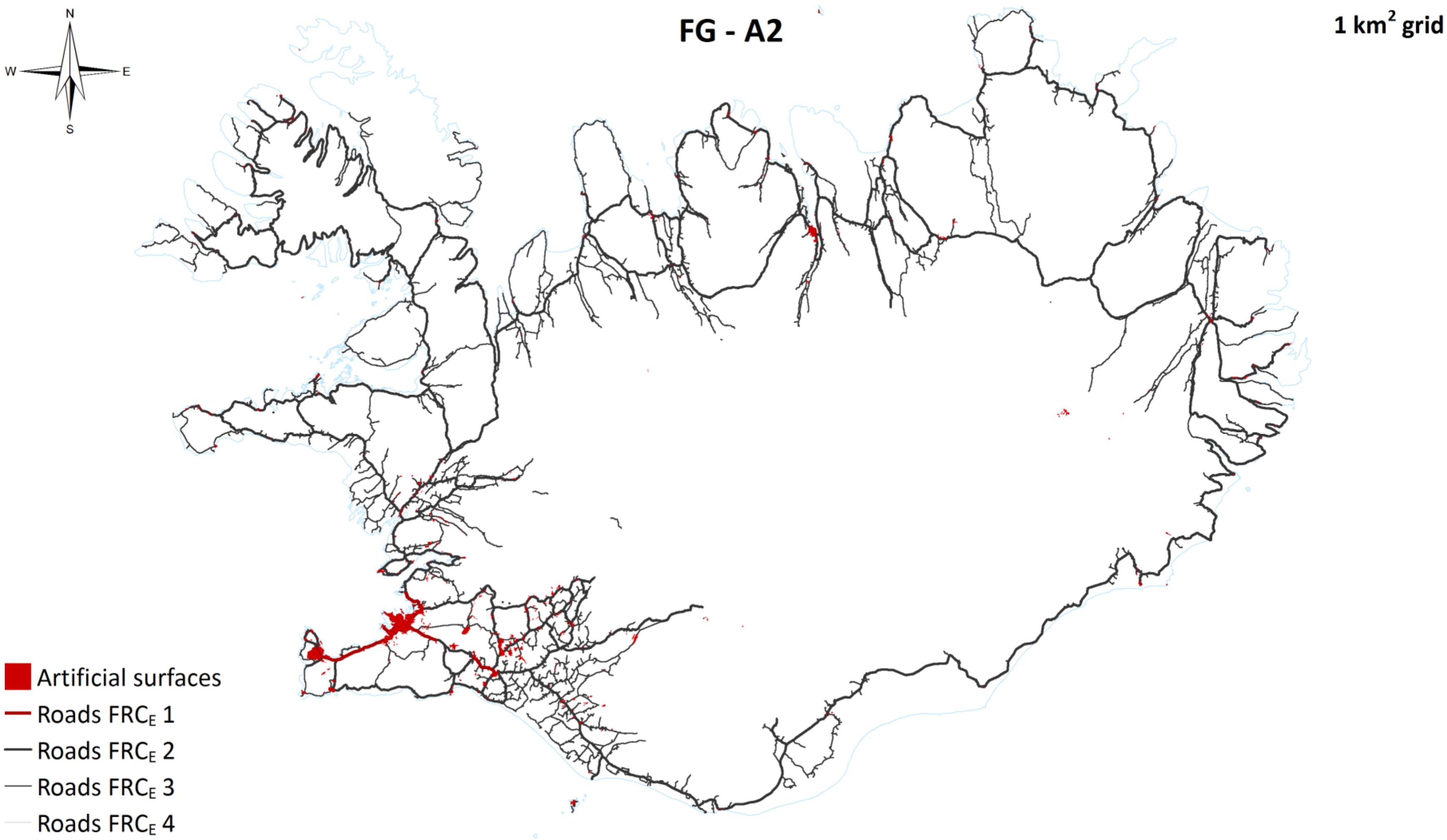
Primary Roads with structure type D are only 4 in total for the whole data set and they are not important for a navigation system.

FRC = 8

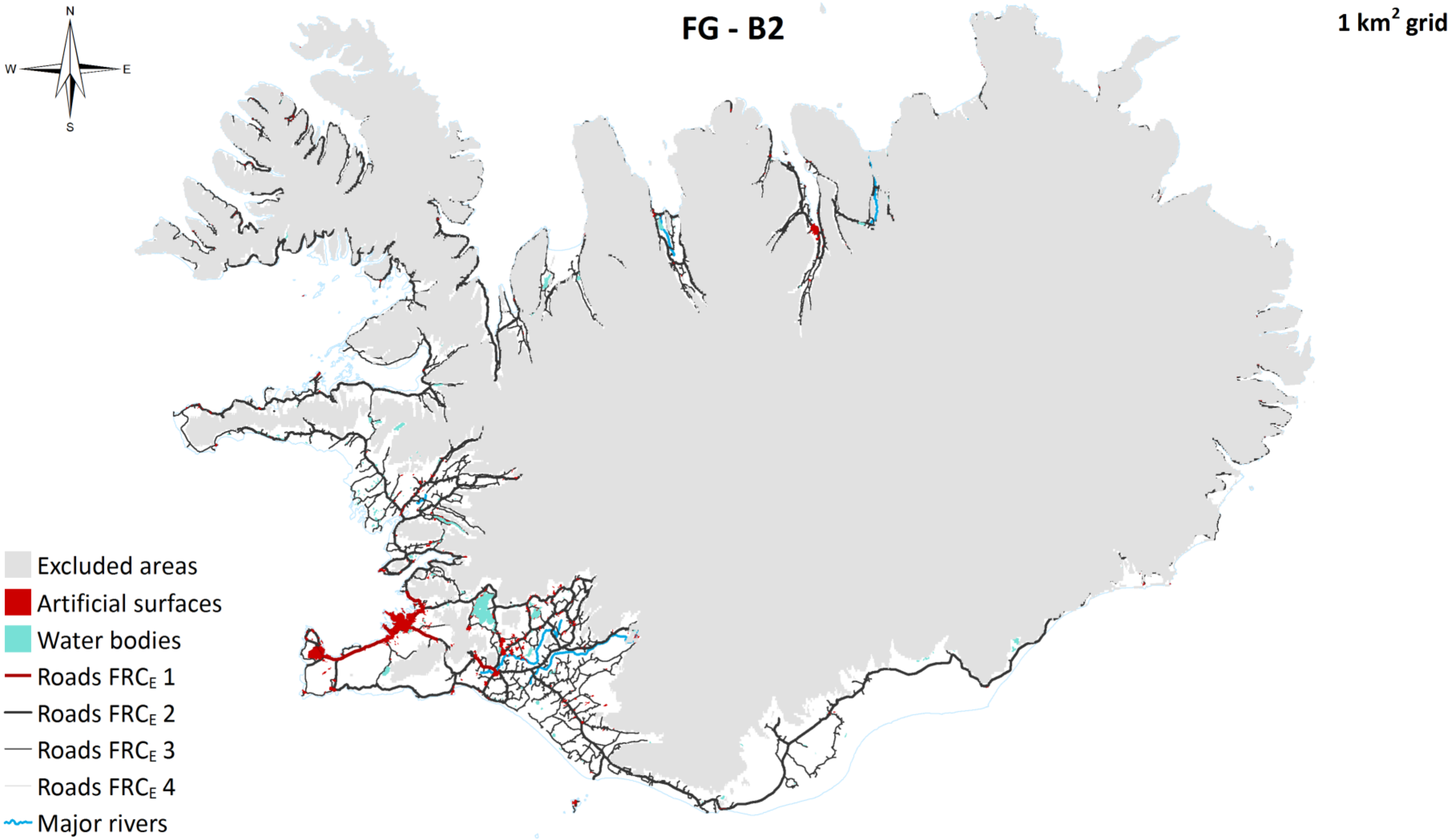
Appendix B

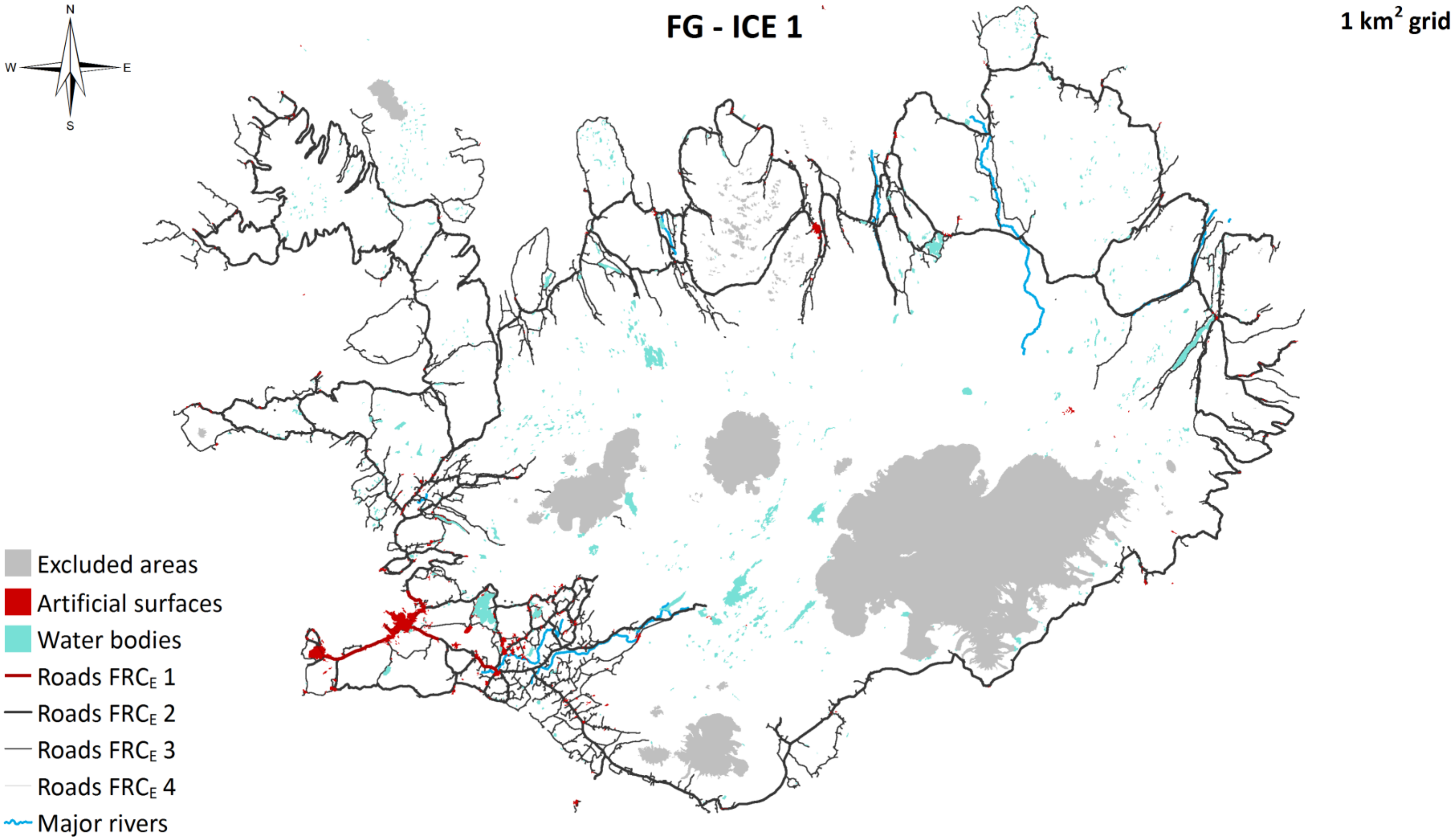
Appendix B displays the transparency sheets intended to overlay the grid based results in the printed version of the thesis.

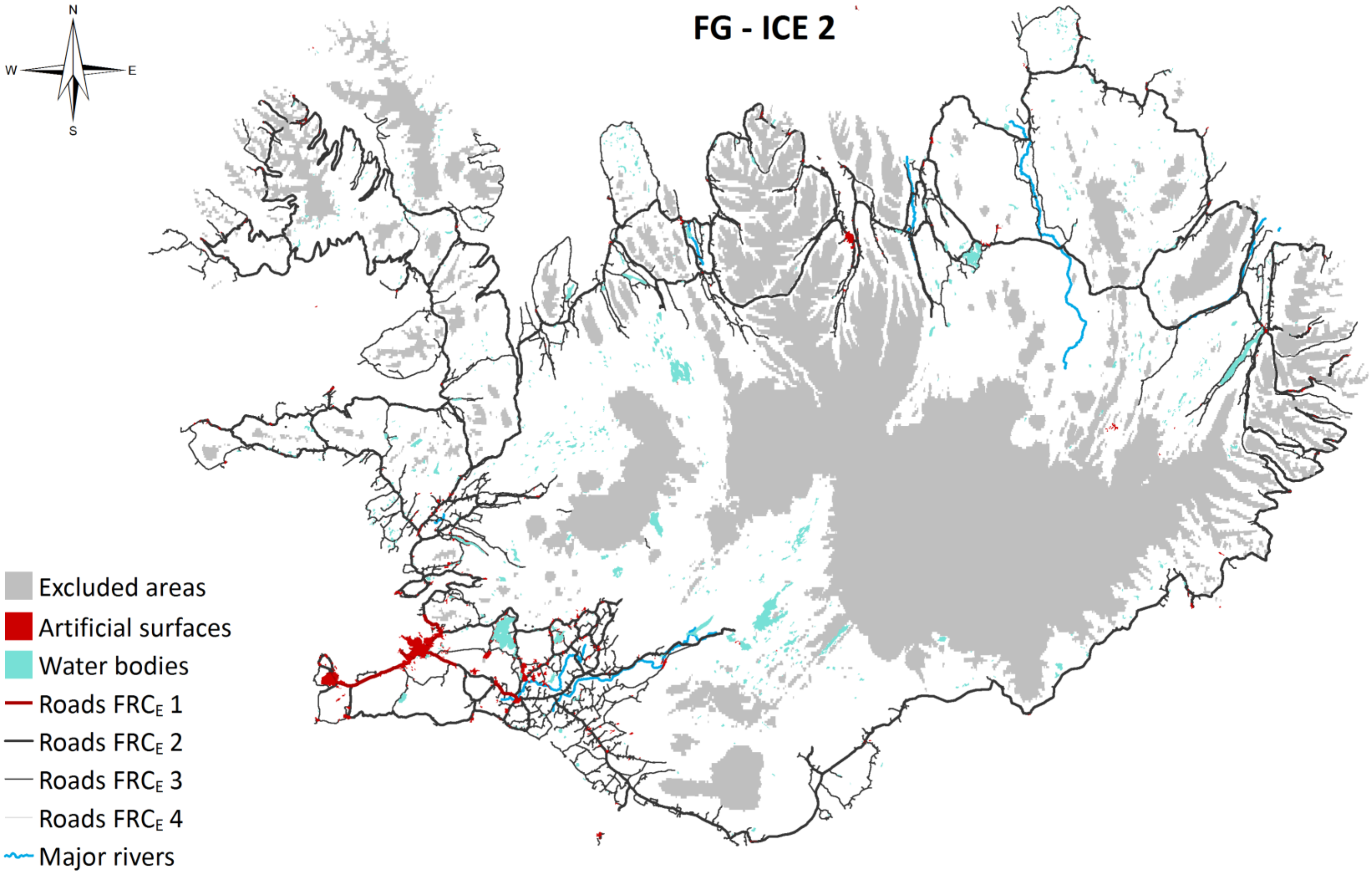

FG - A1
1 km² grid
N
W
E
S
Artificial surfaces
Roads FRCE 1

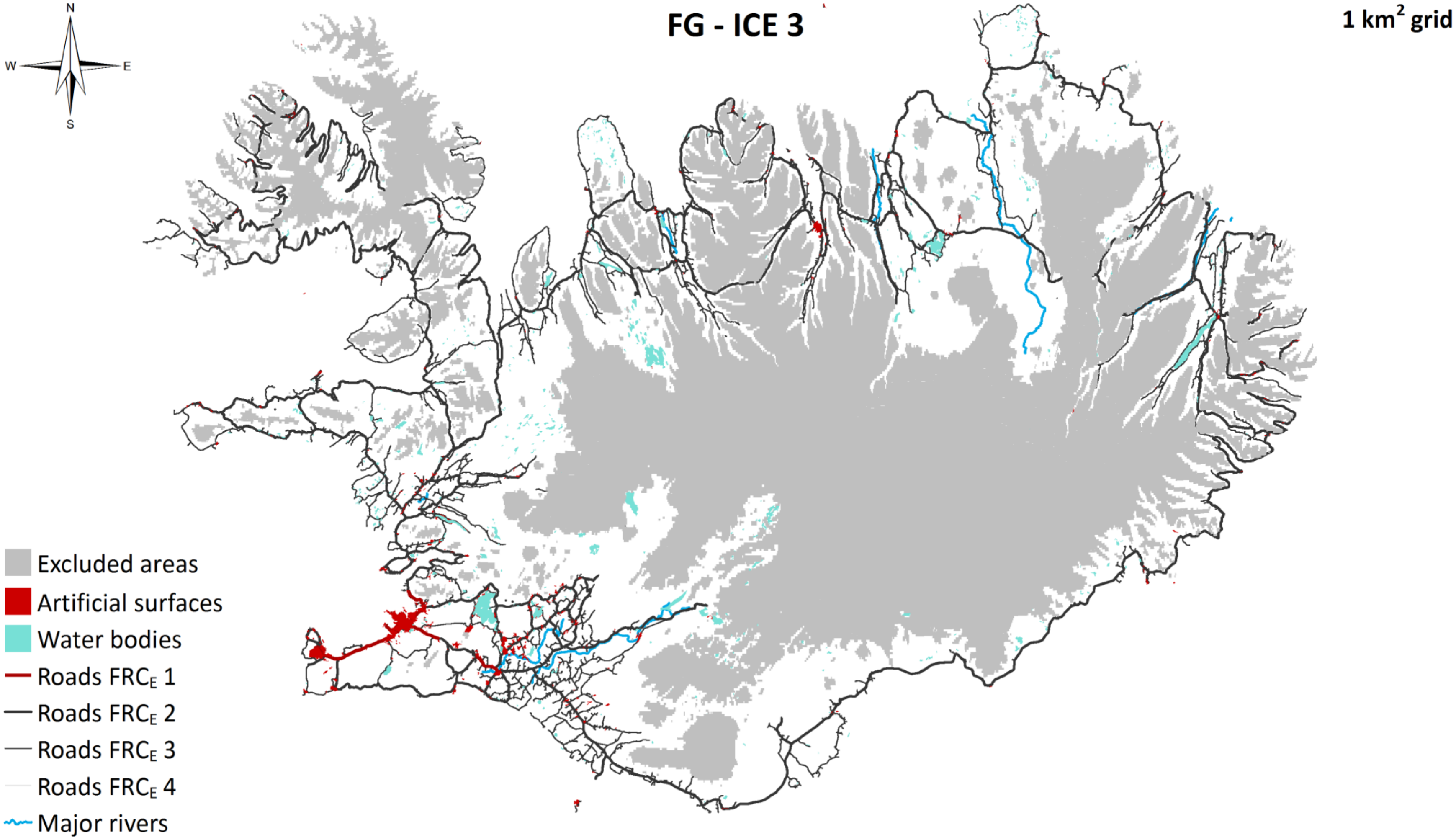


FG - A2
1 km² grid
N
S
W
E
Artificial surfaces
Roads FRCE 1
Roads FRCE 2
Roads FRCE 3
Roads FRCE 4


FG - B2
1 km² grid
N
W
E
S
Excluded areas
Artificial surfaces
Water bodies
Roads FRC_E 1
Roads FRC_E 2
Roads FRC_E 3
Roads FRC_E 4
Major rivers


FG - ICE 1
1 km² grid
N
S
W
E
Excluded areas
Artificial surfaces
Water bodies
Roads FRC_E 1
Roads FRC_E 2
Roads FRC_E 3
Roads FRC_E 4
Major rivers


FG - ICE 2
1 km² grid
N
W
E
S
Excluded areas
Artificial surfaces
Water bodies
Roads FRCE 1
Roads FRCE 2
Roads FRCE 3
Roads FRCE 4
Major rivers


FG - ICE 3
1 km² grid
N
W
E
S
Excluded areas
Artificial surfaces
Water bodies
Roads FRC_E 1
Roads FRC_E 2
Roads FRC_E 3
Roads FRC_E 4
Major rivers