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Mapping *Lupinus nootkatensis* in Iceland using SPOT 5 images

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Master degree thesis, 30 credits in *Physical Geography*

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ABSTRACT

Seeds and roots of *Lupinus nootkatensis* were imported to Iceland from Alaska in 1945 for the purpose of testing it as a re-vegetation plant for eroded land. It has turned out to be an effective and relatively inexpensive plant for re-vegetation, mainly because of its fast growth, high biomass contribution to soil fertility, and its capability to spread. Its ability to spread has however become an increasing worry and is currently seen by many as a disadvantage. *Lupinus nootkatensis* has been recognized as an alien invasive plant in Iceland that can invade well vegetated areas including native heathland. Thus the use of *Lupinus nootkatensis* in re-vegetation of eroded land has become debatable.

Invasive species may not only have negative impact on ecosystems and natural processes but also cause economic cost. For management and any planning of controlling the spread of *Lupinus nootkatensis* in Iceland the knowledge of its distribution is fundamental.

The aim of this study is to develop a remote sensing based methodology for mapping and monitoring the distribution of *Lupinus nootkatensis* in Iceland. Remote sensing has not been used for this purpose in Iceland before.

Field work was carried out in a 45 km^2 study area near Reykjavik in SW Iceland. Within the area both land cover plots for mapping and plots for evaluation of accuracy were sampled. The study involved designing a methodology to map *Lupinus nootkatensis* within the study area based on field sampling. This was done by use of supervised and unsupervised classification, applied on SPOT 5 imagery. These classification procedures were also used to map the occurrences of *Lupinus nootkatensis* within a larger area within the Reykjanes peninsula in SW Iceland.

Whereas the two classification procedures (unsupervised and supervised) gave similar results, the absolute highest classification accuracies were obtained by means of the maximum likelihood supervised classification based on the NIR, red, green and MIR bands of the image. This classification procedure gave 94-95% producer accuracy and 90-97% user accuracy, and an overall Kappa of 0.88 within the study area. Similar classification results were obtained within the larger area outside urban areas, but within urban areas low classification accuracies were obtained.

The study shows that both unsupervised and supervised classification procedures of SPOT 5 images may be used in SW Iceland to detect dense *Lupinus nootkatensis* patches.

Keywords: Geography, physical geography, alien invasive species, remote sensing, maximum likelihood classification, unsupervised classification.

Sammanfattning (abstract in Swedish)

Frön och rötter från *Lupinus nootkatensis* infördes till Island år 1945 med syftet att undersöka artens potential att bidra till återställandet av eroderad mark. Arten, som ursprungligen kommer från Alaska, visade sig vara mycket effektiv i samband med detta och dessutom kostnadseffektiv. Resultaten beror framförallt på *Lupinus nootkatensis* betydande biomassa, som förbättrar jordens bördighet, men artens snabba spridningsmönster bidrar också dess efektivitet. Under senare år har kunskapen om *Lupinus nootkatensis* ökat och den goda spridningsförmågan har identifierats som ett problem, eftersom den hotar den biologiska mångfalden på Island. Arten anses idag av många vara en främmande art, som kan invadera och ta över områden, som är täckta med naturlig isländsk flora. Användandet av *Lupinus nootkatensis* för återställande av skadade markytor är därför mycket omdebatterad.

Omfattande spridning av främmande arter kan ha negativ påverkan på ekosystem och naturliga processer samt leda till ekonomiska förluster. God kunskap om utbredningen av *Lupinus nootkatensis* är grundläggande för planering av åtgärder för begränsning av växtens spridning.

Syftet med denna studie är att utveckla en fjärranalysbaserad metod, som kan användas för att observera och övervaka *Lupinus nootkatensis* utbredning på Island. Fjärranalysbaserade metoder har inte tidigare använts för detta ändamål på Island.

Fältarbetet inom ett 45 km^2 stort studieområde nära Reykjavik på sydvästra Island omfattade lokalisering av prov ytor (*plots*) för kartläggning respektive validering av noggrannhet. Studien omfattade utveckling av metodik som inkluderade användning av fältarbetets resultat för att identifiera *Lupinus nootkatensis* inom studieområdet. För detta används okontrollerade och kontrollerade (*unsupervised* och *supervised*) klassningsmetoder tillämpade på jordresurssatellitdata (SPOT 5). Dessa klassningsmetoder undersöktes även för att identifiera förekomsten av *Lupinus nootkatensis* inom ett större geografiskt område på Reykjaneshalvön på sydvästra Island.

De båda klassningsmetoderna (okontollerad och kontrollerad) gav likartade resultat. Den högsta klassningsnoggrannheten erhölls med en kontrollerad klassningsmetod *maximum likelihood* klassning, baserad på de spektrala banden närainfrarött, rött, grönt och mellaninfrarött. Denna klassningsprocedur resulterade i 94-95% producent- och 90-97% användarnoggrannhet och ett Kappavärde på 0.88 för studieområdet. Inom det större geografiska området erhölls liknande resultat utanför tätbebyggda områden men inom tätbebyggda områden var klassningsnoggrannheten lägre.

Studien visar att okontollerad och kontollerad klassning av SPOT 5 data kan användas på sydvästra Island för att identifiera och lokalisera områden tättbevuxna med *Lupinus nootkatensis.*

ÚTDRÁTTUR (ABSTRACT IN ICELANDIC)

Árið 1945 voru nokkrar rætur og fræ af alaskalúpínu *(Lupinus nootkatensis)* flutt inn til Íslands frá Alaska til að kanna möguleika á að nota tegundina í landgræðslu. Lúpínan hefur verið talin áhrifarík og ódýr uppgræðslutegund. Það skýrist helst með hraðri og mikilli uppbyggingu lífmassa sem eykur frjósemi jarðvegs við rotnun, og einnig með mikilli dreifingarhæfni plöntunnar. Lúpínan hefur dreifst hratt út og verið skilgreind sem ágeng framandi tegund á Íslandi. Hún getur jafnvel yfirtekið vel gróin svæði þar sem fyrir er náttúrulegur gróður. Notkun lúpínu til uppgræðslu hefur því orðið umdeild á síðari árum.

Ágengar framandi tegundir geta haft neikvæð áhrif á vistkerfi og ýmsa ferla í náttúrunni og valdið fjárhagslegum skaða. Þekking á útbreiðslu lúpínu er grundvallaratriði í skipulagningu á stjórnun aðgerða gegn útbreiðslu plöntunnar og ágengni hennar.

Markmið þessarar rannsóknar er að þróa aðferð byggða á fjarkönnun, sem má nota til að rannsaka og fylgjast með útbreiðslu alaskalúpínu á Íslandi. Fjarkönnun hefur ekki verið notuð í þessum tilgangi á Íslandi áður.

Vettvangsvinna fór fram innan 45 km^2 rannsóknarsvæðis í nágrenni Reykjavíkur. Hún fól í sér að staðsetja tvennskonar reiti, annarsvegar til notkunar við kortlagningu og hins vegar við mat á nákvæmni kortlagningar. Skráð var yfirborðsgerð reitanna í fyrra tilvikinu og í því seinna var skráð hvort reitur var með eða án lúpínu. Þróuð var aðferðafræði, þar sem niðurstöður vettvangsmælinga voru notaðar til að kortleggja útbreiðslu lúpínu af SPOT 5 gervitunglamynd innan rannsóknarsvæðisins. Til þess voru notaðar tvær flokkunaraðferðir, annars vegar sjálfvirk flokkun (*unsupervised classification*) og hins vegar stýrð flokkun (*supervised classification*). Sú síðarnefnda var einnig notuð til að kortleggja lúpínu á stærra svæði, umhverfis rannsóknarsvæðið, sem náði yfir Reykjanesskaga, hluta Ölfuss og höfuðborgarsvæðið.

Sjálfvirk og stýrð flokkun gáfu svipaðar niðurstöður, en mest greiningarnákvæmni náðist með stýrðri flokkunaraðferð, *maximum likelihood,* sem var beitt á nærinnrautt, rautt, grænt og miðinnrautt band gervitunglamyndarinnar, innan rannsóknarsvæðisins. Nákvæmni flokkunar var reiknuð út á þrjá vegu. Í fyrst lagi hvernig vettvangsreitir með og án lúpínu flokkuðust (*producer accuracy*). Þá fékkst mest 94-95% nákvæmni. Í öðru lagi hvernig flokkun í hverri einingu gervitunglamyndarinnar (*pixel*) samsvaraði greiningu á sama stað á jörðu niðri (*user accuracy*). Þá fékkst mest 90-97%. Í þriðja lagi var reiknaður Kappastuðull, sem var hæstur 0,88 sem þýðir að viðkomandi flokkun er 88% betri en tilviljunarkennd flokkun (*"true" agreement versus "chance" agreement*). Svipuð greiningarnákvæmni fékkst innan stærra svæðisins utan þéttbýlis, en nákvæmni greiningarniðurstaðna á var hins vegar lág innan þéttbýlissvæða.

Rannsóknin sýnir að bæði má nota sjálfvirku og stýrðu aðferðina til að greina þéttar lúpínubreiður á SPOT 5 gervitunglamyndum á suðvesturlandi.

CONTENTS

TERMINOLOGY

LISTED IN ALPHABETICAL ORDER

Alien invasive species: an alien species that threaten biological diversity (Náttúrufræðistofnun Íslands and Landgræðsla ríkisins, 2011) .

Alien species: an animal, plant or microbe that has been moved from its habitat by humans, any part of the organism such as seeds, eggs, roots or other part of a plant (Menja von Schmalensee, 2010a, Náttúrufræðistofnun Íslands and Landgræðsla ríkisins, 2011).

DN value: digital number; satellite images consist of pixels, each pixel has its specific digital number (DN value with interval 0-255), which represent the spectral reflectance, in the image, from the earth surface to the sensor (Lillesand et al., 2008).

Geographical Information System (GIS): "...integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information." (ESRI GIS.com, 2011).

Invasive species: aggressive hostile species that threaten biological diversity, it spreads rapidly by its own, they can have negative impact on ecosystems and natural processes and are liable to cause damage to economy, environment or human health (Menja von Schmalensee, 2010a, Náttúrufræðistofnun Íslands and Landgræðsla ríkisins, 2011). They are mainly brought through human transport, few areas remain untouched of these immigrations (Mack et al., 2000).

Irradiance: the density of radiation incident on a given surface usually expressed in watts per square centimeter or square meter (Merriam-Webster, 2011)

Jökulhlaup: glacier burst.

Landbúnaðarháskóli Íslands: The Agricultural University of Iceland [http://lbhi.is].

Landgræðsla ríkisins: The Soil Conservation Service of Iceland [http://land.is/].

Landmælingar Íslands: The National Land Survey of Iceland [http://lmi.is/].

Loftmyndir ehf.: a company in Iceland that concentrates on cartography and geographical data processing [http://www.loftmyndir.is/].

Lupinus: Lupinus Nootkatensis, nootka lupine (English), alaskalúpína (Icelandic), alaskanlupiini (Finnish) and sandlupin (Norwegian and Swedish).

Lupinus patches: an area covered with *Lupinus*.

Maximum likelihood: supervised classification method to classify pixels in satellite images. It enables all unknown pixels in the image to be categorised, into the classes that has the statistically highest likelihood of occurrence, based on the mean, variance and covariance, of the spectral responses over all bands for each class included in the training data. (Eastman, 2006, Lillesand et al., 2008).

MIR: Mid infrared.

Native or natural species: natural species that is inborn and has developed in its habitat or arrived there naturally (Menja von Schmalensee, 2010a, Náttúrufræðistofnun Íslands and Landgræðsla ríkisins, 2011).

Naturalised species: Alien species that is accepted and is self-sustaining and has started to grow naturally in its habitat (Menja von Schmalensee, 2010a).

Náttúrufræðistofnun: The Icelandic Institute of Natural History [http://www.ni.is/].

Náttúruvefsjá: A web browser for natural phenomenon in Iceland [http://www.natturuvefsja.is/vefsja/].

NIR: Near infrared.

Remote sensing: The science that observes object from afar without contact with the object (Lillesand et al., 2008).

Spatial resolution: specifies the pixel size of satellite images (Satellite Imaging Corporation, 2011), pixels is the smallest unit of a satellite image.

Spectral resolution: specifies the number of spectral bands in which the sensor can collect reflected radiance. Important aspects of spectral resolution are the number of bands and the position of bands in the electromagnetic spectrum. (Satellite Imaging Corporation, 2011).

SPOT: Système Probatoire d'Observation de la Terre; is a satellite that provides satellite images of the surface of the earth, operating from the space.

Supervised classification: an image classification method "…, the software system delineates specific land cover types based on statistical characterization data drawn from known examples in the image (known as training sites)." (Eastman, 2006).

Unsupervised classification: an image classification method "…, clustering software is used to uncover the commonly occurring land cover types, with the analyst providing interpretations of those cover types at a later stage." (Eastman, 2006).

Introduction

Invasive species

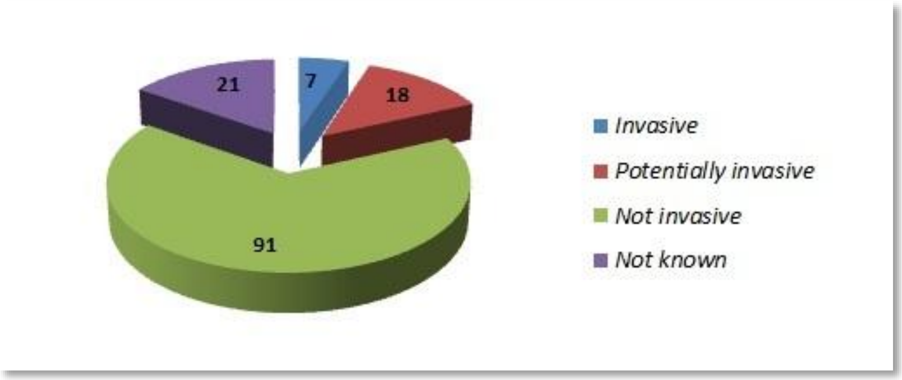
Globalization with increasing global trade and movement of humans and goods are the drivers behind introduction of alien species into new areas (McGeoch et al., 2010). Approximately 100 000 - 550 000 alien species are found worldwide (Menja von Schmalensee, 2010a). Some of them may have negative impact on ecosystems and natural processes and cause economic damage (Mack et al., 2000, McGeoch et al., 2010, Millenium Ecosystem Assessment, 2005). Only small part of alien species prospers and become naturalised, and only small part of those become invasive (Mack et al., 2000). McGeoch et al. (2010) assessed that over 500 alien species worldwide have a negative impact on biodiversity. The reasons for a species to become invasive are many, such as release from predators or parasites, that threaten them in their native habitat, in the new home or some disturbances caused by humans enable, prepare or accelerate its establishment (Mack et al., 2000). It is likely that the number of alien invasive species will increase in the world in the future due to climate change so it is important to manage them and limit their distribution (Menja von Schmalensee, 2010a). It is known that *Lupinus nootkatensis* and other invasive species have harmed natural ecosystems extensively (Borgþór Magnússon, 1995).

According to Mack et al. (2000) the effects that alien invasive plants can cause in natural ecosystems are many. They can increase the fire severity, alter nutrient cycling, hydrology and energy budgets and decrease the abundance or survival of native species. Alien invasive species disrupt processes that supply services in natural ecosystems, create homogeneous ecosystem and are regarded the second greatest threat to species extinction, after habitat destruction (Menja von Schmalensee, 2010a, Pejchar and Mooney, 2009). Invasive alien species have taken their place alongside human-caused changes as major agents of global environmental change (Mack et al., 2000, Pejchar and Mooney, 2009). The changes that invasive species cause can have global consequences like alteration of goods (e.g. fisheries and agriculture) and services (e.g. drinking water and pollination) (Pejchar and Mooney, 2009).

Spread of an alien invasive plant species in a new area classically starts with a small and localized population which may last for long periods (often decades), often called a lag-phase (Hobbs and Humphries, 1995). Then a sudden increase in growth follows and the reasons for that may vary, including changes in environmental conditions that becomes a trigger, such as a mud flow (Hobbs and Humphries, 1995). Such an example is known from South Iceland when *Lupinus nootkatensis* started to diffuse rapidly in the years between 1982 and 1988 on a braided river plain in Morsárdalur (Svavarsdóttir et al., 2004, Þórunn Pétursdóttir, 2003). The driver for this kind of spread could be the modification of the habitat and the dominance of the invasive plant species is therefore an indirect cause of the loss of native species (Didham et al., 2005). Habitat fragmentation may affect the invasive species spreading possibilities by increasing the spread above threshold levels or by decreasing the potential or the competitive abilities of native species to resist invasion (With, 2002). It is important to consider how land use can affect the dispersal of seeds and high risk areas often occur adjacent to currently invaded areas. Human activities such as land use changes can enhance the risk of invasion by alien species (Bradley and Mustard, 2006).

The international and national policy responses to problems associated with the invasion by alien species have been significant during the last decades (McGeoch et al., 2010). Mack et al. (2000) suggests that the "guilty until proven innocent" approach should be used in the control of naturalised invasive alien species. Long-term ecosystem-wide perspective is needed on the effects of invasive species because effects of many invaders changes over time and it will help to improve the ability to generalise from case-studies and to evaluate alternative management approaches (Mack et al., 2000, Strayer et al., 2006). Continuing efficiency and commitments should be made to increase understanding and management of the impacts (Mack et al., 2000). It is also important to understand the effect of landscape structure for management of the spread of invasion (With, 2002).

The Icelandic flora and fauna have been regarded relatively poor in numbers. However variability within species is large and several populations and ecosystems in Iceland have high conservation value (Menja von Schmalensee, 2010b). Alien species has been categorized into four main groups of which three of them descries a known effect (invasive, potentially invasive and not invasive) and the fourth group covers all species in an area that are recognized as alien but with an unknown effect regarding invasiveness (NOBANIS, 2011). There are at least 135 alien species in Iceland, of which 21 or about 15% are alien species with a still unknown effect. The rest, 116 species, are categorized into one of the three above mentioned groups with a known effect regarding invasiveness. Seven (or about 6%) of these 116 species are considered invasive (NOBANIS, 2011). *Lupinus nootkatensis*, which is of a special interest in this study, is one of them. Many other species (about 16% of the alien species with known effect) that are considered potentially invasive could follow and be a threat to native species and natural ecosystem in the future (Menja von Schmalensee, 2010b, NOBANIS, 2011). For comparison the NOBANIS region, which consists of 17 countries in north and central Europe, have 16 216 species that are considered alien. For about 65% of these species the effect on invasiveness is still unknown. The remaining (35%), has known effects and fall into about 19% that are considered invasive and about 11% potentially invasive (see figure 1) (NOBANIS, 2011).



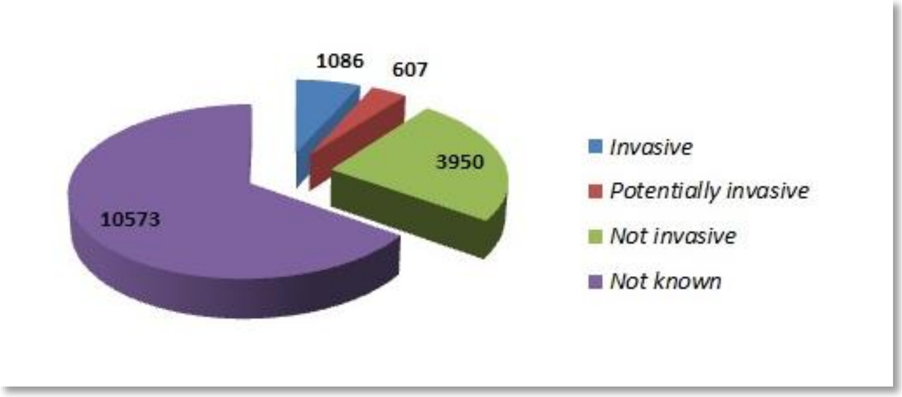


Figure 1. The number of alien species within four main groups: invasive species, potentially invasive species, not invasive species and alien species with an unknown effect regarding invasiveness. The figure above is valid for Iceland. The figure below is valid for the NOBANIS region (north and central Europe) (NOBANIS, 2011).

LUPINUS NOOTKATENSIS

Lupinus nootkatensis (hereafter only genus name used) is identified as an alien invasive plant in Iceland (Magnusson, 2010, Náttúrufræðistofnun Íslands and Landgræðsla ríkisins, 2010) and is one of the first invasive species that spreads in Iceland (Náttúrufræðistofnun Íslands and Landgræðsla ríkisins, 2010).

Lupinus is perennial plant, has high growing rate and can reach the height of about 10 cm in its first year with only one stem (Figure 2). At the age of 2-3 years it usually has 3-5 stems and can reach the height of about 60 cm when it blooms and produces seeds for the first time (Borgþór Magnússon, 1995) and has reached its full height (Rannveig Thoroddsen et al., 2009). It can probably reach the age of 30 years in good conditions and can have up to 100 stems and the average height is 40-120 cm. Figures 3 and 4 shows *Lupinus* plants in different age. (Borgþór Magnússon et al., 2003).

The plant reproduces by self-fertilisation and majority of young plants are located 1-3 m from the mother plant (Magnusson, 2010). It can however disperse considerably further downhill and along rivers and streams (Figures 4 and 5) (Daði Björnsson, 1997) and also by strong wind (Magnusson, 2010). Seeding by human activity is the most common dispersal agent for introduction of *Lupinus* into a new area in Iceland (Menja von Schmalensee, 2010b). *Lupinus* matures relatively early, the growth starts in the middle of May and individual plants are mostly fully grown at the end of June. Flowering starts early in June and the seeds mature in the beginning of August (see figure 6) (Borgþór Magnússon, 1995).

Figure 2. Young Lupinus nootkatensis plants in their early first year, growing in moss heath land. Circles show their locations.

Figure 3. Lupinus nootkatensis plants that have invaded areas that are fully covered with moss heath land. Some plants are in their first year with 1-3 stems and have not bloomed yet. Others plants are older and have many stem and have bloomed.

Figure 4 Lupinus nootkatensis plants in different age have settled into gravel plain. The Lupinus nootkatensis reproduces by self-fertilisation and the plant may disperse rapidly downhill.

Figure 5 Dispersal of the Lupinus nootkatensis plant is common along rivers and streams.

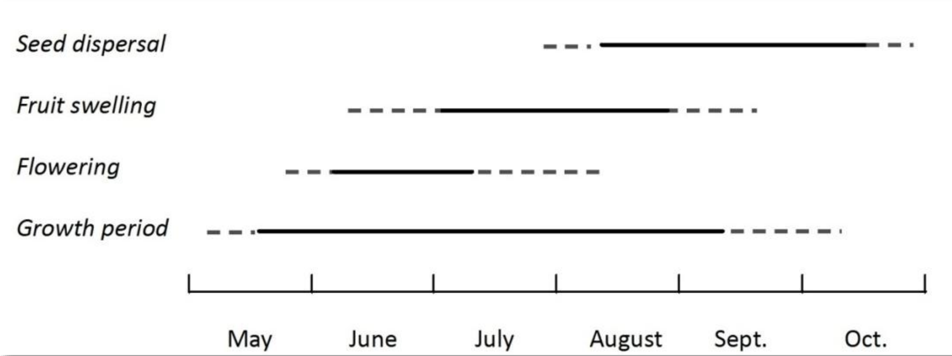


Figure 6. The phenology of Lupinus nootkatensis plants growing in Keldnaholt (Reykjavik, Iceland). Observations of phenological stages were carried over three years in 1987, 1988 and 1993. Solid lines indicate that a considerable part of the population was seen in that stage every year, dashed lines that few plants were seen in that stage. (Borgþór Magnússon, 1995).

Erosion is a serious problem in Iceland (Arnalds and Grétarsson, 2001, Arnalds et al., 2001). *Lupinus* has been seen as an effective and fairly inexpensive tool in reclamation (Borgþór Magnússon et al., 2003, Náttúrufræðistofnun Íslands and Landgræðsla ríkisins, 2010). The plant is tall and grows in wide dense patches. Being a legume it lives in symbiosis with the nitrogen fixating bacteria, *Rhizobium* (Borgþór Magnússon et al., 2003). Therefore no extra fertilizer is needed when or after sawing as long as the seeds are inoculated with the bacteria. In addition the *Lupinus nootkantensis* has a large biomass and when decomposed it contributes to the fertility of the soil (Borgþór Magnússon et al., 2003). *Lupinus* has many factors that are known to characterise invasive relative to native species, such as higher rate of growth, better water utilisation, more grazing endurance, earlier start of blooming time and/or lasting longer, more photosynthesis, higher leaf area index (LAI), seeds sprout early and high survival rate of seedlings (Menja von Schmalensee, 2010a). In addition to these factors the *Lupinus* is higher than most native plants in Iceland advancing the plant in competition for light. Thus *Lupinus* has a good chance of becoming invasive in several places in Iceland.

The history of *Lupinus* in Iceland is over a century long, however its history in reclamation is about 60 years old. *Lupinus* was first recorded in Iceland in 1885 when sowed in plant experiment (Borgþór Magnússon, 1995). Approximately two tablespoons of seeds and few roots of *Lupinus* were imported from Alaska to Iceland in 1945 for the purpose of testing it in reclamation. Plants were cultivated from this and used for land reclamation in barren areas in several places in Iceland (Borgþór Magnússon, 1995). In 1960 effective distribution started by the Icelandic Forestry Service. Later in 1986, the Soil Conservation Service in Iceland started to cultivate and harvest seeds from the plant and sow it in eroded areas (Magnusson, 2010), mostly in sand- and gravel plains, for land reclamation (Náttúrufræðistofnun Íslands and Landgræðsla ríkisins, 2010). The spread of *Lupinus* has mainly increased after 1990 (Náttúrufræðistofnun Íslands and Landgræðsla ríkisins, 2010). Currently the species has established in all lowlands areas and the lower highland in the southwest and northeast Iceland (Magnusson, 2010). The growth and dissemination of *Lupinus* in Iceland is best in high precipitation areas and its conditions for growth are best in south Iceland (Borgþór Magnússon et al., 2003, Magnusson, 2010). Its habitats in Iceland are mostly in disturbed areas, grass and heath lands, riparian zones, rocks and lava fields (NOBANIS, 2011).

Sheep grazing is so far the primary factor that seems to limit its distribution. Since 1991 has been a growing insect grazing of *Lupinus*, followed by withdraw of the plant in quite big areas. It is uncertain whether this is caused by insect grazing or some other factors (Halldórsson, 2011). Studies on this are just getting started in Iceland. Methods that have been tried to eliminate or control *Lupinus* are to cut or poison the plants before flowering (Borgþór Magnússon, 1995, Magnús Jóhannsson and Anne Bau, 2009, Náttúrufræðistofnun Íslands and Landgræðsla ríkisins, 2010). Despite these approaches the seed survives in the soil for years, possible decades and a new generation of plants will grow up, therefore any activity for control needs to be repeated until seed bank has been eliminated (Magnús Jóhannsson and Anne Bau, 2009).

In recent years it has been observed in some places in Iceland that *Lupinus* improves conditions for other alien species such as cow parsley (*Anthriscus sylvestris*) that then may take over old *Lupinus* patches (see figure 7) (Borgþór Magnússon et al., 2003, Rannveig Thoroddsen et al., 2009) and by that assist another propagation to take place.

Figure 7. The cow parsley (Anthriscus sylvestris) commonly invades areas with old Lupinus nootkatensis.

The damage that the *Lupinus* plants cause in Iceland is mainly when the species invade and overtake areas that are half or fully covered with vegetation such as dwarf-shrub heath lands and moss heath (see figures 8 - 10). In areas where most of the species are lower than 20 cm, *Lupinus* easily displaces native vegetation and reduces species diversity (Borgþór Magnússon et al., 2003, Magnusson, 2010, Náttúrufræðistofnun Íslands and Landgræðsla ríkisins, 2010, Rannveig Thoroddsen et al., 2009). When nitrogen fixing plants alter the chemical composition in the soil they may harm the possibility to reclaim previous vegetation (Menja von Schmalensee, 2010b).

The visual impression of *Lupinus* is large. It has become invasive in some areas and its use in soil conservation management has become debatable (Borgþór Magnússon et al., 2003). There have been a lot of speculations and controversial discussion about the plant, its existence, distribution and if it has a rightful place in Iceland.

Figure 8. Land with native moss heath vegetation in Iceland.

Figure 9. Invasion of Lupinus nootkatensis into moss heath land.

Figure 10. Monotonous landscape covered with Lupinus nootkatensis.

The figures 8-10 illustrate how the land cover changes associated with an invasion by Lupinus nootkatensis.

It is not known exactly how big the areas are in Iceland that the *Lupinus* covers or exactly where they are. In the year of 2009 the Ministry of the Environment assigned the Icelandic Institute of Natural History and the Soil Conservation Service of Iceland to make guidelines for limiting the spread of *Lupinus* (above 400 m) and eradicate from national parks and other areas where it does not belong. In order to do that an attempt was made to estimate and map the distribution of *Lupinus* in Iceland on the basis of information on where it had been seeded or planted, and locations where people, organisations and institutions had found it and informed upon (see figure 11). Finally, guidelines were made to limit the use of *Lupinus* and propositions to eradicate it in certain areas. (Náttúrufræðistofnun Íslands and Landgræðsla ríkisins, 2010).

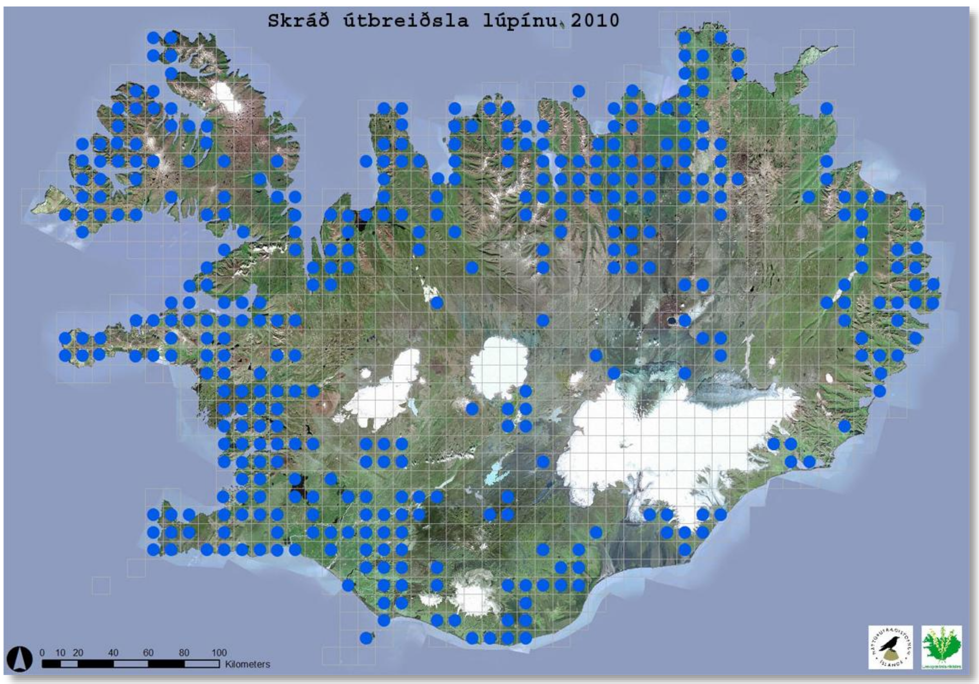


Figure 11. The spatial occurrences of Lupinus nootkatensis plants in Iceland 2010. Every grid cell is 10 x 10 km. Blue dots indicate that Lupinus nootkatensis has been observed or sown/planted somewhere in the area that the grid cell represents (Náttúrufræðistofnun Íslands and Landgræðsla ríkisins, 2011).

From late 1970s Icelandic scientists have studied biology and ecology of *Lupinus* (Magnusson, 2010). Researchers have since shown the subject increased interest in the last decades. That has led to more knowledge and understanding of its development and behaviour which contributes to better management and control of the use of the plant and its propagation (Magnusson, 2010).

Remote sensing

Different surfaces on earth have different spectral reflectance depending on, for example, the irradiance and the temperature, chemical composition and texture of surfaces. Remote sensing is the science that observes objects from afar without contact with the object (Lillesand et al., 2008). Various satellite sensors differ in spectral and radiometric resolution and their images differ in spatial resolutions. These factors limit the recognition potential of an object on the surface of the earth and also the classification possibilities of the object. The spatial and spectral resolution limits the ground observation such that the scale of observation should not be smaller than the spatial resolution of the satellite image (McCoy, 2005). The image acquisition date is important due to the phenology and growing season (McCoy, 2005).

Passive remote sensing, as used in this study, measures the amount of electromagnetic radiation with the sun as an energy source in different wavebands and scales, is a powerful tool for classification and mapping (Townsend et al., 2009). It is an inexpensive approach for large area study and it is a compromise between the extent of each image and spatial resolution (Chen et al., 2007). All methods using remote sensing require comparison with ground observations (Felinks et al., 1998). Large area classifications require a lot of manpower for collecting data in the field which is an important part but also an expensive part of such studies.

Satellite images with a medium to coarse spatial resolution are useful for vegetation classification in large areas (Franklin and Wulder, 2002, Kofler, 2004). For the most part, it is possible to derive landscape pattern from coarse scale data with high accuracy, still the accuracy will be higher at finer spatial scale (Townsend et al., 2009). Even though it seemed all right to combine data from multiple satellite sensors classifying vegetation, one should be cautious doing that when monitoring and detecting changes (Townsend et al., 2009).

SPOT-5 images have wide imaging swath, which covers 60 x 60 km and provides course to high resolution and wide-area coverage. It has a high resolution panchromatic band but rather low spectral width, which means increased spatial rather than spectral resolution or colour diversity (Corbane et al., 2008).

Currently the SPOT 5 satellite images of Iceland are the ones with highest resolution available locally. Iceland is around 103 000 km^2, the SPOT 5 images that cover the whole country were taken 2002-2009, more than one image in some areas. About 60 SPOT 5 images cover Iceland with overlap and each image shows 3 500 - 4 600 km^2. A mosaic image of the country has been prepared consisting of 79 image parts.

Just a few investigations, using remote sensing classification other than drawing maps on hard copies of aerial photographs or satellite images, have been done in Iceland. Automatic remote sensing processes have mostly been used when measuring the extent of sea ice drifting from Greenland towards and along the shores of Iceland, detecting changes in glaciers and effects of *jökulhlaup*, mapping lava surfaces and doing some meteorological studies. These studies mostly use radar, albedo and lidar data. No study has been done in Iceland using automatic remote sensing processes to identify the extent of invasive alien species as far as can be found in the literature. One of the first projects made in Iceland using automatic remote sensing processes to classify land cover is the project *Nytjaland* that aimed at making a data information service for resources in rural areas in Iceland (Ólafur Arnalds et al., 2001). Landsat 7 and SPOT 5 satellite images were used and maximum likelihood classification to classify land cover into 10 vegetation classes that reflect potential yield with respect to grazing (Ólafur Arnalds et al., 2001). Another study including classification of land cover characteristics was made in Northeast Iceland using Landsat TM satellite images, where lava-, barren sediment-, vegetation- and water/snow- cover were identified, for the purpose of detection of *jökulhlaup* routes by major sand transportation pathways (Alho, 2003). Two, detect changes studies, from before and after a big flood from under the glacier Vatnajökull were done on Skeiðarársandur in South-Iceland, using remote sensing on satellite images from SPOT and Landsat (Kofler, 2004, Shoopala, 2008). Kofler also made classification of vegetation types using maximum likelihood supervised classification.

It is practical to apply remote sensing to investigate the spatial extent of invasive plants and to see the extent of changes in the area in some time intervals. Remote sensing is also applicable to find the relationship between land use and topography on the one hand and invasive species on the other, and how they change over time and to predict future risk of invasion (Bradley and Mustard, 2006). Two studies have been done on the propagation of the *Lupinus* plant in specific places, in Heiðmörk near Reykjavík in SW-Iceland (Daði Björnsson, 1997) and in Morsárdalur in South Iceland (Þórunn Pétursdóttir, 2003), in both cases measurements and overlay analysis is done in a geographical information system (GIS), on aerial photographs, to detect changes in *Lupinus* propagation for some years.

Methods to classify invasive species

To provide land cover maps it is practical to use spatial data such as satellite images, aerial photographs or maps and georeferenced field data, within a geographical information system (GIS). Satellite images consist of pixels, each pixel has its specific digital number (DN value), which represent the spectral reflectance that is reflected from the ground surface that the pixel represents. Different vegetation types have different spectral reflectance. Handling of images can be done in several different ways. Hard copy that is used in the field to draw outlines of the extent of land covers classes or automatic classification processes, as e.g. maximum likelihood, where the reflectance value from each pixel in the image is used to cluster pixels with similar reflectance values and classify the land cover into different land cover types. Other processes featuring different kind of algorithm to prepare the image and its reflectance values for classification like the: normalised difference vegetation index (NDVI), principal components analysis (PCA), support vector machine (SVM) and different kind of geostatistical techniques, ratioing etc.

Several methods have been used to map invasive plants and a few of them will be mentioned here. A maximum likelihood classification, using GLCM algorithm texture analysis, was used to map *Lantana camara L*. in the Himalayan foothills (Kimothi and Dasari, 2010). A support vector machine (SVM) algorithm used for classification of duckweed (*Lemna obscura*) in Lake Maracaibo (northwest Venezuela), by including a bootstrap step during the training phase, gave good result (Castillo et al., 2008). Mapping the spatial extent of cheatgrass (*Bromis tectorum*) by comparing remote sensing and geostatistical techniques, using elevation and soil stratification techniques, to overcome the soil effect on the spectral reflectance from the cheatgrass (Singh et al., 2004). A high spatial and low spectral resolution airborne remote sensing data used to map the Chinese tallow trees (*Sapium sebiferum*) gave high classification accuracy (Ramsey III et al., 2002).

AIMS AND OBJECTIVES

The Ministry of environment in Iceland has initiated a plan to develop a suitable strategy to control and prevent the invasion of *Lupinus,* in several places and eradicate it in other, in order to prevent negative ecological consequences of the spread. Knowledge of the distribution of *Lupinus* is fundamental to develop procedures for actions against the spread and possible invasions of the plant, and also for prioritising actions to halt or reduce its distribution. Also studies aiming to improve actions related to the re-vegetation of eroded surfaces may benefit from improved knowledge of the distribution of *Lupinus*.

The Soil Conservation Service and other institutions in Iceland have taken the initiative to develop remote sensing based methodology to determine and map the distribution of *Lupinus*. The present study is a pilot study for this long term research project.

The overall aim of this study is to develop remotely sensed methods that may be used country-wide in Iceland for detecting and monitoring the distribution of *Lupinus* and for detection of changes in its distribution. Given the extensive areas that need to be inventoried, the methods must be semiautomatic and accurate enough to give good estimation of the distribution of *Lupinus* all over the country. Additionally the methods must be repeatable and it must be possible to compare studies from different seasons and years. Furthermore, the methods must be inexpensive and simple to use for persons without expert knowledge in remote sensing.

In the present study, SPOT 5 images are used to analyse the potential of remotely sensed data for inventorying the distribution in *Lupinus* cover. The following questions are addressed:

Are the methods chosen for field sampling good for this kind of study?

What preliminary studies are needed before the classification?

What are the available satellite images of Iceland and is those data suitable for this study?

Is it possible to detect the plant *Lupinus* from a SPOT 5 satellite image?

Do the field samplings give enough information to detect different frequency of the *Lupinus*?

Is the method used in this pilot study transferable to a larger area?

Do the field samples give a good correlation to the classified image?

Are there some other possible applications for further inspection of the issue?

MATERIAL AND METHODS

STUDY AREA

Iceland is an active volcanic island where earthquakes and volcanic actions are common. It is located on the North Atlantic ridge in the North Atlantic Ocean (63°30'-66°30'N, 13°30'-24°30'W). The rift zone between the North American continental plate and the Eurasian plate runs through Iceland from the north-east to the south-west and the continental plates are rifting apart with a speed of approximately 1 cm per year.

The main study area (approximately 45 km^2 in size) is located in the regions of Heiðmörk and Hafravatn in the vicinity of Reykjavík in SW-Iceland (Figure 12). The bedrock of the area consists of sedimentary layer, lava beds (Dolerit) and lava (Náttúruvefsjá, 2008). The soil is mostly Brown Andosol which is the classical dry-land soil in Iceland, containing a great deal of volcanic ash and small amount of clay particles and Leptosol, the latter consisting mainly of lava and containing small amounts of fine soil particles (Arnalds and Einar Grétarsson, 2002, Landbúnaðraháskóli Íslands and Landgræðsla ríkisins, 2008). Analysis in ArcGIS (information provided by the company Loftmyndir ehf.) shows the overall topography to vary from 40 - 170 m a.s.l. The average daily minimum - maximum temperature is 8.3 - 13.3°C in July and -3.0 - 1.9°C in January, the average annual precipitation being about 800 mm (World Weather Information Service, 2011). The history of the distribution of *Lupinus* within the study area is relatively well known through Andrés Arnalds and Borgþór Magnússon (Andrés Arnalds, 1979, Borgþór Magnússon, 1995) and from previous studies of the spreading tendencies of *Lupinus* (Daði Björnsson, 1997). The study area is located outside grazed areas and is covered mostly by moss and scrubs in lava and lava beds.

An attempt to transfer the method used in this pilot study to a large area of the Reykjanes peninsula in SW Iceland (see figure 13), was done. The Reykjanes peninsula is an active volcanic area. Its bedrock consist mostly of sedimentary layer, lava beds (Dolerit) and lava, in some areas palagonite and pillow lava points to sub glacial eruptions (Náttúruvefsjá, 2008). The soil is

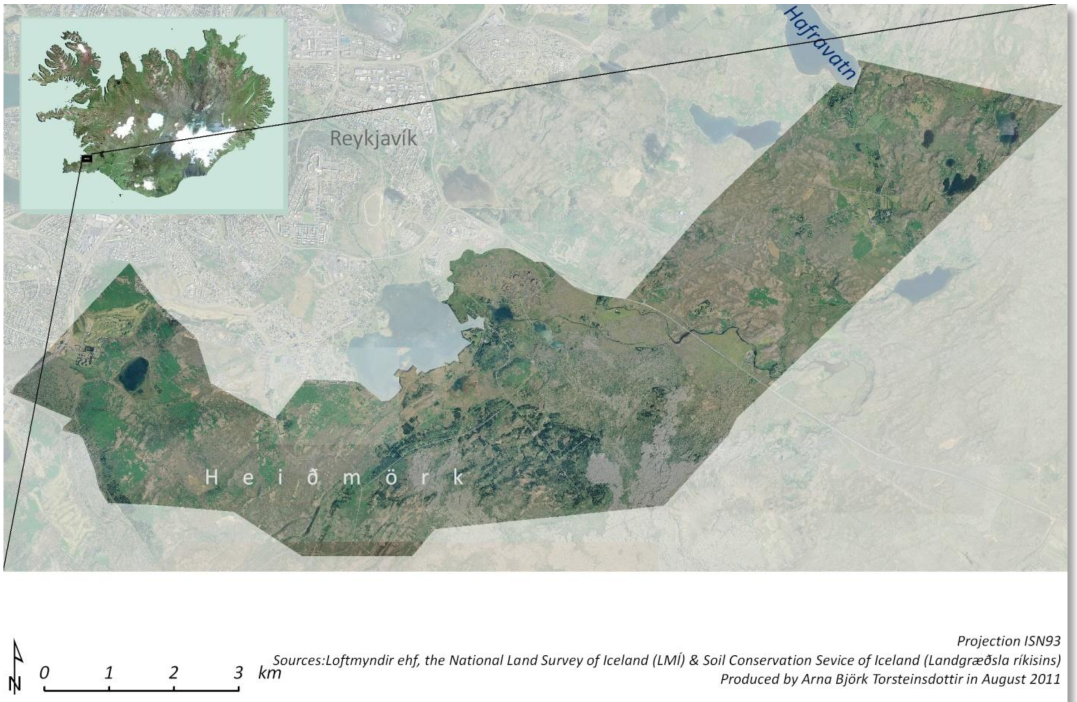


Figure 12. The study area covers the Heidmörk and Hafravatn regions in the vicinity of Reykjavík in SW-Iceland (aerial photograph taken over the study area in 2009).

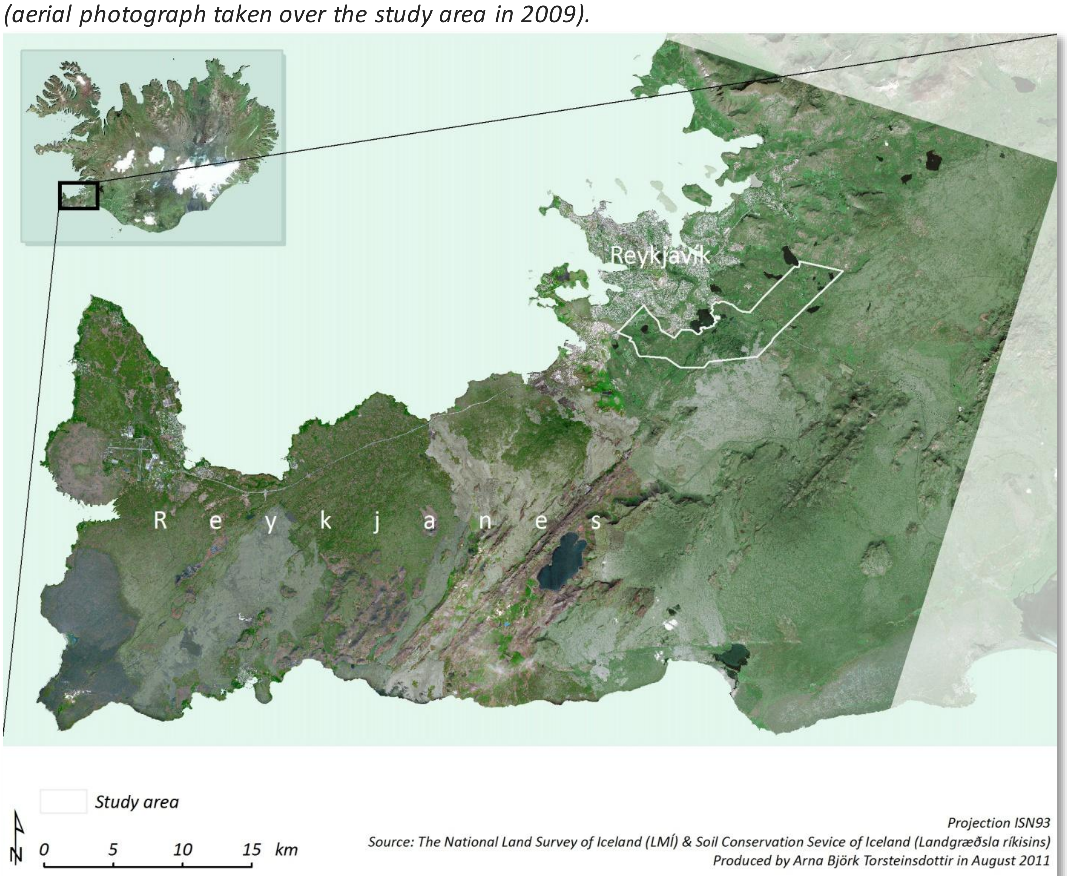


Figure 13. A SPOT 5 images mosaic showing the Reykjanes peninsula in SW Iceland. The study area is marked with white outlines.

mostly Brown Andosol, Leptosol and in some area the soil consist of sand and gravel (Arnalds and Einar Grétarsson, 2002, Landbúnaðraháskóli Íslands and Landgræðsla ríkisins, 2008).

FIELD SAMPLING OF *LUPINUS NOOTKATENSIS*

Field based data were collected and used as training data in the digital classification of satellite data. Field work included the inventory of *Lupinus* cover within 52 sample plots. Each plot was 20 x 20 m (Figure 14). Within each *Lupinus* plot a number of characteristics were noted (see table 1).

Table 1. The vegetation and environmental factors that were registered in each sample plot.

Frequency and pattern of *Lupinus*	**Cover of *Lupinus***	**Other types of vegetation**	**Types of surface**	**Slope**	**Slope direction**
Dense patch [1]	50-100%	Moss	Soil	Flat	N
Dense with freestanding *Lupinus* on edges					NE
	20-50%	Heath/ling	Sand	Machinable [3]	
Small dense knots [2]	0-20%	Grass	Gravel	Not machinable	E
Freestanding plants		Scrubs of birch	Rocks		SE
Row		Scrubs of willow	Lava		S
		Conifer			SW
		Cow parsley (Anthriscus sylvestris)			W
					NW

1 Patches of Lupinus means here, an area covered with Lupinus.
2 Knots of Lupinus means here, an island of Lupinus inside another kind of vegetation or in non-vegetated area.
3 Machinabel means here, that it's being possible to work the land by use of tractors or other machines in sowing or in gathering the seeds.

Based on these characteristics, each sample plots was categorised into one of 20 land-cover classes (Appendix 1). In addition to the field based inventory of plot characteristics, photographs were taken in the sampling plots to support the categorisation of plots into land-cover classes.

To avoid the need of difficult and time-consuming walking tours and to obtain good accessibility to the plots, the plots were selected so as to be located within a distance of 200 m or less from the nearest road present in the study area. The total area of the buffer zone was 19 km^2 (see figure 14). The road data is vector data from The National Land Survey of Iceland measured by GPS and used as an overlay in ArcGIS. To ensure that the plots were spread broadly throughout the area in question and to obtain diversity as well (Stehman et al., 2003), a systematic pattern

(McCoy, 2005) was implemented inside the buffer zones. This was done by laying a 500 x 500 m grid over the buffer zones in ArcGIS such that a sample plot was situated at half of the intersections involved. The starting point for the grid was selected so as to be at an intersection of a grid currently in use in environmental research in Iceland. Some of the plots were moved in order to avoid their being located along edges separating different classes and in effort to obtain clear spectral reflectance on the image of a typical surface class. For each plot, the position was recorded in the middle of it and its characteristics (Table 1) were determined. The accuracy of the position as measured by Magellan Meridian GPS units (position corrected by WAAS/EGNOS) is +/- 3 m (MiTAC International Corporation, 2011, Map-GPS-Info.com, 2011). Five photographs of the plot area were taken, one at each cardinal point along with one sward photograph.

To evaluate the accuracy of the satellite-based classifications, 67 plots, including both ones that contained *Lupinus* patches and ones that did not, were sampled. The plots were selected to be within the same buffer zone and grid that were used when selecting the field based data to use as training data. It was decided to have at least 50 plots, based upon the rule of thumb that at least 30 samples are needed for statistical calculations (Rogerson, 2001) and the study area being considered a small one with only two major categories (Townsend et al., 2009). A combination of two sampling methods was employed (McCoy, 2005). One of the two, a cluster method, involves use of the buffer zone. Five plots were randomly assigned a position in each grid cell. This method provided a systematic unaligned pattern (McCoy, 2005). Thus, all parts of the gridded area were assigned plots randomly. This ensured variation within the area studied (Stehman et al., 2003). In employing this method, 30 plots were assigned to the area that included *Lupinus* plants and 74 plots to the area without *Lupinus*. It was considered to suffice that there were approximately an equal number of plots containing *Lupinus* plants as those not containing them (Lillesand et al., 2008). In line with this the 74 plots, without *Lupinus*, were cut down to 37 by randomly selecting half of them. Thus the 19 km^2 buffer zone within the study area ended up having 67 evaluation plots (Figure 14).

The sample plots represented homogenous land-cover (Lillesand et al., 2008) with regard to the *Lupinus* plants, each of them being at least 20 x 20 m in the case of either a *Lupinus* patch or a patch without *Lupinus*. Any potential evaluation plots that fell on the boundary between two patches, one of them having *Lupinus* and the other not having it, as well as plots that were not readily accessible, were rejected (Stehman et al., 2003). The sample plots used for the evaluation of the digital classification were divided into five different groups. The classes were 1) dense *Lupinus* if cover > 30%, 2) sparse *Lupinus* if cover < 30%, 3) no *Lupinus*, if *Lupinus* was lacking, 4) point rejected, the reason for this being filed, and 5) point not reached, the reason for this being filed.

Since it was assumed that areas with less than 30% *Lupinus* cover would be difficult to use as evaluation plots, it was attempted, in all cases that were uncertain, to evaluate the *Lupinus* cover in a more precise manner than before. It would then be decided on the basis of photographs and aerial ones, whether a reclassification was in order, and if so, which of the other 4 classes was appropriate.

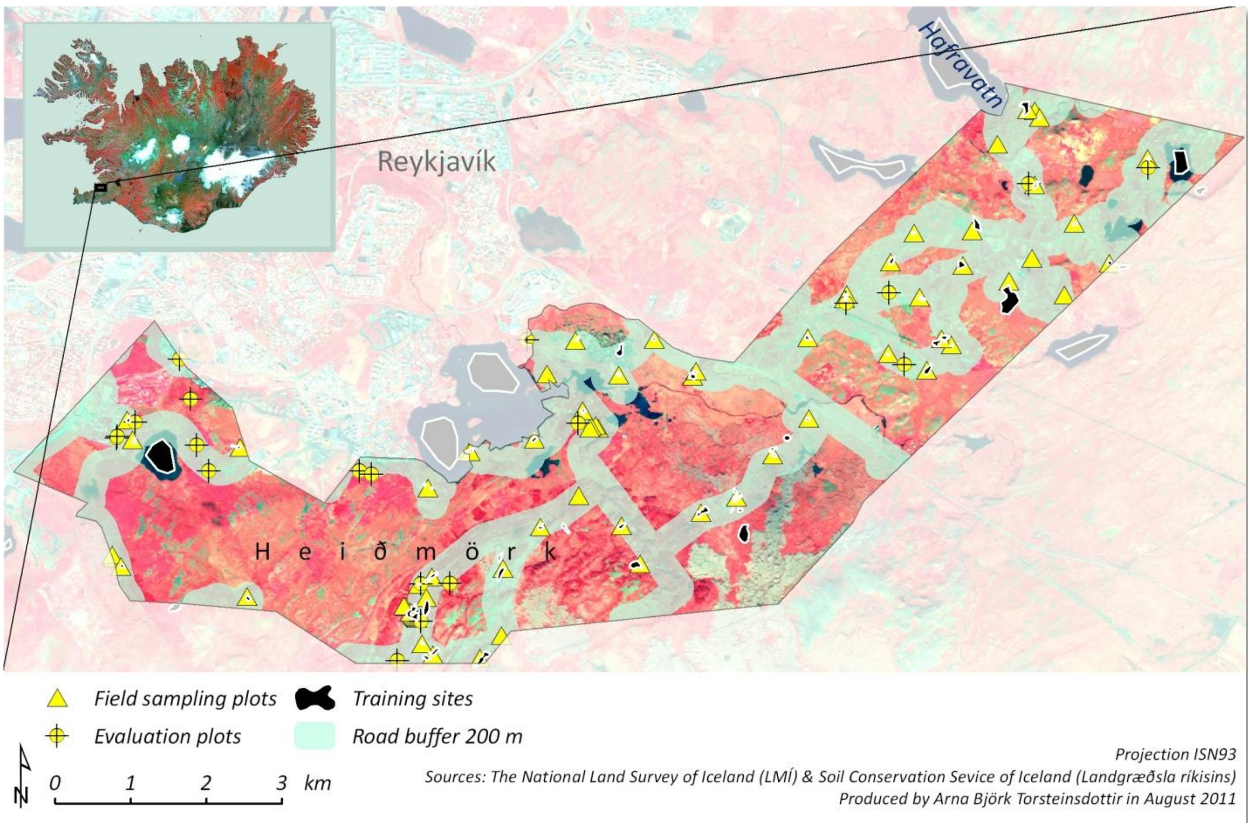


Figure 14. The study area and the 200 m buffer zones overlay a SPOT 5 image. The field sampling and the evaluation plots are marked with yellow points and the small black flecks with white outlines are the training sites that were used for the satellite based classification.

In order to ensure objectivity in the field sampling of *Lupinus*, it is essential that collection procedures be consistent (Stehman et al., 2003). In the present case, two teams of observers were involved. Each team was provided with the same general guidelines in order to avoid as far as possible any variation in how the task was conceived. An approach of this sort is particularly important in large studies that require many observers.

Remotely sensed data

Satellite data

A SPOT 5 image recorded on August 30. 2009 was used in the present study. The image was provided by the Soil Conservation Service of Iceland. The SPOT 5 data consists of three multispectral bands in the green, red, and near-infrared (NIR) region and short-wave infrared band, also termed a mid-infrared (MIR) band, as well as two panchromatic bands having a 5 m spatial resolution. These last mentioned have been combined to generate product with a spatial resolution of 2.5 m (Table 2) (CNES, 2002).

Table 2. Spectral bands in the SPOT 5 images.

Band nr.	Colour	Spectral resolution	Spatial resolution
3	Green	0.50 - 0.59 µm	10 m
2	Red	0.61 - 0.68 µm	10 m
1	Near infrared	0.78 - 0.89 µm	10 m
4	Short wave infrared	1.58 - 1.75 µm	20 m
	Panchromatic	0.48 - 0.71 µm	2.5 m

In order to remove possible distortion of topography the providers of the satellite data generated ortho-rectification at a basic radiometric processing level (CNES, 2002) from the SPOT 5 image. This was supported by the National Land Survey of Iceland (Landmælingar Íslands, 2011b), which provided a digital elevation model (DEM) and for geometric corrections, ground-control points from the road net of Iceland as measured by GPS. Since the accuracy of the roads measurements by means of GPS was +/- 5 m (Landmælingar Íslands, 2011a), it is presumed that the geometrically corrected images had a geometric accuracy within about 5 m (Wang et al., 2005).

Training stage

The program Idrisi Andes was used to draw training sites from the field-based inventory of sample plots (Table 1). Small areas were drawn around the separate plots, each of which was assigned a number to identify the land-cover class of the training site. The DN values of the pixels within each training site class were used to describe the spectral signature of each class (Lillesand et al., 2008, Malik and Husain, 2006). This information was used for classifying the image of the study area in terms of categories of land-cover in the supervised, maximum likelihood classification process. The DN values of the final *Lupinus* class were also plotted into a histogram that provide a visual sight on its spectral response distribution (Lillesand et al., 2008).

Considering if some of the 4 bands should be excluded from the classification process, scatter plots were generated and the regressions between bands were examined. Statistical information about the image is drawn from comparison of the corresponding DN values in the bands and correlation between them. The locations of some of the training areas are included on the bands scatter diagrams in Appendix 3.

Classification of Satellite data

In the computer program IDRISI Andes that was employed, two methods – supervised maximum likelihood and unsupervised classifications respectively – were used in classifying the SPOT 5 image in order to differentiate *Lupinus* from other forms of vegetation. All operations on the image were applied to the DN values.

Preliminary studies of the image used in this study involved visual examination aimed at getting to know the area and looking for clouds and clouds shadows. For detecting these areas, either each band separately or two of them together were clustered by means of unsupervised classification to investigate what band combination captured them best and to enable clouds and shadows, if any, to be masked out from an image prior to classification. The unsupervised classification program is one in which the categories involved are not predetermined, the unknown pixel in the images being clustered into classes on the basis of the natural clusters in the image (Franklin and Wulder, 2002, Lillesand et al., 2008).

An unsupervised classification was carried out in the study area for the purpose of detecting *Lupinus* on the basis of the NIR, red and MIR bands. The green band was left out because of it being the most nebulous one. The classified image was examined carefully by visual inspection in ArcGIS with the aim of determining where there were *Lupinus* plants and where there were none. Unsupervised iterative classification of spectral data was needed for some mixed classes. Spectrally mixed classes including *Lupinus* plants and large areas in between, in which there were no *Lupinus* plants at all, were re-clustered and divided into spectrally cleaner classes with and without *Lupinus* (Franklin and Wulder, 2002). All classes in which dense *Lupinus* was included were combined into a single category and all others into a second category. The map thus obtained, served as background when the evaluation plots were placed partly within and partly outside the classes in which *Lupinus* were included.

A supervised classification was performed by using a maximum likelihood classifier. It enables all unknown pixels in the image to be categorised, into the classes that has the statistically highest likelihood of occurrence, based on the mean, variance and covariance, of the spectral responses over all bands for each class included in the training data. (Eastman, 2006, Lillesand et al., 2008).

Initially a maximum likelihood classification of the study area was carried out. This involved different band combinations: 1) the NIR and MIR bands, 2) the NIR, red and MIR bands and, 3) the NIR, red, green and MIR bands. The maximum-likelihood-classified images were scrutinised in ArcGIS to identify where *Lupinus* was present and where it was not. Spectrally mixed classes were re-clustered employing unsupervised classification. New classes were divided into spectrally cleaner classes with and without *Lupinus*. All classes in which *Lupinus* was found were merged into one class and all the others into another class.

A maximum likelihood classification on a SPOT 5 image of SW Iceland as a whole that covered the Reykjanes peninsula and the area around Reykjavik (Figure 13) was carried out as an attempt to transfer the methodology used in the pilot study to a large area. This involved use of all four colour bands. This image includes the study area and covers approximately 2 000 km^2 (2%) of Iceland. The classification was carried out without any prefabricate as masking out the ocean, clouds and clouds shadows or lakes. Training sites used for this purpose were constructed from the field-based inventory of plot characteristics from the study area in addition with inventory of characteristics of 35 field-based plots, selected the same way as the sample plots in the study area. These 35 additional plots were selected inside the area that the image covers but outside the study area (Figure 15). This time the sample plots were all together, categorised into 31 different land-cover classes (respectively the sample plots were categorised into 20 land cover classes in the case of the study area) (Appendix 2). Spectrally

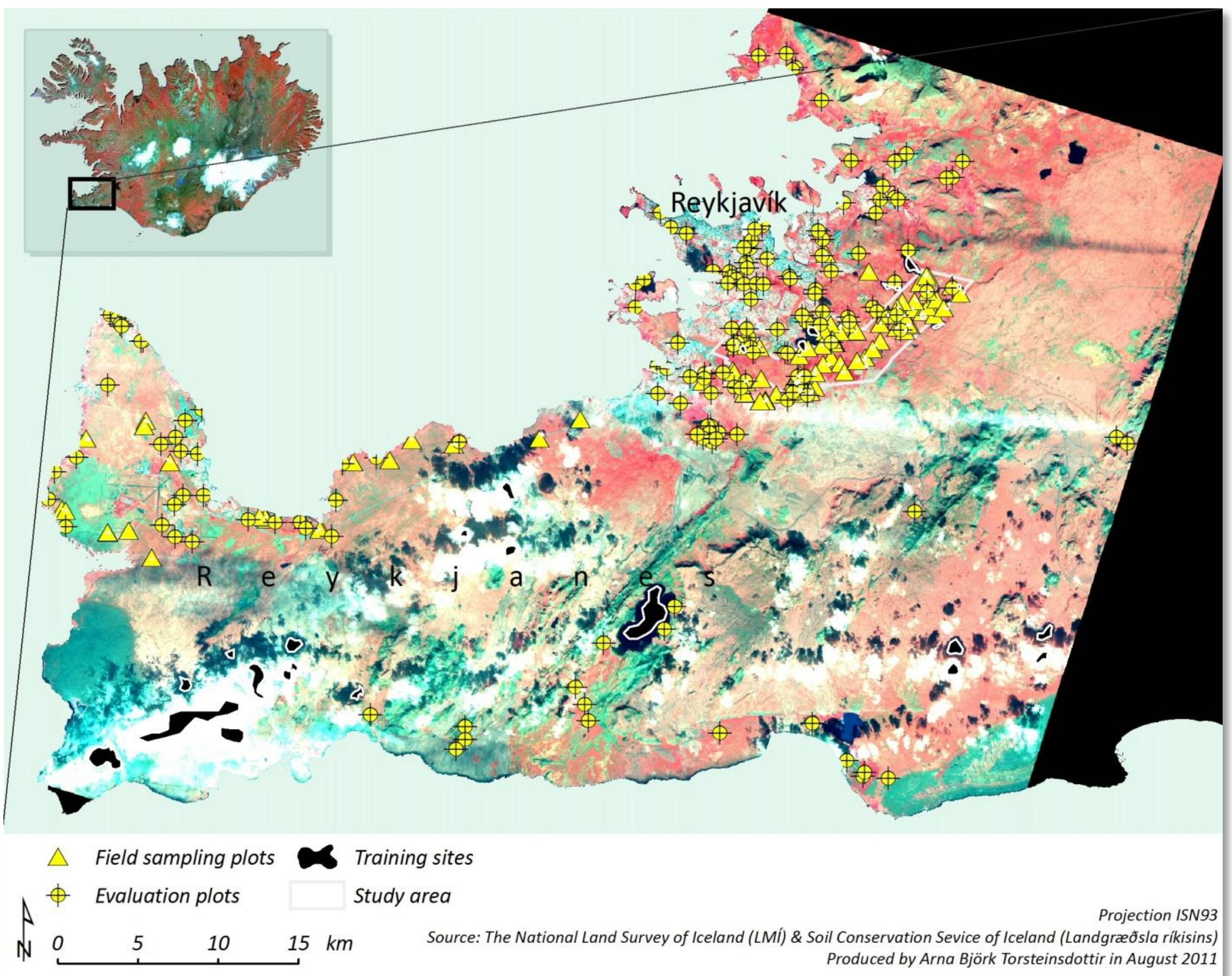


Figure 15. An infrared SPOT 5 image showing the Reykjanes peninsula and the area around Reykjavík. The field sampling and the evaluation plots are marked with yellow points and the small black flecks with white outlines are the training sites that were used for the classification. The image contains a lot of clouds and cloud shadows.

mixed classes with *Lupinus* and variety of other vegetation or surface types were not investigated. No further examinations were done on this classification results other than validation. The evaluation plots (Figure 15) were located the same way as was done for the study area. The validation was executed with evaluation data entirely generated in ArcGIS from aerial photographs that were taken in the years of 2005 to 2009. The aerial photographs are 0.5 m in spatial resolution, provided by the company Loftmyndir ehf.

A visual comparison of the classified data with aerial photographs that was provided by the company Loftmyndir ehf. was carried out in ArcGIS. The aerial photographs, with a spatial resolution of 0.5 m, were taken in the years of 2005 to 2009. The two were compared while examining the categorised classes in terms of splitting and combining some of them during the classification process.

Evaluation of the classification results

To evaluate the accuracy of the classification, Kappa statistics and user and producer accuracy (Lillesand et al., 2008, Malik and Husain, 2006) were calculated on the basis of the error matrix in Idrisi Andes. Pixels were used as validation units. "Users accuracy" explains how well a pixel classified into a specific category, represents that category on the ground. "Producer accuracy" explains how well field sampling of a specific cover type are classified. To calculate overall accuracy total number of correctly classified pixels are divided by total number of evaluation field sample plots. Kappa statistics or Kappa Index of Agreement (KIA) is a measure of the difference between the actual agreement between field sampling and the classified data and the chance agreement between the field sampling and a random classifier ("true" agreement versus "chance" agreement). For example an overall Kappa of 0.96 means that the classification in question is 96% better than one resulting from a chance. “An overall Kappa of 0 suggests that a given classification is no better than a random assignment of pixels”. (Lillesand et al., 2008).

Coordinate system

The projected coordinate system for all the data is ISN 1993, Lambert 1993. The geographic coordinate system is GCS ISN 1993 (Appendix 4).

Results

Field sampling of *Lupinus nootkatensis*

The portion of field based evaluation sample plots were: 37% that contained *Lupinus* patches with dense *Lupinus* cover, 13% that contained patches with sparse *Lupinus* cover, 42% contained no *Lupinus* plants and 8% was rejected of various reasons. After re-classing each plot with sparse *Lupinus* cover into one of the other 3 classes that were considered appropriate, and deleting the rejected plots the final number of evaluation plots had decreased from 67 to 53 plots, 36% was categorised as dense *Lupinus* patches and 64% as no *Lupinus* patches.

Remotely sensed data

Training stage

Each training sites, classified into land-cover types, was analysed and compared in a chart to determine its spectral reflectance in the four colour bands of the image and their separability (Figure 16). The DN value ranges for the land-cover types represented in the training sites had notably the largest distribution in the infrared bands, even more in the NIR band where the DN values scatter from 30 to 255, than in the MIR band where it scatter from 20 to 190. The distribution in the green and the red bands is very little, all classes scatter from DN value 70 to 120 in the green band and from 50 to 120 in the red band. It is not easy to separate between the training areas, they overlap each other frequently, though more in the red and green bands than in the more distributed infrared bands.

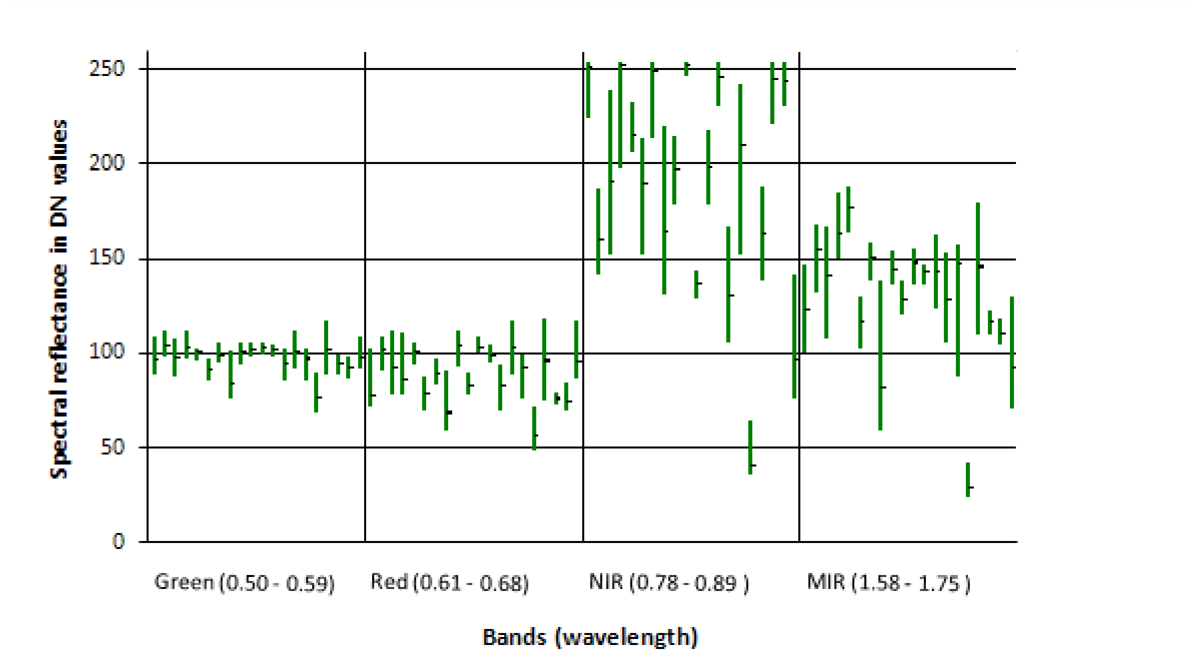


Figure 16. Spectral signature comparison chart showing the spectral response in DN values as expressed in the pixels for each training site class, in each band, for the study area. Bands and wavelength interval for each band are shown on the x-axis and DN values on the y-axis. The green bars in the chart represent the range between minimum and maximum DN value and black dash the average DN value, as expressed in pixels for each of the 20 land-cover classes in each band (the bars in each band counted from left to right match the REC nr. in the list in appendix 1).

After the classification and the thorough examination on the classes and what land-cover they represent, it was decided which of the classes should be merged into the final *Lupinus* class. The spectral signature comparison for the final *Lupinus* class and the four classes that were merged together in the final *Lupinus* class may be observed in a chart in figure 17. The chart illustrates similar reflectance from the training areas that contained *Lupinus* plants within each band, except in the NIR band where bars nr. 11 and 20 both within *Lupinus* cover 20-50%, represent respectively: willow scrubs, and birch and willow scrubs and conifer, are considerabley lower than the other *Lupinus* areas.

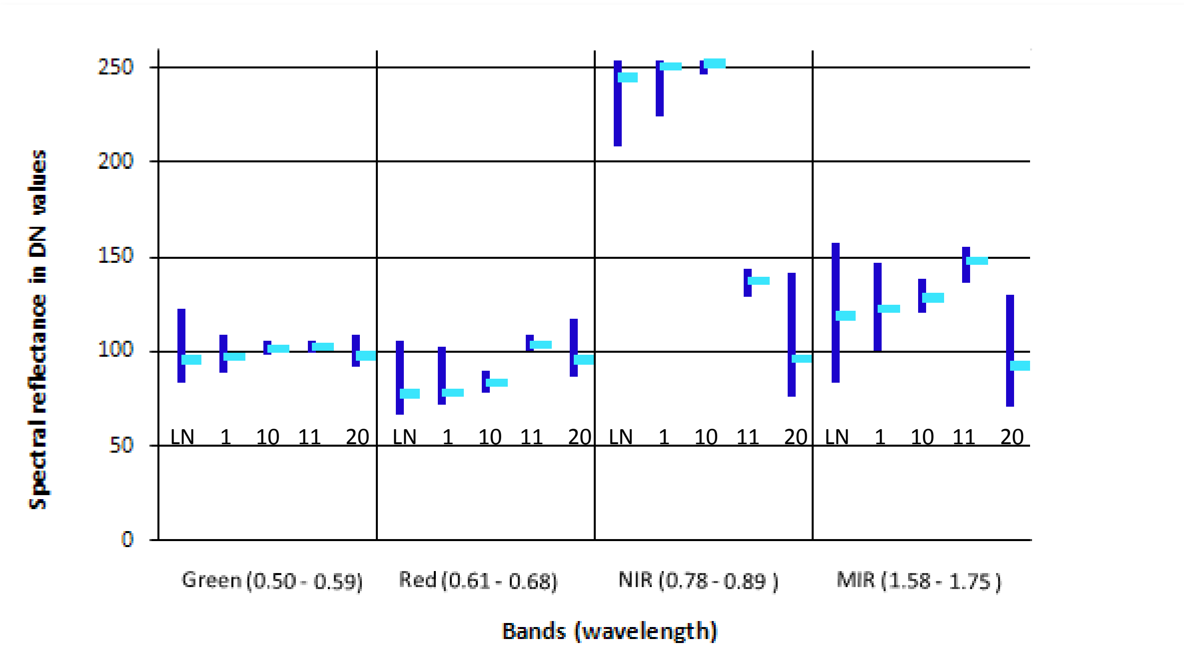


Figure 17. Spectral signature comparison chart showing the spectral response in DN values range in each band as expressed in pixels for: LN) the categorised Lupinus nootkatensis classes merged together, and as expressed in the pixels for respective training sites land-cover classes (the numbers match the REC nr. in the list in appendix 1): 1) dense Lupinus nootkatensis, cover >50%, 10) birch scrubs in dense Lupinus nootkatensis, cover >50%, 11) willow scrubs in Lupinus nootkatensis, cover 20-50% and 20) birch and willow scrubs and conifer in Lupinus nootkatensis, cover 20-50%. Bands and wavelength interval for each band are shown on the x-axis and DN values on the y-axis. The dark blue bars shows the range between minimum and maximum DN value for the Lupinus nootkatensis class and each of the four training areas and light blue dash the average DN value.

Histograms of the final *Lupinus* class in each band provided a visual check on the normality of the spectral response distributions of the *Lupinus* class in all bands except the NIR band in which the spectral values lies all at the upper limit of the DN values (Appendix 5).

The three classes that may be observed in the chart in figure 18 are the classes that were most spectrally alike the classes that contained *Lupinus*. In this chart the reflectance from the training sites for all these three land-cover classes within both the green and red bands overlap each other but they differ more from each other, and the *Lupinus* classes, in the two infrared bands, particularly classes 5 and 9.

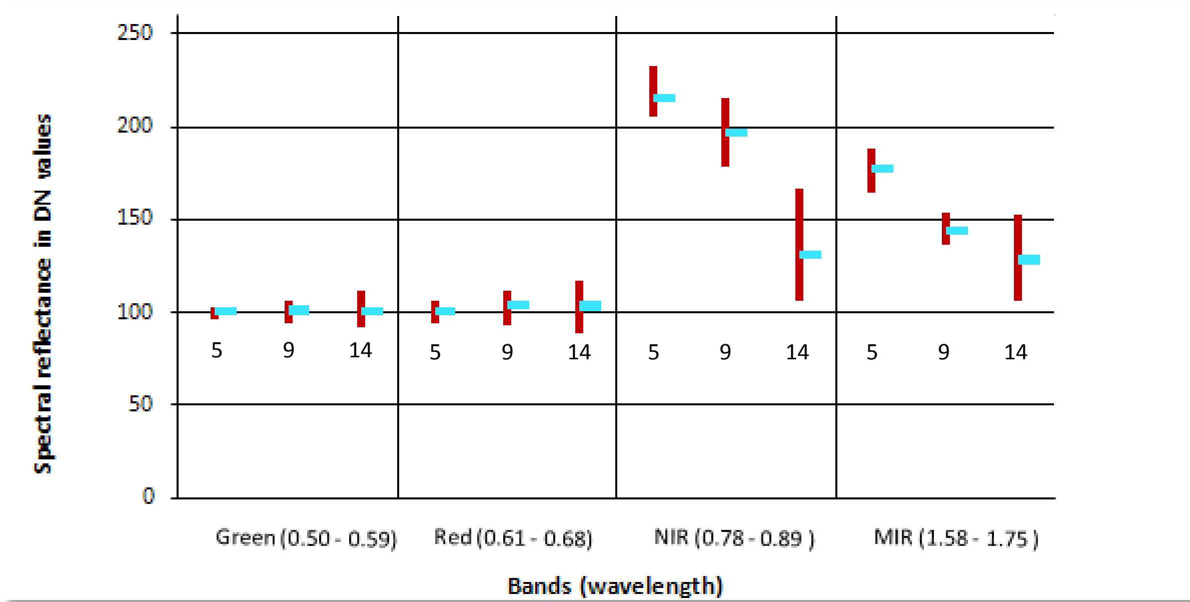


Figure 18. Spectral signature comparison chart showing the DN values range in each band as expressed in pixels for respective training sites land-cover classes (the numbers match the REC nr. in the list in appendix 1): 5) heath, 9) conifer and 14) birch and willow scrubs in wetland. Bands and wavelength interval for each band are shown on the x-axis and DN values on the y-axis. The red bars shows the range between minimum and maximum DN value for each of the three training areas and light blue dash the average DN value.

Regression between bands showed that the infrared bands and the green band were less correlated, with correlation coefficient (r) 0.75 for MIR/green bands and 0.77 for NIR/green, to each other than to other bands. On the other hand the two infrared bands, NIR and MIR were highly correlated to each other with r 0.97 and the red and the green bands were also correlated to each other with r 0.96. The scatter plots in appendix 3 illustrate the correlation with the frequency of pixels that have a relevant DN value in the two bands examined at the time. The spectral location of the training areas, from the land-cover classes that were merged into the final *Lupinus* class and from the three classes that were most spectrally alike the *Lupinus* classes (showed in figure 18), give good impression of which classes overlap each other and spectral reflectance from them. This is particularly notable in the plots that include the NIR/MIR correlation and the NIR/green correlation where three different groups have developed. Dashed circles on figures B and D in appendix 3 define the three groups that include, from left to the right in the figures: 1) *Lupinus* cover 20-50%, 2) the tree classes showed in figure 18, and 3) the classes that have *Lupinus* cover > 50%.

CLASSIFICATION OF SATELLITE DATA

For detecting clouds and clouds shadows some combinations of bands in unsupervised classification captured these areas better than others but in most cases it required scrutinising viewing and dividing of mixed classes and merging. It was easier to capture the clouds than the clouds shadows, with this method. The clouds shadows were, in the image, extensively mixed with dark coloured lava and some area covered with vegetation that may contain the *Lupinus* plant. The mixed classes containing the clouds shadows therefore needed iterative unsupervised classification. They were then re-clustered and divided into spectrally cleaner classes with and without shadows and classes containing shadows were combined into single category of clouds shadows. The unsupervised classification on the red band alone seemed to be effective to capture thick clouds, but this method made mixed classes containing thin clouds and light coloured lava. The red and green bands together classified with the same method made homogeneous clusters of thick and thin clouds respectively and one other cluster mixed with thin clouds, asphalt and light coloured lava. That cluster required therefore more dividing and combining work. It was easily revealed that the image of the study area had no clouds or clouds shadows, therefore no more effort was put into making clouds and clouds shadows mask for this study.

Lupinus patches were easily recognised on the aerial photograph taken the same year, 2009, as the satellite image. Visual comparison of the classifications and the aerial photograph revealed different quality of the mapped coverage of the *Lupinus* (see figures 19 and 20).

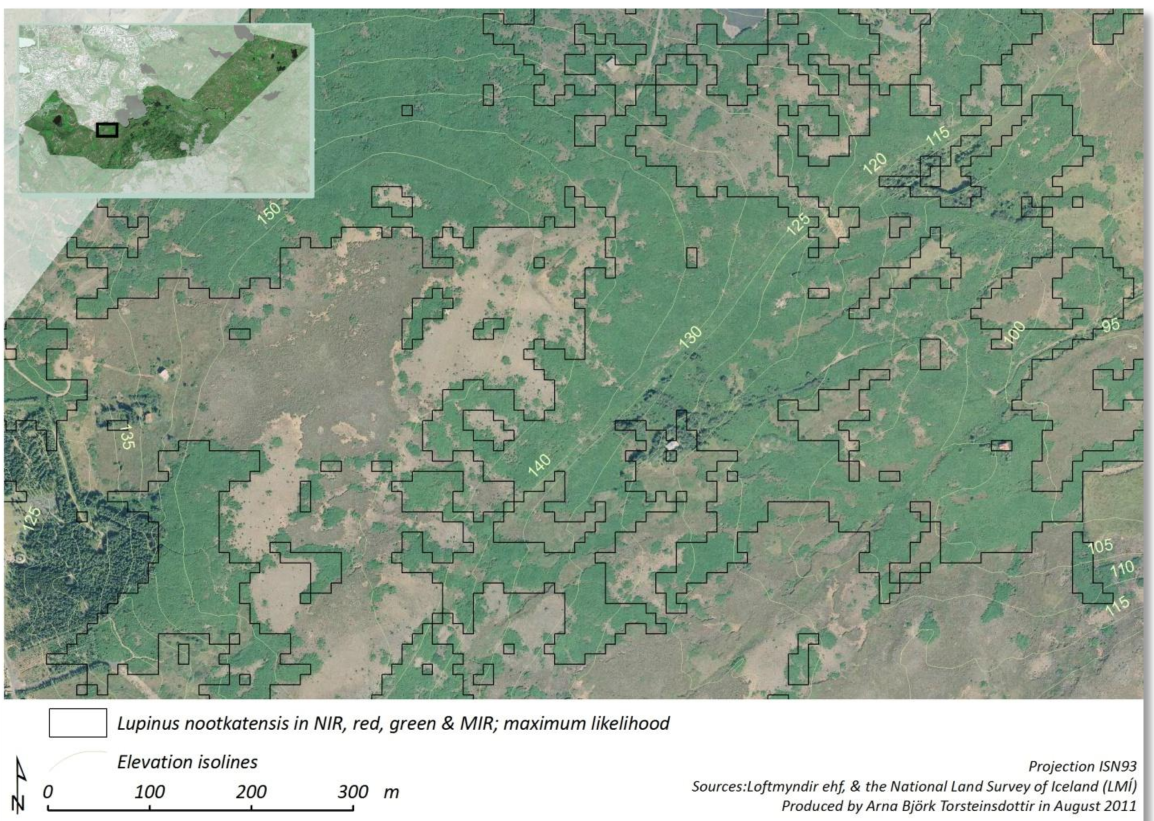


Figure 19. The distribution of Lupinus nootkatensis patches obtained by supervised digital maximum likelihood classification of SPOT 5 data. The classified Lupinus nootkatensis patches are marked on an aerial photograph (spatial resolution 1 m). The classification overall accuracy is 94%. The figure shows an area where the classification of Lupinus nootkatensis is accurate.

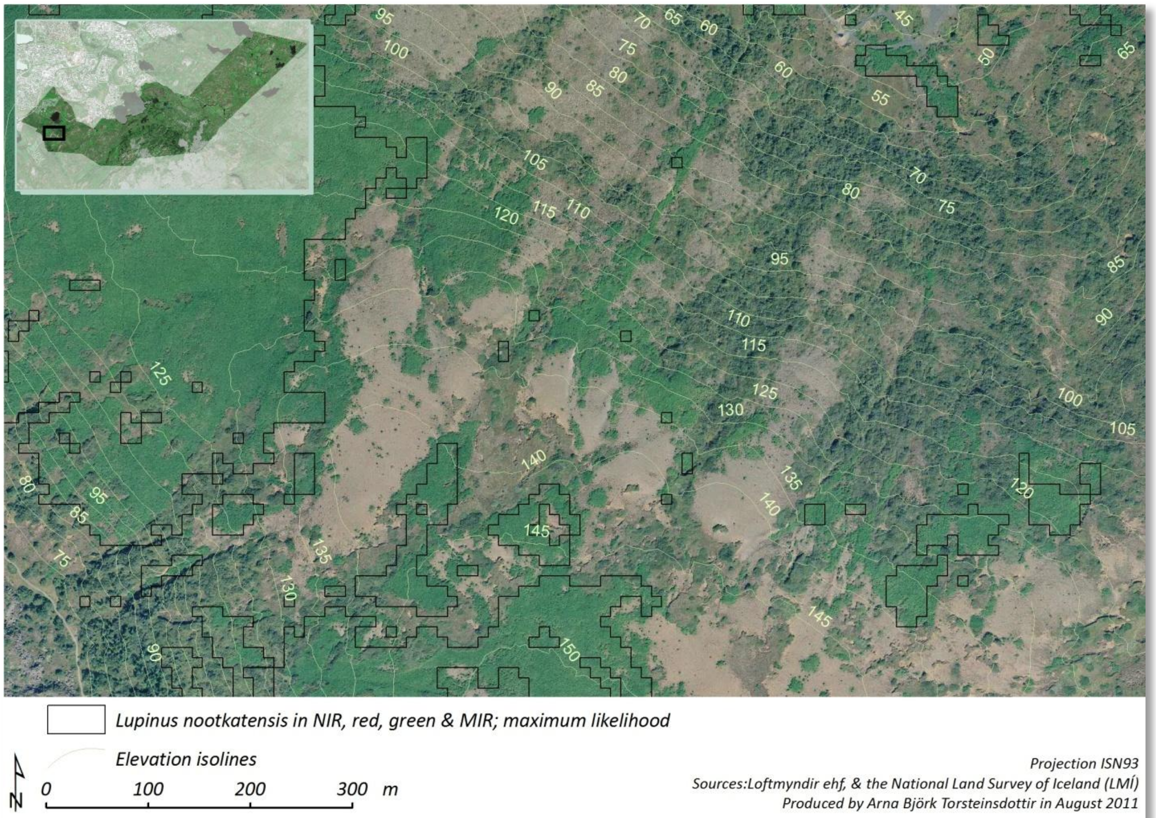


Figure 20. The distribution of Lupinus nootkatensis patches obtained by supervised digital maximum likelihood classification of SPOT 5 data. The classified Lupinus nootkatensis patches are marked on an aerial photograph (spatial resolution 1 m). The classification overall accuracy is 94%. The figure shows an area with particularly poor classification accuracies which were obtained where the land is in steep slope to north-east (the middle of the figure).

Results from the unsupervised classification using the NIR, red and MIR bands revealed in two classes that represented dense *Lupinus* patches. In these classes however some areas with grass, like hay fields, and other areas with flowers and bushes in plant nurseries, gardens, parks and graveyards were mixed together with the *Lupinus*. Iterative or repeated classification on these mixed classes did not give any new result. Some areas of *Lupinus* in quite steep slopes to northwardly directions were not registered as *Lupinus* (but detected when examined visually). These *Lupinus* areas were classified into one mixed class with other areas that were vegetated with forests and scrubs. Repeated classification did not give better results.

In the case of maximum likelihood supervised classification the three different approaches that indicated two (NIR and MIR), three (red, NIR and MIR) and four (green, red, NIR and MIR) bands combination of the SPOT 5 image were different in the way of how precisely the classes that represented the *Lupinus* in the map covered the *Lupinus* patches. The approach that gave the most precise results seems, after comparing it with the aerial photographs, to be the one with all four colour bands. The other two did not catch the dense *Lupinus* patches as well in the *Lupinus* classes.

The approach using all bands provided four classes representing dense *Lupinus* patches and three mixed classes with *Lupinus* and variety of other vegetation. Iterative classification on the three mixed classes did not give much success, though it was possible to extract part of one of the mixed classes as homogeneous *Lupinus* class. In two of these mixed classes in quite steep slopes facing north some areas of *Lupinus* were not registered as *Lupinus* (Figure 20). These *Lupinus* areas were classified into one mixed class with other areas that were vegetated with forests and scrubs. It was not possible to extract homogeneous *Lupinus* areas from them with repeated dividing and re-classifications using unsupervised classification.

After combining all the unmixed *Lupinus* classes it resulted in a cover of dense *Lupinus* patches in the study area (see table 3). Nevertheless the best *Lupinus* class, resulting from the maximum likelihood four bands approach (see figure 21), was still a little bit mixed with well mowed grass as on golf courses and some groves and wetlands.

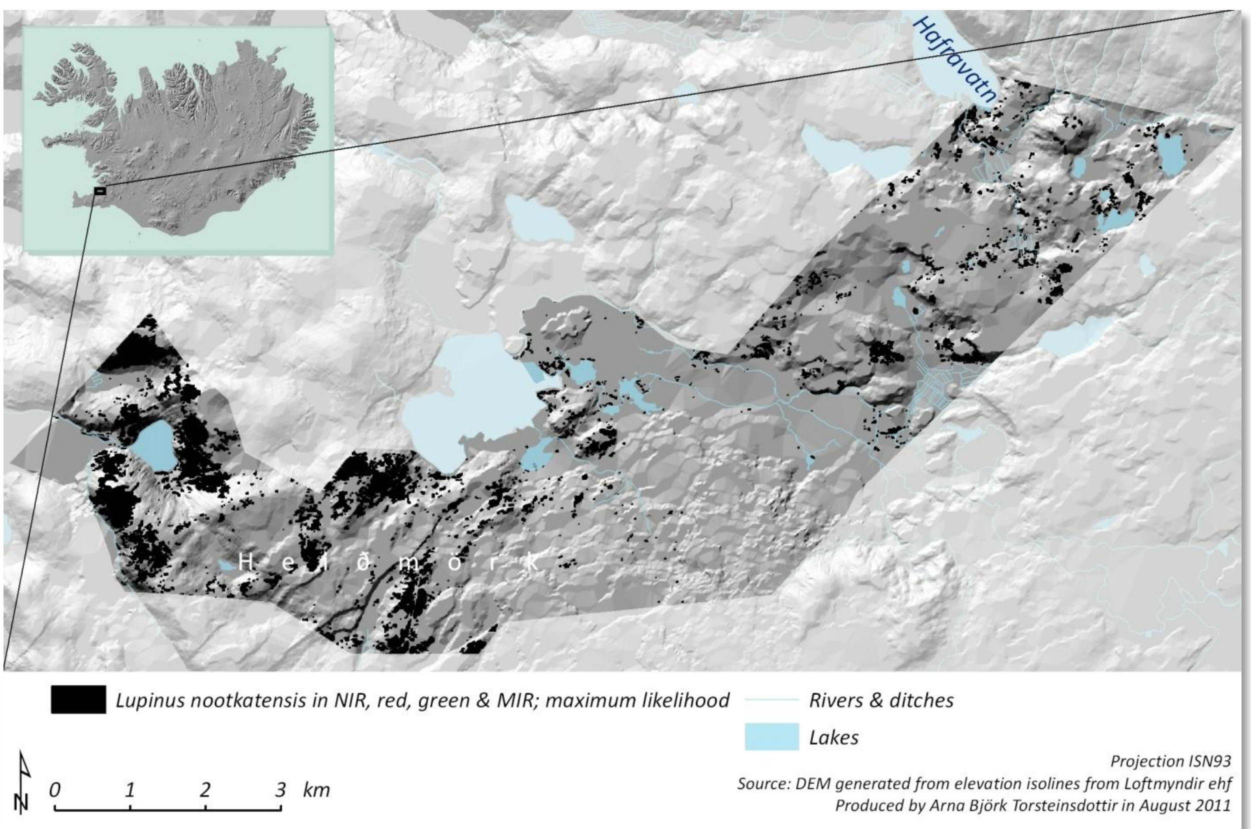


Figure 21. The distribution of Lupinus nootkatensis patches (in the study area) obtained by maximum likelihood classification of SPOT 5 data (four bands). The classified Lupinus nootkatensis patches are marked in black. The classification overall accuracy is 94%.

A transferred maximum likelihood classification approach to the Reykjanes peninsula gave similar results, considering the *Lupinus*, as the corresponding classification for the study area.

Four classes of the 31 land-cover classes (Appendix 2) classified represented dense *Lupinus*. After combining all the *Lupinus* classes it resulted in a cover of dense *Lupinus* patches. Areas in quite steep slopes facing north where some patches of *Lupinus* were not registered as *Lupinus* and also considerably big areas with trees and scrubs had been identified as *Lupinus* inside urban areas. This was notably in parks, cemeteries and in organised forestry or experiments such as plant nurseries. Outside urban areas, much smaller area were misclassified as *Lupinus*, this was mainly when newly mowed hayfields were classified as *Lupinus*.

Table 3. The classified area (km2) of Lupinus nootkatensis patches in the study area and in the Reykjanes peninsula. The area (km^2) of Lupinus nootkatensis patches estimated by means of different classification methods and different band combinations are shown.

Extents of mapped area	Classification method, band combination	Area containing dense *Lupinus* (km^2)
Study area	Unsupervised, NIR, red and MIR	3.86
	Maximum likelihood, NIR, red, green and MIR	3.25
	Maximum likelihood, NIR, red and MIR	3.12
	Maximum likelihood, NIR and MIR	3.13
Whole image	Maximum likelihood, NIR, red, green and MIR	16.37
	Thereof inside the study area	3.49

The different classification methods and bands combinations gave similar results in most ways. The *Lupinus* classes covered the dense *Lupinus* patches very well in most areas (Figure 19) apart from the areas in quite steep slopes facing north where some areas covered with *Lupinus* were not registered as *Lupinus* (Figure 20). Areas with freestanding *Lupinus* plants and single rows of *Lupinus* plants were not captured in separate classes. The classification result showed that the image classification process did not detect the difference between areas with no *Lupinus* plants and areas containing freestanding *Lupinus* plants in combination with other vegetation or in non-vegetated areas. When the maximum likelihood classification approach was transferred to the Reykjanes peninsula it was quiet clear that the classification process misclassified *Lupinus* much more inside urban areas than outside those.

EVALUATION OF CLASSIFICATION RESULTS

Evaluation of accuracy of the satellite based classifications revealed similar outcomes for all executions in different band combinations of the maximum likelihood classifications of the study area (see Table 4). The correlation between the classified image and the evaluation plots

Table 4. Results of the accuracy assessments for two different classification methods (three different band combinations in one of them) and the two different extents of mapped area. See explanation of terms in appendix 6.

Classification method	Extents of mapped area		Band combin.	Category	Producer accuracy %	User accuracy %	Overall accuracy %	Classified image Kappa Index of Agreement (KIA)	Field sampling Kappa Index of Agreement (KIA)	Overall Kappa
Unsupervised classification	Study area		NIR, red and MIR	*Lupinus*	89	81	89	0.70	0.83	0.76
				no *Lupinus*	88	94	89	0.83	0.70	0.76
Maximum likelihood supervised classification	Study area		NIR, red, green and MIR	*Lupinus*	95	90	94	0.84	0.92	0.88
				no *Lupinus*	94	97	94	0.92	0.84	0.88
			NIR, red and MIR	*Lupinus*	89	89	92	0.84	0.84	0.84
				no *Lupinus*	94	94	92	0.84	0.84	0.84
			NIR and MIR	*Lupinus*	95	90	94	0.84	0.92	0.88
				no *Lupinus*	94	97	94	0.92	0.84	0.88
	SPOT 5 image of SW Iceland as a whole	Total area	NIR, red, green and MIR	*Lupinus*	100	62	82	0.47	1.00	0.64
				no *Lupinus*	75	100	82	1.00	0.47	0.64
		Inside urban areas		*Lupinus*	100	5	58	0.03	1.00	0.06
				no *Lupinus*	57	100	58	1.00	0.03	0.06
		Outside urban areas		*Lupinus*	100	82	91	0.7	1.00	0.82
				no *Lupinus*	86	100	91	1.00	0.7	0.82

seem to be similar for different combinations of bands, even entirely alike for the maps were all bands and the NIR, MIR bands combination were used respectively. The unsupervised classification method did on the other hand generate slightly less accurate map than the maximum likelihood method (Table 4). When the maximum likelihood classification method was applied on a larger area, the Reykjanes peninsula, a different accuracy results appear (see Table 4). The accuracy was very low inside urban areas. Only one reference plot was inside *Lupinus* patches and it was correctly classified as *Lupinus*, but about 40% of the plots that were located in an area not containing *Lupinus* patches were incorrectly classified as *Lupinus* patches (see appendix 6, table F). The accuracy outside the urban areas was less than the corresponding classification for the study area and slightly better than the accuracy for the unsupervised classification of the study area.

More detailed results are presented in tables A - G in appendix 6.

Discussion

Field sampling of *Lupinus nootkatensis*

The grid used to spread the field-based plots has the same scale, and its starting point is in an intersection of a grid widely used in environmental researches in Iceland. This gives possibilities to combine other studies with the present study, and use their results, for example, as reference plots in order to minimise the labour in collecting field samples. This is ideal in a large area study identical to the present pilot study for the *Lupinus* distribution. For instance there is an actual study going on in revegetated areas in Iceland, which are distributed in the same grid, where CO_2 accrual in vegetation and soil is investigated. In this study - vegetation type -, is a field in sample plots characteristics. These sample plots would be possible to share and use as training sites or evaluation plots for a classification process.

The method used to collect evaluation plots in the present study is simpler but in some issues similar to methods used for a large area study described by Edwards et al. (1998) and Stehman et al. (2003). To be able to lower the cost and to reduce sampling effort they collected information at clustered locations by making a number of sample quadrangles of specific size placed randomly in the study area. They used either grid that improved the spatial distribution of the plot samples or no grid, which acted on the size of the study area. In each sample quadrangle the area was either divided into a buffer area from the nearest road present and an area outside these buffers, or no buffer was used, which depended on the accessibility in the study area. A number of random sample plots were located within the road buffers and one linear cluster of a number of plots in the off-road buffer area. These methods are simple, low-cost and efficient and would be ideal as sampling methods for the 103 000 km^2 area of Iceland.

The size and number of quadrangles, and the number of plots within it, has to be decided with respect to the size of the study area and the budget. For a large area classification, it is possible to view reference plots on aerial photographs and by that reduce the number of field sample plots (Stehman et al., 2003).

To cut corners after maybe a long walking tour, or drive, to reach a potential plot in present study, it was considered as a possibility, to move an evaluation plot at least 20 m if it fell on the boundary between two patches, one of them having *Lupinus* and the other not having it, rather than rejecting them. It is possible that such an approach will be necessary when collecting field samples for a large area. Also it would be profitable for a large area study, and even for a small study as well, to collect the sample plots used to prepare training sites and evaluation plots together the same way.

Remotely sensed data

Satellite data

The available satellite data country-wide in Iceland are SPOT 5 images recorded from July - September in the years 2002-2009. Thus, the images are not recorded at the same time of the year, and therefore the *Lupinus* is not at the same maturity stage in all of them. This demands attention when comparing two or more images, e.g. radiometric correction is preferred (Song et al., 2001) and it is recommended that field work be as near in time as possible to the images recording time (McCoy, 2005). The *Lupinus* plants reach their full size at the end of June and the growth period ends in September-October (figure 6) (Borgþór Magnússon, 1995). Therefore it is assumed that satellite images taken in July, August and September all contain similar reflectance from the *Lupinus* plants, though it is probably slightly different depending on the growth phase of the plant. It would probably be excellent to use satellite images recorded early in June because *Lupinus* matures early, the growth starts in the middle of May and individual plants are mostly grown at the end of June (Borgþór Magnússon, 1995). Therefore it would probably by easily distinguish from other vegetation that has not jet started proper growth at that time, especially in the highland. Because of few users of satellite data in Iceland it is expensive for institutions and companies to buy satellite images. The recording time of the present image cover of Iceland is considered sufficient for most of them.

Training stage

The land-cover classes based on the field plots characteristics and the spectral classes from the imagery are never completely in harmony (Franklin and Wulder, 2002). Therefore, it was essential to thoroughly examine the classified image before deciding what classes contained homogeneous *Lupinus* patches. The spectral reflectance from the 20 land-cover classes were overlapping each other, as is obvious in figure 16, which were confusing and not easy to investigate.

It was not considered necessary for this study to draw histograms of the training sites but useful to assemble spectral signature comparison charts. Histograms of the final *Lupinus* class in all bands are illustrated in appendix 5. If these histograms are compared to the *Lupinus* bars in the chart in figure 17 it is possible to see that the average DN value is not in the middle of the bars, in most cases, even though the histograms are not showing big skewness of the normal distribution. Therefore, it can be concluded from the spectral signature plots that the training sites in figures 17 and 18 are normally distributed, but in some cases a little skewed. This applies mostly to the classes, which were later merged into the final *Lupinus* class, in the red and NIR bands. The spectral signature comparison also contributed, along with regression between bands and other factors, to the decision on which combination of bands might be best to differentiate the *Lupinus* plants from other vegetation.

The low correlation between the infrared bands on the one hand and the green band on the other indicates that it should be effective to join these bands in the classification process. This would take into account how different their corresponding DN values are and that they are less likely to have the same distribution of the categories (Lillesand et al., 2008). The results in the two scatter diagrams B and D, which include the NIR/MIR correlation and the NIR/green correlation in appendix 3, lead to the decision to choose these three bands in the analysis. It is also considered desirable to include NIR and red bands in the classification process since the spectral reflectance of these bands contains much information regarding vegetation (Eastman, 2006). For example water absorbs energy at the NIR wavelengths and the different species of vegetation have the greatest differentiation within that wavelength interval. Since the chlorophyll in plant leaves absorbs energy for photosynthesis within the wavelength interval of the red band, it is easy to distinguish vegetation from non-vegetation on the basis of the red band (Eastman, 2006). Resulting from this, it is possible to draw the conclusion that it is best to use all SPOT 5 bands in the classification process. For the present study, to learn as much as possible about the effects of the different bands, the workflow ended with a trial of different combination of bands and comparison of the resulting maps.

Clouds, clouds shadows, lakes, glaciers and the ocean should be masked out in prior to classification to decrease unnecessary data and unburden the classification process. Masking can be done using a combination of many methods, for example thresholds, on-screen digitizing and, as done in this study, by dividing and merging classes in combination with iterative unsupervised classification of satellite image (Franklin and Wulder, 2002). It gives good result to filter the cluster of clouds and shadow with the mode filter to widen the cluster a little to capture the edge of the clouds and shadows that often contain a very thin slide of clouds and shadows that disturb the real reflection in the image. The SPOT image data lacks thorough spectral information content, which can therefore cause confusion between spectral classes and bring spectrally mixed classes into existence.

CLASSIFICATION OF SATELLITE DATA

Both classification methods, unsupervised and supervised maximum likelihood, are applicable for the purpose of detecting dense *Lupinus* patches from SPOT 5 satellite image. Unsupervised is a more cost-effective way to do this because field sampling data collection does not necessary have to be as extensive as for the supervised classification process. Supervised classification requires great deal of pre-work and field sampling and is, therefore, not necessarily the best option for large area classification, even though it is the most powerful algorithm in the statistical field (Franklin and Wulder, 2002). Unsupervised classification can be a better choice (Franklin and Wulder, 2002) for making the classification process faster, simpler and labour- and cost-effective. To minimise the labour and time factors an alternative option could be collecting sampling data from aerial photographs or fine spatial resolution satellite data instead of field plots (Franklin and Wulder, 2002). It is a good solution to use a hybrid approach of unsupervised and supervised classification (Townsend et al., 2009) as done in the present study. It could also enable a better control of the budget and the time efforts that were required for the pre-work

In the effort to obtain information on the whereabouts of *Lupinus*, its different density and spreading pattern with different backgrounds-vegetations or -surfaces, many characteristics were investigated. This gave not as detailed findings as expected. The classification process did not capture areas with sparse and freestanding *Lupinus* either in combination with other vegetation or in non-vegetated areas (Mosbech and Hansen, 1994). The reason can be that in the present study too few and too small training sites in each density range and pattern classes, were used. Other reason can be that the spatial scale in SPOT 5 images is too course for this purpose and that some pixels in the image have mixed reflectance from heterogeneous surfaces (Malik and Husain, 2006, Mosbech and Hansen, 1994). It is possible that if the panchromatic band were merged to the colour bands it would provide necessary information. The SPOT images don't have high spectral resolution and in sparsely vegetated areas the components of soil, rocks or other types of the surface dominates the spectral value of the image determining colour and texture. Soil background has been shown to have considerable effect (Barille et al., 2011, Mosbech and Hansen, 1994) on the spectral reflectance from the surface to the sensor. This is notable in the chart in figure 17 where the two training areas that contain *Lupinus* cover 20-50% (no. 11 and 20) have considerable lower reflectance than the other *Lupinus* areas containing *Lupinus* cover > 50% (no. 1 and 10) in the NIR band and this is conversely in the red band.

It would require different methodology to detect different patterns of the *Lupinus* plant or freestanding *Lupinus* in separate classes. Further studies that could give information about these issues could consist of precise systematic investigations on several *Lupinus* patches with different density and spreading pattern. The objects of such study would be to find the diversity in the spectral reflectance in these different areas and to be able to classify these differences. The use of satellite data with higher spatial and spectral resolution can improve the results (Malik and Husain, 2006, Mosbech and Hansen, 1994). Study on propagation of *Lupinus* using aerial photographs has shown that individual plants and small knots that develop around them are well distinguishable in the scale of 1:5000 (Daði Björnsson, 1997). At the same time, images with higher spatial scale will increase the labour, time and money spent on it.

It would be highly interesting to monitor the advance and withdrawal of *Lupinus*. A study, for the purpose of providing information about the spreading tendencies of *Lupinus*, would contain investigations of images of similar kind from different record years. Large scale variations in distribution of *Lupinus* can cause some difficulties in the classification due to the course spatial scale of the SPOT images (Malik and Husain, 2006) and as discussed above, higher spatial resolution can improve results.

Dense *Lupinus* patches were successfully differentiated from other vegetation, apart from areas in quite steep slopes to northwardly directions where some areas of *Lupinus* were not registered as *Lupinus* (Figure 20). It was not possible to extract these unclassified *Lupinus* areas by repeatedly dividing mixed classes and combining by the use of unsupervised classification. When detecting changes in distribution of classes from classified images, recorded at different seasons and years, it should not be necessary to correct these images for atmospheric condition or illumination angel of the sun if the field sampling for the training sites and the evaluation are collected for each image respectively (Song et al., 2001). The same applies if a comparison is done on the land-cover classes but not on the images itself (Song et al., 2001). In the present pilot study all field sampling were done for the image used in the classification process and no radiometric correction were considered necessary. Nevertheless, the problem described above could be caused by the different scene illumination and viewing geometry in the slopes facing north in comparison to other slope directions. This can result from the seasonal elevation of the sun in late august at latitude 64°N and its illumination angle to the surface examined. To overcome this effect a sun elevation correction could be applied. Another method applicable to solve this problem is based on spectral ratioing. Spectral rationing results from division of the DN values in one band by corresponding values in another, a simple technique to minimise topographic effect, which could be used as input to the classifier (Eastman, 2006, Franklin and Wulder, 2002, Lillesand et al., 2008). It is possible that field sampling for the training sites that were collected in the beginning were not diverse enough to compensate for such topographical and sun illumination effects. Thus the third solution to the problem above could be to add new training sites, in these poorly classified areas, to the process and classify these areas separately, again, using the maximum likelihood method.

If transferring the pilot study to a large area it will be beneficial to mask clouds, clouds shadows, lakes, glaciers and ocean out of the image before classification. This will reduce unnecessary data, lower the spectral interval and minimise the classification process (Lillesand et al., 2008). The mask can be used to cut that same area from another cloudless image and classify those, to put in the holes. The fact that maximum likelihood classification on a SPOT 5 image of the Reykjanes peninsula was carried out without any prefabricate on the image does not seem to affect the classification results much with regard to *Lupinus* outside urban areas. A conflict arose in the classification in other types of land use such as inside urban areas, in parks, cemeteries and in an organised forestry or experiments such as plant nurseries, were trees and scrubs were identified as *Lupinus*. This needs to be handled. It is possible to mask such places from the image before classification and classify these areas separately even with additional sample plots and training sites.

Large area classification or change detection and monitoring require more than one satellite image, as if countrywide classification would be implemented for Iceland. For such a study it would be efficient to generalise sample data for training sites and evaluation, by collecting the data in areas in one image and apply that on areas in other images or images taken in another time. To do this it is absolutely beneficial to do routine atmospheric corrections of the images. (Song et al., 2001).

EVALUATION OF CLASSIFICATION RESULTS

The high level of accuracy is not surprising taking into account that there are only two major categories in the final map, one containing *Lupinus* and another not containing *Lupinus*, which makes it simple and easy, just concentrating on few items in the classification process (Townsend et al., 2009). By this study it is well possible to detect the *Lupinus* plants. Extent measurements should be accurate even though the pixel size limits the exact position of the class. Considering the fact that two band combinations, all bands and NIR, MIR combination, involved in a maximum likelihood classification had entirely comparable accuracy results, it would be interesting to find if the two bands NIR and MIR will give accurate enough results for a large area. It would also be interesting to find out if, a detection of *Lupinus* countrywide in Iceland would be possible by only using these two bands.

When the maximum likelihood classification was applied on the Reykjanes peninsula the accuracy inside urban areas was much lower than expected. The categorisation generated on the evaluation plots ended up so that only one reference plot was inside *Lupinus* patches (see appendix 6, table F). This is possibly because the classified *Lupinus* patches inside urban areas are very small and most of the plots located inside *Lupinus* patches were near the edge of areas that contained *Lupinus* and those who did not contain *Lupinus*. Because of that reason they were rejected from the evaluation plots used for the accuracy assessment. This can have caused the low accuracy results inside urban areas.

Another possible cause of error in the evaluation is probably the difference in the time of collection of the evaluation plots and the date of the satellite image. The evaluation plots in this study were collected May 26.-31. 2011 and the image was recorded in August 30. 2009, the difference is one year and 9 months. This can affect the accuracy of results (Edwards et al., 1998). Because of the simplicity of this study with only two major categories involved, the seasonal difference is not a big risk when classifying *Lupinus* because the plant is well identifiable in the field through the seasons. What could skew the results and add errors in our evaluation are changes that can have occurred in sizes of *Lupinus* patches these two years. To decrease possible errors the training sites were drawn on the image parallel to review of the sampling plots, on photographs (taken in each plot). Another option that is important is to locate reference plots well inside the representing land-cover class or well outside it (Lillesand et al., 2008).

It is essential to be aware of the quality of spatial data used, as the uncertainty and errors from the process of the data (Devillers et al., 2005, Wang et al., 2005). Even though exact calculations of those are outside the scope of this study some of them, that can have affected the present classification, will be mentioned here. A number of problem-errors can affect the classification results. The ortho-rectification of the satellite data can involve errors. It is based on; a DEM that is based on data collected in different periods and with a different technique, and on a GPS measured road net that were used for ground-control points for the rectification. The accuracy of the GPS measurements involve many technical factors such as WAAS/EGNOS corrections, the correction in the GPS instrument is not always constant, thus the expected accuracy (+/- 3 m) in the location is not perfect (Map-GPS-Info.com, 2011). Georeferenced errors planted when rectification of spatial images are performed can accumulate and propagate to products of the images (Wang et al., 2005). Radiometric effects as illumination angel, atmospheric condition and viewing geometry are essential, when a number of satellite images are involved, and could affect processing results (Lillesand et al., 2008). The number of field sampling plots along with the methodology implemented to select their location can affect the accuracy and the bias in the study (McCoy, 2005) and the GPS measured position of the plots is not always reliable. The observer's estimations, of distances in the field affect the location of the extent of each plot, when registering the plot characteristics. Good knowledge of the area can improve the categorisation of the field samples into land-cover categories that the training sites are extracted from. Precision, when drawing the training sites on the image, affect the statistical properties that are the basis for the categorisation (Eastman, 2006).

Further applications

Several possible applications to further improve the classification results and to streamline the sampling and classification procedures have been mentioned in the discussion above. Here is a look at several options that have still not been brought up.

Using ancillary data (Franklin and Wulder, 2002, Lillesand et al., 2008, Malik and Husain, 2006) as drainage systems (rivers and flow directions), slopes and wind direction to predict, follow, and search for the likeliest spread of the *Lupinus* plant. This is done when the map is examined visually, in the intention of looking for misclassification and errors or/and to correct it. Ancillary data can be useful when intending to inspect satellite data over different seasons and years and look for changes in growth and spreading pattern to predict future risk of *Lupinus* invasion (Bradley and Mustard, 2006).

Ratioing and multiregression (Lillesand et al., 2008) are two ways to prepare satellite images data before classification that could make it easier to differentiate one specific plant from other vegetation types. Some different combinations were tried in the beginning of this classification process but there was not enough time to examine it carefully and therefore it was not used further.

If the classification were applied to satellite data of higher spatial- and spectral resolution it would probably as Malik and Husain (2006) discovered, lower the number of pixels with mixed spectral reflectance and make it easier to differentiate between land-cover types with similar spectral reflectance and thus minimise the area classified in mixed classes. As Townsend et al. (2009) discovered when comparing maps with two categories, habitat/non habitat, that were generated from spatial data of different resolution, the proportion between habitat/non habitat mapped area did not vary in a consistent manner across different degree of resolution. Malik and Husain (2006) found that spatial resolution affects the potential to differentiate between different spectral reflectance and that the ratio between habitat/non habitat also depends on spectral resolution, temporal- and radiometric differences, landscape, and the extent of the area mapped. Thus, one can conclude that for mapping areas with fragmented *Lupinus* territories, data with medium spatial scale, as SPOT 5 images, is adequate and optimise for pixel size and extent (Chen et al., 2007). In areas with freestanding *Lupinus* plants, or small *Lupinus* knots, a fine spatial scale would be superior. Comparisons between different sensors and different scales should be done carefully and in awareness of these effects. Townsend et al. (2009) draw attention to this, especially when monitoring and detecting changes.

Conclusions

SPOT5 images are currently the only available satellite images that cover the whole country of Iceland. In addition they provide the highest resolution.

The study showed that the two remotely sensed classification procedures (unsupervised and supervised classification) were applicable for the purpose of detecting dense *Lupinus* patches from SPOT 5 satellite image.

Both classification methods (unsupervised and supervised classification) are semiautomatic, simple in use and easily repeatable. The maximum likelihood supervised classification demanded more field work than the unsupervised classification method and is, therefore, more expensive and time-consuming. It was a good solution to use a hybrid approach of unsupervised and supervised classification. That allowed a better control of the budget and the time efforts that were required for the pre-work, than if just a supervised classification approach were used.

This study showed that objectivity in the field sampling and consistent collection procedures are very important. Photographs taken in the field proved very valuable in association to the classification training procedure.

A preliminary study included spectral signature comparison charts, scatter plots, and regressions between bands in order to see whether some of the four image bands could be excluded from the classification process. It also included a search for clouds and clouds shadows in order to mask them out to decrease unnecessary data and unburden the classification process. This was also made to make it possible to cut the clouded areas out of other images and classify them in order to find if there were some *Lupinus* patches there. For the large area, Reykjanes peninsula, image classification was carried out, without any masking. It did not seem to affect the classification results much with regard to *Lupinus* outside urban areas. It showed, similar results, as the corresponding one from the study area, where there were no clouds, cloud shadows and ocean in the image. This revealed that there were no preliminary studies needed before the classification other than the decision procedure for the images band combination, with regard to the classification accuracy.

The present study also showed that the classification process did detect dense *Lupinus* patches successfully. It did not capture areas with sparse and freestanding *Lupinus*, either in combination with other vegetation or in non-vegetated areas. A conflict arose in the classification in other types of land use such as inside urban areas were trees and scrubs were identified as *Lupinus* and low classification accuracies were obtained.

The project has led to the conclusion that this methodology may be used country-wide in Iceland for detecting and monitoring the distribution of *Lupinus* and to compare studies from different seasons and years. It was possible to convert findings from the study area to a larger area without more complex working procedure and without significant loss of accuracy. Radiometric correction of the satellite images is, however, preferable before a classification of an area that includes more than one satellite image and when comparing images from different seasons and years (Song et al., 2001).

The field samples give a good correlation to the classified image. The absolute highest classification accuracies were obtained by means of the maximum likelihood classification based on the NIR, red, green and MIR bands. It gave 94-95% producer- and 90-97% user accuracy and an overall Kappa of 0.88 within the study area.

There may be several ways to further improve the classification results and to streamline the sampling and classification procedures as described below:

To minimise the labour and time factors an alternative option could be to collect sampling data from aerial photographs or fine spatial resolution satellite data instead of field plots (Franklin and Wulder, 2002). It is also possible to use other study results, as reference plots.

To detect different frequency and pattern of the *Lupinus* some application are useable. If the panchromatic band were merged to the colour bands it could provide the necessary information. Other satellite data with higher spatial and spectral resolution could improve the results (Malik and Husain, 2006, Mosbech and Hansen, 1994). It is also possible that precise systematic investigations on several *Lupinus* patches with different density and spreading pattern would give good results.

To minimise topographic effects, a sun elevation correction applied to the image could improve the classification accuracy, especially in areas located so far to the north as Iceland. Another technique, to minimise topographic effects, is spectral ratioing applied on the different images bands, which could be used as input to the classifier (Eastman, 2006, Franklin and Wulder, 2002, Lillesand et al., 2008). Dividing images up in different areas and classifying them separately could give good results.

Two band combinations, all bands and NIR, MIR combination, involved in a maximum likelihood classification had entirely comparable accuracy results. It would be interesting to find out if, a detection of *Lupinus* countrywide in Iceland would be possible by only using the two bands NIR and MIR.

The use of ancillary data (Franklin and Wulder, 2002, Lillesand et al., 2008, Malik and Husain, 2006) as drainage systems (rivers and flow directions), slopes and wind direction can help to predict, follow, and search for the likeliest spread and pattern of the *Lupinus* plant.

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Appendix 1

Training sites for the study area

The land-cover classes nr. 1, 17, 18 and 39 were merged into the class *Lupinus nootkatensis* and all other land-cover classes were merged into no *Lupinus nootkatensis.*

Training sites for "the study area" (train_01_singl_br_merge_kl)		
(train_01_singl_br_merge_kl_1_10)		
REC nr.	**ID for land-cover classes**	**land-cover classes**
1	1	*Lupinus* -patches, cover 1 (> 50% of the surface)
2	5	Freestanding *Lupinus* but mostly flower ground
3	9	Moss and flower plants
4	10	Moss
5	11	Heath
6	12	Grass (hayfields or old hayfields)
7	13	Birch scrubs and heath in lava
8	14	Willow scrubs
9	15	Conifer
10	17	*Lupinus* -patches, cover 1 and birch
(train_01_singl_br_merge_kl_11_20)		
11	18	*Lupinus* -patches, cover 2 (20-50% of the surface)and willow
12	24	*Lupinus* -knots, cover 3 and rocks
13	25	Wetland with grass
14	27	Wetland with birch and willow scrubs
15	28	Gravel and moss
16	29	Birch and willows scrubs and moss in lava
17	30	Heath in lava
18	31	Rocks and moss
19	32	Water
20	39	*Lupinus* -patches, cover 2, birch and willow scrubs and conifer

Appendix 2

Training sites for a SPOT 5 image of SW Iceland as a whole

The land-cover classes nr. 1, 17, 18 and 23 were merged into the land-cover class *Lupinus nootkatensis* and all other land-cover classes were merged into no *Lupinus nootkatensis.*

Training sites for "the large area" (train_01_singl_br_merg_singl_2)		
REC nr.	**ID for land-cover classes**	**land-cover classes**
1	1	*Lupinus* -patches, cover 1 (> 50% of the surface)
2	2	Freestanding *Lupinus* but mostly moss
3	5	Freestanding *Lupinus* but mostly flower ground
4	6	Freestanding *Lupinus* but mostly heath & soil
5	7	Freestanding *Lupinus* but mostly grass & soil
6	8	Freestanding *Lupinus* but mostly rocks
7	9	Moss and flower plants
8	10	Moss
9	11	Heath
10	12	Grass (hayfields or old hayfields)
11	13	Birch scrubs and heath in lava
12	14	Willow scrubs
13	15	Conifer
14	17	*Lupinus* -patches, cover 1 and birch
15	18	*Lupinus* -patches, cover 2 and willow
16	21	*Lupinus* -knots, cover 2 and Cow parsley
17	22	*Lupinus* -knots, cover 3 and heath
18	23	*Lupinus* -knots, cover 2 and rocks
19	24	*Lupinus* -knots, cover 3 and rocks
20	25	Wetland with grass
21	27	Wetland with birch and willow scrubs
22	28	Gravel and moss
23	29	Birch and willows scrubs and moss in lava
24	30	Heath in lava
25	31	Rocks and moss
26	32	Water
27	33	Clouds
28	34	Thin clouds
29	35	Shadows
30	36	Ocean
31	39	*Lupinus* -patches, cover 2, birch and willow scrubs and conifer

Appendix 3

Scatter diagrams

SHOWING CORRELATION OF DIGITAL NUMBERS (DNs) OF TWO SPECTRAL BANDS AT THE TIME, THE IRCLES SHOW THE LOCATION OF TRAINING SITES

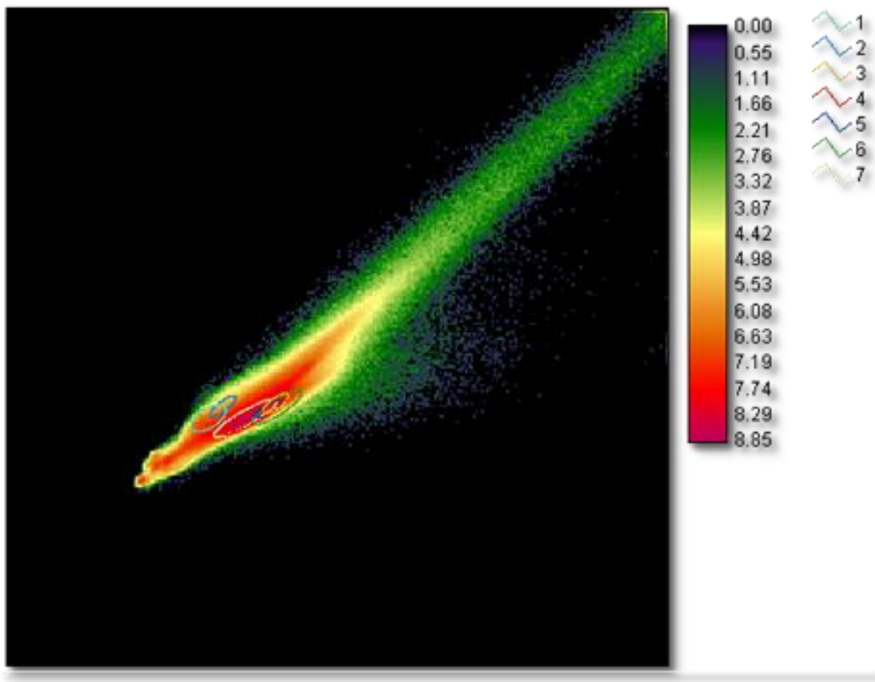


Figure A. Bands on x-axis/y-axis are red/green

For all figures:

The colour-scale illustrates differences in frequency of pixels that have a relevant DN value.

The line legend shows different training site, the numbers stand for:

1. dense Lupinus cover >50%

2. birch scrubs in dense Lupinus cover >50%

3. willow scrubs in Lupinus cover 20-50%

4. birch and willow scrubs and conifer in Lupinus cover 20-50%

5. heath

6. conifer

7. birch and willow scrubs in wetland

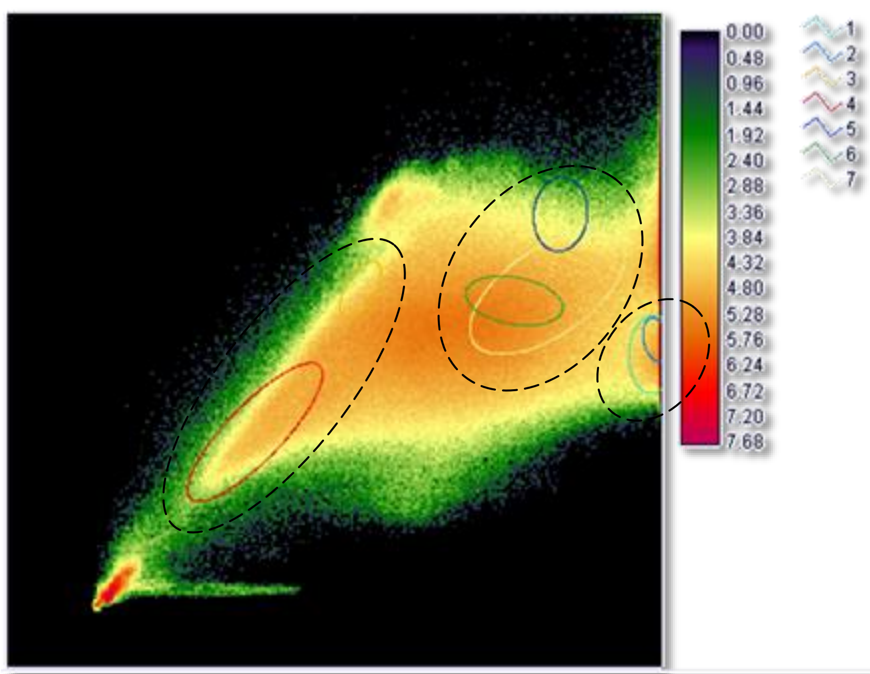
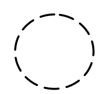


Figure B. Bands on x-axis/y-axis are NIR/MIR



Dashed circles around the groups of training areas define the three different groups: far to the left the two classes that include Lupinus cover 20-50%, the middle one includes the mixed classes and the one far to the right includes the classes that have Lupinus cover > 50%.

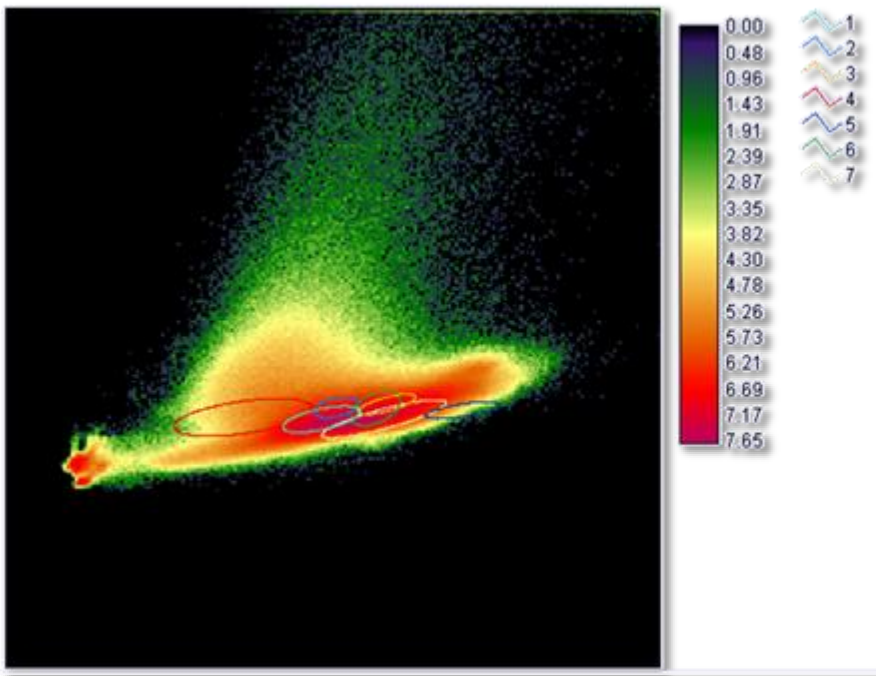


Figure C. Bands on x-axis/y-axis are MIR/green

For all figures:

The colour-scale illustrates differences in frequency of pixels that have a relevant DN value. The line legend shows different training site, the numbers stand for:

1. dense Lupinus cover >50%

2. birch scrubs in dense Lupinus cover >50%

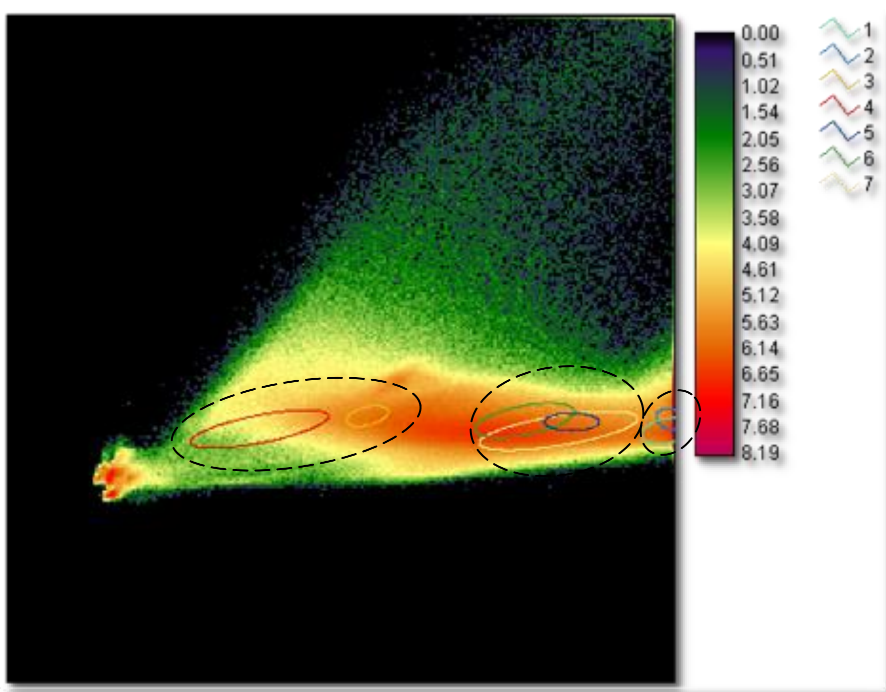
3. willow scrubs in Lupinus cover 20-50%

4. birch and willow scrubs and conifer in Lupinus cover 20-50%

5. heath

6. conifer

7. birch and willow scrubs in wetland



Dashed circles around the groups of training areas define the three different groups: far to the left the two classes that include Lupinus cover 20-50%, the middle one includes the mixed classes and the one far to the right includes the classes that have Lupinus cover > 50%.

Figure D. Bands on x-axis/y-axis are NIR/green

Appendix 4

Projected Coordinate System:

ISN93 / LAMBERT 1993

Projection:	Lambert_Conformal_Conic_2SP
False Easting:	500000.00000000
False Northing:	500000.00000000
Central Meridian:	-19.00000000
Standard Parallel 1:	64.25000000
Standard Parallel 2:	65.75000000
Latitude of Origin:	65.00000000
Linear Unit:	Meter
Authority:	EPSG 3057

(Butler et al., 2011).

Geographic Coordinate System:

GCS ISN 1993

Datum:	Islands Network 1993
Spheroid:	GRS 1980, 6378137, 298.257222101
Prime Meridian:	Greenwich, 0
Angular Unit:	Degree

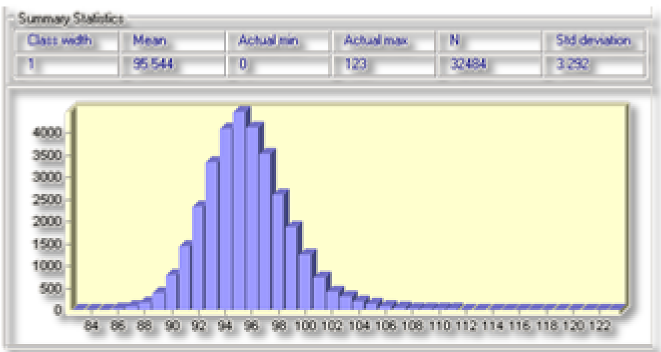
(Butler et al., 2011).

Appendix 5

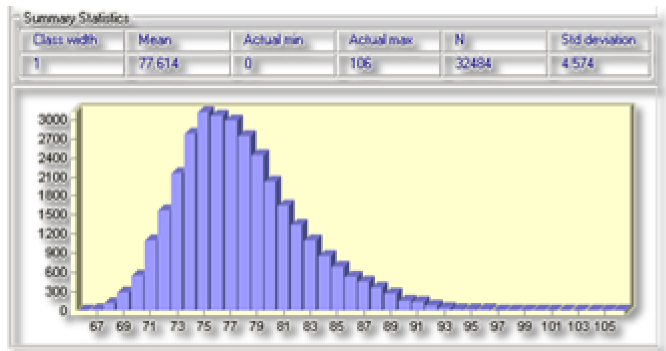
Histograms

SHOWING THE FINAL *LUPINUS NOOTKATENSIS* CLASS IN ALL BANDS IN THE MAXIMUM LIKELIHOOD SUPERVISED CLASSIFICATION

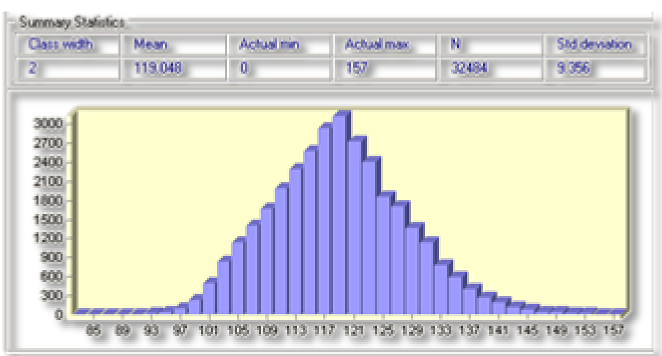
For all histograms: the DN values are on the x-axis and the frequency on the y-axis



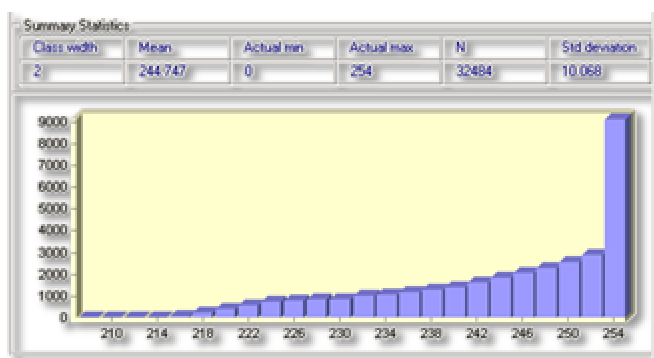
Green: 83 (freq. 1) up to DN 95 (freq. 4463) down to DN 123 (freq. 1)



Red: DN value 66 (freq. 1) up to DN 75 (freq. 3109) down to DN 106 (freq. 1)



MIR: DN value 83 (freq.: 1) up to DN 119 (freq. 3118) down to DN 157 (freq. 2)



NIR: DN value 208 (freq: 1) – 254 (freq: 9093)

APPENDIX 6

ERROR MATRIXES

Definitions of terms in error matrixes (see tables A-G on following pages) are all coming from Lillesand et al. (2008):

ErrorO = Errors of Omission: pixels that should have been classified as a specific category were omitted from that category (as proportions)

ErrorC = Errors of Commission: pixels that were improperly included in a category (as proportions)

"Producer accuracy" explains how well field sampling of a specific cover type are classified

[Producer accuracy for *Lupinus*] = [number of field samplings classified as *Lupinus*] / [total field samplings categorised as *Lupinus*]

"Users accuracy" explains how well a pixel classified into a specific category, represent that category on the ground

[Users accuracy for *Lupinus*] = [number of correctly classified pixels as *Lupinus*] / [total number of pixels classified as *Lupinus*]

[Overall accuracy] = [total number of correctly classified pixels] / [total number of field samples]

KAPPA INDEX OF AGREEMENT (KIA) is a measure of the difference between the actual agreement between field sampling and the classified data and the chance agreement between the field sampling and a random classifier ("true" agreement versus "chance" agreement).

Overall Kappa of 0.9593 means that this classification is 96% better than one resulting from chance. "An overall Kappa of 0 suggests that a given classification is no better than a random assignment of pixels".

Table A. Error matrix for the ***unsupervised classification*** *of two land-cover classes ("Lupinus nootkatensis" (Lupinus) and "no Lupinus nootkatensis" (no Lupinus) in* ***the study area****. The* ***NIR, red and MIR bands*** *were used in the classification. Coloured numbers are used to clarify the procedure used for calculating the classification accuracy. All explanations of terms are from Lillesand et al. (2008).*

Field sampling

Classification: Categ.	*Lupinus*	no *Lupinus*	Total	ErrorC
Lupinus	17	4	21	0.1905
no *Lupinus*	2	30	32	0.0625
Total	19	34	53	
ErrorO	0.1053	0.1176		0.1132 (overall error)

17 + 30 / 53 = 0.89 = 89% (overall accuracy)

ErrorO 2 of 19 pixels that should have been classified as *Lupinus* were omitted from that category
ErrorC 2 of 32 pixels were improperly included in the no *Lupinus* category should have been *Lupinus*

"Producer accuracy" for *Lupinus* = 17/19 = 0.89 = 89%
"Producer accuracy" for no *Lupinus* = 30/34 = 0.88 = 88%

"Users accuracy":

17 (of 21) pixels correctly distinguished as *Lupinus* and classified as such = 17/21 = 0.81 =81%
30 (of 32) pixels correctly distinguished as no *Lupinus* and classified as such = 30/32 = 0.94 = 94%

90% Confidence Interval = +/- 0.0716 (0.0416 - 0.1848)
95% Confidence Interval = +/- 0.0853 (0.0279 - 0.1985)
99% Confidence Interval = +/- 0.1123 (0.0009 - 0.2255)

KAPPA INDEX OF AGREEMENT (KIA)

CLASSIFIED IMAGE: Category	KIA	FIELD SAMPLING: Category	KIA
Lupinus	0.7031	*Lupinus*	0.8257
no *Lupinus*	0.8257	no *Lupinus*	0.7031

Overall Kappa is 0.7595

Table B. Error matrix for the ***maximum likelihood supervised classification*** *of two land-cover classes ("Lupinus nootkatensis" (Lupinus) and "no Lupinus nootkatensis" (no Lupinus) in* ***the study area****. The* ***NIR, red, green and MIR bands****, were used in the classification. All explanations of terms are from Lillesand et al. (2008).*

Classification	Field sampling: *Lupinus*	Field sampling: no *Lupinus*	Total	ErrorC	"Users accuracy"
Lupinus	18	2	20	0.1000	18/20=0.90
no *Lupinus*	1	32	33	0.0303	32/33=0.97
Total	19	34	53		
ErrorO	0.0526	0.0588		0.0566 (overall error)	

"Producers accuracy" *Lupinus*: 18/19=0.95
no *Lupinus*: 32/34=0.94

"Overall accuracy" (18+32)/53=0.94

90% Confidence Interval = +/- 0.0522 (0.0044 - 0.1088)
95% Confidence Interval = +/- 0.0622 (0.0000 - 0.1188)
99% Confidence Interval = +/- 0.0819 (0.0000 - 0.1385)

KAPPA INDEX OF AGREEMENT (KIA)

CLASSIFIED IMAGE: Category	KIA	FIELD SAMPLING: Category	KIA
Lupinus	0.8441	*Lupinus*	0.9155
no *Lupinus*	0.9155	no *Lupinus*	0.8441

Overall Kappa is 0.8783

Table C. Error matrix for the ***maximum likelihood supervised classification*** *of two land-cover classes ("Lupinus nootkatensis" (Lupinus) and "no Lupinus nootkatensis" (no Lupinus) in* ***the study area****. The* ***NIR, red and MIR bands,*** *were used in the classification. All explanations of terms are from Lillesand et al. (2008).*

		Field sampling				
		Lupinus	no *Lupinus*	Total	ErrorC	"Users accuracy"
Classification	*Lupinus*	17	2	19	0.1053	17/19=0.89
	no *Lupinus*	2	32	34	0.0588	32/34=0.94
	Total	19	34	53		
	ErrorO	0.1053	0.0588		0.0755 (overall error)	

"Producers accuracy" *Lupinus*: 17/19=0.89
no *Lupinus*: 32/34=0.94

"Overall accuracy" (17+32)/53=0.92

90% Confidence Interval = +/- 0.0597 (0.0158 - 0.1352)
95% Confidence Interval = +/- 0.0711 (0.0044 - 0.1466)
99% Confidence Interval = +/- 0.0936 (0.0000 - 0.1691)

KAPPA INDEX OF AGREEMENT (KIA)

CLASSIFIED IMAGE:		FIELD SAMPLING:	
Category	KIA	Category	KIA
Lupinus	0.8359	*Lupinus*	0.8359
no Lupinus	0.8359	no *Lupinus*	0.8359

Overall Kappa is 0.8359

Table D. Error matrix for the ***maximum likelihood supervised classification*** *of two land-cover classes ("Lupinus nootkatensis" (Lupinus) and "no Lupinus nootkatensis" (no Lupinus) in* ***the study area****. The* ***NIR and MIR bands,*** *were used in the classification. All explanations of terms are from Lillesand et al. (2008).*

	Field sampling				
Classification	*Lupinus*	no *Lupinus*	Total	ErrorC	"Users accuracy"
Lupinus	18	2	20	0.1000	18/20=0.90
no *Lupinus*	1	32	33	0.0303	32/33=0.97
Total	19	34	53		
ErrorO	0.0526	0.0588		0.0566 (overall error)	

"Producers accuracy" *Lupinus*: 18/19=0.95
no *Lupinus:* 32/34=0.94

"Overall accuracy" (18+32)/53=0.94

90% Confidence Interval = +/- 0.0522 (0.0044 - 0.1088)
95% Confidence Interval = +/- 0.0622 (0.0000 - 0.1188)
99% Confidence Interval = +/- 0.0819 (0.0000 - 0.1385)

KAPPA INDEX OF AGREEMENT (KIA)

CLASSIFIED IMAGE:		FIELD SAMPLING:	
Category	KIA	Category	KIA
Lupinus	0.8441	*Lupinus*	0.9155
no *Lupinus*	0.9155	no *Lupinus*	0.8441

Overall Kappa is 0.8783

*Table E. Error matrix for the **maximum likelihood supervised classification** of two land-cover classes ("Lupinus nootkatensis" (Lupinus) and "no Lupinus nootkatensis" (no Lupinus) in **Reykjanes peninsula and the neighbourhood of Reykjavík**. The **NIR, red, green and MIR bands**, were used in the classification. All explanations of terms are from Lillesand et al. (2008).*

Classification	Field sampling: *Lupinus*	Field sampling: no *Lupinus*	Total	ErrorC	"Users accuracy"
Lupinus	46	28	74	0.3784	46/74=0.62
no *Lupinus*	0	84	84	0.0000	84/84=1.00
Total	46	112	158		
ErrorO	0.0000	0.2500		0.1772 (overall error)	

"Producers accuracy" *Lupinus*: 46/46=1.00;
no *Lupinus*: 84/112=0.75

"Overall accuracy" (46+84)/158=0.82

90% Confidence Interval = +/- 0.0500 (0.1272 - 0.2272)
95% Confidence Interval = +/- 0.0595 (0.1177 - 0.2368)
99% Confidence Interval = +/- 0.0784 (0.0988 - 0.2556)

KAPPA INDEX OF AGREEMENT (KIA)

CLASSIFIED IMAGE: Category	KIA	FIELD SAMPLING: Category	KIA
Lupinus	0.4662	*Lupinus*	1.0000
no *Lupinus*	1.0000	no *Lupinus*	0.4662

Overall Kappa is 0.6359

Table F. Error matrix for the ***maximum likelihood supervised classification*** *of two land-cover classes ("Lupinus nootkatensis" (Lupinus) and "no Lupinus nootkatensis" (no Lupinus) in* ***Reykjanes peninsula and the neighbourhood of Reykjavík, inside urban areas****. The* ***NIR, red, green and MIR bands****, were used in the classification. All explanations of terms are from Lillesand et al. (2008).*

	Field sampling *Lupinus*	no *Lupinus*	Total	ErrorC	"Users accuracy"
Lupinus	1	18	19	0.9474	1/19=0.05
no *Lupinus*	0	24	24	0.0000	24/24=1.00
Total	1	42	43		
ErrorO	0.0000	0.4286		0.4186 (overall error)	

"Producers accuracy" *Lupinus*: 1/1=1.00
no *Lupinus*: 24/42=0.57

"Overall accuracy" (1+24)/43=0.58

90% Confidence Interval = +/- 0.1238 (0.2948 - 0.5424)
95% Confidence Interval = +/- 0.1475 (0.2711 - 0.5661)
99% Confidence Interval = +/- 0.1941 (0.2245 - 0.6127)

KAPPA INDEX OF AGREEMENT (KIA)

CLASSIFIED IMAGE: Category	KIA	FIELD SAMPLING: Category	KIA
Lupinus	0.0301	*Lupinus*	1.0000
no *Lupinus*	1.0000	no *Lupinus*	*0.0301*

Overall Kappa is 0.0584

Table G. Error matrix for the ***maximum likelihood supervised classification*** *of two land-cover classes ("Lupinus nootkatensis" (Lupinus) and "no Lupinus nootkatensis" (no Lupinus) in* ***Reykjanes peninsula and the neighbourhood of Reykjavík, outside urban areas****. The* ***NIR, red, green and MIR bands****, were used in the classification. All explanations of terms are from Lillesand et al. (2008).*

Classification	Field sampling: *Lupinus*	Field sampling: no *Lupinus*	Total	ErrorC	"Users accuracy"
Lupinus	45	10	55	0.1818	45/55=0.82
no *Lupinus*	0	60	60	0.0000	60/60=1.00
Total	45	70	115		
ErrorO	0.0000	0.1429		0.0870 (overall error)	

"Producers accuracy" *Lupinus*: 45/45=1.00
no *Lupinus*: 60/70=0.86

"Overall accuracy" (45+60)/115=0.91

90% Confidence Interval = +/- 0.0432 (0.0437 - 0.1302)
95% Confidence Interval = +/- 0.0515 (0.0355 - 0.1385)
99% Confidence Interval = +/- 0.0678 (0.0192 - 0.1547)

KAPPA INDEX OF AGREEMENT (KIA)

CLASSIFIED IMAGE: Category	KIA	FIELD SAMPLING: Category	KIA
Lupinus	0.7013	*Lupinus*	1.0000
no *Lupinus*	1.0000	no *Lupinus*	0.7013

Overall Kappa is 0.8244

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