Hnignun skóg- og kjarrlendis í Þjórsárdal frá 1587 til 1938 og ástæður hennar

Friðþór Sófus Sigurmundsson

Líf- og Umhverfisvísindadeild
Háskóli Íslands
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60 eininga ritgerð sem er hluti af
Magister Scientiarum gráðu í landfræði

Leiðbeinendur
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Háskóli Íslands
Reykjavík, maí 2011

Yfirlýsing

Hér með lýsi ég því yfir að ritgerð þessi er byggð á mínum eigin athugunum, er samin af mér og að hún hefur hvorki að hluta né í heild verið lögð fram áður.

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Hnignun skóg- og kjarrlendis í Þjórsárdal frá 1587–1938 og ástæður hennar.

Um helmingur Þjórsárdals var vaxinn skóg- og kjarrlendi árið 1587. Skóg- og kjarrlendi dróst mest saman milli áranna 1587 og 1708. Skógurinn var nýttur til eldiviðar, kolagerðar, kýrfóðurs, búfjárbeitar og efniviðar til smíða. Landnýtingin hafði gríðarleg áhrif á skóg- og kjarrlendi dalsins, að auki bættist við kólnandi veðurfar litlu ísaldar og endurtekið gjóskufall vegna eldgosa í Heklu.

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Ágrip

Skóg- og kjarrlendi voru mikilvægar náttúruauðlindir áður fyrr. Nákvæm útbreiðsla birkiskóga er ekki þekkt nema síðustu áratugi og fáar rannsóknir hafa verið gerðar á staðbundinni útbreiðslu þeirra gegnum aldirnar. Megin markmið þessarar rannsóknar er að (1) kortleggja útbreiðslu birkiskóga og kjarrlendis í Þjórsárdal (14.000 ha) á 350 ára tímabili og (2) meta áhrif náttúrulegra, félags- og efnahagslegra þátta á útbreiðsluna á þremur tímabilum, 1587-1708, 1708-1880, 1880-1938. Við kortlagningu á útbreiðslu skóg- og kjarrlendis var notast við sögulegar ritheimildir, staðsetningu og útbreiðslu kolagrafa og gróðurleifar í jarðvegi, gamlar ljósmyndir og loftmyndir. Kortlagningin var unnin í landfræðilegum upplýsingakerfum (LUK). Á vettvangi var núverandi útbreiðsla skóg- og kjarrlendis kortlögð, gróðurleifar í jarðvegi kortlagðar og tímasettar með hjálp þekktra gjóskulaga auk þess sem kolagrafir voru staðsettar. Helmingur Þjórsárdals var vaxinn skóg- og kjarrlendi á seinni helmingi 16. aldar. Frá 1587-1938 dróst skóg- og kjarrlendi saman úr 6170 ha í 388 ha eða um 94%. Breytingar urðu mestar á tímabilinu 1587-1708, þegar skóg- og kjarrlendis dróst saman um 71%. Skógurinn var nýttur til eldiviðar, kolagerðar, kýrfóðurs, beitar og efniviðar til smíða. Fjöldi kolagrafa á svæðinu sýna að kolagerð var mikið stunduð í Þjórsárdal. Þessi landnýting hafði gríðarleg áhrif á skóg- og kjarrlendi dalsins, en að auki bættist við kólnandi veðurfar litlu ísaldar og gjóskufall vegna stórra eldgosa í Heklu. Beit var ekki ráðandi þáttur í hnignun skóg- og kjarrlendis í dalnum en hafa ber í huga að vetrarbeit í vistkerfi sem var ofnýtt hefur haft neikvæð áhrif á nýliðun skóganna. Eignarhald og skógarítök skiptu meginmáli við stjórnun á nýtingu skóglendis og þar með afdrifum þess. Skóg- og kjarrlendi kirkjujarðanna (Skálholts og kirkjuléna) voru ofnýtt en það sem var í einkaeigu eða undir stjórn ábúanda breyttist lítið og þar var að finna stærstu skógarleifar Þjórsárdals árið 1938

Abstract

Land-use is a well known driver for ecosystem change, such as deforestation and soil erosion. Changes in birch woodland cover in Iceland are well documented over the last decades, but few studies have focused on the spatial distribution of birch woodland change over centuries. The main objectives of this study are (1) to map the changes of birch woodland cover in Þjórsárdalur (14,000 ha), over 350 years, from 1587-1938, and (2) understand the impact of socio-economic and natural forces on the birch woodland development over three periods (1587-1708, 1708-1880 and 1880-1938). For this purpose we used combined approach of historical reconstruction from diverse written archives, GIS-techniques and field work. The historical data and GIS were used to reconstruct maps showing birch woodland cover and the field work included location of place-names used for birch woodland in historical archives, mapping of present distribution of birch woodland, birch tree remnants, as well as old charcoal pits. The field work was used to verify the historical data. Half of the Þjórsárdalur valley was covered by birch woodland in the late 16th century. Over a period of 350 years 94% of the woodland had been depleted; its cover changed from 6,170 ha in 1587 to 388 ha in 1938. The woodland was used for firewood, leaf-fodder and charcoal making. The land-use had huge impact combined with natural hazards on the birch woodland cover. Grazing was limited, but winter grazing had negative effects on the ecosystem that was damaged by deforestation. The main driving force for this development is socio-economic but in combination with climate, volcanism and extreme event further exacerbated the woodland decline.

Þakkir

Fyrst og fremst vil ég þakka leiðbeinendum mínum Guðrúnu Gísladóttur og Hreini Óskarssyni fyrir jákvæðni og fagleg ráð sem gerðu þessa ritgerð að veruleika. Ég vil þakka Bjarka Friis jarðfræðingi fyrir tæknilega aðstoð við kortagerð, Kjartani Davíð Sigurðssyni landfræðingi fyrir endalausar umræður um orðalag og enskt málfar. Bjarni Kristinn Gunnarsson fær bestu þakkir fyrir yfirlestur og gagnlegar ábendingar. Guðrún Sigríður Þorsteinsdóttir fær þakkir fyrir yfirlestur á veðurfarslýsingum. Ólafur Eggertson hjá Skógrækt ríkisins tegundagreindi viðarkol sem fundust við vettvangsvinnu í Þjórsárdal og fær fyrir það hinar bestu þakkir.

Foreldrar mínir fá hinar bestu þakkir fyrir þær fjölmörgu stundir sem þeir eyddu með mér í Þjórsárdal og alla þá aðstoð og hvatningu sem þau veittu mér við vinnu í þessu verkefni.
Síðast en ekki síst vil ég þakka unnustu minni Sigurbjörgu Rut Hoffritz fyrir allt umburðarlyndið og þá hvatningu sem hún hefur veitt mér meðan á verkinu stóð.

Inngangskafli

Hnignun skóg- og kjarrlendis í Þjórsárdal frá 1587 til 1938 og ástæður hennar

Friðþór Sófus Sigurmundsson

Landfræði, Líf- og Umhverfisvísindadeild, Háskóla Íslands Öskju 101 Reykjavík

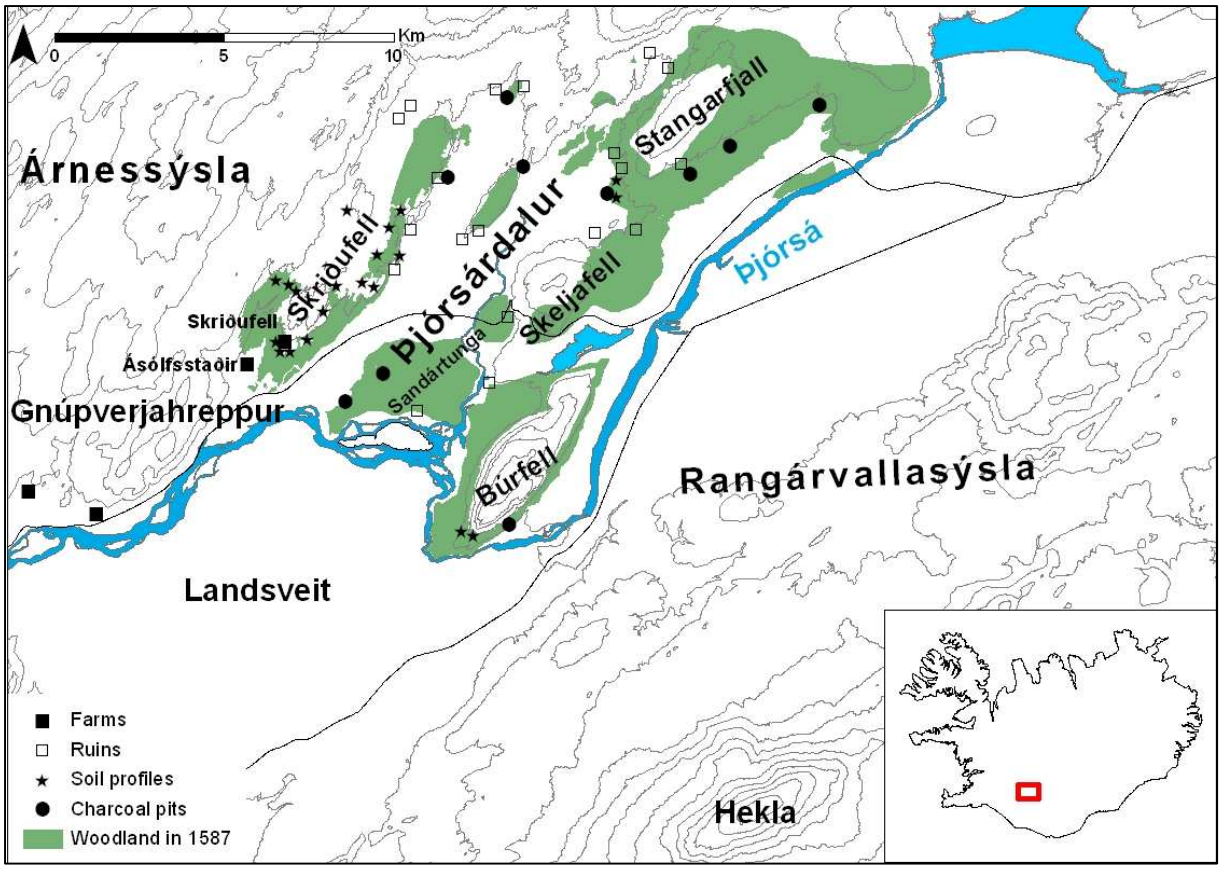
1.1 Inngangur

Ritgerð þessi samanstendur af einni grein sem birt er í næsta kafla.

Sigurmundsson, F. S., Gísladóttir, G., Óskarsson, H., Decline of birchwoodland in Þjórsárdalur from 1587 to 1938.[Verður send til birtingar í Landscape Ecology] 2. Kafli

Gróðurfar hefur tekið miklum breytingum frá landnámi (Þorleifur Einarsson 1962 og 1963; Margrét Hallsdóttir; Egill Erlendsson 2007). Birkiskóglendi dróst hvarvetna saman þar sem menn settust að (Egill o. fl. 2009; Dugmore o.fl. 2009). Þessi þróun er nokkuð vel þekkt og hefur verið rannsökuð með frjókornagreiningu í jarðvegi (Þorleifur Einarsson 1962; Margrét Hallsdóttir 1987; Egill Erlendsson 2007; Gathorne-Hardy o.fl. 2009; Vickers o.fl. 2011). Það er hinsvegar ekki eins vel þekkt hvernig útbreiðsla birkiskóglenda þróaðist á síðasta árþúsundi. Fáar rannsóknir hafa verið gerðar á staðbundinni útbreiðslu birkis gegnum tíðina. Erlendar rannsóknir hafa sýnt fram á að eignarhald hefur talsverð áhrif á útbreiðslu og tegundasamsetningu skóglendis og hefur það verið rannsakað erlendis (Brown 2003; La Pierre og Germain 2005). Guðrún Sveinbjarnardóttir o.fl. (2009) röktu hvernig Reykholt í Borgarfirði varð að kirkjuléni og hvernig ýmis hlunnindi féllu staðnum í skaut þar með talinn réttur til skógarhöggs meðal annars á Geitlandi. Eignarhald hefur hinsvegar ekki verið rannsakað hérlendis með tilliti til birkiskóglendis.

Hér er gerð grein fyrir niðurstöðum rannsóknar á þróun birkiskóglendis í Þjórsárdal frá 1587–1938 og hverjar ástæður breytinganna voru. Greint verður frá útbreiðslu skógarins 1587, 1708, 1880 og 1938, hvernig eignarhaldi og skógarítökum var háttað og hvernig skógurinn var nýttur, jafnframt voru metnir þeir þættir í veðurfari og eldvirkni sem höfðu áhrif á gróðurfar á svæðinu. Örnefni tengd skóg- og kjarrlendi voru staðsett og kortlögð ásamt því hvaða bæir áttu skógarítök og hvar þau voru staðsett í dalnum.



1. mynd. Rannsóknarsvæðið Þjórsárdalur.

1.2 Samantekt úr öðrum kafla

Í 2. kafla er gerð grein fyrir breytingum sem orðið hafa á útbreiðslu skóg- og kjarrlendis í Þjórsárdal frá árinu 1587–1938. Rannsakaðar voru ritaðar heimildir um Þjórsárdal er vörðuðu veðurfar, búsetu, landbúnað, eignarhald, stýringu skógarnytja, skógarítök og lýsingar á staðsetningu skóg- og kjarrlendis. Gögnum var safnað á vettvangi, en þar var leitað eftir ummerkjum um skóglendi í jarðvegi á stöðum þar sem enginn skógur er í dag. Einnig voru kolagrafir kortlagðar og viðarkol sem fundust við þrjár þeirra tegundagreind. Útbreiðsla skóg- og kjarrlendis var kortlögð út frá staðsetningu örnefna og umhverfislýsingum í handritum úr Hinu íslenska fornbréfasafni og Jarðabók Árna Magnússonar og Páls Vídalín. Unnið var með öll gögnin í landfræðilegum upplýsingakerfum (LUK).

Á grundvelli gagnanna var rannsóknartímabilinu skipt upp í þrjú tímabil, 1587–1708, 1708–1880 og 1880–1938.

Útbreiðsla skóg- og kjarrlendis var mest árið 1587 en dróst mikið saman þegar leið á 17. öldina. Eignarhald á skóg- og kjarrlendi var að mestu á hendi biskupsstólsins í Skálholti. Hann átti árið 1708 flestar jarðir sem höfðu skógarítök í Þjórsárdal eða 83 af 131. Ábúendur á

þeim jörðum voru leiguliðar biskupsstólsins. Þar af voru allar þrjár jarðirnar í Þjórsárdal; Ásólfsstaðir, Sandártunga og Skriðufell. Ábúendur þar höfðu jafnframt nytjar af skóg- og kjarrlendi í Þjórsárdal en voru einnig leiguliðar biskupsstólsins. Þessar jarðir höfðu þó nokkuð aðra stöðu en aðrar jarðir í eigu biskupsstóls með skógarítök í Þjórsárdal þar sem skóg- og kjarrlendið sem jarðirnar nýttu voru í nánasta nágrenni þeirra. Ábúendur þessara jarða höfðu því meiri möguleika á að stýra nýtingu skógarins. Aðrir stórir landeigendur í Þjórsárdal voru Beneficium (Kirkjulén) og einkaaðilar sem síðan leigðu jarðirnar leiguliðum.

Bein ítök biskupsstólsins og ítök jarða í eigu hans hnignuðu mest á fyrsta tímabilinu, að undanskildu skóg- og kjarrlendi í umsjá leiguliða á Ásólfsstöðum og Skriðufelli. Það skóg- og kjarrlendi breyttist lítið á þessum tíma. Hins vegar eyddist skóg- og kjarrlendi í Sandártungu, sem hafði nokkra sérstöðu miðað við hinar tvær jarðirnar í dalnum. Í heimalandi bæjarins voru flókin ítök margra annarra jarða og því ekki víst að ábúandi hafi getað stjórnað skógarnýtingu eins og ábúendur á Skriðufelli og Ásólfsstöðum gátu gert. Sandártunga fór í eyði 1693.

Hnignun skóglendis var mun minni, þar sem ítök voru frá jörðum leiguliða sem voru í eigu einkaaðila, en hjá leiguliðum biskupsstólsins. Skóg- og kjarrlendi í eigu kirkjulénanna fór hins vegar afar illa og var ekki nema svipur hjá sjón í lok fyrsta tímabilsins.

Nánast allt skóg- og kjarrlendi í austurhluta dalsins eyddist milli 1587 og 1708. Á sama tíma fóru skóg -kjarrlendi illa í miðju dalsins en héldu velli í vesturhluta hans. Árið 1587 náði útbreiðsla skóg- og kjarrlendis til 6170 ha lands en árið 1708 hafði það dregist saman í 1810 ha.

Skóg- og kjarrlendi í Þjórsárdal var nýtt til kolagerðar og eldiviðar af 131 jörð í austurhluta Árnessýslu. Þessi nýting hafði afar neikvæð áhrif á skóg- og kjarrlendið og gerði því erfitt fyrir að standast harðindaár litlu ísaldarinnar. Undir lok 17. aldar var ástand skóg- og kjarrlendis afar bágborið, en stærsta einstaka áfall reið yfir vistkerfi Þjórsárdals með eldgosi í Heklu sem hófst 13. febrúar 1693. Þetta eldgos var ekki með stærstu eldgosum sem orðið hafa í eldfjallinu en vindáttin sendi gjóskumökkinn beint yfir dalinn. Áhrifin af þessu gosi voru þau að allt skóg- og kjarrlendi dalsins skemmdist og uppblástur hófst í kjölfar þess á láglendi dalsins. Jarðirnar í dalnum fóru í eyði vegna gossins, Ásólfsstaðir í tvö ár, Skriðufell í fjögur ár og Sandártunga endanlega.

Frá 1708 til 1880 hélt samdráttur skóg- og kjarrlendis áfram og í lok tímabilsins náði svæðið ekki yfir nema 425 ha lands. Skóg- og kjarrlendi í eigu kirkjuléna eyddist nærri því og það sem var í eigu biskupsstólsins og leiguliða hans, utan þess sem ábúendur jarðanna í

Þjórsárdal nýttu, eyddist alveg. Skóg- og kjarrlendi í umsjá leiguliða á Ásólfsstöðum og Skriðufelli breyttist mun minna og stóð sumstaðar í stað. Miklar breytingar urðu á eignarhaldi á tímabilinu. Biskupsstóllinn í Skálholti var lagður niður árið 1787 og eignir hans seldar. Jarðirnar Skriðufell og Ásólfsstaðir voru seldar 5. janúar 1791 og voru kaupendur að þessum jörðum leiguliðar sem þannig gerðust sjálfseignarbændur. Þar með var allt skóg- og kjarrlendi í Þjórsárdal í einkaeigu bænda sem bjuggu á jörðunum og engar heimildir eru um að nokkrar aðrar jarðir hafi nýtt eða getað nýtt skóg- og kjarrlendi í Þjórsárdal eftir þetta. Sökum þessa og vegna skógareyðingar í dalnum var orðinn skortur á skóg- og kjarrlendi til skógarhöggs fyrir jarðir í Gnúpverjahreppi. Afréttarmál urðu því hitamál í Gnúpverjahreppi á þessum tíma, og hafin var barátta fyrir því að hreppurinn og íbúar hans hefðu yfirráð yfir náttúruauðlindum á sínum afrétti. Skóg- og kjarrlendið í Búrfelli var eina skóg- og kjarrlendið sem eftir var á afréttinum í lok 18. aldar og sóttu Gnúpverjar fast að sitja einir að skógarhöggi þar. Árið 1797 skoruðu þeir á sýslumann Árnesinga að banna öðrum sveitarfélögum skógarhögg í Búrfelli.

Á næstu 60 árum virðist hafa verið almennt viðurkennt að Gnúpverjar einir ættu rétt til skógarhöggs í Búrfelli. Í kjölfar mikillar skógareyðingar austan Þjórsár fór að bera á því að Landsveitarmenn og Rangvellingar færu yfir Þjórsá til að sækja sér skóg. Þeir fóru bæði í skóginn hjá Ásólfsstöðum og á Skriðufelli með leyfi landeiganda en einnig í Búrfellsskóg og var það illa séð hjá Gnúpverjum. Árið 1854 endurvöktu Gnúpverjar máls á skógarhöggi í Búrfelli og sendi hreppsnefnd sýslumanni áskorun um að ítreka að Gnúpverjar sætu einir að skógarhöggi og sérstaklega var tekið fram að íbúum austan Þjórsár væri bannað skógarhögg í Þjórsárdal. Hreppsnefndin fór þess einnig á leit við bændur í Skriðufelli og á Ásólfsstöðum að selja ekki skóg til Rangvellinga. Í lok tímabilsins voru skóg- og kjarrlendi takmörkuð við land jarðanna Ásólfsstaða, Skriðufells og syðst í Búrfelli. Skóg- og kjarrlendi fannst enn efst á Sölmundarholti í miðjum dal og er eignað kirkjunni að Stóra-Núpi í Gnúpverjahreppi.

Uppblástur sem hófst eftir gosið 1693 hélt áfram og jarðvegseyðing var talsverð í dalnum allan þennan tíma. Eldgos í Heklu sem hófst 5. apríl 1766 skildi eftir sig nokkuð myndarlegt lag í jarðvegi og jók uppblástur í austanverðum dalnum. Það virðist hinsvegar hafa haft lítil bein áhrif á skóg- og kjarrlendið. Í kjölfar þessa goss jókst samt uppblástur á svæðinu tímabundið. Eldgosið í Laka (Skaftáreldar) í maí 1783 hafði einnig áhrif á gróður í Þjórsárdal. Lauf á birkitrjám gulnaði í móðunni sem lagði frá gosinu og féll af. Þetta olli þó ekki varanlegum skemmdum á skóg- og kjarrlendi og ekki er hægt að segja að þessi mengun hafi valdið eyðingu á skóg- og kjarrlendi í dalnum.

Á árunum 1750–1790 var sérlega kalt og grasbrestur var tíður. Þetta jók mjög á álagið sem var á skóginum og bændur tóku að sækja sér skógarlim til þess að drýgja hey fyrir kýr í hörðum árum. Þetta bættist við hina venjulegu skógarnýtingu; kolagerð og eldivið. Einnig er þess getið að á 19. öld sóttu menn efnivið í hrífutinda og klyfbera. Það hafa menn örugglega gert áður þó þess sé ekki getið. Kolagerð og eldiviður voru engu að síður aðal skógarafurðirnar. Eldiviður var mjög mikilvægur í landi þar sem annað eldsneyti var af afar skornum skammti, sérstaklega meðan voru notaðir gömlu íslensku samsuðuljáirnir sem þurfti að hita upp til þess að „dengja“ á hverjum degi yfir sláttinn.

Frá 1880–1938 dróst skóg- og kjarrlendi saman um 37 ha eða frá 425 í 388 ha. Ekki er hægt að greina að eignarhald hafi stjórnað neinu um þennan samdrátt enda eignarhaldið orðið mun skýrara og þar af leiðandi einfaldara en var fyrr á öldum. Náttúruöflin héldu áfram að leika svæðið grátt en fyrsti áratugur þessa síðasta tímabils var með kaldari áratugum frá upphafi veðurmælinga og afar erfiður bæði gróðri, skepnum og mönnum. Við þessar aðstæður gat óvarleg nýting skipt sköpum um afdrif skóga, eins og raunin var í Þjórsárdal. Vorið 1880 seldi ábúandinn á Skriðfelli mönnum úr Rangárvallasýslu skóg. Rangæingarnir rjóðurfelldu 8 ha lands í Vatnaási fyrir framan bæinn í Skriðufelli. Næstu tvö ár á eftir voru afar köld og erfið og keyrði um þverbak 25. apríl 1882 þegar brast á norðaustan stormur er stóð til 30. apríl. Í þessu veðri blés allur Vatnaás upp og var eftir það kallaður Moldarás í nokkurn tíma. Einnig fóru í þessu veðri skógarleifar efst á Sölmundarholti sem áður höfðu tilheyrt kirkjunni á Stóra-Núpi. Það eina sem eftir stendur af þessu skóglendi er 30m^2 rofabarð þakið víði og birkihríslum.

Veðurfar var frekar hagstætt gróðurfari það sem eftir var rannsóknartímans en þó sýndi skóg- og kjarrlendi þess enginn merki að það dreifði sér, heldur stóð útbreiðslan í stað. Nýting á skóg- og kjarrlendi í Þjórsárdal minnkaði mjög og hætti loks alveg þegar komið var á 20. Öldina. Með tilkomu nýrra innfluttra ljáa með bitstáli sem hægt var að brýna án hitunar dró mjög úr kolaþörf í sveitum landsins. Með aukinni tæknivæðingu í landbúnaði um aldamótin 1900 hvarf kolaþörfin alveg. Eldiviður var hins vegar enn sóttur í Þjórsárdal og var það ekki lagt af fyrr en um 1930. Nokkur dæmi voru um að sóttur væri smíðaviður í skóginn en það var í litlum mæli. Beitarálag jókst nokkuð jafnt og þétt eftir því sem leið á 20. öldina enda fjölguðu bændur kindum sínum í kjölfar breyttra neysluhátta þjóðarinnar.

1.3 Helstu ályktanir

Gróðurfar í Þjórsárdal tók miklum breytingum á rannsóknartímanum. Skóg- og kjarrlendi dróst mikið saman, eða frá því að þekja 6170 ha lands í að þekja 388 ha. Ástæður þessarar hnignunar voru margþættar. Í fyrsta lagi ofnýting skóg- og kjarrlendis, sérstaklega þess sem var í eigu biskupsstólsins eða annarra kirkjujarða, en ekki í umsjá ábúanda með búsetu á svæðinu. Einnig var aukin þörf fyrir skógarafurðir í kólnandi veðurfari og eftirspurn jókst eftir því sem skógar minnkuðu almennt. Náttúruleg áföll svo sem köld ár, og síðast en ekki síst, eldgos í Heklu höfðu mikil áhrif. Eldgosið í Heklu 13. febrúar 1693 olli varanlegum og illbætanlegum skaða á gróðurfari í Þjórsárdal sem vistkerfið hefur ekki enn jafnað sig á. Nýting mannsins gekk á þol vistkerfisins þannig að það mátti ekki við frekari skakkaföllum og hrundi með skelfilegum afleiðingum þegar náttúrulegu áföllin gengu yfir. Það er því afar mikilvægt að gera sér grein fyrir hvaða afleiðingar nýting lands hefur í för með sér og hvaða hættur geta falist í henni. Hnignun skóg- og kjarrlendis kringum jafn virk eldfjöll og Heklu hafa leitt til stórfelldrar jarðvegseyðingar á umfangsmiklu svæði. Það er því mikilvægt að ganga ekki of nærri vistkerfinu til að tryggja að vistkerfið sé sjálfbært og geti tekið við stórum áföllum. Því skiptir miklu máli að þekkja sögu svæðisins og þær breytingar sem átt hafa sér stað í gegnum aldirnar og taka út frá þeim upplýstar ákvarðanir um nýtingu og skipulag svæðisins.

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Decline of birch woodland in Þjórsárdalur Iceland from 1587 to 1938

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Land-cover changes in Iceland have been immense over the last millennium, which has resulted in birch (*Betula pubescencs*) woodland depletion, severely reduced vegetation coverage and inevitably extensive soil erosion. Changes in birch woodland cover in Iceland are well documented over the last decades, but few studies have focused on its spatial distribution change over centuries. Therefore the main objectives of this study were (1) to map the changes of birch woodland cover in Þjórsárdalur (14,000 ha) in southern Iceland over 350 years, from 1587-1938, and (2) to understand the impact of socio-economic and natural forces on the woodland over three periods: 1587-1708, 1708-1880 and 1880-1938. For this purpose we used a combined approach of historical reconstruction from diverse written archives, GIS-techniques and field work. The historical data included socio-economic and environmental descriptions, such as location of birch woodlands and shrub cover and conditions, demography and agriculture, woodland ownership and restriction on the use of woodlands, climate descriptions including extreme events such as cold spells and extreme northern storms, and tephra layers from volcanic eruptions. The historical data and GIS were used to reconstruct maps showing birch woodland cover; field work was conducted to verify location of place-names used for birch woodland in historical archives, to map present distribution of the woodland, birch tree remnants, and old charcoal pits. About half of the Þjórsárdalur valley was covered by birch woodland in the late 16th century but over a period of 350 years 94% of the woodland had been depleted; its cover changed from 6,200 ha in 1587 to 390 ha in 1938. The woodland was intensively used for firewood, leaf-fodder and charcoal making. Grazing pressure was limited, but winter grazing had negative effects on ecosystems that were already damaged by deforestation. The main driving force for this development was socio-economic, particularly ownership and management but in combination with climate, volcanism and extreme events which further exacerbated the woodland decline.

Keywords: Þjórsárdalur, Deforestation, Soil erosion, Land ownership, Tenure, GIS, Historical maps.

Introduction

Vegetation in Iceland has declined severely since the beginning of human settlement around 874 AD (Einarsson 1957; Þórarinsson 1961; Hallsdóttir; 1987; Erlendsson 2007; Vickers et al., 2011). The most extensive changes have been in the massive removal of the native birch forests (*Betula pubescens*), which have been suggested to have declined from approximately 15%−40% of the land area at the beginning of settlement to only 1% in the beginning of the 20th century (Þórarinsson 1961; Sigurðsson 1977; Ólafsdóttir 2001; Wöll 2008). However, it is not known how the vegetation changed spatially through time over the last millennium. Palynological studies have shown a sudden decline of the birch forest in many early settlement farmsteads when climate was mild, which indicates a strong human impact on the forests (Einarsson 1962; Hallsdóttir 1987; Erlendsson 2007; Gathorne-Hardy et al., 2009; Vickers et al., 2011). The subsequent changed vegetation pattern and vegetation depletion initiated severe soil erosion (e.g. Ólafsdóttir and Gudmundsson, 2002; Dugmore et al., 2009; Gathorne-Hardy et al., 2009; Gísladóttir et al., 2010; Vickers et al., 2011; Gísladóttir et al., 2011) and in combination with tephra deposition and the generally harsh climate of the Litte Ice Age (LIA) degradation became irreversible in some areas (e.g. Ólafsdóttir and Gudmundsson, 2002). Birch is resilient to tephra deposition (Aradóttir et al, 2005) but when lightweight and sharp tephra or sediment, 10 cm thick or more, submerges low stature vegetation it is easily abraded and suffocated (Blong 1984; Vilmundardóttir et al., 2009). Explosive volcanic eruptions which produce massive amount of tephra can have great impact on vegetation and woodland coverage (Blong 1984; Guðmundsson et al., 2008).

Although resistant to short time cooling, birch forest distribution responded to climate changes before human settlement (Caseldine et al., 2003; Norðdahl et al., 2008) and Palynological data from southern and western Iceland show rising values of *Betula pubescens* pollen during the short-lived climatic amelioration in AD 600–800 (Erlendsson et al., 2009). The onset of the Medieval Warm period (MWP) started around 800 – 980 AD (Sicre et al., 2008; Axford et al., 2009; Gathorne-Hardy et al., 2009) but ended with cooling, the Little Ice Age (LIA), around 1250-1350 to 1500 AD and lasted until around 1900 AD (Ogilvie and Jónsson 2000; Axford et al., 2009; Gathorne-Hardy et al., 2009; Geirsdóttir et al., 2009). The LIA is represented by two minimum at 1500 and 1800-1850 AD followed by a temperature rise culminating in 1930 AD (Dahl-Jensen et al., 1998; Geirsdóttir et al., 2009), and by the

end of the 16th century the mean annual temperature was almost ~1°C lower than at present (Huang et al., 2000; Ogilvie and Jónsson 2000; Mann and Jones 2003; Oerlemanns 2005).

Land ownership and land use are by many believed to be the fundamental driver of woodland change (Brown 2003; LaPierre and Germain 2005). For example, in Oregon USA, considerably higher rates of forest fragmentation occurred on private land than on public land according to Spies et al. (1994), and private ownership had negative impact on rare species affluence in comparison to areas in public ownership (Lovett-Doust et al., 2003). Stanfield et al. (2002) demonstrated that when forests belonged to a single ownership class they were more spatially connected than those of diverse ownership. In 344 protected natural areas in Canada, the affluence of rare species was greater in public ownership than in areas under private ownership (Lovett-Doust et al., 2003).

Despite the proposed ownership impact on forests and the drastic forest cover decline in Iceland over the last millennium, we do not know of any studies which discuss the impact of ownership on Icelandic woodland resources (Sveinbjarnardóttir et al., 2009). Woodland was a valuable resource in Iceland and used mainly for charcoal making, firewood, and as a building material (Magnússon 2004), but also as leaf fodder (Magnússon and Vídalín 1918-1921). Because of the depletion of woodland in the lowlands of Iceland soon after the settlement it became common for estates to have woodcutting rights far away from the farm (Eyþórsson, 2008; Sveinbjarnardóttir et al., 2009). These rights were considered a valuable asset and farms with wood cutting rights were more valuable (Eyþórsson 2008). In 1695, 94% of all farmers in Iceland were tenants paying rent to a landowner which could be a private landowner, the Church, or the Crown (Lárusson 1967; Gunnarsson 1987). The Church was an important landowner in Iceland and owned about 32% of all estates in Iceland in 1696 (Lárusson 1967). Priests and bishops obtained estates as fiefs from the church (Karlsson 2000). These estates were valuable and usually had many rights to natural resources such as woodcutting rights. These estates, called Beneficium, were intended to provide the priest with a comfortable income to take care of his church and his family. Annexia was a church on an estate that was not a vicarage (Sveinbjarnardóttir et al., 2009). These churches had their own rights and assets which were sometimes not part of the estate that they were built on (Eyþórsson 2008).

Because of the complex interaction of environmental and human impacts on forests or woodland distribution and land degradation (e.g. Brandt et al., 1999; Wimberly and Ohmann

2004; Haase et al., 2007; Wulf et al., 2010), it is of special interest to understand the role of different factors that drove land cover changes in Iceland.

To understand and present the connection between land-cover changes and their relationship with driving forces geographical information systems (GIS) have been used as a practical tools (Cousins 2001; Wulf et al., 2010). Handling and analysis of digital spatial data is comparatively easy and effective and has already been applied to reveal land-cover changes over long periods (Wulf et al., 2010). Studies using historical data which are more than 200 years old are rare, especially those focusing on environmental conditions and land-cover changes over centuries (Cousins, 2001). The main reason for this is the lack of reliable historical data and maps and the very time consuming work of locating the data and rectifying the old maps, and digitising them for intersection with modern maps (Wulf et al., 2010).

The purpose of this study was to map and quantify birch woodland changes in Þjórsárdalur during the cold period of the Little Ice Age, (LIA) through 1587-1938 by using historical data and field evidence, and to link the data with the main driving forces of woodland change. More specifically we address the following questions:

1. What are the main changes in woodland-coverage from 1587-1708, 1708-1880 and 1880-1938?
2. To what extent are driving forces associated with woodland changes?

We denote environmental, demographic, political/institutional, and economic/technological and cultural factors as driving forces for land use/cover changes. For simplification we termed the environmental factors as natural driving forces and all the others as non-natural driving forces.

Methods and materials

Study area

Þjórsárdalur (14,000 ha) is located in southern Iceland (64°05´N- 64°12´N, 19°55´W-19°35´W), close to the central highlands and 15-20 km from the volcano Hekla (Fig. 1). It is a lowland area (100-320 m a.s.l. (Jóhannesson and Sæmundsson 2009) bordering the central highlands to the north. The river Þjórsá (Fig. 1) marks the eastern boundary of the research area and is also the boundary between the Rangárvallasýsla and Árnessýsla districts. The eastern part of the valley floor is composed of two Holocene lava fields from the volcanic system Veiðivötn-Bárðarbunga (Hoskuldsson and Thordarsson 2002). Þjórsárdalur is close to the border of the eastern volcanic zone that goes through Iceland (Jóhannesson and Sæmundsson 2009). Therefore, many eruptions have had an impact on this valley, especially the nearby Hekla from where many tephra layers originate (Table 1).

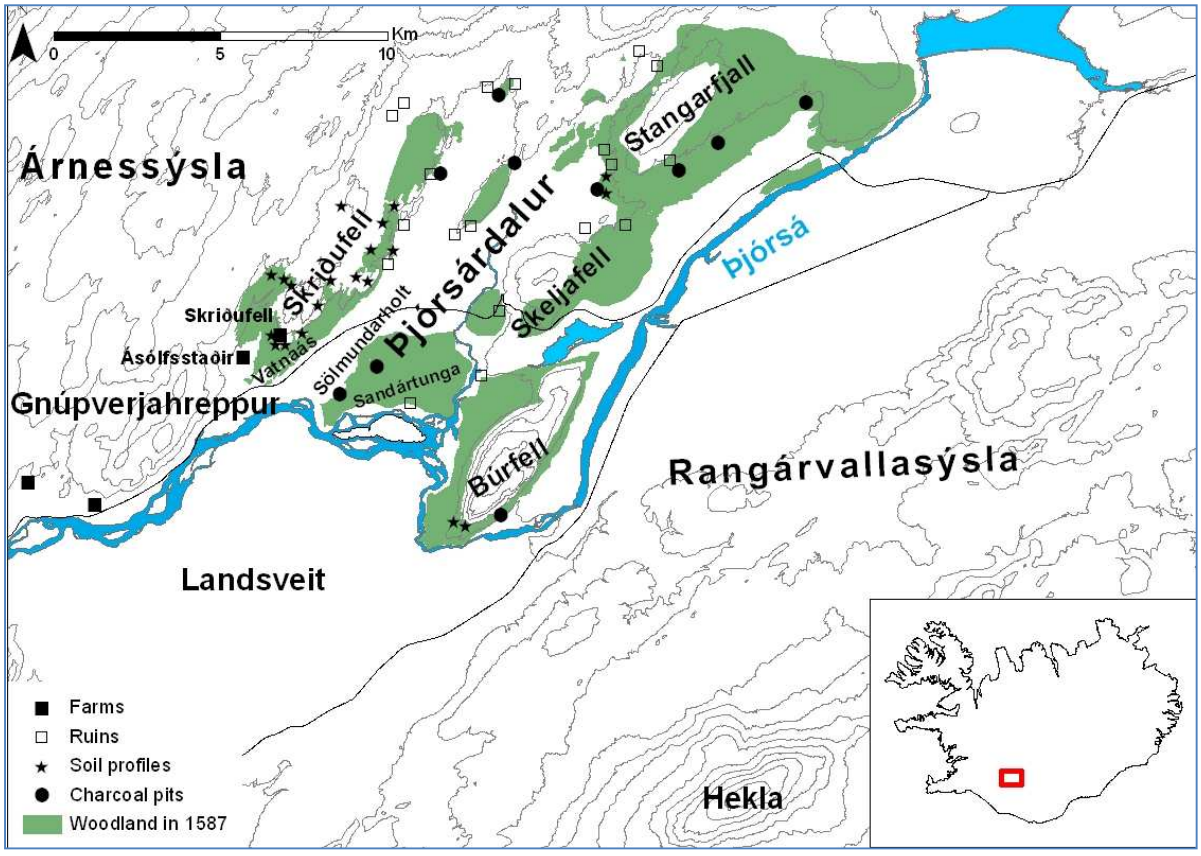

Figure.1 The study area. Þjórsárdalur valley in southern Iceland. The past and present settlement is marked, as well as the field sampling sites.

Table 1 Largest eruptions in Hekla that have left tephra layers in Þjórsárdalur

Tephra layer	Age in calendar years	Tephra layer thickness	Tephra volume
H5	7000	----------	2.5km^3
H4	4500	---------	9km^3
H3	2900	50 cm-1m	11-12km^3
H 1104	907	0.5-20 cm	2.5km^3
H 1300	701	0,2-10 cm	0,5km^3

Sources (Þórarinsson and Larsen 1977; Eiríksson and Larsen 2008; Hjartarson 1995)

According to the book of settlement (*Landnámabók)* Þjórsárdalur was settled during the Landnám era 900-1000 AD. About 20 farmsteads and other buildings have been located (Fig. 1) but it is uncertain when they were abandoned (Vilhjálmsson 1989; Dugmore et al., 2007).

The 1104 Hekla eruption was assumed to have been the main reason for the farmsteads abandonment (Lárusson 1940; Steffensen 1943; Þórarinsson 1944; Þórarinsson 1968), but the reason is now believed to be more complicated (Vilhjálmsson 1989; Dugmore et al., 2007). The woodland in the valley survived the 1104 eruption and two Palynological datasets show that though woodland declined immediately after the eruption in 1104 it did not disappear (Þórarinsson 1944). According to Dugmore et al. (2007) the woodland recovered in the valley during the 14th and the 15th centuries. Little is known about the ownership of the abandoned estates in valley but it is likely that they were in private ownership and their owners retained their rights for some time after the abandonment (Guðmundsson 1981). As the abandonment was permanent this right was abolished and during the 14th century the first account of wood cutting rights is registered for the Beneficium of Hruni (DI 2: 665). Three estates remained inhabited in the valley: Ásólfstaðir, Skriðufell and Sandártunga. These were private estates that became owned by the Episcopal See in Skálholt (Kirkjueignir á Íslandi 1992). It is not known when Ásólfsstaðir and Skriðufell became the property of the Diocese but Sandártunga was bought sometimes between 1134 and 1148 (Kristjánsson 2002).

Many eruptions occurred in Iceland during the research period (Larsen and Eiríksson 2008), but only 5 had immediate effect on the Þjórsárdalur. Information about these eruptions was gathered from various sources (Table 2).

Table 2 Eruptions documented to have an impact on Þjórsárdalur from 1693-1918

Beginning	Duration	Volume Tephra	Volcano	Thickness	Damage
13. Feb. 1693	7-10 months	0.3 km^3	Hekla	2-10 cm	Great
11. May 1721	4 months		Katla	0,5-1 cm	Little
5. April 1766	24 months	0.4 km^3	Hekla	1-5 cm	Some
May 1783	8 months	0,8 km^3	Laki	-------	Some
12. Oct. 1918	24 days		Katla	0,5 cm	Little

Sources (Þórarinsson 1968; Hjartarson 1995; Larsen 2000; Eiríksson and Larsen 2008).

The climate in Þjórsárdalur is mild, cold-temperate oceanic. Mean annual temperature between 1970 and 2010 was 3.1°C (maximum July–August 10.3°C and minimum in January -3.1°C) and on average 150 days per year exceeded 4° C. The mean annual precipitation from 1961-1990 was 1100–1200mm (Einarsson, 1976; Icelandic Meteorological Office, 2011).

Historical source material and mapping methods.

The time frame of the research, 1587-1938, was chosen because of the availability of the source material, historical records of woodland and its ownership, some of which had descriptions of the conditions of the woodland. These records allowed the definition of three different periods: 1587-1708, which we refer to as the early period, 1708-1880, the central period, and 1880-1938, the late period. We chose to end the research in 1938 because the Iceland Forest Service bought the estate of Skriðufell (Fig. 1) and period after that is characterised by attempts to reclaim vegetation and growing forest with various species of conifer and deciduous trees.

Two scripts, from 1587 and 1615 have been preserved from the cadastre of Skálholt, the Episcopal See for Southern Iceland (Karlsson 2000) and published in *Diplomatarium Islandicum* (DI 13: 165-170). They defined woodland location and distribution using place-names and descriptions of the surroundings. A detailed land and census register for Þjórsárdalur was recorded during 1708-09 (Magnússon and Vídalín, 1918-1921). Information of the register includes woodland descriptions, information about ownership and use of woodland. The woodland is demarcated with references to place-names in these registers. Jónsson (1884) located woodland and its conditions as well as he described the landscape over a period of 20 years during 1860-1880. The map for 1938 is based on various data including research of the woodland cover of Þjórsárdalur done by Bjarnason (1937),

photographs from published research on the valley (Stenberger et al., 1943; Þórarinsson 1944) and aerial photographs from 1953 (LMÍ, 1953) .

Place names referring to woodland and its environmental description were used for mapping, but most of the names and locations are known today. We used the place-names and local environmental descriptions in the historical scripts in the field to define the distribution of the historical woodland in the landscape. All mentioned place–names were visited in the field and their surroundings investigated in relation to the description of the surroundings in the source material. On the basis of the investigation the place-names were located, as well as the boundaries of woodland and of various woodcutting rights. Additional field work included analysis of roots and plant remains in soil profiles (Fig. 1) which were dated by using the tephra layers of known age (Þórarinsson, 1968; Berson et al., 2002). Remnants of wood, roots or deadwood, found between tephra layers in woodland depleted areas, were used as an indicator of wooded area for the time defined by the age of the tephra. Location of charcoal pits (Fig. 1) was used to confirm the existence of woodland which was described in the scripts, and charcoal from three pits was identified to *Betula pubescens.*

The mapping was done in the scale of 1:15000. The minimum mapping unit was 10 ha, using Arc Map 10 from ESRI . All maps were in the national coordination system ISN 93.

There is no exact description of the stature of the trees or the density; therefore, we used the term woodland instead of forest or shrubs. Because the dominating tree species at the time of settlement was birch (Hallsdóttir, 1987; Erlendsson, 2007), and the woodland remains in Þjórsárdalur also are birch (*Betula pubescencs*) we assume that the woodland was dominated by birch. The native woodland remaining in Þjórsárdalur varies in stature, but the birch is usually higher than 2m. The other woodland species, *Betula nana, Juniperus communis* and the *Salix* family *S. phylicifolia* and *S. lanata* are normally less than 2m but have substantive coverage inside the woodland, in clearings, and on the edges.

Historical data: Climate records.

A wide range of historical records is available on climate in Iceland and some scholars have categorized them (Thoroddsen, 1916-1917; Ogilvie, 1991; 1995), but not specifically for Þjórsárdalur. Therefore, we investigated *Annales Islandici. Posteriorum sæculorum* (1922-1987), to gather information about climate and specific weather episodes that had an impact on woodland in Þjórsárdalur.

Enquiry on non natural driving forces

After the abandonment of the settlement in Þjórsárdalur sometime after 1104, the region was mainly used for wood products, such as production of charcoal, firewood, building materiel, and grazing. The extensive woodland was a valuable energy source, used by many estates in the eastern part of the Árnessýsla district (DI 13: 165-170). Thus, woodcutting and agriculture played a vital role between 1587 and 1938. We therefore studied the role of ownership and management in changes to the woodland. Because the woodland may have been affected by various forces, the relevance of driving forces for woodland distribution in the valley was compared with as many varied sources as possible. We searched archival documents in the National Archives of Iceland. Additionally, we evaluated a number of publications concerning the history in Þjórsárdalur (Jónsson, 1897; Steindórsson, 1930; Bjarnason, 1937) as well as chronicles concerning the history of the rural district Gnúpverjahreppur (Gestsson and Eiríksson, 1980). Detailed information on woodcutting was obtained from the memoirs of farmers (Gestsson, 1984) and documents from the archive of the Iceland Forestry Service (Sæmundssen, 1918) made by the person instructing woodcutting in Þjórsárdalur.

Results

Birch woodland decline

Over the period 1587-1938, birch woodland had a maximum distribution, in 1587 (Fig. 2), of about 6170 ha or 44% of the research area. By 1708 the woodland coverage had declined to 1810 ha, meaning that the woodland area shrunk by 71% over the 121 year period or by approximately 36 ha pr year. From 1708 to 1880 the woodland cover declined from 1810 ha to 425 ha or by 76%. The small woodland area in 1880 had further shrunk by 10% in 1938.The birch woodland declined greatly over this 350 year period, leaving only 2.7% of the valley wooded in 1938.

Form of ownership

The woodland ownership in Þjórsárdalur in 1587 was mixed (Fig. 2; Table 3). The Diocese or the Episcopal see owned 50% of the woodland through 83 of 131 estates with woodlands holdings in Þjórsárdalur (Fig. 3). Beneficium were the second biggest landowner with 21 % of the woodlands. Tenants living on estates in the valley, owned by the Diocese managed 14% of the woodland, and tenants living on estates owned by private landowners managed 9%. The commons were 6% and the only Annexia that owned woodland managed less than 1% (Table 3).

The type of ownership remained the same in 1708, but their relative share of the woodland changed considerably (Fig. 2; Table 3). All in all the woodland declined by 71%, and there was a shift in the woodland dominance by owner group; the Diocese lost their dominance as their woodland decreased by 85% to only 14% of the woodland left in the valley. Concurrently the privately owned woodland, used by tenants, was the only form of woodland ownership that increased its holdings. Privately owned land became the largest category of woodland and increased its share to 28%, or 680 ha, of all woodland in valley. The area of privately owned woodland had remained mostly unchanged and in addition 150 ha of woodland, previously belonging to a Diocese and a common, became privately owned (Fig. 2). Tenants living on estates owned by the Diocese managed 29% of the woodland. The commons occupied 13% of the woodland. The woodland owned by Beneficium became greatly depleted and was only 5% of the whole woodland. The Annexia still owned 20 ha or less than 1% of the woodland.

The ownership pattern had changed greatly at the end of the 18th century. The Episcopal See in Skálholt was abolished in 1787 and all its estates were sold (Karlsson, 2000). Although the woodland owned by the Diocese had disappeared by this time, Skálholt did still own the Ásólfsstaðir and Skriðufell estates (Fig. 1) until 1791 when they were sold to the tenants, which then became private landowners (for year 1880 see Table 3).

Only three forms of ownership did exist in the valley after 1880. Private farmers were the biggest woodland owners with 78% of all woodland and the commons were limited to 17%. The old Beneficium still had 20 ha of woodland or 5%.

By 1938 only two forms of ownership were left; Private/farmer and Commons. Private ownership was 81% of all woodland and the commons had 19%.

In general there was a total collapse of the woodlands owned by the Diocese and almost total collapse in other church owned woodlands, while the privately owned woodland and the commons were the only preserved woodlands in 1938 (Fig. 2).

Table 3. Ownership/tenancy of woodland in Þjórsárdalur in 1587-1938. Changes in birch woodland coverage (ha) and ownership and total % of woodland cover of research area

Year	Diocese	D/T	Beneficium	Annexia	P/T	Commons	Total	Percent
1587	3060	840	1330	20	530	390	6170	44%
1708	260	520	90	20	680	240	1810	13%
1880*	0	0	20	0	330	75	425	3%
1938	0	0	0	0	311	77	388	2,7%

D/T Diocese/tenant. P/T Private/tenant. *From 1791 woodland that was previously owned by Private landowners and Diocese became owned by the farmer.

Deforestation was greatest during the first period. Woodland became more fragmented and large areas suffered complete depletion, especially the lowland in the eastern and central part of the valley. Although it shrunk severely, the largest, though fragmented, preserved woodland during the central period was around Skriðufell. Only fragments remained close to Búrfell and Sandártunga. The woodland cover remained similar over the last period but was small (Fig. 2).

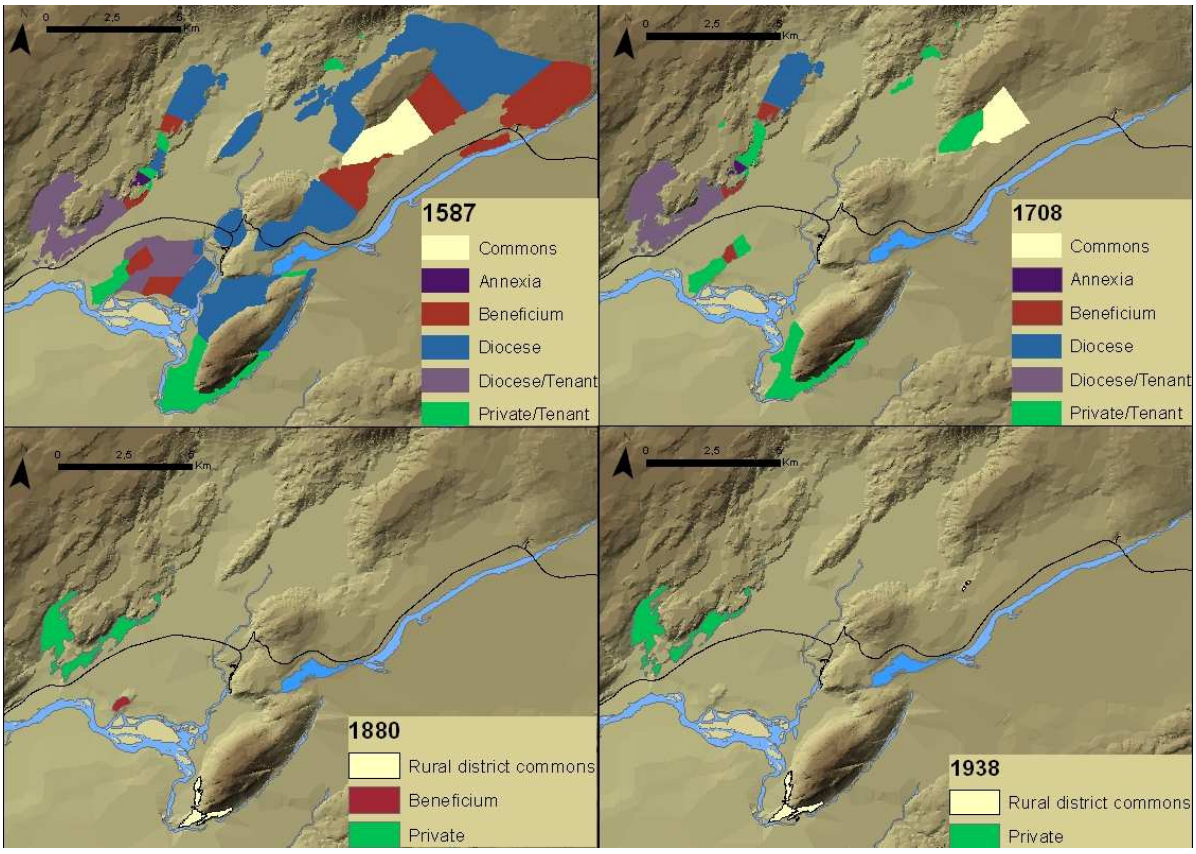

Figure. 2 Decline of woodland in Þjórsárdalur and the changes in ownership.

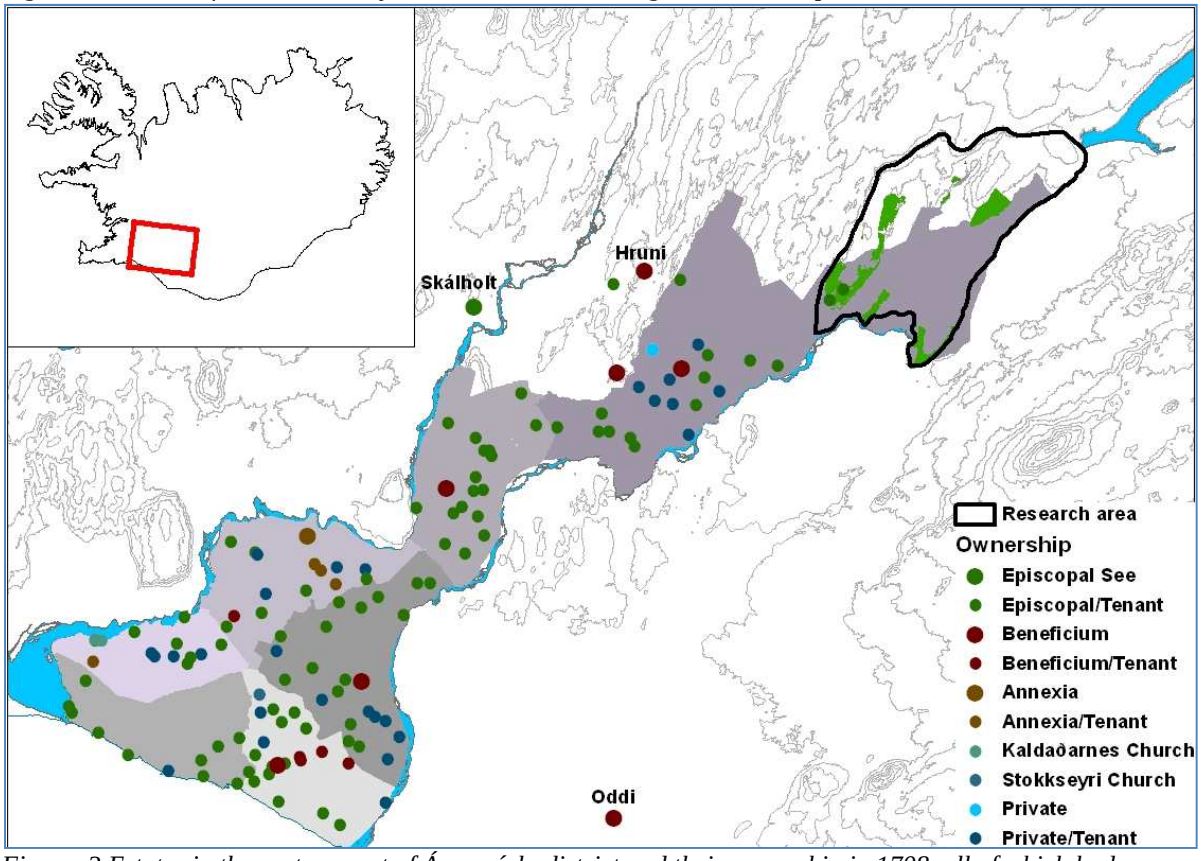

Figure. 3 Estates in the eastern part of Árnessýsla district and their ownership in 1708, all of which had woodland rights in Þjórsárdalur. Rural districts are shaded.

Non natural forces for land cover changes

Investigation of diverse sources revealed a complex form of driving forces for woodland cover changes in Þjórsárdalur (Fig 2). While several demographic, institutional and economic/technological factors are vital, no indication was found that cultural factors played a role in woodland cover change in the valley (Fig. 4).

A total of 131 estates owned woodcutting rights in Þjórsárdalur, out of which 83 were owned by the Diocese (Fig. 3). Other churches (Beneficium) owned 21 estates and 26 estates were in private ownership (Fig. 3). The main use of woodland was for charcoal, firewood and grazing. The number of people living in the area who had access to the woodland was highest at the end of the early period (Fig. 4). Number of livestock was also high at the end of this period (Magnússon and Vídalín 1918-1921).

The Diocese started as the biggest landowner in the valley in the central period (Fig. 2) and despite their woodland depletion, their ownership of land remained the same, but their economical conditions changed dramatically as the Diocese, Skálholt, became impoverished and was abolished as an Episcopal see for South Iceland in 1787 (Karlsson 2000). After that the rural district of Gnúpverjahreppur endeavoured to govern woodcutting rights in Búrfell with success in 1854. The tenants bought the estates and became private owners of their land. The population decreased through the 18th century, but started to increase slowly in the 19th century. The number of livestock is variable but declined in general until the last decade of the period (Fig. 4). The woodland was used for firewood and charcoal throughout the central period, along with leaf-fodder and material for the maintenance of tools (Fig. 4). Also, for the first time, early spring grazing was mentioned in the central period. Technology improved and the importing of new scythes in 1870 reduced the need for charcoal production. Imported energy sources, such as oil and stone coal, also reduced the need for firewood at the end of the central period (Karlsson 2000).

Ownership did not change during the last period but the population and livestock increased (Fig 4). The use of woodland became less and less important with new and better energy sources being imported and better technology in agriculture reducing the importance of early spring grazing which was abolished in the spring of 1882.

Year	**1587**	**1630**	**1670**	**1710**	**1750**	**1790**	**1830**	**1870**	**1910**	**1940**
Demographic Factors										
Population (Inhabitants										
Gnúpverjahreppur				286			173	194	190	
In eastern Árnessýsla				2382			1843	2233	2376	
Political/Institutional										
Factors										
Diocese	1587-1615 Ownership of woodland further Established by the Diocese restrictions on wood cutting for people from Rangárvallasýsla				End for Episcopal See in Skálholt 1787 and estates sold in the next decade					
Rural district						1797 Rural district of Gnúpverjahreppur claims the woodland south of Búrfell		1854 Authority for Wood cutting control established south of Búrfell		
Forestry service									1917-1922 Instruction for woodcutting	
Economic/Technological Factors										
Livestock	High number of livestock compared to later periods in 1708			1710-1750 decreased number of livestock. Causes: cold years, eruptions		1759 -1784 decreased number of livestock; Causes: sheep scab (*psoroptes ovis)* and pollution from Laki Eruption			1870-1900 increased number of sheep. Reasons: Export and increased demand for meat consumption	
Grazing						Early spring grazing in 1830s		starting	1882 early spring grazing stopped	
Technological								1870 New type of scythes introduced reduces need for charcoal		
Wood products		1587-1615 Charcoal and firewood		1708 Charcoal and firewood		1797 Charcoal, firewood and leaf-fodder. Material for repairing tools		1870 Charcoal	1910-1930 Firewood	
Year	1587	1630	1670	1710	1750	1790	1830	1870	1910	1940

Figure. 4 Driving forces for land cover changes in Þjórsárdalur. The lines show the boundaries between the periods. Sources (DI 13: 165-170; Sæmundssen 1918; Magnússon and Vídalín 1918-1921; Jónasson 1934; Bjarnason 1937; Gestson 1984; Gestson and Eiríksson 1980; Jónsson and Magnússon 1997).

Natural driving forces

Climate

Drift ice on the south coast of Iceland was recorded for nine years during the early period 1587-1708 (Table 4). The climate was very harsh in the early and late 17th century, with drift ice every third year in 1605-1617 and 1687-1697. In the middle period drift ice was recorded for 15 years, which included the harsh climate from the mid 18th century onwards, with drift ice reported three times in 1756-1766 and limited grass growth (Table 5) almost every second year during 1750-1790.

While drift ice was not recorded at the south coast in the early 19th century, grass growth was limited for every second year during the first decade of the century. Drift ice was frequent for the rest of the 19th century. There is a short interval period from 1810-1835 with only two years reported with hampered grass growth, but drift ice was reported four times for the same period. The 1850s were cold with hampered grass growth every second year. The last period started with the 1880s, which was also a cold decade with three summers of hampered grass growth and four drift ice occurrences in every second year. After that only one year was recorded for limited grass growth in the 20th century (Table 5).

Table 4 Registered drift ice incidents at the south coast of Iceland, and consequently cold spells in Þjórsárdalur valley. The shaded area represents the different mapping periods; 1587-1708; 1708-1880; 1880-1938.

Year	Months	Record description
1605	April-May	Drift ice along the South Coast
1610	In Spring	Long winter.
1615	April.-June.	Very hard year.
1617	In Spring	Drift ice south of Iceland
1639	In spring	Hard winter.
1687	In spring	Beginning of a cold decade
1694	In spring	Cold year.
1695	April-May	Ice all around Iceland.
1705	April-May	Hard year
1745	April-May	Beginning of the “cold decade”
1756	April-August	drift ice along the South coast
1759	In spring	Drift ice on the South coast
1766	April-June	Drift ice from the west coast reached the South coast
1791	In spring	Drift ice drifting around Iceland
1792	April-June	Cold year
1815	April	Drift ice on the South coast
1817	April	Drift ice on the South coast.
1820	All winter	Drift ice was drifting south of Iceland
1826	26 May- 9 June	Drift ice south of Iceland
1835	May-June	Cold year,
1837	May	Drift ice south of Iceland
1840	May- August	Drift ice all summer on the South Coast
1859	May	Ice between Faroe islands and Iceland
1866	Jan.-May	Lots of ice around Iceland
1881	Jan.-Feb.	Very cold and hard winter
1882	May-June	Very short summer
1887	May-August	Drift ice all summer
1888	June	Drift ice on the South coast
1898	May	Little drift ice
1902	March	Little drift ice
1918	Nov.-Dec.	Ice formed on Faxaflói

Sources (Thoroddsen 1916-1917; *Annales Islandici. Posteriorum sæculorum* 1922-1987)

Table 5. Years with hampered grass growth because of cold spells in southern Iceland. Shaded areas refer to different mapping periods.

1601	1602	1623	1628	1632	1634
1636	1637	1639	1642	1653	1659
1665	1668	1674	1680	1682	1684
1686	1687	1690	1692	1695	1696
1697	1698	1701	1703	1705	1715
1717	1725	1727	1728	1729	1730
1734	1737	1741	1745	1749	1751
1754	1756	1761	1767	1768	1771
1772	1774	1777	1782	1784	1787
1788	1790	1791	1793	1796	1802
1803	1807	1808	1809	1812	1823
1835	1836	1840	1848	1851	1855
1856	1859	1862	1863	1866	1870
1873	1877	1881	1882	1888	1918

Sources: *Annales Islandici. Posteriorum sæculorum* (1922-1987), Thoroddsen (1916-1917); Friðriksson (1954)

Extreme weather

No storms or floods were recorded to have damaged woodlands in the early period, but heavy snow is reported to have damaged trees in 1699 (Thoroddsen 1916-1917). In the central period wind erosion was reported to start in Þjórsárdalur as early as 1709. Storms that caused damage to trees were recorded in 1836, 1875 and a heavy snowfall in 1791. In the last period one severe storm was recorded to have caused severe woodland damage during 5 days in April 1882.

Volcanic Eruptions

Out of the volcanic eruptions that occurred during the research period, the 1693 Hekla eruption was the one that caused the most severe woodland damage (Fig. 5; Table 6). According to (Magnússon and Vídalín, 1918-1921) this eruption caused farm abandonment. Ásólfsstaðir for 2 years, Skriðufell for 4 years and Sandártunga permanently. The majority of the woodlands of the period was reported to have been damaged by this eruption and thus contributed to the depletion of the woodland (Table 6, Fig. 3). As for the eruptions in the middle period, the 1721 Katla eruption caused no damage to woodlands but some minor damage was reported from the 1766 Hekla eruption. Pollution from the Laki eruption in 1783

hit the valley and this caused defoliation of trees and shrubs (Thoroddsen, 1916-1917). There was some tephra precipitation in the valley from Katla in 1918 (Table 2) but it was not recorded to have damaged woodland.

Table 6 Place-names of woodlands in 1587-1708 and descriptions of the conditions in the 1587 and the 1615 scripts and in the 1708 land register.

Place-name	**1587 /1615**	**1708**
Steinsholtsskógur	Woodland	Damaged woodland because of Hekla 1693
Hamartorfa	Woodland	Damaged woodland from Hekla 1693 and land-use
Oddgeirshólaskógur	Woodland	Woodland used for charcoal making but damaged from eruption of Hekla 1693
Háholtsskógur	Woodland	Used for charcoal and firewood but is now declining
Hlíðartorfa	Woodland	Not used and declining from over-use and tephra from Hekla 1693 but not eroded away
Bæjartorfa	Woodland	Damaged from over-use and fallout
Fagriskógur	Woodland	Good forest. Before useable for house building, but now declining but still used for charcoal making.
Brúnaskógur	Woodland	Damaged woodland
Berghálsstaðir	Woodland	Eroded
Lóþrælar	Woodland	Eroded
Geldingaholtsskógur	Woodland	Heavily damaged but still used
Brassholtstorfa	Woodland	Not used and declining
Neistastaðatorfa	Woodland	Used on occasion
Staðarskógur	Woodland	Eroded
Hjallaskógur	Woodland	Eroded
Langholtskógur	Woodland	Not used for some time eroded
Gjáskógur	Woodland	Large part are damaged, but still used
Hellisskógur	Woodland	Damaged, but used
Hólaskógur	Woodland	Eroded
Kalldnesingur	Woodland	Disappeared from over-use and tephra from Hekla 1693
Bláskógar	Woodland	Gone since 60 years (1703)
Álftavellir	Woodland	Gone since 60 years (1703)
Hrossatungur Nyrðri	Woodland	Damaged by eruption in Hekla 1693 but still used but only on occasion
Hrossatungur Fremri	Woodland	Eroded
Skeljafell	Woodland	Eroded
Egilsstaðaskógur	Woodland	Eroded
Hurðarbakshrís	Woodland	Eroded
Grafarskógur	Woodland	Eroded
Gegnishólatorfa	Woodland	Rarely used
Stokkseyringur	Woodland	Used to be wood for house building but is now declining because of over-use and tephra from Hekla 1693
Gjáskógur við Búrfell	Woodland	Eroded
Sandvíkingur	Woodland	Has been used for charcoal making
Hróarshyltingur	Woodland	Eroded
Haursholtstorfa	Woodland	Eroded
Tunga	Woodland	Eroded
Horn	Woodland	Eroded
Fossrófur	Woodland	Eroded
Oddaskógur	Woodland	Eroded
Sandártunga	Woodland	Eroded
Núpsskógur	Woodland	Used for charcoal and firewood
Þórðarholt	Woodland	Damaged from fallout and rapidly declining
Minni-Mástungnahöfði	Woodland	Eroded
Hofsskógur	Woodland	Eroded
Mosfell	Not mentioned	Damaged from over-use and fallout from Hekla in 1693

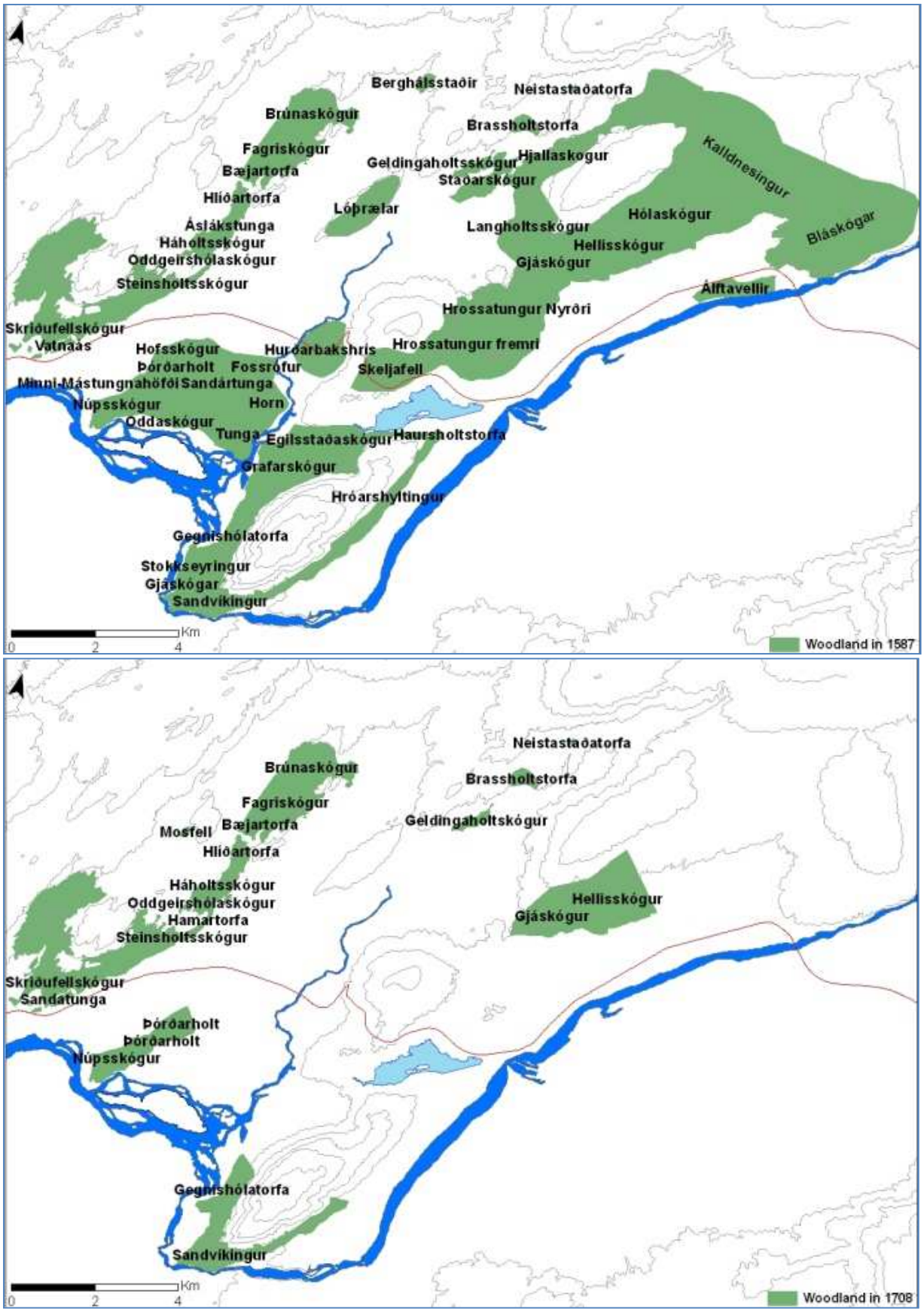

Figure 5. Location of place-names in the 1587 and the 1615 scripts and place-names, with woodland in 1708.

Discussion

Overall woodland declining

The traditional use of woodland led to the loss of 4360 ha of wooded area in Þjórsárdalur from 1587 to 1708. The woodland was under pressure from various driving forces: Ownership and management, intensive land-use, harsh climate, wind erosion and the effects of eruptions.

The most striking decline was in the first two periods when 93% of woodland was lost in less than 300 years. Palynological studies in Iceland have shown a similar rate of birch woodland decline when under pressure from land-use (Gathorne-Hardy et al., 2009; Vickers et al., 2011). Both studies showed a rapid decline in birch woodland soon after the settlement in the 9th century and that the birch woodland around farmsteads was largely depleted in 200-500 years.

Non-natural driving forces, the use of Woodland

There were various socio-economic reasons for the non-natural driving forces. After the abandonment of the medieval farmsteads in Þjórsárdalur, the valley became a vital energy source for the rural district in the eastern part of Árnessýsla (Di 13: 165-170). The intensive use may have been even more concentrated in Þjórsárdalur because the eastern part of Árnessýsla had very limited woodland resources outside Þjórsárdalur (Magnússon and Vídalín, 1918-1921). We propose that the intensive use of the woodland in Þjórsárdalur for charcoal production and later firewood was the single most important factor related to land use.

There was no indication of bog iron production in Þjórsárdalur during the research period, but charcoal was essential for heating and sharpening the scythes used to cut hay for the livestock (Jónasson, 1934). The only native fuel that could give enough heat for iron casting was the charcoal from birch trees. The need for charcoal was therefore consistent for every farm; one farm would need at least 25 kg of charcoal just for minimum maintenance of scythes during harvest times (Magnússon, 2004). Given the number of estates (131) that had access to the woodland in Þjórsárdalur, this would have required a considerable amount of wood every year, or ca. 13 tonnes just for charcoal production. The biggest trees would have been used first, but according to Jónasson (1934) trees that were usable for charcoal were 10 to 15 cm in diameter. Trees with smaller stems and shrubs were used for firewood. The

gradual increases of firewood extraction in comparison to charcoal indicate a general stature reduction, and thus effected the regeneration of the woodland. Similar vegetation changes because of over-exploitation have been recorded in other places in Iceland (Erlendsson et al., 2007; Gathorne-Hardy et al., 2009; Gísladóttir et al., 2010; Vickers et al., 2011).

Firewood was vital in a country that had limited fuel for heating and cooking and selling firewood generated substantial income for the owners of Skriðufell and Ásólfsstaðir in the 19th century (Bjarnason, 1937). Firewood became the main wood product in the valley during the 19th century. As the woodlands shrunk in size and stature this wood cutting could have dire consequences and this was sometimes the end for the woodland. Cutting firewood in woodlands that no longer possessed trees sufficient for charcoal production put pressure on the weak ecosystem and the result was often devastating. Farmers in the area in the 19th century realized that the over-cutting and clearing of small trees and shrubs invited the danger of soil erosion and therefore loss of much needed vegetation cover. One striking event is recorded in Þjórsárdalur of over-cutting woodland for firewood. In the summer of 1880 farmers from Rangárvallasýsla bought wood from the owner of Skriðufell. They cut every tree and shrub on Vatnaás (Fig. 1) in front of the farm in Skriðufell, altogether 8 ha of woodland. Two years later, this area was eroded in a single extreme northeast storm and lost all vegetation cover (Bjarnason 1937). The fate of the woodland demonstrates the poor state of the surface vegetation by that time, which resulted in its depletion during one storm event.

Other use, such as leaf-fodder for cows and the use of birch for tools were rarely mentioned in written sources and seem to have had little impact on the woodland except for adding pressure on a weakened ecosystem.

Large parts of woodland in Þjórárdalur were summer pastures for the rural districts in eastern Árnessýsla. Also, the farmers in Gnúpverjahreppur used the pastures in the valley for early spring grazing from 1830 to 1882 (Bjarnason 1937). Farmers in Ásólfsstaðir and Skriðufell used the woodland for winter grazing sheep both in the 18th and the 19th centuries. However, number of sheep was highest in the beginning of the 18th century and then declined and their number did not start to rise considerably until the beginning of the 20th century.

There is no evidence that grazing caused woodland depletion but it probably decreased the ability of the woodland to regenerate, as has been seen in recent times (Sigurðsson, 1977; Aradóttir, 2005).

Woodcutting and free-range grazing are thought to be the main factors for the birch disappearance shortly after the settlement (Hallsdóttir, 1987; Erlendsson, 2007). The woodland decline in Þjórsárdalur seems to be a part of a similar development.

Ownership and woodland decline

Because of the valuable woodland remaining in the valley after the abandonment of the farmsteads sometime after 1104, the Beneficium and the Diocese established woodcutting rights in the valley. When and how the valley became a major property of Beneficium and Diocese is not clear but Bjarnason (1937) suggests that it might have been through the possession of estates that had inherited this right or simply by a takeover in the vacuum after the claim of ownership on the abandoned estates had expired (Guðmundsson 1981).

The woodlands belonging to the Diocese and the Beneficium declined much faster and more than woodland under other forms of ownership in the first period (Fig. 2). The Diocese owned 83 estates with woodcutting rights, including the estates Skriðufell, Ásólfsstaðir and Sandártunga. The Beneficium were five and owned seven estates which had woodcutting rights through the Beneficium in the valley. On many occasions it is the same with the Diocese; Estates in the possession of the Diocese had woodcutting rights in the woodland belonging to the Diocese. This meant unlimited access for 96 estates, belonging to either Diocese or Beneficium to 85% of the woodland in Þjórsárdalur in 1587. Therefore, there was an intense pressure on the valuable woodland resources. The complete lack of regulation of the quantity of wood-cutting of each estate, and the lack of appropriate responses to restrict land use and ecosystem preservation resulted in highly decreased and degraded woodland of the Diocese and the Beneficium, a fate consistent with Hardin's (1968) model of the commons.

Woodland on the estates located within the valley fared much better and changed little with the acceptation of the woodlands around Sandártunga. All the rights that other estates had for woodcutting on the land of Ásólfsstaðir and Skriðufell were clearly located by place names and none were close to where the farms were located. In Sandártunga it was the opposite situation, six estates had right for wood cutting and the woodcutting areas were large according to the place-names. The tenant living there had to allow woodcutting next to his hayfields. As mentioned before Sandártunga was abandoned permanently after the 1693

eruption of Hekla. Most of the vegetated land belonging to this estate was lost due to soil erosion in 1708 (Magnússon and Vídalín, 1918-1921).

Privately owned woodland was used by tenants and none of it declined in the early period. This was probably due to that fact that only one estate used each of the woodland and these woodlands were more clearly demarcated than the woodlands of the churches.

The only restrictions on woodcutting in Þjórsárdalur during the first period was that the bishop in Skálholt, in 1615, proclaimed that people from Rangárvallasýsla should not cut wood in Þjórsárdalur.

The tendency of the church and the elite class in Iceland was to go for the next holdings when one resource was depleted locally (Sveinbjarnardóttir et al., 2009). In Þjórsárdalur that was definitely the trend in the beginning and the manuscripts proving this are a part of the cadastre of the Episcopal See.

During the middle period, the ownership of the woodlands changed during their decline. The woodland belonging to the Diocese ceased to exist and following the economic breakdown of the Episcopal See in Skálholt in 1787 the estates of Ásólfsstaðir and Skriðufell were sold in 1791. The tenants living on these estates bought the land and became owners of land which included the important woodland resources. The subsequent land management involved abolishing woodcutting on their land without permission. Consequently, and because of the declining woodland, other estates in the rural district of Gnúpverjahreppur had limited opportunities for woodcutting (Gestson and Eiríksson 1980). The woodland south of Búrfell was the only woodland left on the eastern part of the valley at that time. This was the summer pasture of Gnúpverjahreppur and therefore the inhabitants decided to claim this woodland as commons for the estates in the rural district. Hence the rural district council sent the district magistrate a letter in 1797 claiming that all inhabitants in other rural districts in Árnessýsla would be prohibited to cut wood or take roots in the woodland south of Búrfell. This claim was accepted and for the next 60 years nothing is heard from the rural district counsel but in 1854, when woodland was declining east of the river Þjórsá, woodcutting pressure on the remaining woodland in Þjórsárdalur was increased from inhabitants of Rangárvallasýsla district. The rural council acted again, sending complainants to the district magistrate asking him to intervene and also to ban the landowners of Skriðufell and Ásólfsstaðir from selling wood to others than inhabitants of Gnúpverjahreppur. This permanently stopped any unwanted woodcutting in Búrfell but the landowners of Skriðufell and Ásólfsstaðir sold wood to whoever they wanted to (Bjarnason, 1937; Gestsson and Eiríksson, 1980; Gestsson, 1984).

This was the first regulation on woodland management in the valley. It was meant to stop the depletion of woodland south of Búrfell, but elsewhere woodland continued to decline.

Despite the long term depletion, the woodland has been able to recover. Similar ecosystem recovery has been shown in Örnólfsdalur in western Iceland before and during the LIA (Gísladóttir et al., 2011) and in Goðaland and Þórsmörk South Iceland (Óskarson et al., 2011).

Woodland decline in relation to natural driving forces

The tephras that was deposited during the research time were not the ones with greatest tephra volume of historical Hekla eruptions (Hjartarson, 1995). The 1693 eruption in Hekla had severe consequences for the woodland and vegetation in the research area (Þórarinsson, 1968) and the damage was beyond what would have been expected if the woodland had been vigorous (Blong, 1984; Aradóttir, 2005; Vilmundardóttir et al., 2009). By 1693 the fractioning of the woodland and the general depletion of the woodland recourses were beyond the point of recovery from pumice and ash deposits up to 10 cm thick. The timing of the eruption, in the middle of a cold spell followed by two years that were probably the coldest of the 17th century (Tables 4 and 5), made the consequences for the ecosystem even worse. Fifteen years after the eruption the woodlands were reported severely damaged and the ecosystem was still declining (Table 6). Similar developments have been found elsewhere where the resilience of the ecosystem had been pressed beyond its recovery and in combination with cold spells and tephra deposit degradation was unavoidable (Ólafsdóttir and Gudmundsson, 2002; Dugmore et al., 2009; Gathorne –Hardy et al., 2009; Gísladóttir et al., 2010). Other eruptions had little immediate effect on the woodland, even the Hekla eruption of 1766, because the direction of the tephra fallout was more to the north (Þórarinsson, 1968). The Laki eruption 1783-1784 caused air pollution which damaged leafs on shrubs and birch trees. However, this was only a temporary effect as most of the trees survived and set leaves the next year (Thoroddsen, 1916-1917).

Cold years with freezing temperatures in the summertime and unusual storms have undoubtedly affected the vegetation, reduced seed formation on birch, and slowed the regeneration of the woodland. The decline in woodland cover was often associated with extremities in weather, especially wind erosion. Wind erosion has been active for long in this area (Dugmore et al., 2007) and it came much more intense after the 1693 eruption. At the end of the 18th century wind erosion was reported to have depleted some of the woodland in

the valley (Bjarnason, 1937). When woodland in Þjórsárdalur had been depleted by human activity, the soil was unprotected from wind and water erosion that was amplified by large amounts of pumice from Hekla that were repeatedly deposited in the area. The pumice and wind erosion brought on the devastation of many of the remaining woodlands. The last major event was the storm in April 1882. This storm depleted at least 28 ha of former woodland in Þjórsárdalur.

Conclusion

The woodlands / ecosystem in Þjórsárdalur changed on a large scale between 1587 and 1938. The drastic decline of birch woodlands was due to several integrated driving forces. The main driving factors are socio/economics especially form of ownership and the lack of woodland management. The form of ownership was fundamental for the decline in birch woodlands. Woodlands belonging to the Diocese and Beneficium were overexploited and therefore declined much faster than woodlands under other form of ownership. Due to the weakened state of the woodland, single events like eruptions and severe storms pushed the ecosystem over a threshold of recovery and increased wind erosion. The cooling during the LIA, especially the shorter growing season, affected the ability of the woodlands to renew themselves by seed and therefore interrupted their sustainability. Because of the resilience that the birch woodland shows against tephra fallout, climate and especially human interference, it is highly recommended that the birch woodland is reclaimed in Þjórsárdalur. This would prevent soil erosion, increase biodiversity, increase carbon sequestration. Reduce the danger of soil erosion following eruption in Hekla and improve options for future land use.

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