GIO Land Monitoring 2011 – 2013 in the framework of regulation (EU) No 911/2010

Pan-EU Component

Grant Agreement 3541/B2013/R0-GIO/EEA.55299

Final Report

Iceland

Tasks:

1. **Verification** of products (HRLs – high resolution layers)	**Y**
2. **Enhancement** of products (HRLs – high resolution layers)	**Y**
3. New **Corine Land Cover inventory** (2012)	**Y**
4. **Dissemination** of final products	**Y**

1. BACKGROUND

Reference to previous CLC exercises. Iceland joined the CLC programme in 2007 and the CLC2006 classification was finished in December 2008. It was the first CLC classification to be implemented for the country. Parallel to the CLC2006 exercise data and information on land cover changes between 2000 and 2006 were compiled and CLC2000 and CLC-Changes$_{2000\text{-}2006}$ databases were produced by down-dating the CLC2006 results to year 2000.

Organisation at national level. As with the CLC2006 and CLC2000 projecs The National Land Survey of Iceland (NLSI) was responsible for the implementation of the GIO Land Monitoring 2011-2013 exercise. Several other institutions and municipalities also contributed to the exercise by providing relevant data and information which were subsequently processed and integrated by NLSI into the working databases. The main institutions involved were the following: The Icelandic Institute of Natural History (IINH), the Icelandic Met Office (IMO), the Icelandic Forestry Research (IFR) and the University of Iceland (UoI).

Connections with other projects. The new Corine Land Cover inventory connects directly or indirectly with several other projects which are currently being implemented at other institutions in Iceland. Of these projects the 4 following are most important:

- Vegetation mapping (Icelandic Institute of Natural History - IINH). Ongoing mapping since decades. All highlands and large parts of the lowlands have been finished.
- Habitat type mapping (IINH). Ongoing mapping since 2013 (starting as an IPA project), will be concluded by end og 2015.
- Construction of high resolution land use database, meeting the requirements of UNFCCC greenhouse gas inventories. (Agricultural University of Iceland - AUI)
- Water framework directive (The Environment and Food Agency of Iceland – EFAI and the Icelandic Met Office - IMO)

NLSI has cooperation contracts with all these institutions for mutual use of data and information. Results of these projects have been taken into consideration for the CLC2012 mapping and will in future provide valuable information to further CLC updates and verification and enhancement of the HRLs.

Use of CLC at national level. As CLC is the only LC/LU database at a large scale that comprises Iceland completely it has been used for colouring and displaying background maps in several map services. Also the CLC inventory finds regular use by students of environmental sciences at the University of Iceland.

Besides CLC2006 has found a practical application at the Icelandic Met Office (IMO) that uses the CLC2006 results as the necessary land cover information for its principal weather forecast model “Harmonie”. http://www.vedur.is/

CLC can be visited and downloaded free of charge at the NLSI web sites: http://gis.lmi.is/geoserver/LMI_vektor/ows? , http://atlas.lmi.is/LmiData/ and http://gis.lmi.is/geoserver/wfs . The NLSI web site is visited regularly and in the last two years, 2013 and 2014, the CLC data files were downloaded 873 times in 457 log-ins.

HRL expected use at national level. The HRLs 2012 were verified and enhanced for the first time in Iceland (GMES FTS Land Monitoring Precursor soil sealing layer for Iceland was in fact verified at NLSI but the concurrent forest layer was newer sent to Iceland for verification). As the accuracy/ quality of the HRLs 2012 is generally poor it is not to be expected that they will be of any use for the time being. This can and will of course change with improved results of the 2015 and later updates.

Copernicus in general. Copernicus (and previously GMES) has been a godsend for Iceland. It is evident that a nation that only counts some 320.000 individuals living in a relatively large (103.000 km^2) and very dynamic country is not able, due to financial as well as man-power

restrictions, to map and monitor LU/LC changes as accurately or frequently as is considered necessary in most other countries. For Iceland it is therefore invaluable to have access to high quality satellite images that are updated regularly. The Copernicus participation has completely and permanently changed mapping and monitoring possibilities in this physically continuously changing country.

2. ORGANISATION OF WORK AT NATIONAL LEVEL

- **Overview of the production process.** The project was executed in a similar way as the CLC2006 exercise with one very important difference; this time the work was an update of already existing CLC database. Before virtual production started information on possible and known changes was compiled from respective institutions and municipalities. Some land cover classes were taken care of by other institutions, e.g. glacier outlines (IMO), forests and new trees plantations (IFR), but overall generalisation and integration of all changes were done at the NLSI.

  The standard "Change mapping first approach" was applied to create the CLC2012 update. Change mapping and revision of CLC2006 results was made simultaneously by visual comparison of CLC2006 and Image 2006 with Image 2012 imagery and subsequently the CLC2012 was implemented.

- **CLC2012 training.** Training was not requested. The staff involved in the GIO Land Monitoring 2011-2013 consisted of the same individuals as in the CLC2006 and CLC-Change$_{2000\text{-}2006}$ exercises and therefore already possessed necessary experience.

- **Project management; project meetings.** The GIO Land Monitoring 2011-2013 was managed by the same person, Kolbeinn Árnason, and in a similar manner as the CLC2006 exercises. All participating staff members have been NLSI employees for many years. No regular or formal meetings were necessary as the allocated staff worked very closely together at the same premises and met on an every-day basis. A communication network between NLSI and all the various partners and data providers in Iceland was established during the CLC2006 exercises and worked well, mainly via telephone and email.

- **Participating experts.** Four employees of the NLSI worked on the GIO Land Monitoring 2011-2013 exercise:

Project coordinator:	Dr. Kolbeinn Árnason
Database and IT expert:	Mr. Ingvar Matthíasson
CLC GIS unit:	Mr. Ingvar Matthíasson Mrs. Thórey D. Thórðardóttir Mrs. Sigrún Árnadóttir Dr. Kolbeinn Árnason

HRL verification and enhancement:
Dr. Kolbeinn Árnason
Mr. Ingvar Matthíasson

Field verification: Dr. Kolbeinn Árnason
Mr. Ingvar Matthíasson

Dissemination: Mr. Ingvar Matthíasson

These four NLSI staff members all had previous experience with CLC as they were all involved in the CLC2006 and CLC-Change$_{2000\text{-}2006}$ exercises.

One change from the National Proposal has occurred; Sigrún Árnadóttir replaced Ásta Óladóttir since Ásta was allocated to other projects at NLSI, mainly open source web solutions.

- **Processing methodology, software; working units preparation, etc.** The country was divided into 6 working units; NW-, N-, NE-, SE-, S-, and SW-Iceland (see Fig 1. Next page) and the processing was performed individually in each working unit. Change mapping and revision of CLC2006 results was made simultaneously by visual comparison of CLC2006 and Image 2006 with Image 2012 imagery. Before virtual processing started information on possible and known changes (such as new roads, construction areas, reservoir lakes, agricultural parcels, etc.) was compiled from respective institutions and municipalities. Some land cover classes were taken care of by colleagues at other institutions, e.g. glacier outlines (IMO), forests and new trees plantations (IFR). Final generalisation and integration of these classes were however done at the NLSI.

  The software used for the project was ArcMap (versions 10.1 and 10.2) from ESRI and the CLC2012 Support Package InterCheck and InterChange from FÖMI, Hungary, that was specially developed for CLC change mapping. ArcMap was used for the preparation of GIS layers, internal technical quality control, integration of individual working units and creation of the CLC layers. InterChange and InterCheck were used for interpretation and internal thematic quality control during revision of the CLC2006 layer and CLC change mapping.

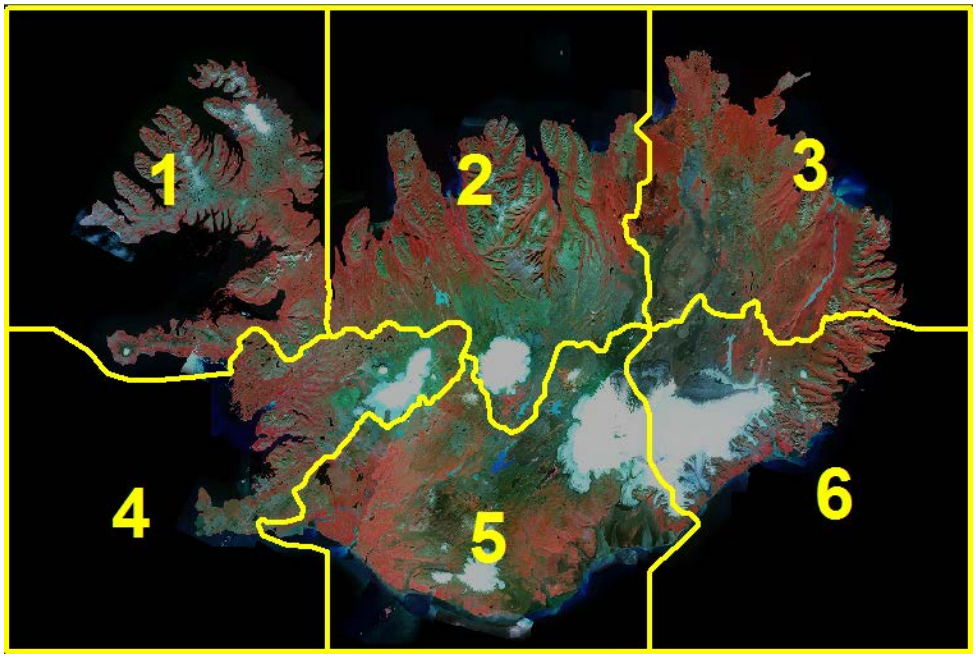

Fig. 1. Working units in Iceland. *The country was divided into 6 working units and the CLC change mapping and revision performed individually in each working unit by one member of the national team and subsequently checked by another one.*

- **Satellite data processing.** The basic satellite data used for the GIO Land Monitoring 2011-2013 exercise were Image2012 imagery which for Iceland are SPOT-4 and -5 images. CORE_03 (SPOT-5) images from the GSC Data Warehouse were also thoroughly considered to facilitate identification and interpretation of changes. Only most basic processing of satellite data was performed, e.g. different band combinations and histogram stretching.

- **Internal quality control results.** After change mapping and revision of CLC2006 results in each working unit the results were thoroughly checked by another team member. New findings and corrections were discussed if considered necessary. Verification and enhancement of the HRL intermediate results was performed by one team member and always checked by another one.

- **Accuracy assessment.** No statistical accuracy assessment was performed but results were assesses at random quite thoroughly throughout the country especially for classes that are changeful with time.

- **External quality control (CLC Technical Team remote or on-site verification) results.** External verification of the CLC2012 results were made twice, both verifications were implemented remotely at EEA premises. The 1st verification was done on working unit NW-Iceland and

the 2nd one on SW-Iceland. Both verifications revealed the same results: Revision layer was accepted (A), change layer was conditionally accepted (CA). The technical quality of the databases was good in both cases (György Büttner, 2013 and 2014).

All remarks of both verification reports were checked and carefully verified using in-situ data by the national team. Many of the remarks were truly referring to mapping mistakes, some remarks must be regarded as "matter of taste" but others were simply due to the fact that several classes, e.g. young forests and tree plantations in Iceland, are hardly or not at all discernible in the satellite images provided for the exercise. All mistakes identified by in the verification reports were corrected and remaining working units were especially checked on these types of errors.

- **Verification HRL (summary of results).** As previously stated there was no experience with HRLs in Iceland before the verification of the 2012 HRLs (GMES FTS Land Monitoring Precursor soil sealing layer for Iceland was indeed verified at NLSI but no feedback to this verification was provided. The concurrent forest layer was, on the other hand, never sent to Iceland for verification). It was therefore with some expectation and even anticipation that the national team awaited the HRLs verification. The disappointment was enormous as the accuracy/ quality of the HRLs 2012 turned out to be insufficient to very poor in most cases. The overall evaluation of the HRLs gave the following ratings:
    - IMD intermediate results: Insufficient
    - TCD intermediate results: Insufficient
    - FTY intermediate results: Insufficient
    - GRA intermediate results: Acceptable
    - WET intermediate results: Very poor
    - PWB intermediate results: Acceptable for lakes, Very poor for rivers

  Before the verification process it was expected that the HRLs results would be helpful for the CLC mapping in Iceland, especially it was expected the GRA and WET layers could deliver valuable information for mapping of respective CLC classes for which no countrywide accurate information exists.

  It is obvious that the WET results are of no use but The HRL grassland results are interesting and could as the only HRL intermediate layer turn out to be of valuable help to improve the accuracy of future CLC mapping in Iceland. The accuracy of the HRL grassland results with regard to omission errors alone is very poor. If however commission errors relative to CLC2012 results are examined the HRL results reveal many areas that presumably are correctly mapped and will have to be checked further. The overall evaluation of HRL GRA was therefore considered acceptable.

  For further information on the HRL verification results the interested reader is referred to the corresponding reports (see chapter 4).

- **Enhancement HRL (summary of results).** The overall evaluation for the quality of the enhanced HRLs is as follows:
    - IMD intermediate results: Good
    - TCD intermediate results: Weak
    - FTY intermediate results: Weak
    - GRA intermediate results: Was not enhanced
    - WET intermediate results: Good
    - PWB intermediate results: Good (lakes: excellent, rivers: average).

  A condition for the enhancement of the HRL intermediate results was that features should only be corrected if they were visible in the satellite images (Image2012, 20 m pixel size) provided for the production of these layers. Iceland has several peculiarities that make it difficult to obtain good enhancement results for some of the HRLs if this condition is to be fulfilled.

  Difficulties in obtaining good enhancement results. Firstly: Concerning the IMD layer. Almost all roads in Iceland are narrow, only have one lane in each direction, and more than 50% of the road network consists of gravel roads. Large parts of the roads are in sparsely vegetated or barren areas. Therefore roads are not clearly discernible everywhere in the country and it is impossible to discern paved roads from non-paved without special information from the digital road database. That was however not allowed and hence all roads had to be deleted from the IMD intermediate results instead of corrected that would, on the other hand, have brought excellent enhancement results.

  Difficulties in obtaining good enhancement results. Secondly: Concerning the TCD and FTY layers. Icelandic forests are small and scattered and often hard to differentiate on satellite images. The only native tree species is birch which in many areas does not reach 2 m height (which is the tree height used in definition of forests in Iceland) and is therefore classified as shrub lands which have however the same spectral signature as the birch forests (>2m) and are therefore not discernible from these without using the forest maps from the Icelandic Forestry Research (IFR) for reference. Most of the planted coniferous forests are still young and don´t have high enough crown density necessary to be detected in satellite images with only few (and often highly correlated) spectral bands. Hence, it was not possible to correct the omission errors in the TCD and FTY layers without the detailed information from the IFR maps. As a result the enhancement quality of these layers is weak instead of excellent/good as would have been the case if use of the IFR mapping was permitted.

  CLC2012 results were used as in-situ data for enhancement of all HRLs intermediate layers and proved to be very good for this purpose, especially for the IMD, WET and PWB layers. It is clear that the accuracy of the HRLs will improve with new updates, in particular if satellite images with more spectral bands in the near-infrared and especially in the short-

wave-infrared portions of the electromagnetic spectrum will be provided for their production in future.

For more information on the verification and enhancement results of the HRLs in Iceland the reader is referred to the respective reports uploaded to https://gaur.eea.europa.eu/gioland/country/is . These reports can also be viewed and downloaded from the NLSI web sites: http://gis.lmi.is/geoserver/LMI_vektor/ows? , http://atlas.lmi.is/LmiData/ and http://gis.lmi.is/geoserver/wfs . (also see HRL report list in section 4 of this report).

- **Main difficulties and solutions.** Main "difficulties" with the handling of the HRL intermediate layers was the fact that use of accurate national data for improving their accuracy was not warranted. Allowing these in-situ data would have guaranteed "excellent" quality of the enhanced IMD, TCD, FTY and PWB layers, only grasslands and wetlands would have remained "good" due to missing accurate in-situ information except for limited parts of the country for these surface classes.

  Main difficulties in the CLC mapping concern the land cover classes 321, 322, 231 and 412, firstly due to very similar spectral characteristics of these land cover classes in Iceland (difficult to discern from each other in the Image2012 data) and secondly due to still missing detailed reference data for precisely these classes. The current solution is intensive field work which unfortunately is too time consuming and expensive. The future solution will be provision of improved multispectral satellite images with more numerous and less correlated spectral bands.

3. ANCILLARY DATA USED IN THE PROJECT

- **CLC, CLC-changes;** CLC2000, CLC2006 and CLC-Changes$_{2000\text{-}2006}$ were all used for the GIO Land Monitoring 2011-2013 exercise. These datasets were among the most important ones for the implementation of the project.
- **Topographic maps;** Two types of countrywide topographic maps, in scale 1:100.000 and 1:50.000, were useful for the project. The 1:100.000 maps are scanned paper maps that can be accessed on the NLSI web page free of charge (http://gis.lmi.is/geoserver/raster/ows? , http://atlas.lmi.is/LmiData/ and http://gis.lmi.is/geoserver/wfs).

  The 1:50.000 maps can also be accessed as scanned paper maps at the NLSI web page but these maps also build the basis for the IS50V vector database with 8 individual data layers including DEM, place names, road network, hydrography and outlines of protected areas and municipalities.
- **LUCAS data;** Iceland is not (yet) part of LUCAS and there is no comparable land information grid in the country. A collection of georeferenced photographs showing land cover and land use is however available at NLSI, IINH and AUI.
- **Ortho-photos;** Ortho-photo-mosaics of Iceland are accessible in several web services on the internet. One is the "place names" service on NLSI homepage (http://gis.lmi.is/geoserver/LMI_vektor/ows? , http://atlas.lmi.is/LmiData/ and http://gis.lmi.is/geoserver/wfs). Other services using ortho-photos as background for routes and addresses are: ja.is and map.is. These web services can be very helpful but an important drawback for their use is the unknown acquisition times of the images.
- **Thematic maps;** The Icelandic Institute for Natural History (IINH) is currently working on two thematic maps; a very detailed vegetation map that is a long term project and a habitat map of Iceland that will be finished by the end of 2015. Some parts of the vegetation map have already been published and IINH has also provided access to their unpublished information for the GIO Land Monitoring 2011-2013 exercise as well.
- **Google Maps;** Google Maps are very useful but a drawback for its use is the unknown acquisition times of the images. The street view is however invaluable as a tool for ground "truth" checking close to the roads.
- **Forest inventories;** The Forestry Research (IFR) has very kindly provided access to its inventories and maps. This data has proven to be essential for the project since tree plantations and many forested areas are very hard to discern on satellite images without additional information.

- **City maps, etc;** The National Planning Agency (NPA) has made its data accessible on its website using aerial ortho-photos as background: http://www.skipulagsstofnun.is/skipulagsmal/skipulagssja/. Other ancillary data to be listed here (also mentioned under topographic maps) are the IS50V digital data layers including DEM, road network, hydrography and outlines of protected areas and municipalities.

4. DELIVERABLES

Deliverables of the CLC2012 exercise

Deliverables of the new CORINE land cover inventory were uploaded to the Eionet Central Data Repository http://cdr.eionet.europa.eu/is/eea/clc in November 2014. The following files were uploaded:

Filename	content
clc2012_is.mdb	• CLC-Changes$_{2006\text{-}2012}$ • CLC2012 • CLC2006 revised
clc2012_country_level_metadata_is.xml	INSPIRE compliant country level metadata of CLC2012 datasets
clc2012_working_unit_level_metadata_is.pdf	Working unit level metadata of CLC2012 datasets
New_Datum_parameters_for_the_Icelandic_CLC_is_data.docx	New datum parameters for the CLC2012 datasets

Table 1. *Deliverables of CLC2012 inventory. CLC2012 country-level metadata is presented in Annex 1.*

- **CLC-changes**

  A total of 785 km^2 or 0,76% of the total area of Iceland changed land cover class between 2006 and 2012. This is a considerably higher change rate than in the 2000-2006 period when total changes were 0,62%. The reason for increasing changes is mainly twofold; 1) the continuing decrease of the glaciers at a greater speed and 2) the construction of a new hydropower plant with the formation of a large reservoir lake and an accompanying draining of one of the main glacial rivers in the country. Apart from this is the change pattern between 2006 and 2012 very similar to the 2000-2006 interval.

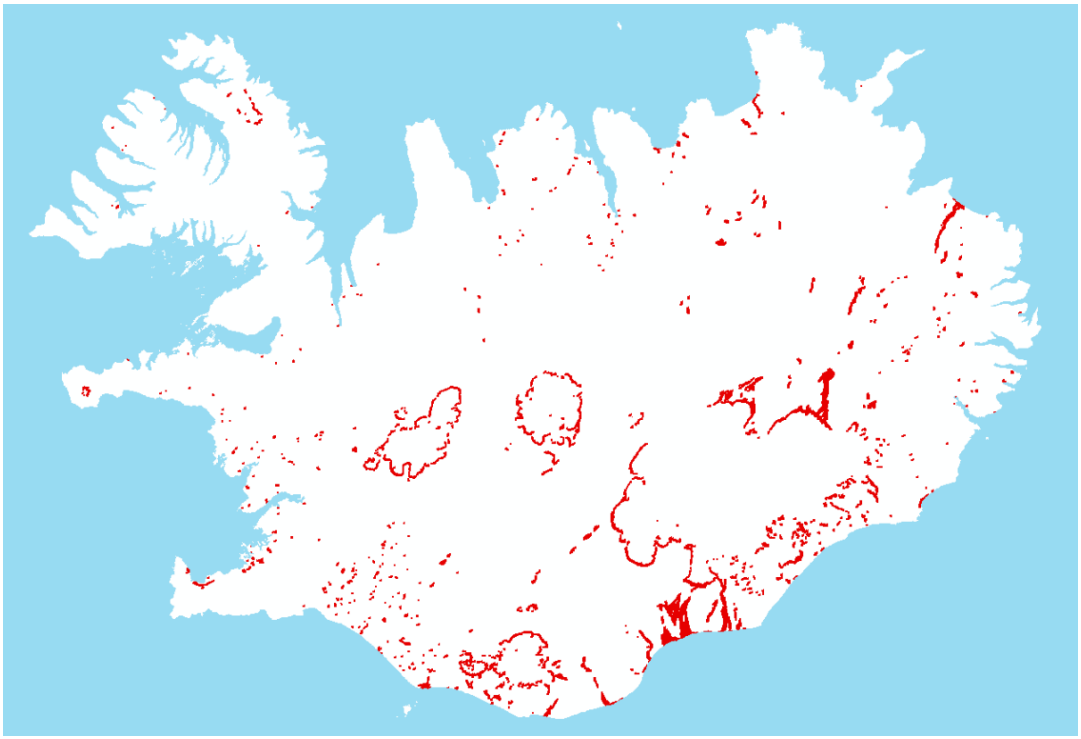

Fig. 2. *CLC-changes$_{2006\text{-}2012}$ in red colour. The most obvious changes are due to melting (decrease) of the icecaps and changes (mostly spatial fluctuations) of some of the major glacial rivers.*

The overall CLC-changes$_{2006\text{-}2012}$ are displayed in red in Fig. 2. This figure is very similar to the corresponding figure of CLC-changes$_{2000\text{-}2006}$ in the CLC2006 final report with most obvious changes due to melting (decrease) of the icecaps and changes (mostly spatial fluctuations) of some of the major glacial rivers. One new obvious change type is the formation of a large reservoir lake (>60km^2) adjacent to the northern border of the largest icecap Vatnajökull.

Table 2 lists the results of CLC2012 for all classes (in km^2 and % of total area), areal changes for each class (decrease and increase) and the net aerial change (in km^2 and % of total) between 2006 and 2012.

CLC Class	CLC 2012			Decrease	Increase	Area changed	
	km²	% national	polygons	km²	km²	km²	% internal
112	103,84	0,10	114	0,01	4,27	4,26	4,29
121	66,42	0,06	86	2,60	1,84	-0,76	-1,39
122	2,85	0,00	1		1,21	1,21	74,00
123	10,69	0,01	27	0,07	0,29	0,22	2,11
124	28,23	0,03	17	0,05	1,34	1,29	4,99
131	11,81	0,01	24		0,11	0,11	0,00
132	0,47	0,00	1			0,00	0,00
133	12,05	0,01	15	13,82	3,77	-10,05	-48,81
141	16,93	0,02	20	0,27		-0,27	0,00
142	140,74	0,14	218	1,34	6,35	5,01	4,08
211	22,71	0,02	34		0,55	0,55	2,39
231	2527,49	2,44	1930	2,53	21,61	19,08	0,75
242	51,87	0,05	126		0,89	0,89	3,25
311	319,69	0,31	200	0,57	2,32	1,75	0,55
312	30,73	0,03	52		1,03	1,03	3,03
313	75,23	0,07	72	0,10	0,42	0,32	0,43
321	3064,88	2,96	1972	11,26	43,93	32,68	1,03
322	35450,12	34,25	2014	84,92	4,26	-80,66	-0,21
324	311,42	0,30	420	4,55	25,91	21,36	5,95
331	3410,28	3,30	777	117,92	217,19	99,27	3,01
332	23727,54	22,93	1385	56,64	226,38	169,75	0,71
333	13480,07	13,03	3868	22,88	26,47	3,60	0,02
335	10600,16	10,24	187	267,14		-267,14	-2,42
411	385,91	0,37	119	1,10		-1,10	-0,27
412	6627,00	6,40	2360	13,08		-13,08	-0,19
421	28,19	0,03	35			0,00	0,00
423	614,01	0,59	207	0,17	0,62	0,45	0,10
511	736,07	0,71	76	159,00	100,18	-58,82	-7,43
512	1296,96	1,25	844	7,97	83,57	75,60	6,09
521	284,88	0,28	68	0,43	5,75	5,32	1,90
522	52,51	0,05	21	9,46	1,59	-7,88	-11,25
523	127707,07		1				
	103491,77	**100**	**17290**				

Table 2. *Areas and number of polygons for all CLC classes in Iceland for the 2012 mapping, the area changes for each class (decrease and increase) between 2006 and 2012 and the net aerial change for each class in this 6 years time interval (last two columns).*

Table 3. summarises the 22 most abundant land cover changes that make up 90% of all changes in Iceland between 2006 and 2012. The total changes due to fluctuations of glacial rivers (511–331, 331–511, 332–331 and 522–331) add up to 35% and changes involving retreat of glaciers (335 to 332, 331, 512 and 521) are 34% of all land cover changes. This means that changes due to shifting of glacial ice and water make up 70% of all changes in the country.

Change (2006-2012)	Explanation of the change process	nr. of areas	Area in hectares	Area percent of total change	Area cumulative percent
335-332	Glacier retreat	436	21852	27,88 %	27,88 %
511-331	Fluctuations of glacial rivers	60	15692	20,02 %	47,9 %
331-511	Fluctuations of glacial rivers	88	9112	11,63 %	59,53 %
322-512	Mainly three new dams north of Vatnajökull	6	3754	4,79 %	64,32 %
335-331	Sand and gravel emerging from beneath the glaciers	33	2767	3,53 %	67,85 %
332-512	Mainly due to one of the new dams north of Vatnajökull	19	2300	2,93 %	70,79 %
332-321	Soil reclamation (revegetation activities)	17	1743	2,22 %	73,01 %
322-331	Mainly due to fluctuations of the glacial rivers	23	1579	2,01 %	75,03 %
333-321	Mainly soil reclamation north of Vatnajökull	13	1526	1,95 %	76,97 %
322-324	Afforestation on Moors and heathland	63	1453	1,85 %	78,83 %
335-512	Retreat of the glaciers	46	1247	1,59 %	80,42 %
332-333	Natural vegetation spreading	14	1174	1,5 %	81,92 %
331-333	Natural vegetation spreading	15	1057	1,35 %	83,26 %
522-331	Changes in riverbeds due to fluctuations of glacial rivers	12	862	1,1 %	84,36 %
331-321	Soil reclamation and natural vegetation spreading	7	722	0,92 %	85,28 %
412-231	Peat bogs changed into pastures	38	720	0,92 %	86,2 %
321-231	Natural grassland changed into pastures	44	644	0,82 %	87,03 %
322-231	Moors and heathland changed into pastures	43	636	0,81 %	87,84 %
512-332	Glacial lakes dry out due to glacial changes	10	539	0,69 %	88,53 %
333-512	Land submerged due to dams north of Vatnajökull	7	528	0,67 %	89,2 %
335-521	Retreat of Breiðamerkurjökull and increase of the glacial lagoon	1	429	0,55 %	89,75 %
523-331	Changes in the outlets of the fluctuating glacial rivers	19	410	0,52 %	90,27 %

Table 3. *Dominant CLC-changes between 2006 and 2012 with explanations. The listed 22 most abundant changes are responsible for 90% of all land cover changes in Iceland. Land cover changes involving retreat of glaciers are 34% and changes due to fluctuations of glacial rivers make up 35% of the total land cover changes. Thus changes due to shifting of glacial ice and water are almost 70% of all changes in the country.*

In the following there is a summation of the most important changes with short analysis or explanation of their causes.

Glaciers and barren areas (335, 332). Between 2000 and 2006 the total area of glaciers in Iceland decreased by 180 km^2 or 1.62%. This process continued between 2006 and 2012 at an increased rate when the decrease in total icecap area was 267 km^2 or 2.42%. Due to the melting of the glaciers the barren areas, mainly class 332 but also 331 have increased by a comparable amount. The reason for glacier melting is simply higher atmospheric temperatures through global warming.

Glacial rivers and sand planes (511, 331). The glacial rivers are not confined to certain riverbeds but instead they continuously change their courses across the large alluvial sand and gravel planes that they have created in front of the main glaciers over the centuries. This behaviour results in a continuous change from class 511 to class 331 or vice versa. According to the CLC Change layer class 331 has increasd by 99 km^2 and class 511 has decreased by 59 km^2. The high increase in 331 compared to the decrease in 511 can be explaned with less spreading of the rivers in

2012 than 2006 (presumably because of less water flow) and thus covering less gravel planes (class 331 areas). These changes are unpredictable and this process might just as well have turned around in the next CORINE update.

Water bodies (512). The total area of lakes enlarged by 76 km^2 (or 6%) between 2006 and 2012. This was due to the construction of a new hydropower plant with 3 new reservoir lakes north of glacier Vatnajökull. The largest of these reservoirs is 62 km^2 and is now the third largest lake in Iceland.

Forests and tree plantations (311, 312, 313, 324). Forests in Iceland are very small but gradually growing through systematic afforestation activities in the last decades. Coniferous forests (312) expanded by 3% between 2006 and 2012 and young plantations (class 324) by 6%.

Roads and associated land (122). Almost all roads in Iceland only have one lane in each direction and hence don´t fullfil the 100 m width of narrowest CLC mapping elements. After 2000 construction activities for widening the roads out of the capital Reykjavík started. There were no roads in CLC2000, 1,64 km^2 in CLC2006 and 2,85 km^2 in CLC2012. This makes a 74% enlargement of class 122!

Construction sites (133). In the booming years before the country´s financial meltdown in 2008 there were many and pronounced construction sites in Iceland followed by a complete ruin of the construction industry. The situation is gradually returning to normal. Between 2006 and 2012 class 133 decreased by 10 km^2 or 49%!

Industrial and commercial units (121). It is interesting that the size of this class decreases a little (0,76 km^2) between 2006 and 2012. This is due to a diatomite factory (together with a geothermal power plant) at lake Mývatn that was shut down in this time interval.

The total area of Iceland. Currently the total area of Iceland is growing, it increased by 4,4 km^2 between 2000 and 2006 and again by 4 km^2 2006 – 2012. This is due to coastline changes caused by sediment deposits of the glacial rivers at the coast close to their estuaries. This process is absolutely unpredictable and the changes are not permanent.

Overview of changes displayed in bar graphs. The bar graphs in figures 3 and 4 give a nice graphical overview of the land cover changes that occurred in Iceland between 2006 and 2012. Figure 3 shows areal changes (in hectares) and figure 4 shows changes as proportion of the area of each class (in %). Increased areas are indicated by positive bars and decreases by negative columns.

Comparison of the two figures shows that the largest negative changes apparent in fig. 3 (glaciers 335 and moors and heathland 322) and the largest area increase (bare rocks 332) almost disappear in fig. 4 due to the huge areas of these classes. On the other hand are the changes of the very small surface classes, like the artificial classes (1xx), not discernible in figure 3 but very obvious in figure 4.

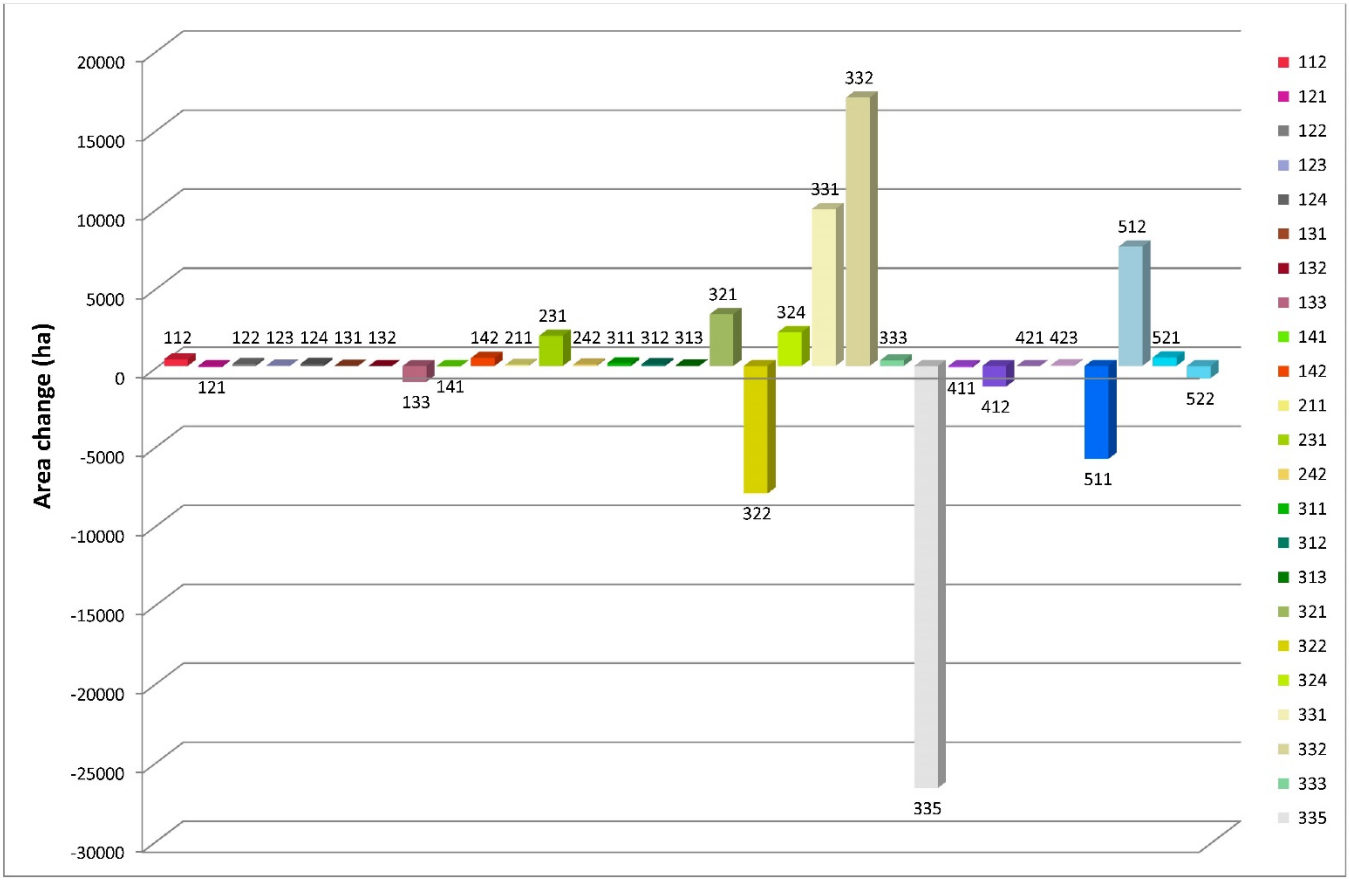

Fig 3. *Absolute changes in hectares of all CLC classes in Iceland between 2006 and 2012. Increased areas are shown by positive columns, decreased areas by negative columns.*

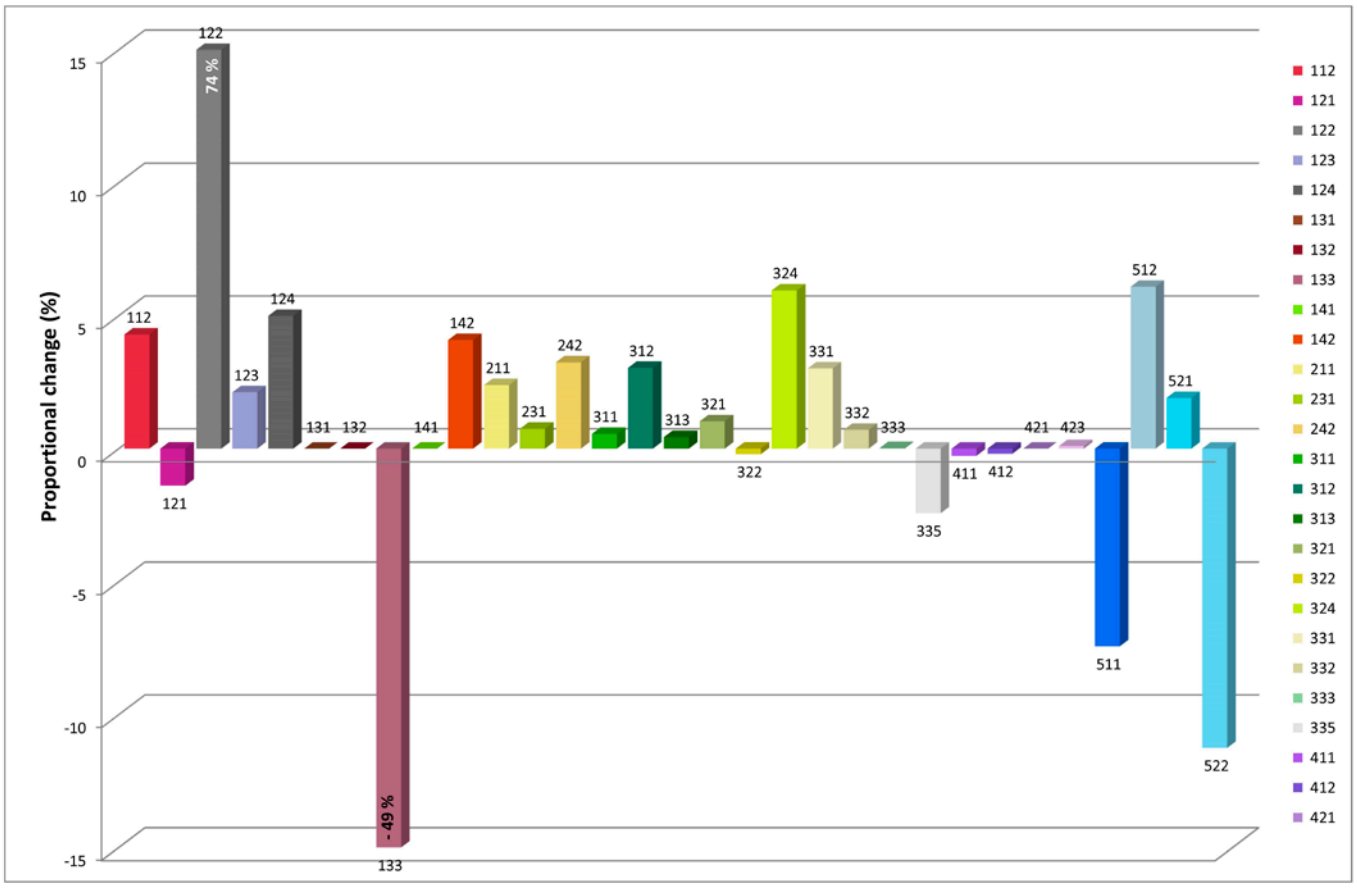

Fig. 4. *CLC changes between 2006 and 2012 in Iceland as proportion of the area of each class (in %). Increased areas are indicated by positive columns and decreases by negative columns. The length of the change columns for classes 122 (roads) and 133 (construction sites) are +74% and -49% but were cut off by +15% and -15% respectively.*

Further comparison between the both figures (and of course table 2 which contains all the figures) reveals that the following classes change very little or not at all.

- 131 Mineral extraction sites
- 132 Dump sites
- 141 Green urban areas
- 421 Salt marshes
- 423 Intertidal flats.

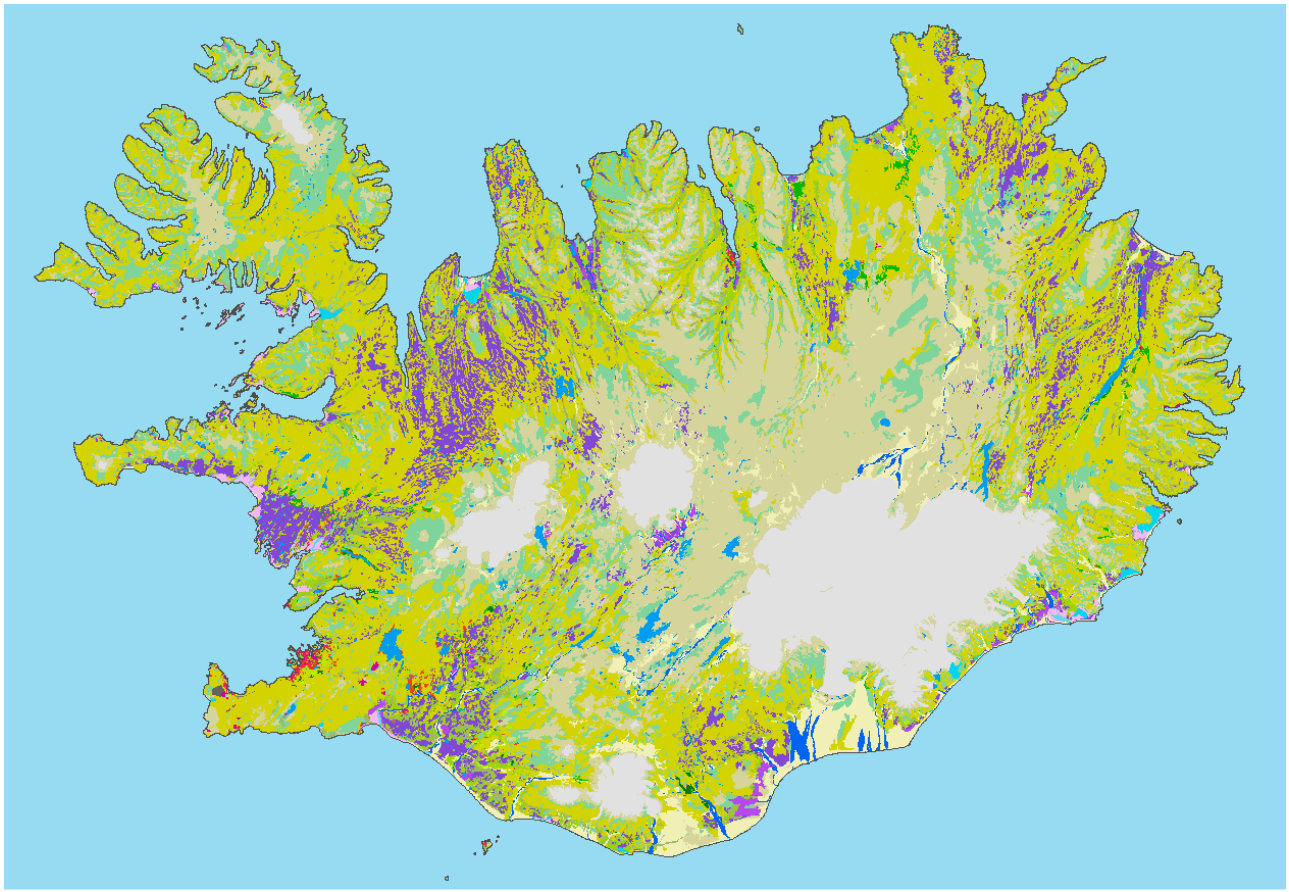

Fig. 5. *CLC2012 map of Iceland. Class 322 (Moors and heathland) is by far the largest class in Iceland with 34% of the total area of the country. Other large classes are 332 (23%), 333 (13%), 335 (10%) and 412 (6,4%). Visible changes compared to the CLC2006 map (in this small scale) are the new reservoir lakes north and main river courses south of Vatnajökull icecap (see also Fig. 2).*

- **CLC2012**

  The CLC2012 results were created by the combination of the revised CLC2006 and CLC-Changes$_{2006\text{-}2012}$ layers. Figure 5 shows the CLC2012 map of Iceland but associated statistics are shown in table 4.

  The largest CLC classes in Iceland are moors and heathland (with 34% of the total area of the country), followed by barren areas (332: 23%), sparsely vegetated areas (13%), glaciers (10%) and wetlands (6,4%).

  Table 5 summarizes the areas and proportionate areas of the five level 1 CLC classes in Iceland. It is striking how large class 3 “Semi-natural areas” is (forests are very small) or 87% of the total area of Iceland. The sum of the “natural” land categories 3 and 4 (level 1 classes 3 and 4) has an area of 98.125 km^2 that amounts to 95% of the country´s total area.

CLC 2012			
class	No. of polygons	Area (ha)	Percent of total
112	114	10384,5	0,10
121	86	6641,6	0,06
122	1	285,0	0,003
123	27	1068,6	0,01
124	17	2822,6	0,03
131	24	1181,1	0,01
132	1	47,1	0,00
133	15	1205,3	0,01
141	20	1693,0	0,02
142	218	14074,5	0,14
211	34	2271,1	0,02
231	1930	252749,5	2,44
242	126	5186,7	0,05
311	200	31969,3	0,31
312	52	3072,9	0,03
313	72	7523,3	0,07
321	1972	306487,7	2,96
322	2014	3545012,2	34,25
324	420	31142,2	0,30
331	777	341027,6	3,30
332	1385	2372753,8	22,93
333	3868	1348007,3	13,03
335	187	1060016,4	10,24
411	119	38590,9	0,37
412	2360	662700,4	6,40
421	35	2819,4	0,03
423	207	61401,0	0,59
511	76	73607,5	0,71
512	844	129695,5	1,25
521	68	28488,4	0,28
522	21	5250,9	0,05
523	1	12770707,3	Not included in calc.
Total	17290	10349177,2	100,000

Table 4. *CLC2012 statistics. Number of polygons, area (in hectares) and percentage area of each CLC class in Iceland.*

CLC 2012 level 1 statistics		
	km2	% of Iceland
Artificial surfaces	394	0,38
Agricultural areas	2602	2,51
Forests and semi-natural areas	90470	87,42
Wetlands	7655	7,40
Water	2370	2,29
Total	103492	100,00

Table 5. *CLC2012 statistics. Total areas (km^2) and proportionate areas of the five level 1 CLC classes in Iceland. The sum of the "natural" land categories 3 and 4 (Forests and semi natural areas + Wetlands) amounts to 95% of the country´s total area.*

- **Revised CLC2006**

  The CLC code was revised for 1775 km^2 or 1,7% of the total area of Iceland. The 20 most abundant corrections are presented in Table 6, next page. The four largest correction types (45% of the total) were the following:

  - Moors and heathland corrected to natural grassland
  - Natural grassland corrected to moors and heathland
  - Moors and heathland corrected to wetlands
  - Bare rock corrected to sand planes.

  This is not surprising as the classes playing part in the individual correction types can be very difficult to discern from each other using only satellite images (due to similar spectral characteristics) but detailed reference data, such as accurate vegetation maps, are still not available except for limited parts of the country.

  The CLC2006 revision was based on field check as well as consultancy with local people providing information on the respective places.

Correction	Explanation of corrections	Count	Area km²	Percent of total corrections
322-321	Moors and heathland corrected to natural grassland	236	349,34	19,7 %
321-322	Natural grassland corrected to moors and heathland	160	172,79	9,7 %
322-412	Moors and heathland corrected to peat bogs	125	154,36	8,7 %
332-331	Bare rock corrected to beaches, dunes and sand planes	16	126,82	7,1 %
322-311	Moors and heathland corrected to broad-leaved forest	74	74,47	4,2 %
332-333	Bare rock corrected to sparsely vegetated areas	59	69,15	3,9 %
523-423	Sea and ocean corrected to intertidal flats	79	67,98	3,8 %
322-324	Moors and heathland corrected to transitional woodland/shrub	126	47,31	2,7 %
322-333	Moors and heathland corrected to sparsely vegetated areas	130	46,52	2,6 %
333-322	Sparsely vegetated areas corrected to moors and heathland	120	44,50	2,5 %
335-332	Glaciers and perpetual snow corrected to bare rock	25	44,00	2,5 %
321-231	Natural grassland corrected to pastures	126	34,64	2,0 %
511-331	Water courses corrected to beaches, dunes and sand planes	24	29,35	1,7 %
333-332	Sparsely vegetated areas corrected to bare rock	31	28,00	1,6 %
322-231	Moors and heathland corrected to pastures	155	25,93	1,5 %
322-313	Moors and heathland corrected to mixed forest	14	24,86	1,4 %
321-412	Natural grassland corrected to peat bogs	57	20,56	1,2 %
333-321	Sparsely vegetated areas corrected to natural grassland	33	19,91	1,1 %
522-423	Estuaries corrected to intertidal flats	7	16,48	0,9 %
423-523	Intertidal flats corrected to sea and ocean	24	16,17	0,9 %
324-322	transitional woodland/shrub corrected to moors and heathland	51	15,13	0,9 %

Table 6. Dominant correction types for the CLC2006 database. The CLC code was revised for 1775 km^2 or 1,7% of the total area of Iceland. The most abundant correction types concern semi-natural areas, notably grasslands (321), moors and heathland (322), barren land (331 and 332) and wetlands (412).

- **Enhanced HR layers**

  Deliverables of verification and enhancement of GIO High Resolution Layers were uploaded to the Eionet GIO Land – High Resolution Layers data exchange site: https://gaur.eea.europa.eu/gioland/country/is.

  Deliverables of the HRL´s verification exercise for Iceland are (verification reports in DOC-format):

  - Degree of Imperviousness: is_imd_ntl_020m_full01_100_ver01
  - Tree Cover density: is_tcd_ntl_020m_full01_100_ver01
  - Forest Type: is_fty_ntl_020m_full01_100_ver01
  - Permanent Grasslands: is_gra_ntl_020m_full01_100_ver01
  - Wetlands: is_wet_ntl_020m_full01_100_ver01
  - Permanent Water Bodies: is_pwb_ntl_020m_full01_100_ver01

  Deliverables of the HRL´s enhancement exercise for Iceland are (enhancement reports in DOC-format and data files in TIFF-format):

- Degree of Imperviousness: is_imd_ntl_020m_full01_100_ver01
- Tree Cover density: is_tcd_ntl_020m_full01_100_ver01
- Forest Type: is_fty_ntl_020m_full01_100_ver01
- Permanent Grasslands: HRL grasslands was not enhanced*
- Wetlands: is_wet_ntl_020m_full01_100_ver01
- Permanent Water Bodies: is_pwb_ntl_020m_full01_100_ver01

* HRL grassland was not enhanced as EEA gave up the layer

The HRLs verification and enhancement reports include detailed quality assessment of the respective data layers as well as many examples on their overall quality/accuracy and prevailing errors, both commissions and omissions. For more information on the verification and enhancement results of the HRLs in Iceland the reader is referred to the respective reports uploaded to https://gaur.eea.europa.eu/gioland/country/is . These reports can also be viewed and downloaded from the NLSI web sites: http://gis.lmi.is/geoserver/LMI_vektor/ows? , http://atlas.lmi.is/LmiData/ and http://gis.lmi.is/geoserver/wfs .

- **Metadata**

  See Annex 1.

5. CONCLUSIONS

The CLC update and revision was executed at the same institution (NLSI: The National Land Survey of Iceland) and by the same staff as previous CLC exercises in the country. The work procedure was similar to before, i.e. most of the mapping was done at NLSI but several other institutions and municipalities provided relevant data and information which were subsequently processed and integrated by NLSI into the working databases. No training was needed and the work went smoothly.

CLC-Changes. Change mapping reveals that 785 km^2 or 0,76% of the total area of Iceland changed land cover class between 2006 and 2012. This is a considerably higher change rate than in the 2000-2006 period when total changes were 0,62%. The reason for increasing changes is mainly twofold; 1) the continuing decrease of the glaciers at a greater speed and 2) the construction of a new hydropower plant with the formation of a large reservoir lake and an accompanying draining of one of the main glacial rivers in the country. Apart from this is the change pattern between 2006 and 2012 very similar to the 2000-2006 interval.

Revised CLC2006. The CLC code was revised for 1775 km^2 or 1,7% of the total area of Iceland. The largest correction types concern transformations between classes of very similar spectral characteristics and thus difficult to map correctly by use of satellite images alone. The most abundant correction types (45% of the total) were the following:

- Moors and heathland corrected to natural grassland
- Natural grassland corrected to moors and heathland
- Moors and heathland corrected to wetlands
- Bare rock corrected to sand planes.

HRL verification and enhancement. The general feeling about the HR layers was a bitter disappointment. The quality of five out of the six intermediate layers was insufficient or very poor, only one layer, GRA, was rated as acceptable. The GRA layer was not enhanced (as EEA gave it up) and its rating “acceptable” does not actually describe the accuracy of the intermediate results but more the fact that the results seem to be interesting and could be of substantial use for improving future CLC updates for natural grasslands.

After enhancement the quality of the HR layers, IMD, WET, and PWB is good, two layers, TCD and FTY, are weak and GRA was not enhanced. The reason for the bad quality of the FTY and TCD layers is the fact that Icelandic forests are small and scattered and often hard to differentiate on satellite images. The only native tree species is birch which either forms birch forests (>2 m height, definition of forests in Iceland) or birch shrub lands (<2 m height) which have however the same spectral signature as the birch forests and are therefore not discernible from these in satellite

images provided for the task. Thus only commission errors were corrected but it was not possible to correct the omission errors in the TCD and FTY layers without extra (non-warranted) reference information.

It is obvious that the accuracy of the HRLs will improve with new updates, in particular if satellite images with more spectral bands in the near-infrared and especially in the short-wave-infrared portions of the electromagnetic spectrum will be provided for their production in future.

- **Remark for future Copernicus services.** The accuracy and hence the usefulness of future CLC as well as HRL results can be improved considerably by use of multispectral satellite images with more spectral bands, especially NIR and SWIR bands, than hitherto could be provided for these exercises. It is believed that the Sentinel 2 satellite could provide the necessary data for better classification of land use and land cover. In the case that Sentinel 2 imagery will be made the basic material for future actions it is very important that as many bands as possible, and preferably all bands, will be made available for the work.

6. REFERENCES

Büttner, G.: CLC2012 Verification Report. 1st verification (remote), Iceland. 11 November 2013.

Büttner, G.: CLC2012 Verification Report. 2nd verification (remote), Iceland. 25 June 2014.

Kosztra, B., Arnold, S.: Deliverable "Proposal for enhancement of CLC nomenclature guidelines". EEA subvention 2013. WA1 Task 261_1_1; Applying EAGLE concept to CLC guidelines enhancement. 2o14.

Büttner, G., Kosztra, B.: CLC2006 Technical Guidelines, EEA, Technical Report No 17/2007. ISSN 1725 – 2237.

Büttner, G., Kosztra, B.: CLC2012, Addendum to CLC2006 Technical Guidelines, EEA/ETC SIA Working document. 2011.

Büttner, G., Soukup, T., Kosztra, B.: CLC2012, Addendum to CLC2006 Technical Guidelines, EEA/ETC SIA Final Draft, V2. 2014.

Büttner, G., Kosztra, B.: Manual of CORINE Land Cover changes. EEA subvention 2011. EEA Technical Report. 2011.

Büttner, G.: Guidelines for verification of high-resolution layers produced under GMES /COPERNICUS Initial Operations (GIO) land monitoring 2011 – 2013. Version 4. 2012

Büttner, G.: Guidelines for enhancement of high-resolution layers produced under GMES /COPERNICUS Initial Operations (GIO) land monitoring 2011 – 2013. Version 2. 2012

Árnason, K., Matthíasson, I.: CLC2006, CLC2000 and CLC-Changes in Iceland Grant agreements: 3601/B2007.EEA53004 and 3601/RO/CLC/B2007. EEA52971 Final report. National Land Survey of Iceland / Landmælingar Íslands. October 2009

Árnason, K., Matthíasson, I.: CORINE landflokkunin á Íslandi 2000 og 2006. Niðurstöður CLC2006, CLC2000 and CLC-Changes$_{2000\text{-}2006}$. (In Icelandic). Landmælingar Íslands, nóvember 2009.

Done at NLSI, Akranes, Iceland

Date: 27. February, 2015

Name: Kolbeinn Árnason

Signature: 

Annex 1: CLC-Changes,CLC2012 and revised CLC2006 metadata[1]

File Identifier: *{4F1C8C99-B40C-4523-AC57-C10C9605AA74}*

Metadata Language: English

Resource Type: Dataset

Responsible Party:

Organisation Name: National Land Survey of Iceland, Stillholt 16-18, 300 Akranes, Iceland

Role: Point Of Contact

Contact Info:

E-Mail Address: lmi@lmi.is

Metadata Date: 2014-12-01

Metadata Standard Name: INSPIRE Metadata Implementing Rules

Metadata Standard Version: Technical Guidelines based on EN ISO 19115 and EN ISO 19119 (Version 1.2)

Data Identification

Abstract: Corine Land Cover (CLC) 2012 and CLC change 2006-2012 are two of the datasets produced within the frame of the Initial Operations of the Copernicus programme (the European Earth monitoring programme previously known as GMES) on land monitoring.Corine Land Cover (CLC) provides consistent information on land cover and land cover changes across Europe. This inventory was initiated in 1985 (reference year 1990) and established a time series of land cover information with updates in 2000 and 2006 being the last one the 2012 reference year.CLC products are based on photointerpretation of satellite images by national teams of participating countries - the EEA member and cooperating countries – following a standard methodology and nomenclature with the following base

[1] Metadata compliant with the EEA Metadata Profile (INSPIRE compliant metadata with some extended elements) available at http://forum.eionet.europa.eu/nrc_land_covers/library/gio-land/corine-land-cover-clc/technical-guidelines/metadata/country-level-metadata

parameters: 44 classes in the hierarchical three level Corine nomenclature; minimum mapping unit (MMU) for status layers is 25 hectares; minimum width of linear elements is 100 metres; minimum mapping unit (MMU) for Land Cover Changes (LCC) for the change layers is 5 hectares. The resulting national land cover inventories are further integrated into a seamless land cover map of Europe.Land cover and land use (LCLU) information is important not only for land change research, but also more broadly for the monitoring of environmental change, policy support, the creation of environmental indicators and reporting. CLC datasets provide important datasets supporting the implementation of key priority areas of the Environment Action Programmes of the European Union as protecting ecosystems, halting the loss of biological diversity, tracking the impacts of climate change, assessing developments in agriculture and implementing the EU Water Framework Directive, among others.More about the Corine Land Cover (CLC) and Copernicus land monitoring data in general can be found at http://land.copernicus.eu/.

Language: English

Citation:

Title: Copernicus Land - corine land cover Iceland

Date:

Date: 2014-11-25

Date Type: Revision Date

Identifier: {62415C0C-816A-441A-8262-F4C924685056}

Point Of Contact:

Organisation Name: National Land Survey of Iceland, Stillholt 16-18, 300 Akranes, Iceland

Role: Originator

Contact Info:

E-Mail Address: **kolbeinn@lmi.is**

Organisation Name: National Land Survey of Iceland, Stillholt 16-18, 300 Akranes, Iceland

Role: Custodian

Contact Info:

E-Mail Address: **kolbeinn@lmi.is**

Organisation Name: European Environment Agency, Kongens Nytorv 6, 1050 Copenhagen, K, Denmark

Role: Point Of Contact

Contact Info:

E-Mail Address: **eea.enquiries@eea.europa.eu**

Organisation Name: European Commission - Directorate-General Enterprise and Industry (DG-ENTR)

Role: Owner

Contact Info:

E-Mail Address: **entr-copernicus-services@ec.europa.eu**

Representation Type: Vector

Equivalent Scale: 1: 100000

Topic Category: Environment and Conservation

Keyword Collection:

Keyword: Iceland

Keyword: land use

Keyword: land cover

Associated Thesaurus: GEMET - INSPIRE themes, version 1.0

Spatial Extent:

West Bounding Longitude: -24.6836

East Bounding Longitude: -13.08204

North Bounding Latitude: 62.57812

South Bounding Latitude: 68.02734

Constraints: Access to data is governed by Commission delegated regulation (EU) No 1159/13 of 12.7.2013 supplementing Regulation (EU) No 911/2010 of the European Parliament and of the Council on the European

Earth monitoring programme (GMES) by establishing registration and licensing conditions for GMES users and defining criteria for restricting access to GMES dedicated data and GMES service information. [http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32013R1159]Although Regulation (EU) No 911/2010 was repealed by Regulation (EU) No 377/2014 of the European Parliament and of the Council of 3 April 2014 establishing the Copernicus Programme, any measure adopted on the basis of Regulation (EU) No 911/2010 shall remain valid under Article 33 (2) of Regulation (EU) No 377/2014 [http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.122.01.0044.01.ENG].Without prejudice to the provisions contained in the Commission delegated regulation (EU) No 1159/13 (in particular under Chapters 2 and 3), free, full and open access to this data set is made on the conditions that:1. When distributing or communicating Copernicus dedicated data and Copernicus service information to the public, users shall inform the public of the source of that data and information.2. Users shall make sure not to convey the impression to the public that the user's activities are officially endorsed by the Union.3. Where that data or information has been adapted or modified, the user shall clearly state this.In addition, articles I.10.2 (ownership/use of results) and I.10.4 (visibility) of grant agreement for an action established between EEA and the “participating country” for implementing the pan-European continental component of the Copernicus Land Monitoring service also apply, implying that any information and data produced in the framework of the action shall be the sole property of the European Union and that any communication and publication by the beneficiary shall acknowledge that the action was carried out “with funding by the European Union”.

Legal Constraints:

Access Constraints: Other Restrictions

Other Constraints: no limitations

Distribution

Distribution Format:

Format Name: SHP

Format Version: 6,2

Transfer Options:

URL: http://gis.lmi.is/geoserver/LMI_vektor/ows?
http://atlas.lmi.is/LmiData/ **and** http://gis.lmi.is/geoserver/wfs

Function: Download

Quality

Scope: Dataset

Conformance Result:

Validation Performed:

Explanation: See the referenced specification

Specification:

Title: Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services

Date: 2010-12-08

Date Type: Publication Date

Lineage: The Corine Land Cover database for Iceland has been updated for the reference year 2012. Main objective of the project was the detection, identification and mapping of all land cover changes larger than 5 ha. Satellite images acquired in 2011 and 2012 served as the basis for image interpretation. Topographic maps, GoogleEarth and high resolution public map services (e.g. ja.is) were used to support the interpretation process.

The latest version of the InterCange Support Package software (InterChange 3.1) was used for computer assisted visual photo-interpretation. Main steps of the processing were the following: 1. Revision of CLC2006 data layer, 2. Interpretation of CLC changes 2006-2012 and 3. Creation of CLC2012 data layer by integration of CLC2006 and CLC changes 2006-2012 data.