# LANDSLAGSFLOKKUN MEÐ VETTVANGSGÖGNUM OG STAFRÆNUM AÐFERÐUM

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Rammaáætlun

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## FORMÁLI

Landslag og víðerni eru á meðal þeirra náttúruverðmæti sem meta skal í *Áætlun um vernd og orkunýtingu landssvæða* (Rammaáætlun). Fyrirliggjandi rannsóknir á þessum verðmætum eru þó af afar skornum skammti. Á vegum 2. áfanga Rammaáætlunar var ráðist í viðamikið rannsóknarverkefni sem hafði það meginmarkmið að þróa og prófa aðferðir til að flokka náttúrlegt landslag á Íslandi. Verkefnið var unnið á árunum 2006-2009 en skýrsla um niðurstöður þess var gefin út í ársbyrjun 2010.[1] Við lok 2. áfanga Rammáætlunar lagði þáverandi faghópur 1 fram tillögur að brýnustu rannsóknar-verkefnum og voru áframhaldandi rannsóknir á landslagi þar ofarlega á blaði.

Sumarið 2015 hófust landslagsrannsóknir á ný á vegum Rammaáætlunar. Hér verður gerð grein fyrir þeim hluta rannsóknanna sem laut að greiningu landslags með tilliti til flokkunar út frá sjónrænum einkennum. Markmið núverandi rannsókna var annars vegar að afla gagna um landslag innan áhrifasvæða skilgreinda virkjunarhugmynda sem metnar skyldu í 3. áfanga Rammaáætlunar og hins vegar að þróa aðferðir til að flokka landslag með stafrænum hætti, þ.e. út frá gögnum sem tiltæk eru í landupplýsingakerfum. Báðir ofangreindir þættir byggðu á þeirri rannsóknarvinnu sem fór fram á vegum 2. áfanga. Söfnun vettvangsgagna fór fram á sama hátt og í 2. áfanga nema að því leyti til að söfnunarstaðir voru miðaðir við áhrifasvæði virkjanahugmynda, en ekki landið allt. Stafræna flokkunaraðferðin leggur aðferðafræðina sem þróuð var í 2. áfanga til grundvallar, eins og sjá má í seinni hluta skýrslunnar.

Skýrsla þessi er í tveimur hlutum og fjallar sá fyrri um söfnun og úrvinnslu vettvangsgagna sem aflað var sumarið 2015 en hinn síðari um aðferðafræði og fyrstu niðurstöður stafrænu greiningaraðferðarinnar.

Rannsóknirnar eru hluti af langtímaverkefni sem ráðgert er að ljúka fyrir árslok 2016. Það efni sem hér er birt ber því að líta á sem fyrstu niðurstöður verkefnisins. Hér er um talsvert flókin viðfangsefni að ræða, ekki síst þróunarvinnuna við stafrænu aðferðina. Næstu skref í verkefninu snúa að því að ljúka við stafræna flokkun landslags á miðhálendinu öllu og síðan að víkka þá greiningu út til láglendissvæða. Jafnframt verður safnað frekari vettvangsgögnum, meðal annars til að geta gert skipulegan samanburð á milli kerfanna tveggja.

Rannsóknir af þessum toga hafa ekki einungis gildi fyrir matsvinnu á vegum Rammaáætlunar heldur er hér um grunnrannsóknir að ræða sem geta haft mikið gildi fyrir margvíslega aðra stefnumótunarvinnu af hálfu hins opinbera, svo sem varðandi landsskipulag og gerð verndaráætlana fyrir friðlýst svæði. Rannsóknirnar geta einnig skipt verulegu máli fyrir áframhaldandi þróun aðferða við mat á landslagi og víðernum í mati á umhverfisáhrifum framkvæmda.

Umhverfis- og auðlindaráðuneytinu eru færðar bestu þakkir fyrir fjárhagslegan stuðning við rannsóknirnar.

[1] Þóra Ellen Þórhallsdóttir, Þorvarður Árnason, Hlynur Bárðarson og Karen Pálsdóttir (2010). *Íslenskt landslag. Sjónræn einkenni, flokkun og mat á fjölbreytni*. Reykjavík: Háskóli Íslands.

# I. Landscape classification based on field data from 2015

This section of the report provides an overview of the updates made to the original Icelandic Landscape Project (ILP) landscape categories proposed in 2010, based on the addition of 67 new data points collected during the field work of summer 2015. The report begins with a brief introduction to the 2015 data collection and methodology. The next section discusses the process of incorporating this new data into the current landscape database. The last section proposes a refined set of landscape categories based on these additions along with a short description of each new category. This incorporation of new data is part of an ongoing research project to continue expanding the ILP classification system into a more robust database and strengthen the methodology for evaluating the 'landscape' variable for energy projects assessed by Work Group I in Rammaáætlun.

In this report, *old* points and *new* points will refer to the data points collected in the summer 2006-2008 and 2015 sampling periods respectively. Also, *old* landscape categories will refer to the original 2010 landscape report categories, and *new* landscape categories will refer to the newly-proposed landscape categories discussed below.

## 2015 Data Collection and Methodology

The landscape data collection for Rammaáætlun Phase III occurred during the summer of 2015, between July 14 and September 21. The data collection trips were broken into seven general travel regions based on travel logistics and proximity amongst energy site impact areas. Table 1.1 shows the energy sites within each of these travel regions as well as the energy sites that were not sampled due to either time constraints or other factors. New landscape data was collected for 20 of the 25 potential energy sites under assessment. For four sites (geothermal areas), data was used from the original ILP, collected in 2006-2008.

A total of 67 individual data points were visited and sampled in 2015. It is important to note that since some of the impact areas from different energy sites overlapped, many of the points were shared points. In other words, data collected at one point may have been used for two or more impact areas.

The specific locations for the data collection within each impact area were GPS coordinate points based on the systematic 10 x 10 km grid system, adopted from Náttúrufræðistofnun Íslands. Unlike the orginal sampling method in ILP, which had a nation-wide focus and was based on data collected at roughly 30 km intervals, the sampling work in 2015 attempted to collect as much data as possible within each given site, with an interval of 10 km between prospective data collection sites. Four types of data were gathered and recorded at each of the 67 points: (1) checklist of landscape characteristics (visual features), (2) checklist of wilderness characteristics (both subjective and objective variables), (3) 360-degree photography, and (4) 360-degree videography.

*Table 1.1 Listing of energy sites grouped into general travel regions along with unsampled energy sites*

| Travel Region | Energy Site |
|---|---|
| Southwest (Selfoss/Hella) | Holtavirkjun<br>Urriðafossvirkjun<br>Hvammsvirkjun<br>Búrfellslundur |
| Central West (Kjölur/Kerlingarfjöll) | Búðartunguvirkjun<br>Hagavatnsvirkjun<br>Stóra-Laxá |
| South (Kirkjubæjarklaustur/Laki) | Búlandsvirkjun<br>Hólmsárvirkjun - án miðlunar<br>Hólmsárvirkjun við Atley |
| West Fjörds (Ófeigsfjarðarheiði) | Austurgilsvirkjun |
| Central North (Skagafjörður) | Villinganesvirkjun<br>Skatastaðavirkjun C |
| Central East (Askja/Vatnajökull) | Hrafnabjargavirkjun A and B<br>Hrafnabjargavirkjun C<br>Hágönguvirkjun<br>Fljótshnúksvirkjun<br>Skrokkölduvirkjun |
| West (Reykjanes) | Trölladyngja<br>Austurengjar |
| Impact Areas not sampled in 2015 | Innstidalur<br>Þverárdalur<br>Hverahlíð<br>Fremrinámar<br>Blöndulundur |

Figure 1.1 (below) shows the intended data point locations: 10 x 10 km grid points (*Landslagsstaðir*) and dam points (*Stíflustaðir*) within the impact areas.[2] Figure 1.2 shows the locations of the 67 data points (*Söfnunarstaðir*) that were ultimately collected within the impact areas. Figure 1.3 shows a combination of the intended points and actual points.

[2] The impact areas of the two windpower projects had not been fully defined when fieldwork started and these are therefore not shown in Figures 1.1, 1.2, and 1.3.

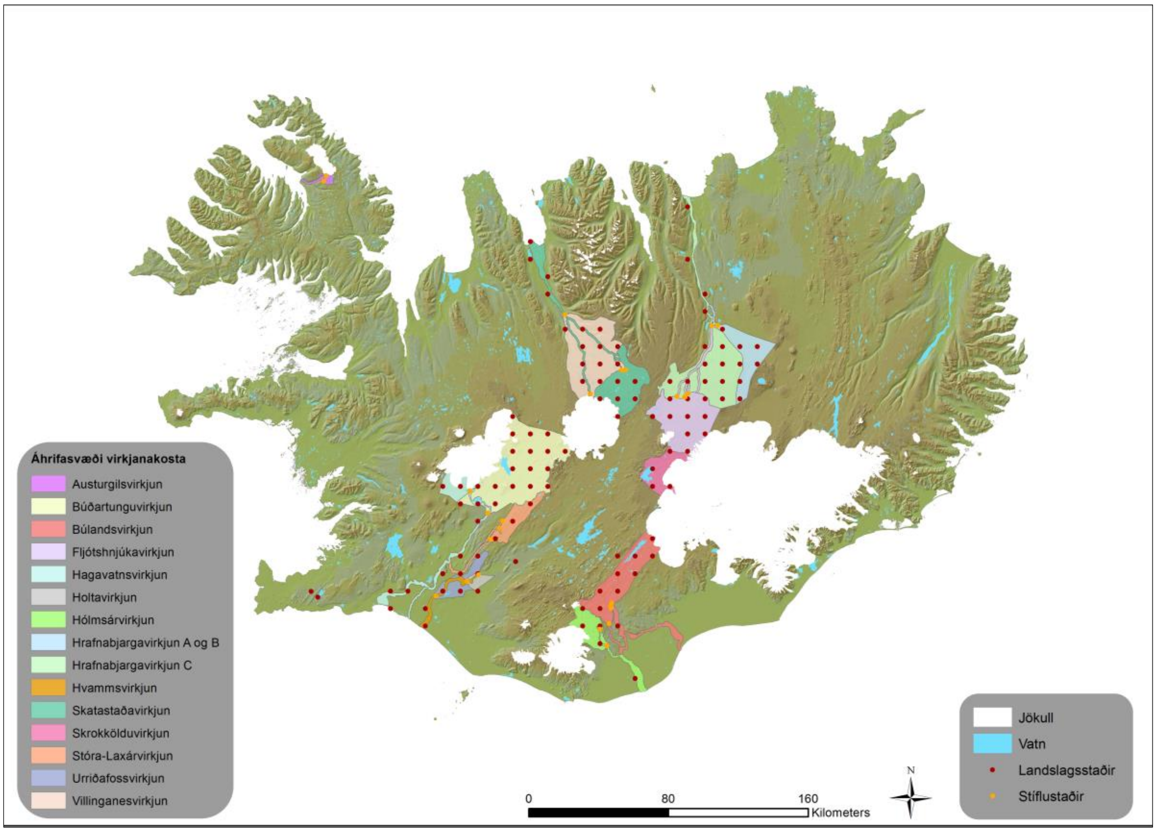



*Figure 1.1 Location of the intended data collection points- grid points (RED) and dam points (ORANGE) - within the proposed energy site impact areas*

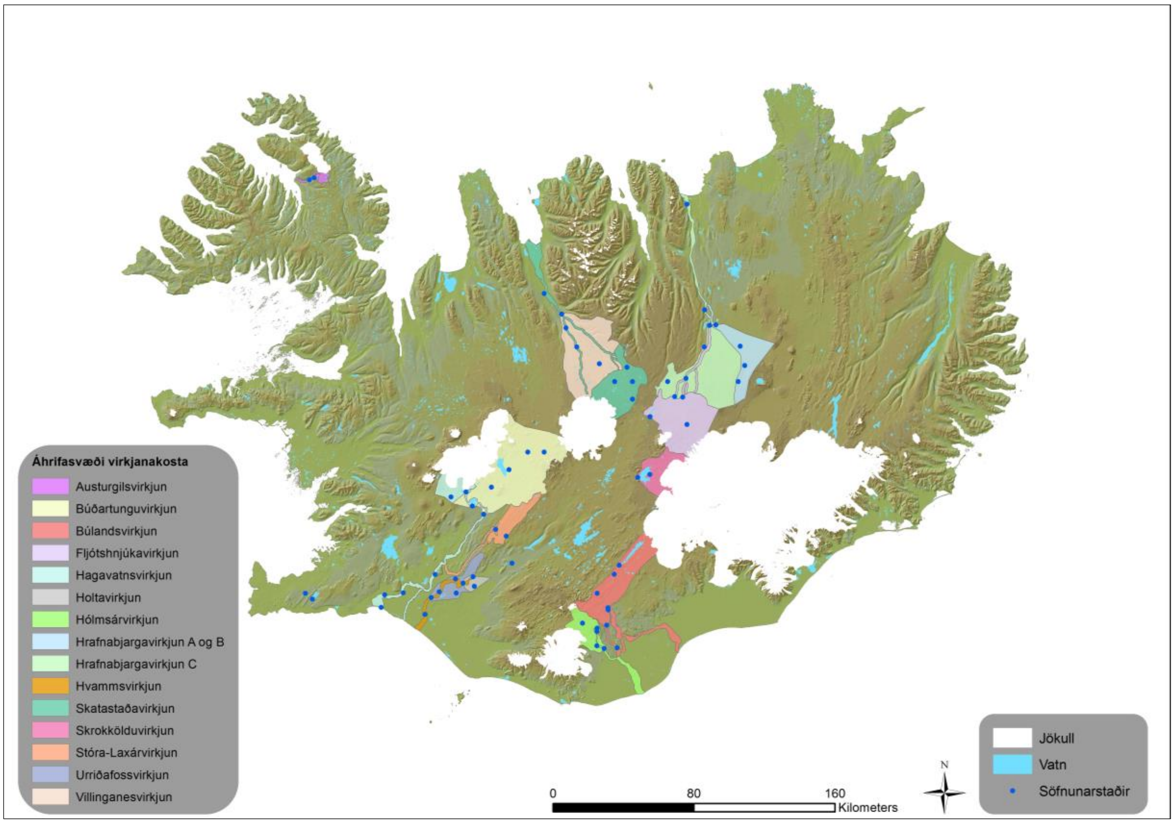



*Figure 1.2 Location of the 67 data collection points (BLUE) ultimately sampled within the proposed energy site impact areas*

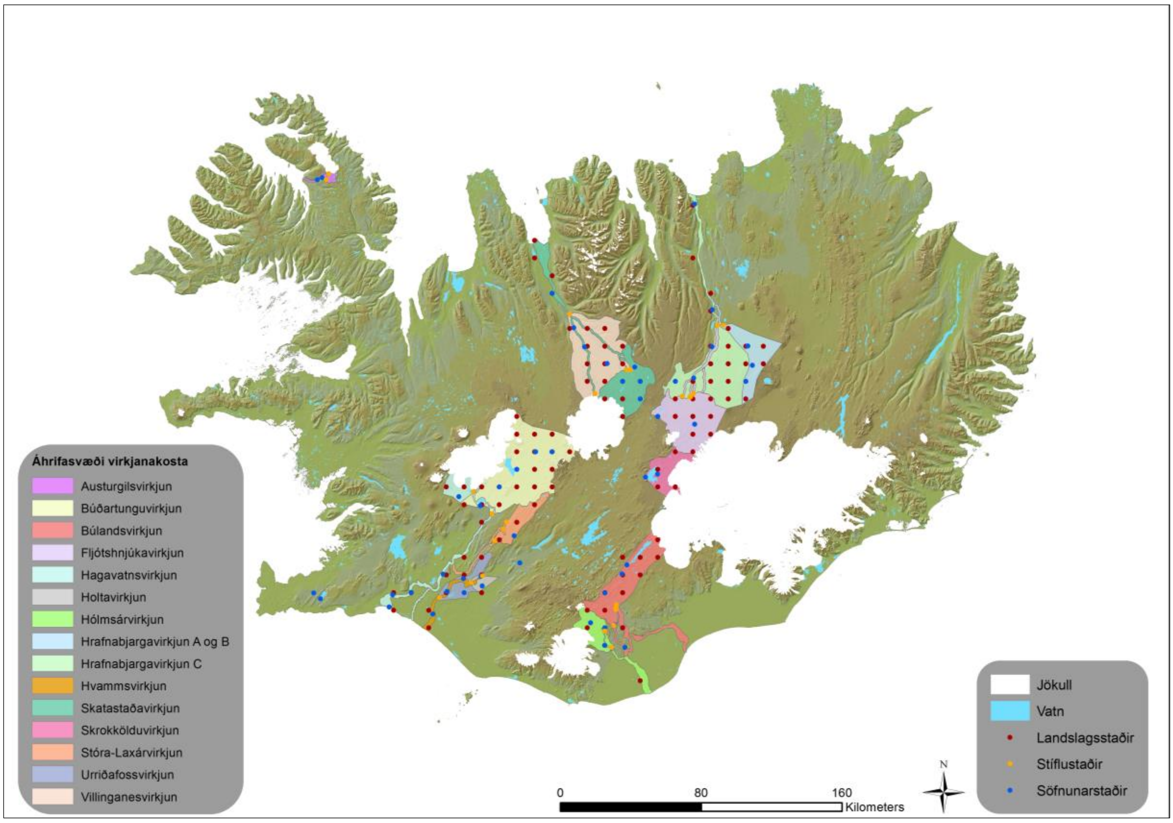



*Figure 1.3 Location of the intended data collection points (RED and ORANGE) overlapped with the actual data collection points (BLUE) ultimately sampled within the proposed energy site impact areas*

## Data Processing and New Point Additions

The 67 new data points collected in 2015 were processed in the same way as the original 108 data points collected during the first round of ILP fieldwork between 2006-2008. This process involved running the data through a cluster analysis in R, which grouped the points based on similar visual landscape features to produce a dendrogram. This visual representation showed the clustered points and allowed certain groups/categories to be distinguished, based on a generally-defined dendrogram branch height or 'cut-off' line. Figure 1.4 shows the original dendrogram along with the 11 landscape category descriptions based on the 108 data points collected between 2006-2008. Further information on each category can be found on p. 87 in Þórhallsdóttir, Árnason, Bárðarson, & Pálsdóttir (2010).

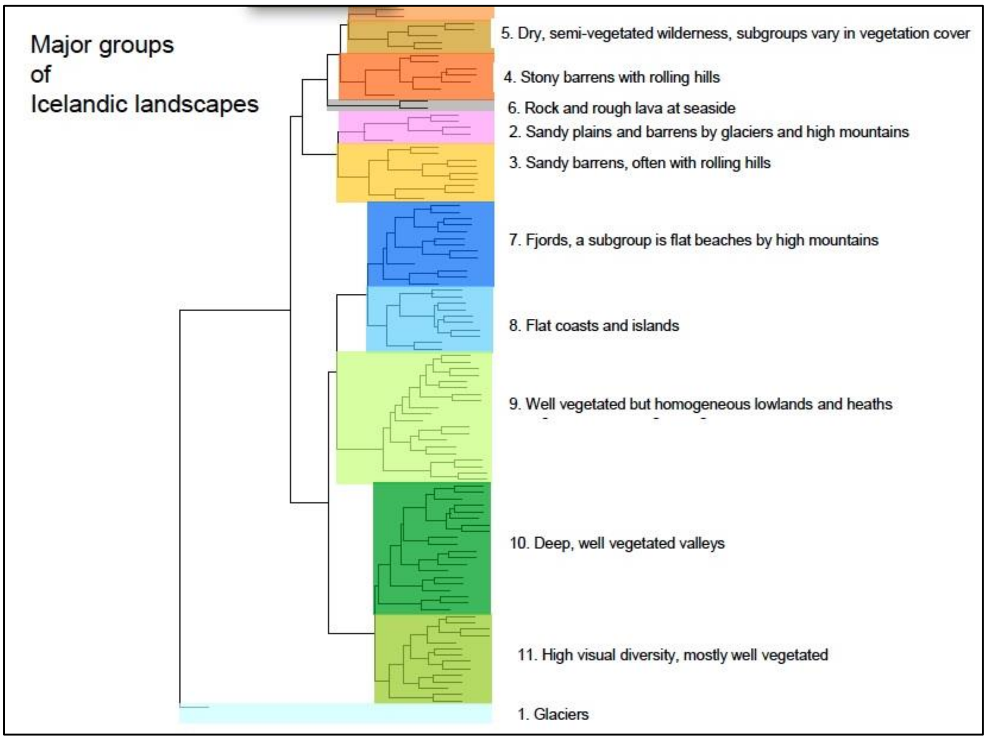



*Figure 1.4 Original dendrogram results and 11 landscape categories based on the initial 108 data points collected between 2006-2008 (Þórhallsdóttir et al., 2010)*

The only main difference in this new round of R data processing was that 4 of the 22 landscape variables - basic shape (*grunnlögun*), vegetation cover (*gróðurþekja*), sea presence (*sjór*), and glacier presence (*jökull*) - were determined to be more defining and dominant visual characteristics of the landscape and were therefore given a weight (0.5) in the dataset.

After the 67 new points were added with the 108 old points and processed together in R, the resulting dendrogram showed that a few of the original categories based on the original 2010 dendrogram were 'broken apart'. In order to try and pinpoint the cause for these categories breaking apart and movement of some of the other old points in general, 3 different iterations of adding in the new points to the original dendrogram by smaller groups were attempted: (1) By groups of 20 random points, (2) By how the new points were grouped in the combined old and new point dendrogram, and (3) By watershed regions based on impact areas for proposed energy projects in Rammaáætlun.

By looking at the 'timeline' of these dendrogram progressions it is clear that most of the points (old and new) held steady next to each other throughout the succession and also that any outliers from the beginning typically remained as outliers. The outliers also suggested that maybe some of the old points were on the border between groups and could potentially fall into 2 categories.

One of the other general reasons for this 'breaking apart' could simply be the inherent nature that when adding in more data (i.e. the new points), the original grouping will expand and contract with some points getting 'pushed away' from others. This tends to be the case especially if the new points (which were more “clumped” together) had more similar data as a group than the older points (which were collected over a larger area and with more widely distributed data collection sites). Here it should be noted that examples of some major landscape categories in ILP (e.g. fjords) were not included in the 2015 data, as these were not found within any of the impact areas under consideration.

The next step was to begin distinguishing new groupings based on how the combined 175 new and old points clumped together in the dendrogram and see how these new preliminary groupings compared with the old categories. After finding some logical divisions in the branches and using a general 'cut-off' height of about 0.123, 11 new categories were demarcated. These 11 new categories were color-coded and can be seen in Figure 1.5. Each of these categories will be elaborated upon in the next section.

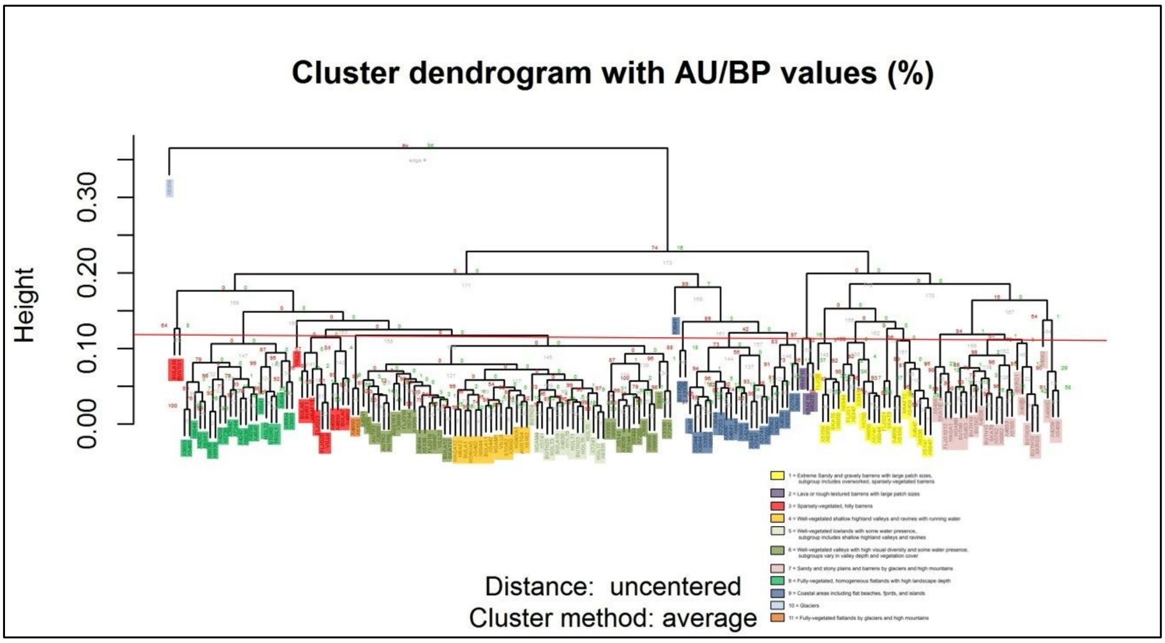


*Figure 1.5 Dendrogram results from R cluster analysis of old and new data points, also showing the color-coded 11 new ILP categories. The RED line indicates the general cut-off height (0.123) used to help determine general group divisions.*

The new points were also processed on their own (i.e. without the old points) and then color-coded based on the preliminary groupings above to see if they would be grouped together in a similar manner. The resulting dendrogram is shown in Figure 1.6. With a few outliers to be expected, it is visually clear that the preliminary groupings remain relatively resilient.

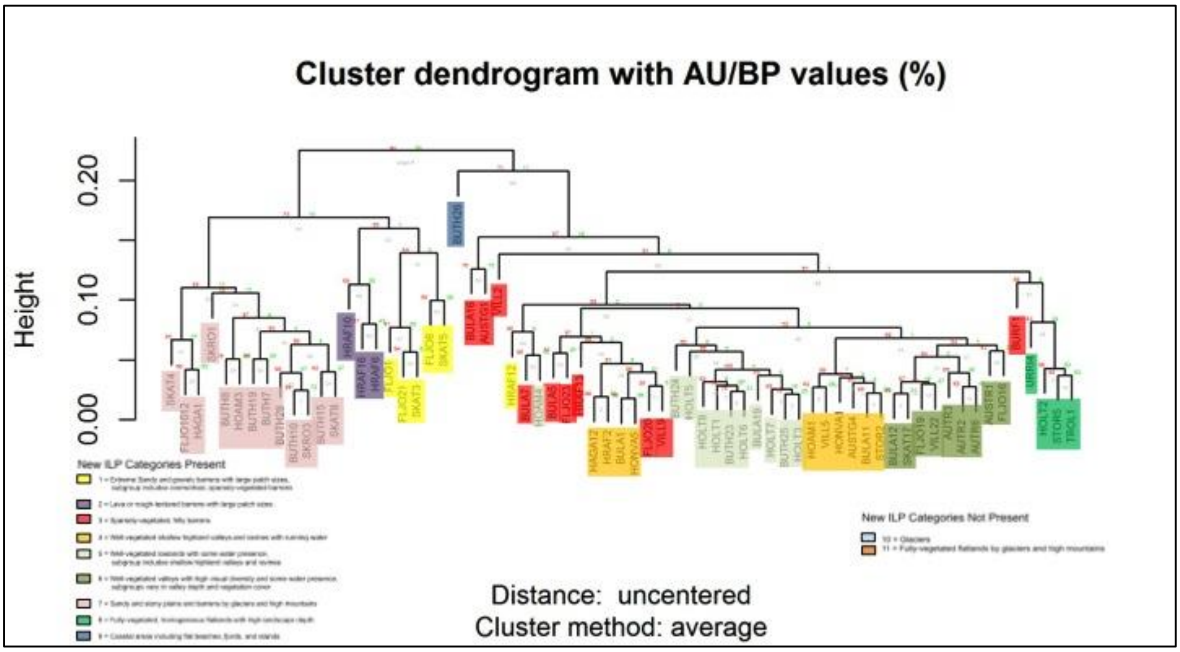



*Figure 1.6 Dendrogram results from cluster analysis of only new data points showing 9 of the 11 new ILP categories. New category 10 and 11 consist of only old data points and therefore are not represented in this dendrogram.*

The data from both the old and new points were then put into an excel spreadsheet and grouped based on these new preliminary categories. The averages of all 22 landscape variable ratings for each of the 11 new landscape categories were calculated. The rating scale for each variable was 0-5 (0=lowest, 5=highest). A heat map was then created (Table 1.2) for these averages to help highlight extreme high and low variable ratings and ultimately help reveal any distinct landscape features within a particular category. These heat map results, along with reference to photos and video for each old and new point, determined distinguishing features and justification for each new category and resulted in its respective written description.

*Table 1.2 Heat map of the 22 landscape variable ratings (scale 0-5) for each of the 11 new landscape categories. Dark RED indicates a lower rating, and dark GREEN indicates a higher rating.*

| new cat | grunnlgn | vithsyni | breythth | beinar | avalar | hvassar | svigthur | fjolform | grththkj | grthfjol | litbrthi | blttstth | mnstfjol | afrthfjl | afrthrjf | afrthslt | vtnthkja | straumur | vatnfjol | sjor | jokull | fjlbrytn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.2 | 3.0 | 2.4 | 0.8 | 3.3 | 0.3 | 2.0 | 1.8 | 1.0 | 0.9 | 1.7 | 4.3 | 1.5 | 1.7 | 2.2 | 3.7 | 1.5 | 1.4 | 1.1 | 0.0 | 0.2 | 1.6 |
| 2 | 2.3 | 2.4 | 3.3 | 3.3 | 2.7 | 2.3 | 1.7 | 2.3 | 0.0 | 0.0 | 1.0 | 4.3 | 1.7 | 1.3 | 4.7 | 3.3 | 0.3 | 0.7 | 0.3 | 0.0 | 0.7 | 1.4 |
| 3 | 2.4 | 1.8 | 3.3 | 1.5 | 3.1 | 1.5 | 2.8 | 2.8 | 2.1 | 1.7 | 2.4 | 2.9 | 2.5 | 2.8 | 3.2 | 3.1 | 1.5 | 2.0 | 1.2 | 0.0 | 0.0 | 2.4 |
| 4 | 2.5 | 1.9 | 3.0 | 1.3 | 3.3 | 0.9 | 2.9 | 2.2 | 4.1 | 2.1 | 2.5 | 2.8 | 2.3 | 2.6 | 2.8 | 3.5 | 1.9 | 3.3 | 1.7 | 0.0 | 0.1 | 2.4 |
| 5 | 2.7 | 2.5 | 2.9 | 2.0 | 2.8 | 0.9 | 1.7 | 2.2 | 4.3 | 3.3 | 2.1 | 3.3 | 2.4 | 2.0 | 1.8 | 4.1 | 2.0 | 1.9 | 1.2 | 0.1 | 0.0 | 2.3 |
| 6 | 1.8 | 1.7 | 3.7 | 2.6 | 2.4 | 1.8 | 2.8 | 2.9 | 3.9 | 2.6 | 2.9 | 2.9 | 3.1 | 3.3 | 2.7 | 3.4 | 2.1 | 2.1 | 1.6 | 0.3 | 0.0 | 2.9 |
| 7 | 3.1 | 2.7 | 3.8 | 1.4 | 3.2 | 1.2 | 2.3 | 2.4 | 1.4 | 1.0 | 1.9 | 3.7 | 2.4 | 2.4 | 2.5 | 3.5 | 1.4 | 1.6 | 1.2 | 0.0 | 3.0 | 2.1 |
| 8 | 2.9 | 3.3 | 2.3 | 0.6 | 2.1 | 0.5 | 0.9 | 1.4 | 4.5 | 2.1 | 2.0 | 3.4 | 1.8 | 2.0 | 2.1 | 3.9 | 1.0 | 0.6 | 0.7 | 0.2 | 0.0 | 1.8 |
| 9 | 2.7 | 3.2 | 3.4 | 1.9 | 1.7 | 1.4 | 1.4 | 2.1 | 3.4 | 1.8 | 2.4 | 3.5 | 2.3 | 2.4 | 2.4 | 3.8 | 0.8 | 0.8 | 0.6 | 3.5 | 0.2 | 2.1 |
| 10 | 3.0 | 5.0 | 2.0 | 0.0 | 4.0 | 3.0 | 0.0 | 2.0 | 0.0 | 0.0 | 1.0 | 5.0 | 2.0 | 1.0 | 2.0 | 4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 | 1.1 |
| 11 | 3.0 | 3.3 | 3.0 | 0.5 | 2.0 | 1.0 | 3.5 | 3.0 | 5.0 | 3.5 | 3.0 | 2.5 | 4.0 | 2.0 | 2.0 | 4.0 | 2.0 | 1.0 | 1.0 | 0.0 | 2.5 | 2.8 |

**Newly-Proposed Icelandic Landscape Categories**

As discussed above, the following proposed classification is based on the systematic sample of 175 data points collected over the two sample periods (2006-2008 and 2015). 67 data points were collected in this most recent sampling period during the summer of 2015, which helped refine the original landscape categories discussed in Þórhallsdóttir et al. (2010) and create a more robust classification. Figure 1.7 shows a map of all 175 data points color-coded by the new landscape categories.

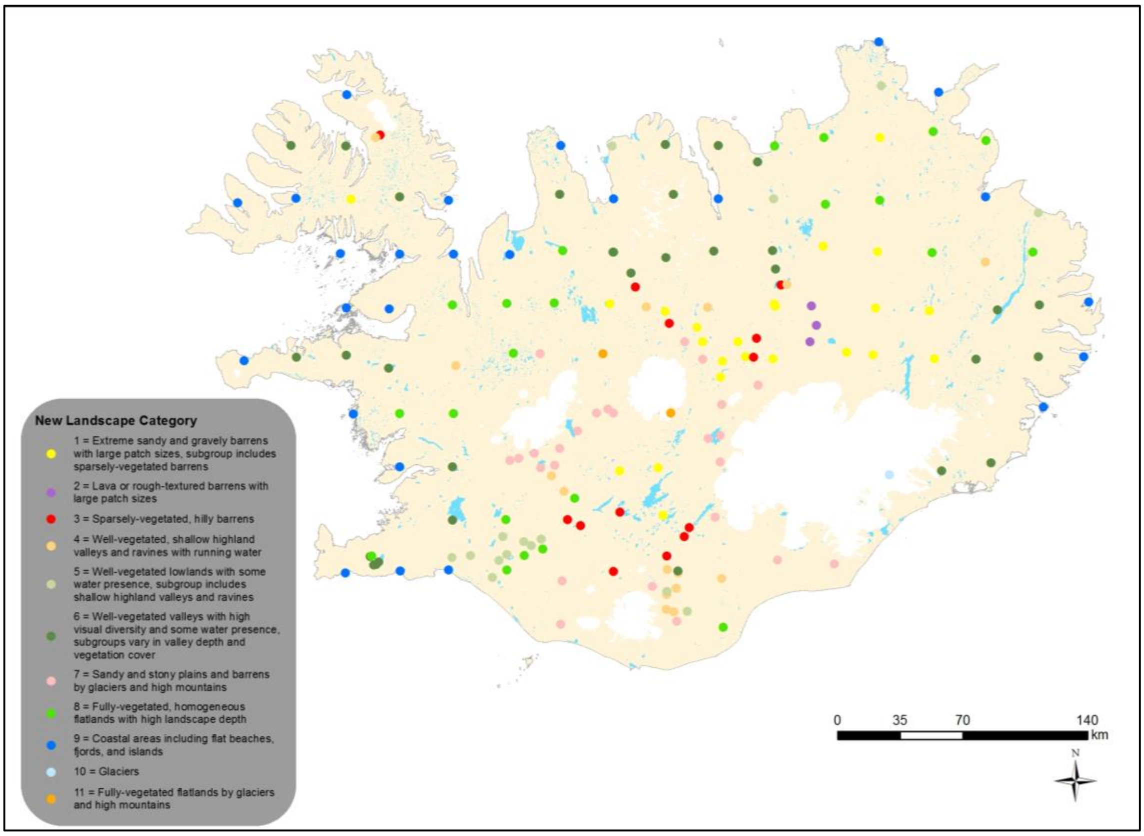



*Figure 1.7 Map showing all 175 ILP data collection point locations color-coded by the 11 newly-proposed landscape categories*

The only old category that disappeared and dissolved into other new categories is old category 6, which only consisted of 2 points. Also, old categories 7 and 8 merged together to form new category 9. Two new categories emerged in this new classification (new categories 2 and 11). The rest of the new categories showed very similar qualities to comparable old categories, and this will be discussed in more detail below. New category 2 consists only of new data points, and new categories 10 and 11 consist only of old data points.

Concerning the changes to the original classification system described above, it is important to keep in mind that landscape classification is still at an early stage in Iceland. A good deal of ground remains to be covered in terms of data collection points around Iceland, which means that as more data points are collected and added to the ILP classification database, new variations of landscape types will likely be discovered, and this may yield a growing number of more refined landscape categories (or at least sub-categories). This may result in some data points switching between categories and changing their dendrogram groupings in order to align more accurately with newly-added data. So the potential of adding new classifications or making fine-tunings to the older categories speaks less about the robustness of the ILP methodology and the resulting dendrogram and more about having to adapt to additional, nuanced data. Based on the results so far, it seems clear that a more detailed database, based on the 10 X 10 sampling technique, needs to be established in order to solidify these landscape categories. As this database would require data from roughly 1300 sites, it will take a long-term, concerted effort to achieve this goal. The use of newly developed digital techniques for landscape classification (see section II of this report) could speed up this process significantly.

*Category 1*

Title: Extreme sandy and gravely barrens with large patch sizes, subgroup includes sparsely-vegetated barrens

Number of new points: 6

Number of total points: 23

Description: This category is very similar to old category 3. The landscape is relatively flat, low to no vegetation cover, low to no vegetation diversity, low color range, large pattern and patch size, smooth texture, low water cover, no sea presence, low to no glacier presence, and low overall visual diversity.

SKAT5 Laugafell

*Category 2*

Title:  Lava or rough-textured barrens with large patch sizes

Number of new points:  3

Number of total points:  3

Description:  This is a new category made up of only new data points. The landscape contains no vegetation, low color range, large pattern and patch size, high rough and smooth texture, little to no water cover, no sea presence, little to no glacier presence, and relatively low overall visual diversity.

HRAF6 Ódáðahraun

*Category 3*

Title: Sparsely-vegetated, hilly barrens

Number of new points: 10

Number of total points: 13

Description: This category shares similar characteristics as old categories 4 and 5. The landscape is relatively flat with some hills, includes sparse vegetation cover, low vegetation diversity, average pattern and patch size, a balance of rough and smooth texture, low water cover, no sea presence, no glacier presence, and average overall visual diversity.

BURF1 Búrfell

*Category 4*

Title: Well-vegetated, shallow highland valleys and ravines with running water

Number of new points: 10

Number of total points: 15

Description: This is a new category, though sharing similar characteristics as old categories 10 and 11. The landscape includes small valleys and ravines in the immediate vicinity, high vegetation cover (mostly highland vegetation) with lower vegetation diversity, average pattern and patch size, some water cover within all locations, including at least some expression of running water, no sea presence, and minimal to no glacier presence.

HOAM1 Ljótarstaðaheiði

*Category 5*

Title: Well-vegetated lowlands with some water presence, subgroup includes shallow highland valleys and ravines

Number of new points: 11

Number of total points: 15

Description: This category is very similar to old categories 9 and 11. The landscape is relatively flat, higher vegetation cover, average vegetation diversity, higher smooth texture, some water cover, minimal to no sea presence, and no glacier presence.

HOLT 8 Flóahreppur

*Category 6*

Title:  Well-vegetated valleys with high visual diversity and some water presence, subgroups vary in valley depth and vegetation cover

Number of new points:  9

Number of total points:  31

Description:  This category is very similar to old categories 10 and 11. The landscape is more valley-shaped, low landscape depth, high vegetation cover, some vegetation diversity, higher color range, some water cover, little to no sea presence, no glacier presence, and high overall visual diversity.

VILL22 Skagafjörður

*Category 7*

Title: Sandy and stony plains and barrens by glaciers and high mountains

Number of new points: 13

Number of total points: 25

Description: This category is very similar to old category 2. The landscape is flat with higher changes in elevation in the greater vicinity, little vegetation cover and diversity, slightly larger pattern and patch size, little water cover, no sea presence, and high glacier presence.

HOAM3 Mælifell

*Category 8*

Title: Fully-vegetated, homogeneous flatlands with high landscape depth

Number of new points: 4

Number of total points: 22

Description: This category is very similar to old category 9. The landscape is flat with high landscape depth, low line diversity, very high vegetation cover, low vegetation diversity, low color range, high smooth texture, little to no water cover, little to no sea presence, and no glacier presence.

URRI4 Hundaþúfuheiði

*Category 9*

Title: Coastal areas including flat beaches, fjords, and islands

Number of new points: 1

Number of total points: 25

Description: This category has combined old categories 7 and 8. The landscape is relatively flat at the immediate coast and more valley-shaped further into the fjords, some vegetation cover, little vegetation diversity, smoother texture, little water cover, high sea presence, and little to no glacier presence.

BUTH26 Óseyrarnes

*Category 10*

Title:  Glaciers

Number of new points:  0

Number of total points:  1

Description:  This category is the same as old category 1 and consists of only old data points. The landscape is flat with high landscape depth, little changes in elevation, no vegetation cover, low color range, predominantly smooth texture, no water cover, no sea presence, full glacier presence.

6356 Vatnajökull*

*Old data point

*Category 11*

Title:  Fully-vegetated flatlands by glaciers and high mountains

Number of new points:  0

Number of total points:  2

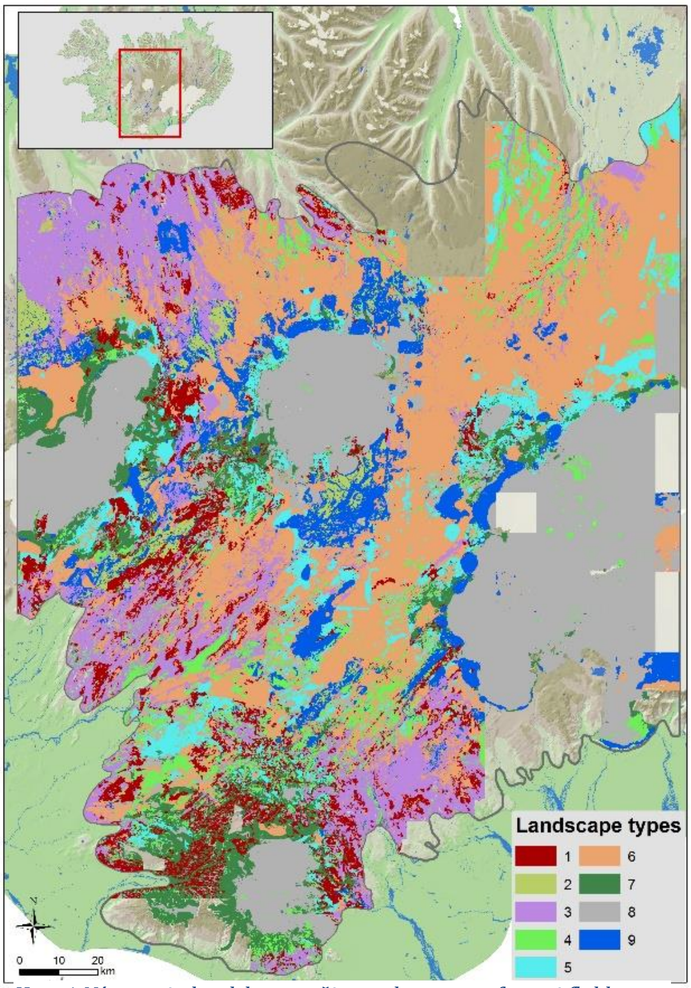
Description:  This is a new category, though consisting of only old data points. The landscape is flat with higher changes in elevation in the greater vicinity, extremely high vegetation cover, high vegetation diversity, higher color range, high pattern diversity, predominantly smooth texture, some water cover, no sea presence, and some glacier presence.

5153 Arnarfellsbrekka nálægt Þjórsárver

*Old data point

## II. Landslagsflokkun í landupplýsingakerfum

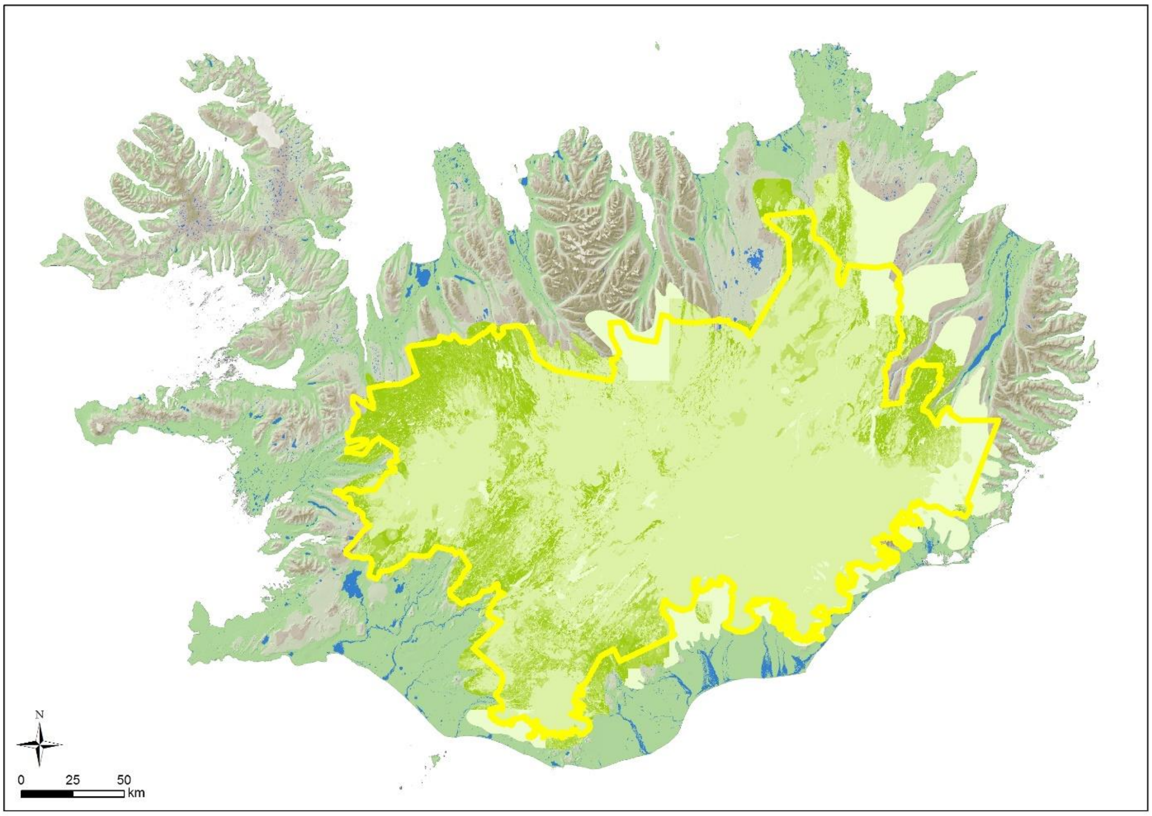
Hér verður gerð grein fyrir þróunarvinnu við stafræna landslagsflokkun og fyrstu niðurstöðum þess verkefnis. Þróun slíkrar aðferðar er viðfangsefni meistararitgerðar Adams Hoffritz í Umhverfis- og auðlindafræði við Háskóla Íslands og er aðferðinni sjálfri líst hér aftast (á ensku). Í meistararitgerðinni flokkaði Adam landslag í níu megin landslagsgerðir fyrir hluta miðhálendis Íslands og notaði til þess níu breytur og fjölbreytugreiningu. Á þessu ári er gert ráð fyrir að ljúka flokkun alls miðhálendisins með þessari aðferð og einnig hefjast handa við flokkun landsins alls, en framgangur síðartalda verkefnisins er háð aðgengi að niðurstöðum vistgerðaflokkun sem Náttúrufræðistofnun Íslands vinnur nú að.



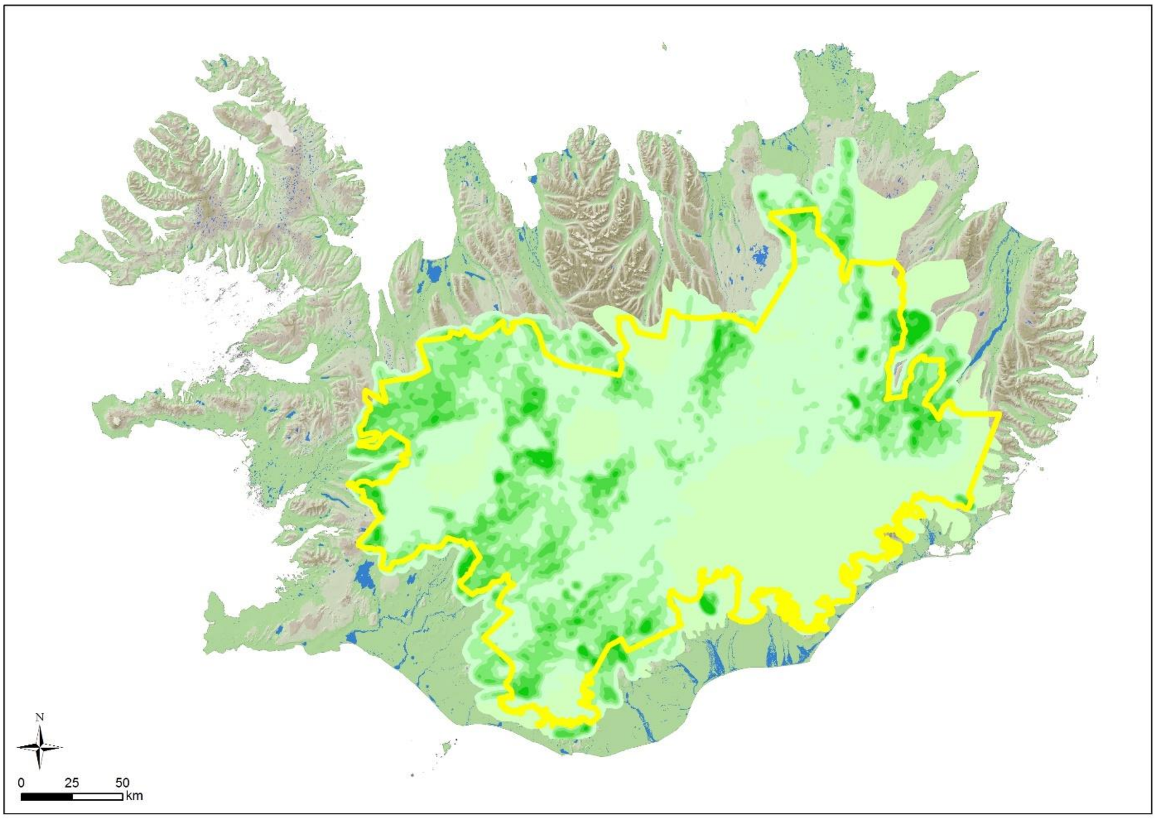
*Kort 1 Níu megin landslagsgerðir samkvæmt stafrænni flokkun*

Kort 1 sýnir níu megin landslagsgerðir á þeim hluta miðhálendis Íslands sem tekinn var til athugunar í áðurnefndu meistaraverkefni. Að svo komnu máli er ekki unnt að svara því hvort fleiri landslagsgerðir muni bætast við þegar allt miðhálendið hefur verið tekið til skoðunar, en þó verður að teljast ólíklegt að mikil breyting verði þar á þar sem þau svæði á hálendinu sem eru utan upphaflega rannsóknarsvæðisins eru mjög lík þeim sem þegar hafa verið tekin til athugunar. Breyturnar sem notaður eru til að flokka landslag eru: grunngerð, blettastærð, gróðurþekju, fjölbreytni gróðurs, vatnsþekju, fjölbreytni vatnsforma, nálægð og sýnileika jökla, breytileika í hæð og víðsýni.

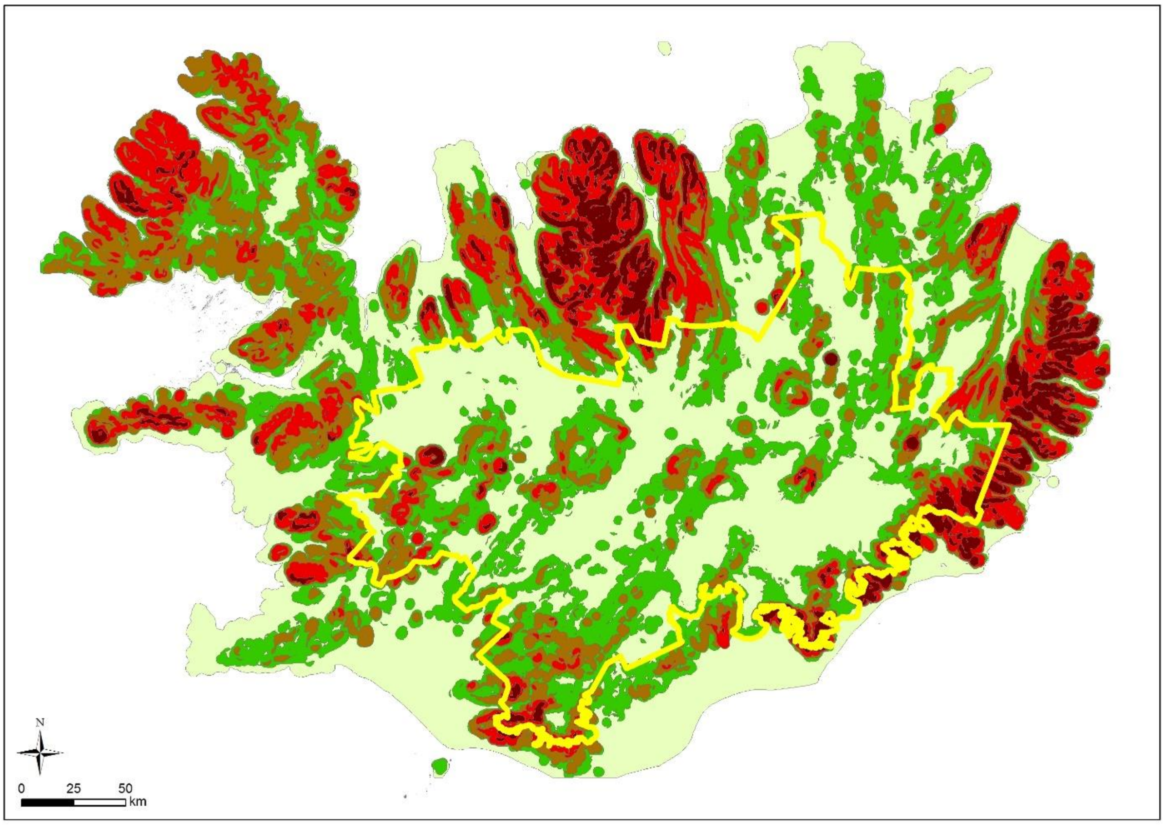
Hér á eftir fylgja kort sem sýna breyturnar ásamt stuttum útskýringum á því hvað þær eru.



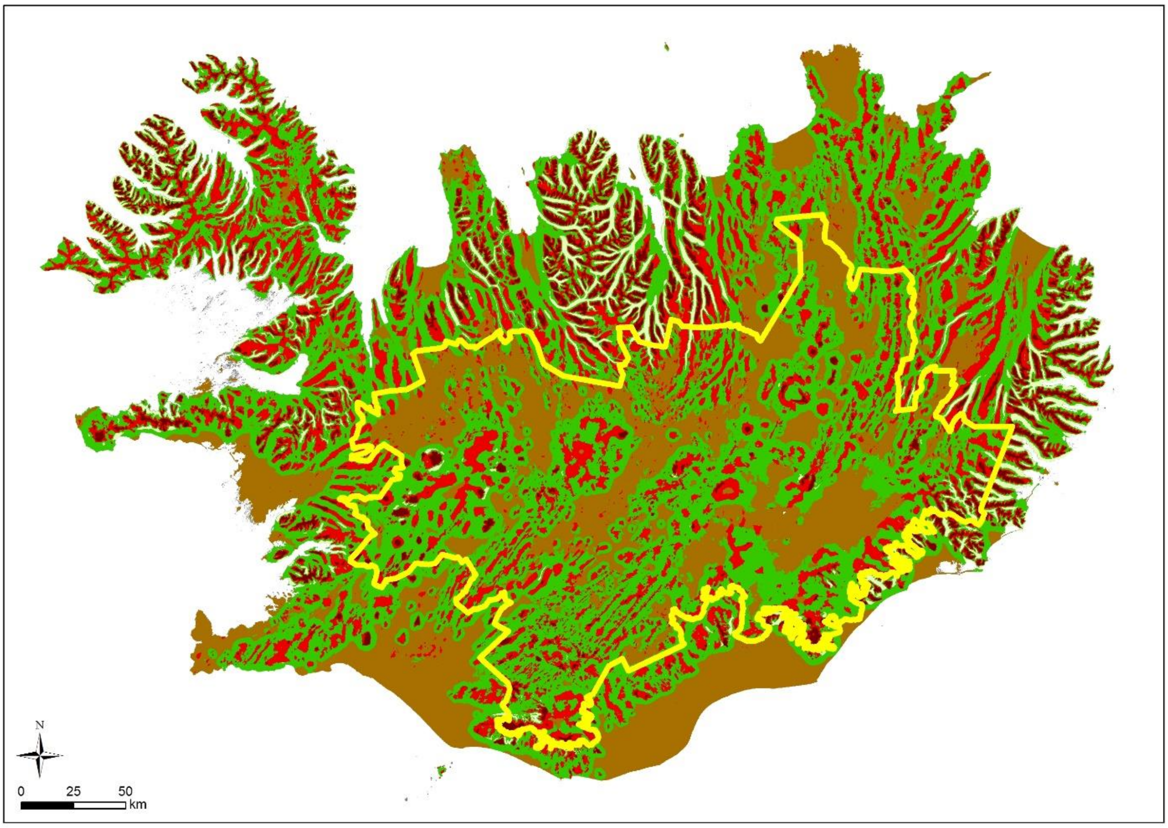

**Gróðurþekja er á bilinu 0 – 6 og á þessu korti er 0 ljósasti græni liturinn sem dökknar eftir því sem svæði færast nær 6 sem er dekksti liturinn. Gula línan er mörk miðhálendis samkvæmt skipulagi.**



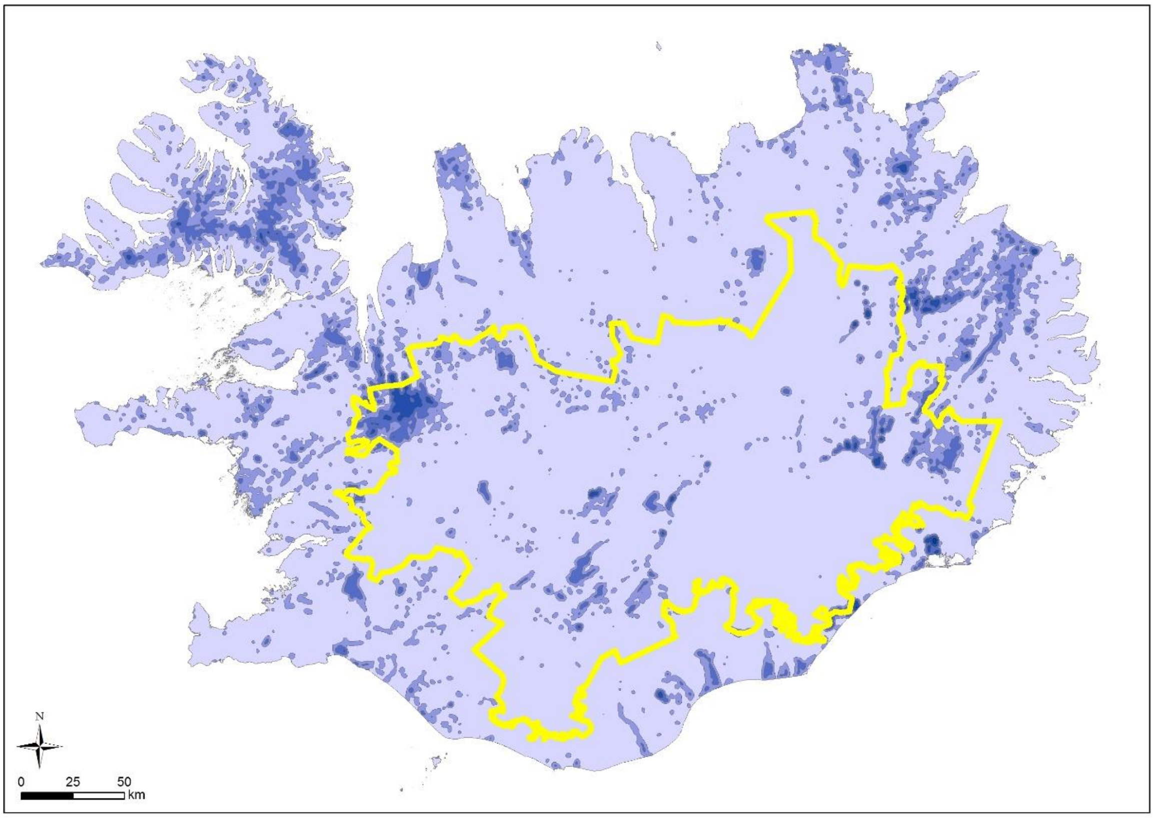

**Þetta kort sýnir gróðurfjölbreytni sem er mest þar sem er dökkgrænn litur og minnst í ljós grænum.**



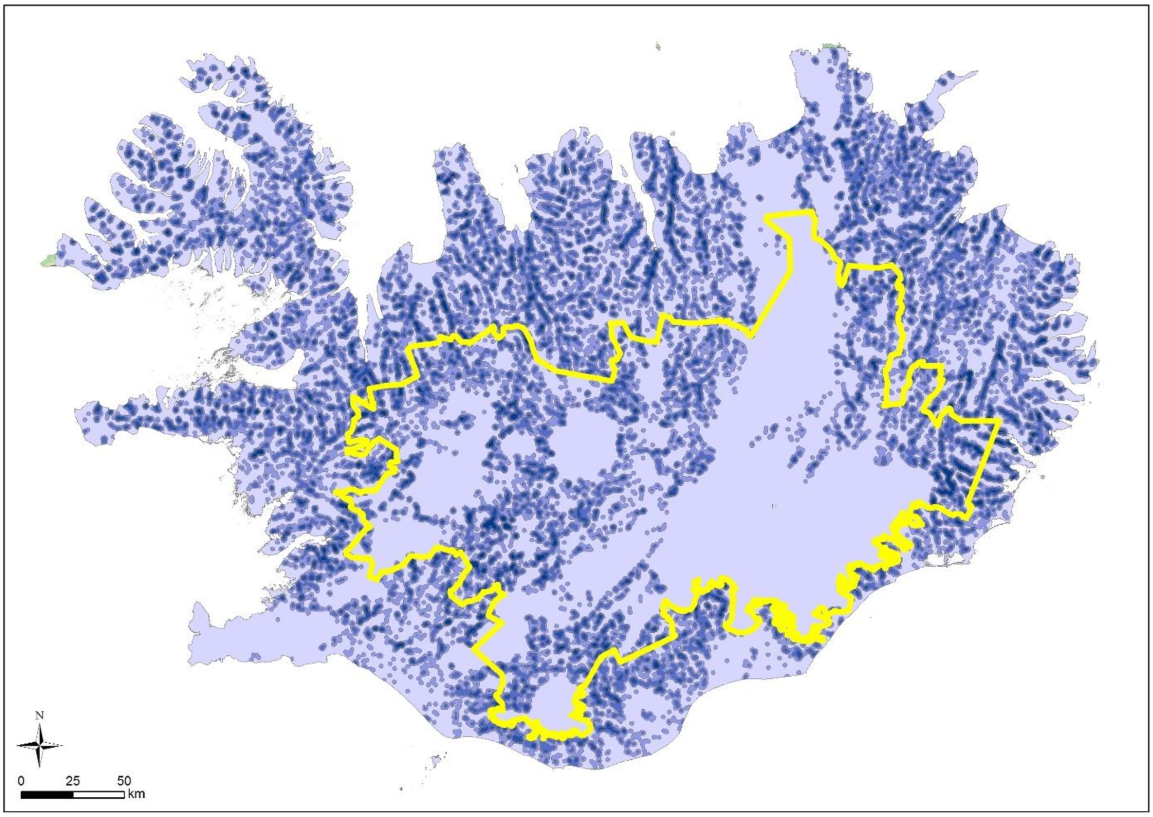

**Þetta kort sýnir breytileika í hæð og er kvarðinn frá ljósgrænum, sem eru svæði með litlum breytileik í hæð yfir í dökkbrúnan sem eru svæði með mikinn breytileika í hæð. Gulan línan er mörk miðhálendis samkvæmt skipulagi.**




**Þetta kort sýnir grunngerð sem skiptist í íhvolfa (ljósgrænn og dökk grænn), flata (brúnn) og ávöl (rauður og dökk brúnn). Gula línan er mörk miðhálendis samkvæmt skipulagi.**




**Þetta kort sýni vatnsþekju sem er meiri eftir því sem blái liturinn dökknar. Gula línan er mörk miðhálendis samkvæmt skipulagi.**




**Þetta kort sýnir fjölbreytni vatnsforma. Ljósblár litur er þar sem fá vatnsform eru og svo dökknar liturinn eftir því sem finna má fleiri vatnsform. Gula línan er mörk miðhálendis samkvæmt skipulagi.**

Til að ljúka flokkun miðhálendisins þarf að klára þrjár breytur: Víðsýni, sýnileika jökla og blettastærð. Þetta eru tímafrekustu breyturnar. Víðsýnisgreiningar kalla á mikið tölvuafl og hefur verið ákveðið að leita til Reiknistofnunar Háskóla Íslands til að fá afnot af reikniþyrpingu (high performance computing) sem stofnunin hefur til umráða. Mun það flýta verkinu talsvert. Sýnileiki jökla er háð víðsýnisgreiningu og mun vinnan við þessar tvær breytur skarast að mesti leyti. Eftir prófanir hefur verið ákveðið að nýta annað forrit í blettagreininguna, *Erdas Imagine*. Mun það flýta verkinu mikið, enda mjög öflugt forrit á sviði fjarkönnunar. Þegar öll gagnasettin ( rastagögn) eru tilbúin verða þau flokkuð saman í fjölbreytu greiningu þar sem forritið fer í gegnum alla pixla í öllum níu rastaþekjunum og leitar að mynstrum í einkunnum fyrir allar breytum. Loks hópar forritið pixlum saman í flokka. Þegar því er lokið taka við nokkur úrvinnsluskref sem enda á flokkun gögnin í landslagsgerðir. Áætlaður tími til að klára landslagsflokkun fyrir allt miðhálendið er um það bil 2-3 mánuðir, ef ofangreindar áætlanir ganga eftir.

# Classifying landscape in the Icelandic highlands using GIS and multivariate analysis[3]

Adam Hoffritz

## Útdráttur

Landslagsgreiningar eru orðnar algengar erlendis. Á Íslandi hafa þær verið framkvæmdar af verkfræðistofum fyrir sveitarfélög vegna skipulagsvinnu og fyrir fyrirtæki sem hluti af mati á umhverfisáhrifum. Aðferðirnar eru ekki samræmdar og þekja smá svæði í einu. Sérstök aðferðafræði fyrir landslagsflokkun var hönnuð fyrir Áætlun um vernd og orkunýtingu landsvæða. Sú aðferð byggir á því að flokka landslag út frá sjónrænum einkennum þess og var verkefnið kallað Íslenska landslagsverkefnið. Þessi ritgerð greinir frá aðferð sem byggir á aðferðafræði Íslenska landslagsverkefnisins en er framvæmd í landupplýsingakerfum. Landslag er greint út frá níu breytum: grunngerð, blettastærð, gróðurþekju, gróðurfjölbreytni, vatnsþekju, fjölbreytni vatnsforma, nálægð og sýnileika jökla, breytileika í hæð og víðsýni. Breyturnar eru flokkaðar saman með óstýðri flokkun í Erdas Imagine. Niðurstöður eru níu megin landslagsgerðir og aðferð sem auðvelt er að endurtaka, bæta við og útfæra eftir aðstæðum.

[3] Drög að mastersritgerð Adams Hoffritz í Umhverfis- og auðlindafræði við Háskóla Íslands. Óheimilt er að vísa í þennan hluta skýrslunnar án samráðs við höfund þessa efnis.

# 1 – Introduction

Landscape classifications, which aim at capturing the character of a landscape or classifying landscape into types, are now common and have been developed for most countries within the European Union (Wascher, 2005) as well as e.g. Russia (Lioubimtseva & Defourny, 1999) and New Zealand (Brabyn, 2009).

In general, such classifications are approached in three ways. One is to base them entirely in geographical information systems (GIS), using multivariate classification methods to identify landscape types. Some examples include the LANMAP classification for the European Union (Mücher, 2010) and Brabyn's New Zealand Classification (Brabyn, 2009). A second method is to combine desktop studies and field work as was the case with the Spanish classification and those that are based on the Landscape Character Assessment methodology (LCA) (Tudor, 2014) (Wascher, 2005). The third method is to gather data in the field and use multivariate analyses to identify landscape types (Þórhallsdóttir, Árnason, & Bárdarson, In prep).

Landscape varibles can be grouped in three ways. Objective variables represent physical natural elements, such as slope, infrastructure, water and vegetation (Wascher, 2005). The second group is made up of variables that are more subjective in nature, such as tranquillity and memories which were used in Landscape Character Assessment (Tudor, 2014). The third group of variables are land use information, physical characteristics of land but manmade, thus not a part of the physical natural elements. All classifications include variables representing physical natural elements but there is variation in how that is done. Many include land use information and some include the subjective elements, though that is mostly presented in the LCA.

There is currently no official landscape classification system in place in Iceland. Most attempts to classify or analyse, landscape have been carried out on an ad hoc basis as part of an environmental impact assessment (EIA) e.g. for road constructions or energy projects. Those have been largely based on the methodology of the Landscape Character Assessment and been carried out by different consulting firms or research institutions. The only landscape analysis to cover the entire highland was made as a part of the Regional Plan for the Central Highland in which the central highland was devided into 8 landscape units and each unit was divided into smaller areas (Miðhálendi Íslands. Svæðisskipulag 2015, 1998). The units were identified based on landscape, surface texture, weather and snow, vegetation and soil. Little is said about the methods used in comparing the variables and it is thus difficult to repeat the process. What the above approaches have in common is that they focus on segregating landscape into unique areas with no numerical information or quantifiable data on the characteristics of each landscape unit. There was therefore a need for a method that would allow for standardized collection and analysis of landscape data.

Such a method was designed and implented during 2006-2008. It was refered to as the Icelandic Landscape Project and was designed for the characteristics of the Icelandic landscape. Methods of classifying landscape have been designed for areas where land use has had a great impact up on landscape. The landscapes of Europe are largely a result of land use with natural landscapes being the excemption. That is not the case in Iceland where most of the land is uninhabited by men. There was therefore a need for designing a new approach to landscape analyses more suited to wild, arctic landscapes and one that would classify landscape based on the similarities drawn from data. The method aimed at evaluating and classifying landscape based on visual physical charactheristics (Þórhallsdóttir, Árnason, & Bárdarson, In prep). It is a field based method where researchers went to predefined coordinates and evaluated landscape based on 22 variables, such as basic landscape contour, landscape depth, forms, vegetation diversity. A total of 108 locations across the country were evaluated and various landscape types identified using cluster analysis. The results were 11 types of landscapes (Þórhallsdóttir, Árnason, & Bárdarson, In prep).

Two of the main drawbacks of the Icelandic Landscape Project are that it does not draw boundaries of the landscapes and that it is time consuming. The method of the Icelandic landscape project is point based meaning that the landscape at a certain point is evaluated and it does not draw spatial boundaries between the landscapes of each point. That problem has not been resolved. The method is time consuming and expensive as it require researchers to physically go to each sampling site. There is therefore a need of a method that draws the spatial boundaries of landscape types while at the same time, building up on the characteristics of the Icelandic landscape project as the only landscape analyses method designed for Iceland.

Geographical Information Systems (GIS) is a logical continuation of the ILP method. A GIS based method would make it possible to cover more area in shorter time than is possible in fieldwork. GIS analysis would draw the spatial boundaries of landscape types. Creating a landscape classification system in GIS opens the possibility of conducting various spatial analyses on landscape and allows for the integration of various datasets. It could form the basis of a standard landscape type map and be easily applied e.g. for planning purposes.

The aim of this paper is to develop a method of classifying landscape based on visual physical characteristics using geographical information systems. The method would have to be transparent, repeatable and allow for an easy way of extending the model to large areas and to add new variables.

# 2 – Study area, data and programs

The study area is located in the central highland of Iceland which is an island in the North-Atlantic. Human settlement is scattered along the coast while inland there is a waste area known as the Central Highland.

Within the boundaries of the Central Highland (see figure 1) are several of the largest glaciers of Iceland as well as several smaller ones and numerous active volcanoes. The area as a whole is scarcely vegetated and is largely covered with sand barrens. There are many rivers and lakes of different sizes as well as, for example, wet areas along glacier edges which have small seasonal streams. There is little land use and anthropogenic factors have little presence, aside from roads and cabins, hydro plants and reservoirs which occupy a small part of the area. The study area itself is 29.080 km$^2$ and covers most of the Central Highland in Iceland as well as some adjacent lowland areas. The initial study area was meant to cover a part of Iceland from north to south. However, as the vegetation data only covers the central highlands it was necessary to redefine the study area based on the extent of the vegetation data. The study area was thus changed.

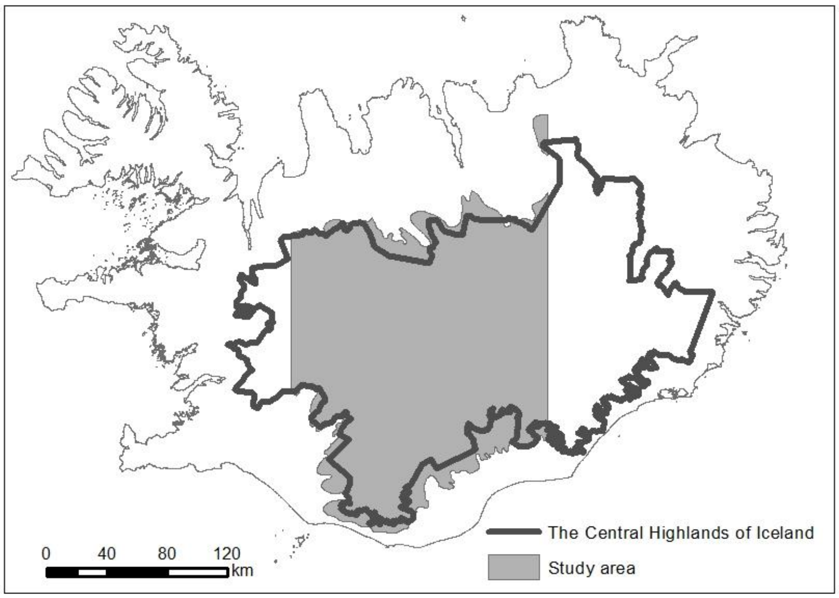



*Figure 1 displaying the study area of this thesis project.*

The landscape model was created in Geographic Information Systems, usually referred to as GIS, which is a “computer-based information system that enables capture, modelling, manipulation, retrieval, analysis and presentation of geographically referenced data” (Worboys, 1995, p. 1). GIS analysis was conducted using ArcMap from ESRI, GRASS GIS which is an open source software and Erdas Imagine from Hexagon Geospatial.

Data consisted mostly of already available spatial data from Icelandic institutions. The National Land Survey of Iceland has several free geographical datasets available online and of those the following were used: a digital elevation model with 20x20 m resolution, water and glacier data, and vector files with squares grids covering Iceland. The National Land Survey of Iceland and the University of Iceland provided Rapideye and Spot images used for patch analysis. Vegetation data, available online, was provided by the Natural History Institute of Iceland. The Icelandic Met Office provided data on water forms and ISOR-Iceland Geosurvey provided a map of springs in Iceland that was digitized in Arc Map.

# 3 - Variables

As this project is based on the Icelandic Landscape Project, it utilizes many of the same variables. The challenge of this project is to transfer a method designed for fieldwork into a GIS based method. Part of the variables used in the Icelandic Landscape Project, such as the evaluation of lines and forms and patterns are not well suited for automatic GIS analyses while other are more suited for the GIS environment. Nine variables were used in this project: basic landscape contour, landscape depth, relief, vegetation cover, vegetation diversity, patch size (patch density), water coverage and diversity of water forms, and visibility of glaciers.

## Basic landscape contours

Landscape analysis typically include the topographic characteristics and are often represented by classifying slope and evaluation based on predefined threshold into areas such as valleys, mountains etc (Brabyn, 2009) or by using elevation and slope directly (Chuman & Romportl, 2010). Landscape contour used in our method is a different approach as it is not concerned with slope numbers or particular areas (valley, ridge etc.). Rather, it is defined as the large scale shape of the land and is divided into three categories: concave, convex and flat. The top of a mountain or a hill is an example of a concave landscape with the surface contours descending from the observation point. The bottom of a valley constitutes a convex landscape and an extensive plain a flat one.

Estimates of landscape contours were generated using two approaches. Convex areas were created using the Topographic Position Index (TPI) extension for ArcMap developed by Jenness (2006). The TPI uses a digital elevation model to calculate the difference between the elevation of a cell and the elevation of the cells in a user-defined neighbourhood. The output values are negative when a cell has a lower elevation value than the neighbouring cells and positive when a cell has a higher elevation value than its neighbours. Areas with zero value are either flat or mid slope areas, depending on the terrain (Jenness, 2006). The TPI is highly scale dependent and the radius can greatly impact the outcome. For example, a hill can be classified as a mountain or flat area depending on the scale used. It may therefore be difficult to use one neighbourhood definition for a diverse area (Jenness, 2006). Tail and Jenness (2008) concluded that using values from two different neighbourhood calculations gave better results.

To represent convex areas, a neighbourhood of 500 m and 2 km were defined. These numbers were the outcome of trial and error process and were seen to represent the area best. Values from the two analyses were combined in Arc Map's Raster Calculator where, in the 500m analysis, values $\leq 4$ were combined with values $\geq 10$ from the 2km TPI raster. When it came to defining flat and convex areas, it was decided that a calculation of elevation range with a radius of 2 km represented the most appropriate scale. Flat areas were defined as areas with an elevation range $\leq 100$m and convex areas as areas which had elevation range >100 and that were not the TPI defined concave areas. The landscape contour categories were combined in the Raster calculator and reclassified so that 1 is flat, 2 is convex and 3 is concave.

## Landscape depth

Viewing characteristics of landscapes is often included as a variable in landscape studies but goes by various names. Related terms are scale and enclosure in the LCA methodology (Swanwick, 2002), landscape enclosure (Palmer & Lankhorst, 1998), visual scale (Ode, Tveit, & Fry, 2008), landscape modifying elements ((Isabel Otero Pastor, Martinez, Canalejoa, & Marino, 2007 et al), viewshed (Germino, Reiners, Blasko, McLeod, & Bastian, 2001) and visibility (L. Brabyn & Mark, 2011). GIS based viewing analyses have become prominent. GIS tool were used in all the previous mentioned studies as well as for example in mapping wilderness characteristics in Death Valley Natural Park (Carver, Tricker, & Landres, 2013). In general, research concerned with viewing characteristics focuses on the visibility of a phenomenon. It can be a building, road, power line, vegetation, archaeological remains, land cover etc. (Depellegrin, Blažauskas, & Egarter-Vigl, 2014; Miller, 2001; Ogburn, 2006; Tims, 2014). The extent of visible area focuses not on the visibility of an object but the area that is visible from a specific location. Viewshed calculations give a very general picture of the visibility of an area or an object. The results do not consider distance from the object thus making it seem as the object is as visible within 3 km or 20 km distance from it. Methods have been designed include distance from the object, such as using a fuzzy membership on the Viewshed results using distance buffers (Ogburn, 2006). An alternative is using only distance buffers and classify the visibility within the buffer zones (Millar & Morrice, No year). DEMs do no not account for objects on the surface and therefore the calculations do not take into account buildings or forests.

This study uses a different method to include visual characteristics. This study does not look at the visibility of certain phenomenon but the visual extent in the entire study area. Landscape depth is therefore the visual extent of an area. This is accomplished by calculating viewsheds from 34.783 points to create with a mesh size of 500*500 m in concave and convex areas and mesh size of 1*1 km in flat areas. The different mesh sizes were used to reduce computing time. The viewshed rasters were added together in ArcMap's Raster Calculator. Adding up the rasters calculates the overlap for each area. An area that can be seen from many points gets a high score while areas that are seen from few points get the lowest scores resulting in the spatial extent characteristics within the entire study area.

## Vegetation

Most landscape classification or analyses have variables for vegetation. In areas that have been mostly shapes by humans, for example agricultural areas in Europe, visual properties of landscapes are heavily shaped by vegetation and some landscape classifications or more or less vegetation map (Wascher (ed), 2005).

Vegetation was scored for diversity and cover. Data were extracted from the *Vegetation Map of the Central Highland of Iceland* dataset, based on data collected from 1999 to 2012 (Gróðurkort af Miðhálendi Íslands 1:25.000 NI_G25v_midhalendi_01). It was selected as it is the most accurate vegetation data for Iceland. Unfortunately, comparable data was not available for lowland areas. There are 40 vegetation types listed in the data, among them marshes, two types of moss, dwarf-shrub heath, Alaskan lupine etc.

Kernel density analysis was used to calculate the diversity of vegetation types. The general concept of kernel density is that it counts the number of points within a defined neighbourhood around each point and then divides the results by the circle area. The results are an estimation of the intensity of the points at a certain area. Another version of Kernel density calculation considers the distance of the points from the center of the area. Points closer to the area center are given more weight than points further away. This method results in a more continuous surface covering the entire study area. The researcher must define a radius, or bandwidth to calculate the Kernel density(James, B. Campell & Wyanne, 2011). That means that there is always some trial and error involved in defining the radius that fits the data. However, as a reference rule, a large radius will generate results showing a similar density everywhere and too small radius will show only individual points (Campbell & Wynne, 2011). By converting the polygons representing vegetation into points it is possible to use density analysis to score vegetation cover. Areas with high point density are areas with high diversity of vegetation types and areas with little density are areas with low diversity of vegetation types.

Polygons representing vegetation diversity were converted to points and the density of the points calculated using Kernel density of 1 km. The output was given a score between 1 (low diversity) to 5 (high diversity) and reclassified using ArcMap's reclassify tool.

The vegetation dataset included a quantitative assessment of vegetation cover. The data was changed from vector to raster format and given a grade of 1 to 6. The vegetation cover was divided into six categories: no live plant cover visible (1), and vegetation cover of 1-10% (12), 11-25% (3), 26-50% (4), 51-75% (5) and >75% cover (6).

## Elevation range/relief

Most landscape studies include relief, using slope or elevation or both and some include aspect as well(Chuman & Romportl, 2010; Lioubimtseva & Defourny, 1999; Wascher (ed), 2005) Elevation range was calculated with ArcMap's focal statistics using a DEM from the National Land Survey of Iceland. The focal statistics calculate the difference between the elevation of a cell and all cells in a user defines radius. Establishing the right radius is a trial by error process. For this project, 2 km radius was used for calculations and scored as follows: 1 = 10-122 m, 2= 122- 293 m, 3 = 293-506 m, 4 = 506-757 m, 5 = 757 – 1360 m. These values are the direct results of the calculations.

## Visibility and proximity to glaciers

Glaciers were evaluated based on visibility and distance. The visibility of certain natural features has been included in previous landscape studies, such as water bodies in New Zealand (Lars Brabyn, 2009). Glaciers in Iceland can be seen from many places in the central highlands and are an important visual characteristic. Visibility analysis does not consider distance and treats all visible areas as equally visible. This does not represent reality and therefore buffers are used. Areas close to the glacier receive a high grade because glaciers are very visible from those places and areas far away from which glaciers can be seen get a lower grade, as the glacier is visible but is not nearly as prominent as it is when standing next to a glacier.

A point grid was overlaid with data outlining glaciers and the overlapping points extracted. For the larger glaciers, defined as => 570 $km^2$, a mesh size of 5*5 km was used and for the smaller glaciers, defined as < 570 $km^2$, a mesh size of 1*1 km was used. To make sure that the smallest glaciers were represented, a point file was created with a point in the center of the glacier vector data. Furthermore, points were placed at the edges of the glaciers, as testing showed that area right in front of the glacier line were overlooked by the visibility calculations.

The results were added together. Buffers of 3, 10, 20, 40 km were placed around the glaciers and the areas visible within each buffer was extracted. In that way it is possible to scale the visibility based on distance and give different value to areas close to glaciers where they are most prominent and to areas farther away. Each distance was given a value from 1-6 where 6 is the surface of the glaciers and a 3 km buffer around them, 2 is 3-10 km, 4 is 11-20, 5 is 21-40 and 6 is >40km.

## Water

Water was scored based on surface area and diversity of expression (lakes, rapids, waterfall and springs, and freshwater or glacial rivers). A point grid with 500*500 m mesh size was overlaid with water features and points within them extracted. Density was calculated with a 20 km. radius. The results were reclassified in a scale of 1-6 where 1 = little or no water and 6 = high water coverage.

The diversity of expression was calculated by placing points inside polygons representing water forms and calculating the kernel density of those points using a 2 km radius. The results were reclassified in a scale of 1-6 where 1 = little diversity and 6 is great diversity.

## Spatial patchiness

Patch in ecology is defined as “a relatively homogenous area in a landscape that differs from its surroundings” (Molles, 2013, p. 537). Patches were analyzed using the object segmentation tool in GRASS GIS, called i.segment. Object based image segmentation is an alternative to pixel classification. Instead of classifying an image into predefined classes, object based image segmentation “divides an image […] into spatially continuous, disjoint and homogeneous regions referred to as segments” (Blaschke et al, 2013, p. 186). This method allows for the mapping of objects such as roads, buildings, trees and patches in the natural landscape on different scales, as well as landforms (Blaschke, 2010) (Burnett & Blaschke, 2003) (Dragut & Blaschke, 2006).

Rapideye images from 2011 and 2012, with a spatial resolution of 5*5 meters, were used as they are the newest available imagery data with a sufficient spatial resolution and were available for most of the study area. As the landscape classification is based on visual characteristics, this analysis used the red, green and blue bands only, to create natural color images. Segmenting images is a computer intense process and segmenting one image at a time proved impractical. Instead, 5*5 km squares were used as a frame for the patch analysis. The squares proved to be a good way to maximize usage of the Rapideye images, some of which had significant cloud coverage. Using 5*5 km squares provided a systematic method of circumventing clouds in one image and then to find the same area without clouds in another image. Spot Images from 2003 to 2006 were used to analyze areas that could not be mapped with Rapideye images. In the end, there were still small areas that could not be object segmented due to cloud coverage in both Rapideye and Spot datasets.

The segmentation consisted of five steps. First, cloudless areas were identified and individual 5*5 km vector layers created for that same area. The second step was the segmentation itself. A python code was used to iterate between the 5*5 squares vector files. The settings for the object segmentation were as follows: threshold= 0.19, minsize = 5, with iterations of 11 and 8 neighbours instead of the default 4. The third step involved filtering the segmentation using both neighbourhood calculations as well as calculating shape area for the patches and eliminating patches below 500 square meters that are the results of converting files from raster to vector format. In the fifth step the patch polygons were converted to points and the Kernel density calculated. For the Rapideye data, a 2 km radius was used and a 500 m radius for patches extracted from Spot images. The density outcome from both datasets was combined and reclassified on a scale from 1-6 where 1= areas with coarse patch size and 6= areas with finer patch.

## Multivariate Classification

Image classification is a common method for extracting information from raster data, most often from satellite images. Image classification can, however, be used on other kinds of data as the function is always the same. The variables were classified together using Erdas Imagine which utilizes an Isodata Clustering method which groups each pixel into a group based on minimum spectral distance. The process starts with the data being split into arbitrary clusters. Each pixel is compared to the neighbouring arbitrary cluster in the first run but as the iterations increase the groups change from the arbitrary clusters to whatever groups fit the data. The method iterates through the pixels, comparing the mean of each pixel to the mean of the neighbouring cluster and assigns the pixel to a cluster that has a similar mean.

Unsupervised classification requires the user to define a specific number of classes into which to group the data. In the first step the landscape variables were classified into 20, 30, 50, 70 and 100 classes. This was done to see if there were any major differences in the results or if the increased number of classes simply meant that the larger classes that could be identified in the 20 and 30 classification were just split into smaller classes. Comparison showed, as expected, great likeness between classifications but a low number of classes resulted in illogical grouping of areas while a high class number generated a classification with many outliers. 75 classes were used for the final merging and identifying of landscape types. Results were merged using a dendrogram (see figure 2) and a cut off line designated at 0.4.

# 4. Results

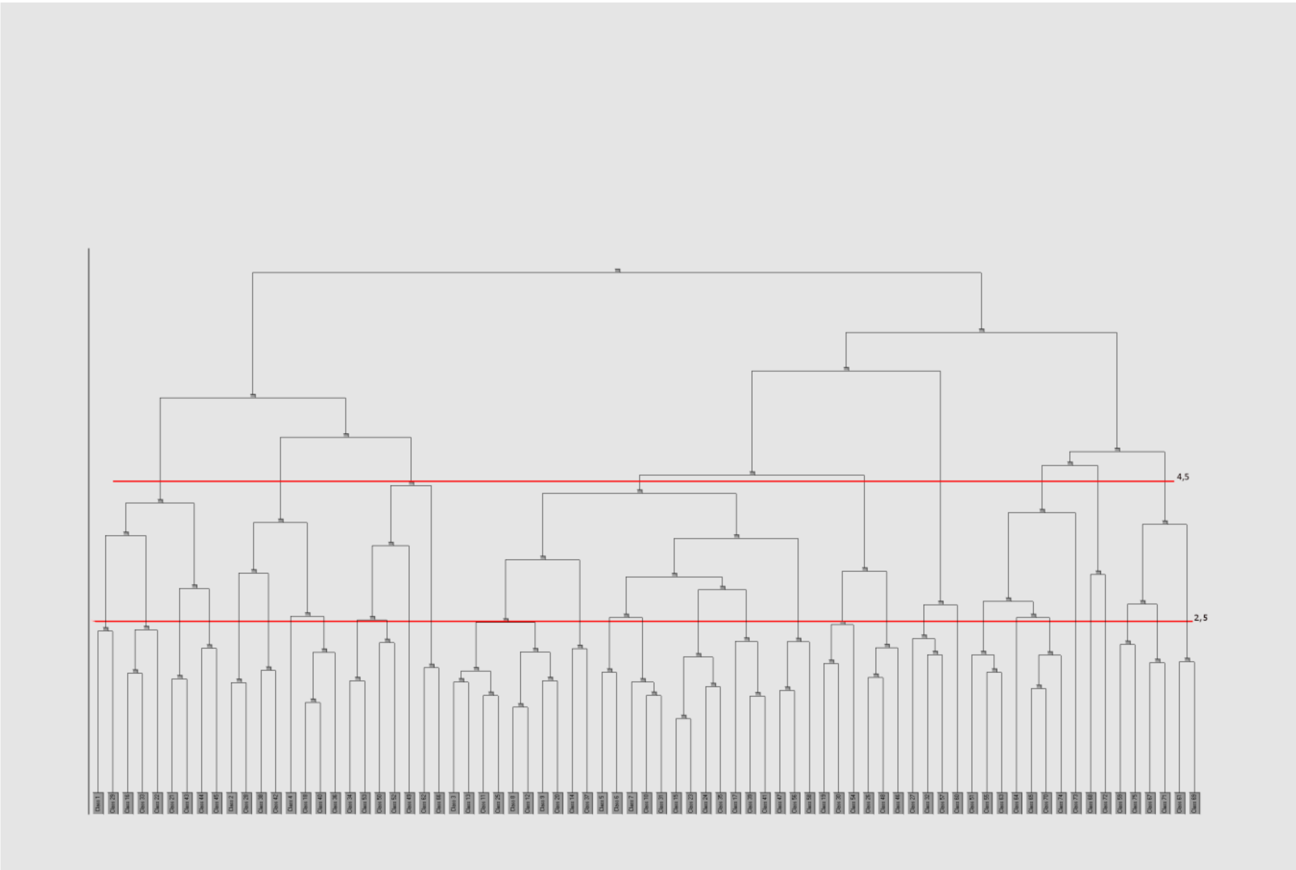



*Figure 2 displaying the dendrogram used to merge classes to narrow down the landscape types. The red lines indicate the cut off lines, the higher line is for level 1 and the line below for level 2*

The multivariate analyses identified 9 major landscape types of different sizes and geographical distribution. The dendrogram splits in two parts. Areas on the branch to the left have proximity to glaciers in common and are split between areas with water (Landscape type 1) and to the far left, glaciers (Landscape type 2) and barren closed off areas close to glaciers or mountains (Landscape type 3). The second big branch splits into vegetated (to the far right) and dry scarcely vegetated areas. Vegetated areas are split into 3 landscape types: Landscape type 1: Vegetated mountainous land; Landscape type 2 contains flat, wet areas with high vegetation cover and diversity; Landscape type 3 is characterized as vegetated hilly area with medium patchiness. Dry scarcely vegetated areas fall into three types; scarcely vegetated valleys (Landscape type 4); Barren sandy areas close to glaciers or mountains (Landscape type 5) and landscape type 6 which are barren flat areas with good landscape depth. The landscape types are split into two levels. Level 1(figure 3 are general) landscape types and level 2 (figure 4) are subgroups of the general landscape types.

The classification reflects known characteristics of the area. Lakes and areas with big rivers or many smaller streams have been grouped together in Water areas (landscape types 1). Glaciers are a distinct branch and landscape types 4, 5 and 6 capture the barren and dry parts of the central highlands and the north eastern parts. Landscape types 1 and 3 capture the areas that have continuous vegetation and landscape type 2 captures highland oasis, Areas with high vegetation

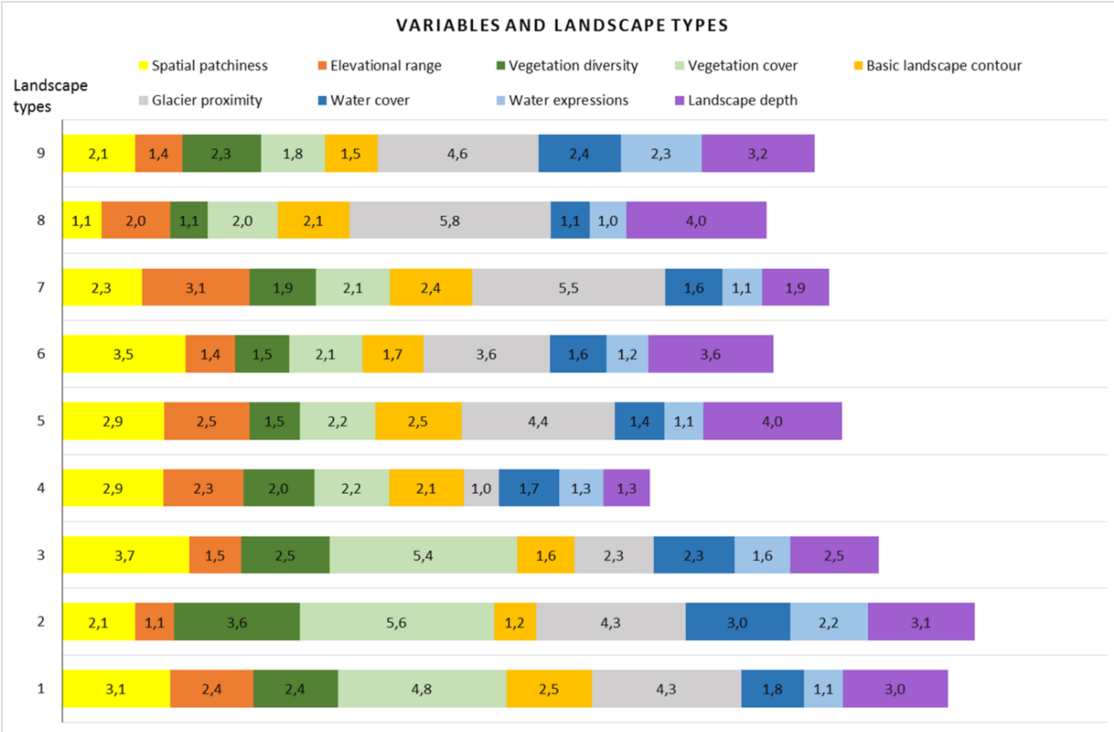



*Figure 3 The averages of each variable within each Level 1 landscape type to display the characteristics of each landscape type*

cover and diversity and high water cover. These areas include for example two tundra areas Þjórsárver and Orravatnsrústir, and Laugarfell, area with a natural source of warm water.

## 3 Strengths, weaknesses and application potentials

This method has many advantages and is greatly different to other previous landscape analyses conducted in Iceland. The landscape types are identified by letting data speak for itself instead of boundaries being drawn by hand based on observed data or preconceived notions about the landscape. The method provides information on how related the landscape types are, how the variables relate to the final classification and provides numerical information on the composition of each variable within each landscape type. This landscape analyses is thus much different from the LCA based analyses and is more transparent then previous landscape analyses conducted in Iceland by consulting firms. This method draws the boundaries of each landscape types, unlike the Icelandic Landscape Project which is point based. It is repeatable in any GIS environment that has available the tools that were used, though some settings will of course have to be modified based on the input data's resolution and spatial extent. This method provides as well, an easy way of adding variables to the classification.

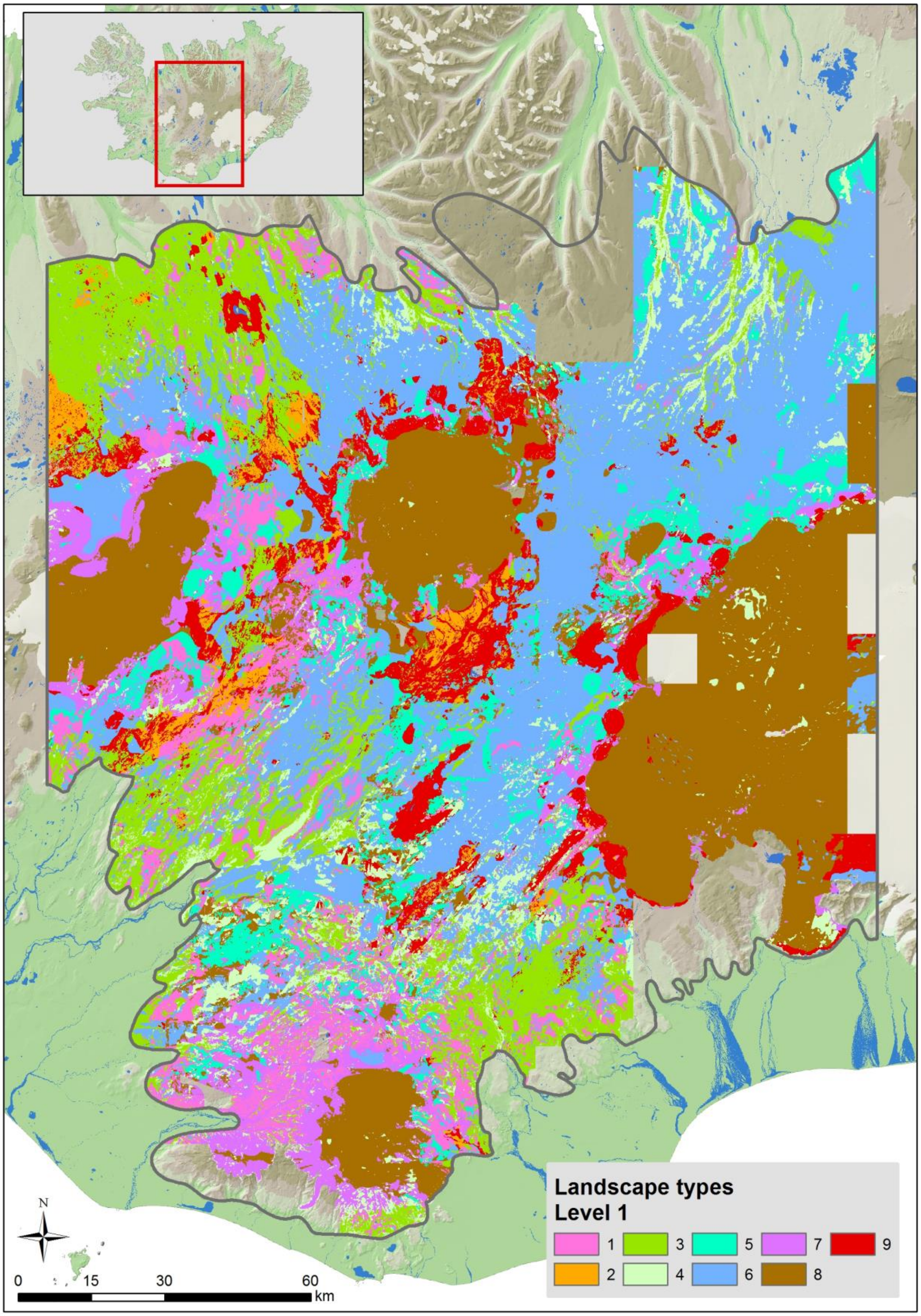



*Figure 3 - The nine landscape types in Level 1. Gaps in the data are clearly visible to the far right.*

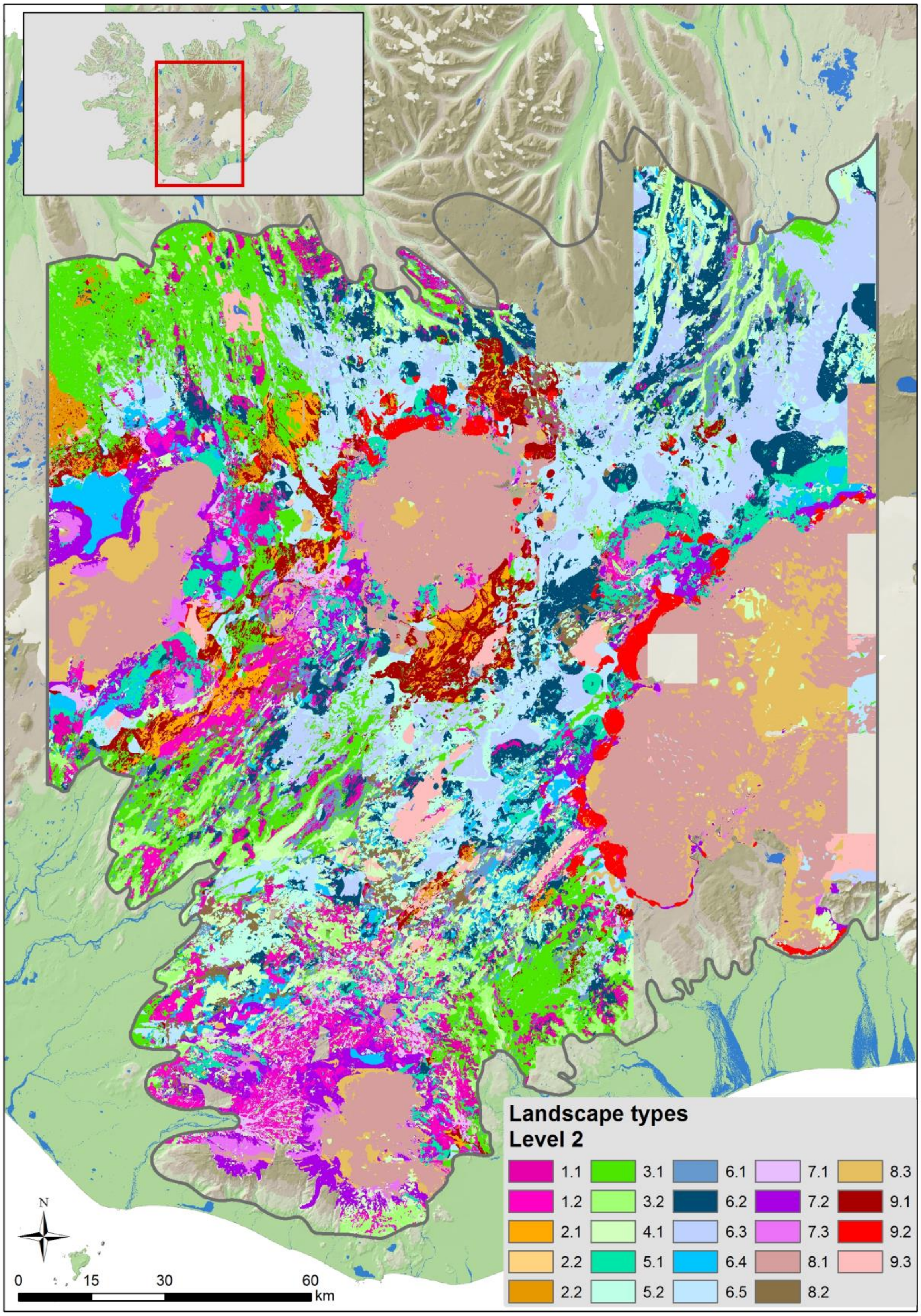



*Figure 2 The 23 landcape types in Level 2. The gaps in the data are visible in the central left part of the map*

The methodology presented in this paper includes several limitations such as its dependency on having standardized data for large areas, which can be restricting. In the case of this study, gaps in the data results in the empty squared areas visible on figure 4. One of the aims of this project was that it would be a quick method. That is true for the most part but the visibility analyses and the object segmentation required are time consuming. They do however need little updating, perhaps every 5 years or more. The variables used in this model can be used for all landscapes but it will always be necessary to consider the physical characteristics of the study area. For Iceland, it is necessary to include glaciers, as they are such a prominent part of the landscape while this is obviously not the case in most other countries where it will be necessary to include new variables and perhaps exclude glaciers, depending on each case.

The next steps in the development of this model could be several. This classification favoured generalization and there are variations within each landscape type. For example, landscape type 10 includes flat areas with sand and gravel but it also includes flat areas with lava which look very different from the aforementioned type. This method makes it possible both to extend the model to other parts of the country and to add further variables. A logical step would be to add layers representing land cover classes such as lava, which is a prominent land cover feature in Iceland. Anthropogenic factors such as roads, buildings and agricultural areas should be included as well, though that is a factor that is more important in the lowlands then in the highland. In terms of the area covered by the model, it should first be extended to the rest of the Central Highlands and to the rest of the country as data becomes available.

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