

Vistfræði bleikju *Salvelinus alpinus* (L.) og urriða

Salmo trutta (L.) í Elliðavatni, Hafravatni og

Vífilstaðavatni

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2. Hluti

The ecology of Arctic charr <i>Salvelinus alpinus</i> (L.) and brown trout <i>Salmo trutta</i> (L.) in Lake Ellidavatn, Lake Hafravatn and Lake Vifilstadavatn in SW-Iceland.	11
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Uppbygging verkefnis

Eftirfarandi 4. árs rannsóknarverkefni er 30 eininga verkefni sem var unnið frá september 2005 til mars 2007. Markmið verkefnisins var að gera samanburð á bleikju- og urriðastofnum Elliðavatns, Hafravatns og Vífilstaðavatns. Ritgerðin er tvískipt, fyrri hlutinn er samantekt um rannsóknina og samantekt um bleikju og urriða á íslensku. Seinni hlutinn er handrit að grein sem er sett upp samkvæmt leiðbeiningum frá *Fisheries management and Ecology* og rituð á ensku.

1. Hluti

Almennur inngangur

Ágrip

Rannsóknir hafa sýnt að bleikju í Elliðavatni hefur fækkað ár frá ári síðan 1987, meðan aflu urriða hefur haldist stöðugur (Pórólfur Antonsson og Guðni Guðbergsson 2000, Pórólfur Antonsson o.fl. 2005). Hér á landi eru þekktar fimm tegundir ferskvatnsfiska, en auk bleikju *Salvelinus alpinus* (L.) og urriða *Salmo trutta* (L.) eru það lax *Salmo Salar* (L.), hornsíli *Gasterosteus aculeatus* og áll *Anguilla anguilla* (Guðni Guðbergsson 2004).

Bleikja og urriði nýta yfirleitt ólík búsvæði í stöðuvötnum. Í búsvæðavalí skipta umhverfisaðstæður miklu máli. Bestu aðstæðurnar fyrir eina tegund fiska geta verið óhentugar fyrir aðra. Þau skilyrði sem móta búsvæði í stöðuvötnum eru m.a. botngerð, hiti og næringarefnin en aðrir þættir svo sem dýpi, gróðurfar, lögur vatnskálarinnar og ljósgleypni vatnsins skipta einnig máli. Bleikjan getur þrifist vel á hrjóstrugum köldum svæðum og hefur yfirleitt betur í samkeppni við urriða á þeim svæðum. En í frjósamari vötnum, þar sem strauma gætir, er urriði oftast ríkjandi (Guðni Guðbergsson og Pórólfur Antonsson 1996).

Markmið verkefnisins var að gera samanburð á bleikju- og urriðastofnum Elliðavatns, Hafravatns og Vífilstaðavatns, með það að leiðarljósi að kanna hlutföll þessara tveggja tegunda og hvort munur á stofnvísítölu og tegundasamsetningu bleikju og urriða mótið af umhverfi, fæðuframboði og/eða samkeppni tegundanna. Niðurstöður rannsókna 2005 voru bornar saman við eldri gögn (Bjarni Jónsson 1998 og Yfirlitskönnun íslenskra vatna, óbirt gögn). Um er að ræða tvö grunn lindarvötn, Elliðavatn og Vífilstaðavatn og eitt djúpt dragvatn, Hafravatn. Í Elliðavatni er mesta dýpi um 2 metrar en í Vífilstaðavatni er meðaldýpi um hálfur metri. Mesta dýpi Hafravatns er 28 metrar, en meðaldýpi þess 8 metrar. Bleikja, urriði, hornsíli og áll eru í öllum

vötnunum, en lax hefur bara fundist í Elliðavatni og Hafravatni. Stangveiði er stunduð í öllum vötnunum, en áhrif hennar á stærð og samsetningu stofnanna er talin vera lítil. Veiði bleikju í Elliðavatni minnkaði á meðan veiði urriða hefur haldist í stað (Veiðimálastofnun, opinberar tölur, www.veidimal.is). Öll vötnin eru á láglendi í nágrenni Reykjavíkur og fóstra stofna bleikju og urriða.

Töluverðar breytingar á vísitölu stofnstaðar bleikju, metið sem afli á sóknareiningu, hafa átt sér stað í öllum vötnunum. Afli bleikju á sóknareiningu í Elliðavatni hefur farið minnkandi á meðan aflinn hefur haldist stöðugur hjá urriða. Í Hafravatni hefur afli urriða á sóknareiningu aukist meðan bleikjaflinn hefur haldist stöðugur. Í Vífilstaðavatni hefur afli bleikju á sóknareiningu minnkað meðan urriðaflinn hefur haldist stöðugur. Vaxtarhraði bleikju og urriða í Elliðavatni hefur lítið breyst síðan 1993. Í Hafravatni hefur vaxtarhraði hjá 5 og 6 ára bleikju minnkað síðan 1998, á meðan vaxtarhraðinn hefur aukist hjá 4, 5 og 6 ára urriða. Bleikjan í Vífilstaðavatni sýndi afgerandi breytingar á vaxtarhraða, sem komu fram í því að vaxtarhraði hefur aukist verulega síðan 1998, en vaxtarhraði urriða hefur haldist svipaður.

Þrátt fyrir að bleikjustofninn í Elliðavatni hafi minnkað, hefur holdafar bleikjunnar ekki breyst síðan 1993. Á sama tíma hækkaði holdafarsstuðull urriða sem var á lengdarbílinu 35-50 cm. Marktæk hækjun var á holdafarstuðli bleikju og urriða sem voru á lengdarbílinu 10-30 cm í Hafravatni. Í Vífilstaðavatni var einnig hækjun á holdafarstuðli beggja tegunda, sem voru á lengdarbílinu 20-35 cm, þó heldur minni hækjun á holdafarsstuðli bleikju.

Greining á magainnihaldi úr bleikju og urriða úr Elliðavatni sýndi að vatnabobbi, *Lymnaea peregra*, var aðal fæða beggja tegundanna, sem var þó ekki marktækt. Í

Hafrvatni var ekki munur á fæðu bleikju og urriða, en þó hafa orðið breytingar á aðalfæðu, þegar bornar eru saman niðurstöður frá 1998 og 2005. Helstu breytingarnar eru að fæða bleikjunnar virðist hafa breyst frá því að vera ríkjandi rykmý yfir í krabbadýr séu ríkjandi í fæðunni. Á hinn bóginn breyttist fæða urriðans frá því vera með hornsíli ríkjandi í fæðunni í það að vorflugulirfur voru ríkjandi. Engar breytingar voru mælanlegar á fæðu bleikju og urriða í Vífilstaðavatni í samanburðinum frá 1998 og 2005.

Þegar breytingar verða milli tímabila er mikilvægt að vita hvort breytingar hafi orðið á öðrum stofnum innan vatnanna. Breytileiki var á fjölda smádýra á mili tímabilanna, bæði á botni og í svifi. Þó voru þessar breytingar ekki marktækar, fyrir utan fjölda svifdýra per 10 lítra í Vífilstaðavatni.

Niðurstöðurnar benda til þess að lífssaga bleikju og urriða mótið af umhverfi vatnanna og að breytingar hafi orðið frá 1993 til 2005 í Elliðavatni og frá 1998 til 2005 í hinum vötnunum. Í öllum vötnunum hefur bleikju fækkað, en urriði staðið í stað eða honum fjölgað. Minnkun á stofnvísitölu bleikju virðist ekki enduspeglast í breyttum vaxtarhraða, fæðu né í minnkuðu holdafari. Ástæður þessara breytinga eru ekki að fullu kunnar en geta bent til minnkunar á nýliðun eða verri afkomu ungvíðis og seiða. Hækkun hita síðastliðin ár hefur verið lögð fram sem ástæða fækkunar hennar í Elliðavatni (Haraldur Rafn Ingvason 2006). Norræn útbreiðsla bleikju gerir hana viðkvæmari fyrir breytingum á hitastigi en urriði. Frekari rannsóknir á fyrstu lífsstigum bleikju eru nauðsynlegar til að ákvarða ástæður fækkunar hennar ennfrekar.

Bleikja

Bleikja, *S. alpinus* finnst umhverfis norður heimskautið og er útbreiðsla hennar norðlægust meðal tegunda ferskvatnsfiska (Johnson 1980, Skúli Skúlason o.fl. 1992, Maitland 1995 og Klemetsen o.fl. 2003).

Bleikjan getur aðlagast mismunandi umhverfi, m.a. þar sem hún getur lifað í köldum, óstöðugum og næringarsnauðum vötnum, auk þess getur hún bæði hryngt í stöðuvötnum sem straumvötnum (Johnson 1980, Skúli Skúlason o.fl. 1992, Klemetsen o.fl 2003).

Hrygningartíminn getur verið breytilegur milli bleikjustofna, algengast er að hrygning sé á haustin. Þó eru dæmi um að bleikjan hrygni í júlí-ágúst eða desemberjanúar (Johnson 1980). Dæmi um slíkt er kuðungableikja í Þingvallavatni sem hrygnir í júlí (Skúli Skúlason o.fl. 1992) og bleikju í Mývatni sem hrygnir frá október til febrúar (Guðni Guðbergsson 1994). Fjöldi hrygninga er mismunandi á milli stofna, hrygning getur verið allt frá einu sinni upp í fjögur skipti á lífsleið hvers einstaklings (Johnson 1980). Í Elliðavatni er þekkt að bleikja hrygnir einungis einu sinni og deyr að lokinni fyrstu hrygningu (Skúli Skúlason o.fl. 1992, Þórólfur Antonsson og Guðni Guðbergsson 2000). Aldur og stærð bleikju við kynþroska er afar breytilegur milli vatna og getur einnig verið breytilegur innan vatns. Fjögur útlitsafbrigði bleikju í Þingvallavatni er gott dæmi um það, en þau eru með mismunandi kynþroskaaldur og kynþroskastærð (Sandlund o.fl. 1992). Umhverfisþættir eins og fæðuframboð, undirlag, rennandi kalt vatn og gerð vatns (þ.e. stærð, dýpt o.s.frv.) skipta sköpum fyrir aldur og stærð við kynþroska (Johnson 1980, Guðni Guðbergsson og Þórólfur Antonsson 1996).

Bleikja getur verið staðbundin eða gengið til sjávar. Staðbundin bleikja er algengari og heldur sig í ám og vötnum, en getur einnig gengið til sjávar ef engar

hindranir eru til staðar og er þá kölluð sjóbleikja (Skúli Skúlason o.fl. 1992, Guðni Guðbergsson og Þórólfur Antonsson 1996). Útbreiðsla sjóbleikju takmarkast af hitastigi og/eða samkeppni við aðrar tegundir, t.d. finnst hún ekki sunnan við 65° N í Noregi (Nordeng 1983). Staðbundin bleikja á það til að verða kynþroska minni og oft yngri en sjóbleikja (Johnson 1980). Til eru dæmi um bleikju sem verður kynþroska við 10-15 cm lengd í Ölpunum, Noregi og Íslandi (Klemetsen o.fl. 2003). Í Elliðavatni er t.d. þekkt að bleikja verði kynþroska við 28 cm lengd (Þórólfur Antonsson og Guðni Guðbergsson 2000). Sjóbleikja yfirgefur yfirleitt uppeldisánna við eins til þriggja ára aldur og gengur til sjávar, þar sem vaxtarmöguleikar eru meiri (Rikardsen o.fl. 2000, Klemetsen o.fl. 2003). Eftir tvö til fjögur sumur í sjónum nær bleikja kynþroska við 35-50 cm lengd (Skúli Skúlason o.fl. 1992). Nýleg rannsókn í Vesturdalsá hefur sýnt að hluti bleikjuseiða gengur fyrst til sjárvar eins árs gömul (Ingi Rúnar Jónsson og Þórólfur Antonsson 2007).

Þegar bleikja og urriði eru í sama vatni sýnir bleikja mikla aðlögunarhæfni, getur breytt fæðuvali og nýtt krabbadýr í meira mæli en urriði (Johnson 1980). Rannsóknir hafa sýnt að sveigjanleiki á fæðuvali bleikjunnar veltur á þáttum eins og fæðugerð, fæðuframboði tengt árstíðabundnum breytingum og samkeppni (Amundsen 1995). Fæða bleikjunnar samanstendur af ýmsum hryggleysingjum eins og lindýrum þá helst vatnabobbum, krabbadýrum (botn- og sviflægum), ýmsum myflugum á öllum stigum og einnig hrognum, fiskseiðum og hornsílum (Johnsson 1980, Sigurður S. Snorrason o.fl. 2002, Klemetsen o.fl. 2003).

Bleikja finnst í öllum stærðum af vötnum, frá mjög litlum yfir í mjög stór eins og t.d. Þingvallavatn (Klemetsen o.fl. 2003). Þróun bleikjunnar í Þingvallavatni í fjögur afbrigði á aðeins 10.000 árum sýnir aðlögunarhæfni hennar, þar sem hún getur nýtt flest

búsvæði innan vatnsins. Bleikjan hefur aðlagast tveimur megin búsvæðum vatnsins, botninum og vatnbolnum. Murta og sílableikja nýta vatnsbolinn, en dverg- og kuðungableikja nýta bontinn (Skúli Skúlason o.fl. 1992, Sigurður S. Snorrason o.fl. 2002). Mismunandi nýting á búsvæðum sést greinilega á mismunandi fæðuvali hjá afbrigðunum fjórum (Sandlun o.fl. 1992).

Urriði

Urriði, *S. trutta* á uppruna sinn í Evrópu, Vestur Asíu og Norður Afríku (Klemetsen o.fl. 2003, Scott & Crossman 1973). Í Evrópu eru Ísland, Norður Skandinavía og Rússland norðlægustu úbreiðslumörkin. Urriðinn hefur töluverða útbreiðslu utan Evrópu, sem er einkum vegna sleppinga og dreifingar af mannavöldum (Elliott 1994, Klemetsen o.fl. 2003).

Urriðinn hrygnir yfirleitt í möl hvort heldur í straum- eða stöðuvötnum (Elliott 1994, Guðni Guðbergsson og Þórólfur Antonsson 1996, Klemetsen o.fl. 2003). Á upprunasvæðum urriða, á norðurhveli jarðar, er hrygningartími hans frá október til mars, en algengasti hrygningartíminn er nóvember og desember (Elliott 1994). Urriðastofnar á hærri breiddargráðum hrygna fyrr vegna lægri vatnshita og lengri klaktíma hrogna (Klemetsen o.fl. 2003).

Aldur við kynþroska er mismunandi, en fæðuframboð og önnur lífsskilyrði hafa áhrif á hversu langan tíma tekur að ná kynþroska. Staðbundnir stofnar ná kynþroska á aldrinum 1-10 ára, en algengasti kynþroskaaldurinn er 4-6 ára. Urriði verður kynþroska eldri í fjallavötnum og ám á norðlægum slóðum þar sem er kaldara (Guðni Guðbergsson og Þórólfur Antonsson 1996, Klemetsen o.fl. 2003). Endurteknar hrygningar eru

breytilegar milli og innan stofna, sumir hrygna einu sinni og deyja eftir fyrstu hrygningu. Algengur meðalaldur urriðans er 5-8 ára hjá mörgum stofnum, en til eru dæmi um þeir geti orðið allt að 14 ára. (Elliott 1994, Klemetsen o.fl. 2003).

Urriði getur verið staðbundinn eða gengið til sjávar hluta ævi sinnar og er þá kallaður sjóbirtingur. Sjóbirtingur gengur yfirleitt til sjávar við 2-3 ára aldur (Elliott 1994, Guðni Guðbergsson og Þórólfur Antonsson 1996, Klemetsen o.fl. 2003). Bæði vaxtarhraði og dánartíðni eru hærri í sjónum en í stöðuvötnum. Það er mismunandi hversu langan tíma urriði dvelur í sjónum. Til eru dæmi að urriði hafi verið í sjó í allt að 18 mánuði áður en hann snýr til baka til hrygningar (Elliott 1994, Klemetsen o.fl. 2003), en á Íslandi eru 3 mánuðir yfir sumarið algengur tími í sjó áður en snúið er til baka í heimaánna (Guðni Guðbergsson og Þórólfur Antonsson 1996). Staðbundinn urriði getur sýnt þrjá megin lífsferla. Fyrsti og annar ferillinn er þegar urriði gengur eftir fyrsta árið annaðhvort í nálægt vatn eða nálæga á og snýr til baka fullþroska til að hrygna. Þriðji ferillinn er þegar urriði er staðbundinn allan lífsferilinn í upprunaánni (Elliott 1994).

Stærð urriða skiptir máli þegar kemur að fæðuvali. Þegar urriði stækkar þá getur hann smámsaman étið stærri fæðu. Helsta fæðan eru rykmýslirfur, vorflugulirfur, vatnabobbar, efjuskeljar og botn- og sviflæg krabbadýr. Sumir stofnar skipta yfir í að nærist á fiski með aukinni stærð og eru hornsíli (*Gasterosteus aculeatus*) aðalupppistaðan í fæðu urriðans hér á landi. Einnig er þekkt að urriði éti bleikjuseiði eða aðrar tegundir fiska þar sem þær eru til staðar (Hilmar J. Malmquist og Jóhannes Sturlaugsson 2002, Klemetsen o.fl. 2003).

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2. Hluti

Handrit að grein til birtingar í Fisheries Management and Ecology

The ecology of Arctic charr *Salvelinus alpinus* (L.) and brown trout *Salmo trutta* (L.) in Lake Ellidavatn, Lake Hafnavatn and Lake Vifilstadavatn, SW- Iceland.

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Abstract

The stocks of Arctic charr have shown a gradual decline in annual monitoring of Lake Ellidavatn during the period of 1987-2005 (Antonsson & Gudbergsson 2000, Antonsson et al. 2005). A comparison of the ecology of the Arctic charr, *Salvelinus alpinus* (L.) and brown trout, *Salmo trutta* (L.) in lowland lakes in southwest Iceland (Lake Ellidavatn, Lake Hafravatn and Lake Vifilstadavatn), with respect to stock size, stock composition, food and invertebrate abundance in 2005 to previous comparable studies show a decline of Arctic charr, while no changes were observed in brown trout. Despite the decline in number of Arctic charr, its body condition had not deteriorated. In Lake Hafravatn the growth rate for older Arctic charr has decreased, while the opposite happened for brown trout. Growth rate for Arctic charr in Lake Vifilstadavatn increased, but stayed similar for brown trout during the monitoring period. In Lake Vifilstadavatn, there was a significant increase in abundance of zooplankton. The results indicate that lower stock size of Arctic charr in these lakes, is not reflected in growth rate, body condition nor diet at least within adult stages. This may however indicate lower recruitment or lower survival during the first life stages of Arctic charr.

Keywords: Stock change, growth rate, condition, diet, invertebrate abundance.

Introduction

Changes in stock size of Arctic charr have been observed in several lakes in Europe. It has been shown that hydropower development, eutrophication and experimental removal of Arctic charr may explain these changes in stock size of Arctic charr (Aass et al. 2004, Elliott & Baroudy 1995, Klemetsen et al. 2002). Annual monitoring of the fish population

in Lake Ellidavatn has shown almost a continuous decline of Arctic charr since 1987 (Antonsson & Gudbergsson 2000, Antonsson et al. 2005). In the beginning of the period the ratio between Arctic charr and brown trout was nearly equal (Fig. 1). During the same period the catch per unit effort, for brown trout, remained stable (Antonsson & Gudbergsson 2000, Antonsson et al. 2005).

Brown trout and Arctic charr usually exploit different habitats in lakes. In sympatry, Arctic charr are known to feed mainly above the bottom but brown trout near or on the bottom (Forseth et al. 2003). Furthermore, stocked and native Arctic charr seem to be entirely constrained to epibenthic habitats, whereas brown trout seems to be more in pelagic and littoral habitats (Kahilainen & Lehtonen 2002). Overlapping between habitat utilization of Arctic charr and brown trout can however occur.

Many environmental factors such as bottom structure, depth, temperature and nutrients are essential for fish condition and habitat selection for these fish species (Gudbergsson & Antonsson 1996, Klemetsen et al. 2003). Arctic charr is very adaptable to various environmental conditions, but generally thrive in lakes where none or few other fish species exist (Kahilainen & Lehtonen 2002).

Arctic charr has a circumpolar distribution, its low tolerance for temperature changes makes it is likely to be vulnerable to changes in the environment, like global warming (Johnson 1980, Maitland 1995). As mentioned above Arctic charr are facing threats like; fish introduction, eutrophication, angling, hydropower constructions and domestic- and industrial pollution (Maitland 1995, Aass et al. 2004). Fish introduction will consequently have effects on native fish species. In cases when Arctic charr have been introduced into a lake inhabited by brown trout, the catch of brown trout decreased

and examples are of extinction in lakes without spawning streams for brown trout (Johnson 1980). Arctic charr and brown trout are also known to live in sympatry without any significant changes in stock size (Forseth et al. 2003). In contrast, introduction of whitefish, *Coregonus lavaretus* is known to have a negative consequences for Arctic charr, as whitefish is known to feed mainly on zooplankton, but can also have positive effects as whitefish can be a source of food for piscivorous Arctic charr and brown trout (Johnson 1980, Aass et al. 2004, Kahilainen & Lehtonen 2002). Long-term study of the effects of hydropower development on both Arctic charr and brown trout showed reduction in catch per unit effort (CPUE) (Aass et al. 2004). Similar changes in Lake Windermere, where charr decreased but trout increased in the south basin of the lake was connected with eutrophication (Elliott & Baroudy 1995). Inter- or intraspecific competition can also have effect, as Arctic charr and brown trout are known to compete intensively (Forseth et al. 2003). In Lake Takvatn (northern Norway) brown trout showed an increase in density after experimental removal of Arctic charr (Klemetsen et al. 2002). Monitoring fisheries in Lake Myvatn have shown decrease of Arctic charr which is correlated with low food availability which may be linked to diatomite mining and heavy fishing pressure (Gudbergsson 2004).

The objective of this study is to compare the fish stocks of three lowland lakes in southwest Iceland, Lake Ellidavatn, Lake Hafravatn and Lake Vifilstadavatn, with emphasis on Arctic charr and brown trout. The main emphasis will be to test whether similar reductions of Arctic charr, as have been observed in Lake Ellidavatn, also occur in Lake Hafravatn and Lake Vifilstadavatn.

Only five native fish species inhabit lakes and rivers in Iceland. They are in addition to Arctic charr and brown trout: Atlantic salmon, *Salmo Salar* (L.), three-spined stickleback, *Gasterosteus aculeatus* and European eel, *Anguilla anguilla* (Gudbergsson 2004). Arctic charr, brown trout and three-spined stickleback are all found in Lake Ellidavatn, Lake Hafnavatn and Lake Vifilstadavatn. European eel is also known in all the lakes but only in small number. Migrating Atlantic salmon can be found in Lake Ellidavatn and Lake Hafnavatn. In all of the lakes, fishing is only for recreational purpose, the effects on the stock sizes and stock composition are regarded as minimal. The catch statistics in Lake Ellidavatn have shown a considerable decline in Arctic charr population, from 2000 to 2005, while catch statistics for brown trout have remained similar (Institute of Freshwater Fisheries, official statistics, www.veidimal.is).

The present study assessed the situation as it was 2005, compared to results from 1993 for Lake Ellidavatn and results from 1998 for Lake Hafnavatn and Lake Vifilstadavatn (Jonsson 1999, Ecological survey of Icelandic lakes, unpublished data).

Study area

Lake Ellidavatn, Lake Hafnavatn and Lake Vifilstadavatn (64°N , 021°W) are located in southwest Iceland (Fig. 2). These three lakes are in close proximity to urbanization and are colonized by Arctic charr and brown trout. Depth and other characteristics vary between the lakes (table 1).

Lake Ellidavatn is a shallow spring fed lake, with maximum depth of 3 meters. The rivers Holmsa and Sudura flow into the lake, but the river Ellidaar drains the lake (Antonsson and Gudbergsson 2000). The surrounding area of Lake Ellidavatn is both rich

in vegetation and bird life. Lake Hafravatn is a deeper lake with maximum depth of 28 meters, and the mean depth is 8 meters. The main characteristics of the surrounding area around the lake is barren gravel plains, on the other hand there can be found more vegetated wetland areas and some ponds in between (Thordarson 2004). Lake Vifilstadavatn is a shallow spring fed lake, with mean depth of 0.5 meters. The characteristic of the surrounding area is with rich vegetation and versatile bird life (Hardardottir 2001).

Methods

Fish

Fish was sampled in late September and early October 2005 from Lake Ellidavatn, Lake Hafravatn and Lake Vifilstadavatn. Two gillnet series were put in each lake over night (12 hours), consisting of 11 gillnets (30 m long, 1.5 m deep), with mesh sizes from 12-60 mm measured between knots. The number of Arctic charr and brown trout caught were counted from each net and catch per unit effort (CPUE) was calculated as the average number of fish caught per gillnet over night.

Fish length was measured to the nearest mm and weighed with ± 1 g precision. Scales and otoliths were taken for age determination. Otoliths were submerged in alcohol and the hyaline (winter) zones were counted (Bagenal and Tesch 1978). In cases where otoliths were unusable for ageing, scales were used. The scales were first pressed onto a plastic plate, for equal light transmission. Then the plate was mirrored with light to a screen where the hyaline zones could be counted. Sex and sexual maturity stage was determined according to Dahl (1943). Similar sample techniques were utilized in Lake Ellidavatn in 1993 and in Lake Hafravatn and Lake Vifilstadavatn in 1998. This earlier

sampling was a part of Ecological survey of Icelandic lakes (Institute of Freshwater Fisheries, unpublished data).

Body condition was estimated as $K = \text{weight (g)} / \text{length (cm)}^3 \times 100$. However, because factors such as sexual maturity can affect the comparison of fish at different age and length (Bagenal and Tesch 1978), the fish populations were split to length groups (5-19, 20-34 and 35-50 cm) for the comparison of the body condition factor. The average K for each length interval was calculated with 95 % confidence limits.

Stomach analysis

Where available, 50 stomachs from Arctic charr and 50 from brown trout were randomly taken from fish sampled in each lake. Stomach content was weighted (wet weight). Each prey species from the stomach content was identified to order, family or species depending on the taxon and its importance in the diet. *Daphnia*, Copepoda and Ostracoda were later grouped under the subphylum Crustacea. The proportion of each prey species was calculated as well. For the comparison of the main prey species from each lake the species ratio \times weight / total weight (of all stomach contents) was calculated. In cases when stomach content was lower than 5 %, it was put under the category “other”.

Invertebrates

Invertebrate samples were taken with Kajak bottom corer, total of 10 replicate samples from each lake (5 samples from 2 areas in each lake). Bottom samples were kept in 70% alcohol until species from each sample were identified to class, subclass, order or family and counted.

Zooplankton samples were taken with a zooplankton net (125 µm), total 6 samples from each lake (3 samples from 2 areas in each lake). Zooplankton samples were fixed with Lugol until they were processed. In Lake Hafravatn and Lake Vifilstadavatn where the samples showed high quantity, a sub-sample had to be taken, which was done by dividing each sample in two equal halves with a specially made dividing box. Some samples were divided further into $\frac{1}{4}$ or $\frac{1}{8}$ if necessary. The number of invertebrates sampled was compared to the samples from 1993 and 1998. Statistical analysis on the total number of species per m² from the bottom samples was conducted using t-test in Sigma Stat (<http://www.systat.com/products/SigmaStat/>). The same statistical analysis was applied for zooplankton samples, where the average number of species in 10 liters was compared. When t-test did not pass Normality test and Equal Variance test, Mann-Whitney Rank Sum Test was applied. Statistical differences were considered significant if P < 0.05.

Results

Fish populations

Previous studies have shown that Arctic charr have gradually reduced in numbers in Lake Ellidavatn (Fig. 1; Antonsson & Gudbergsson 2000, Antonsson et al. 2005). The results in 2005 showed a continuous catch reduction of Arctic charr in one gillnet serie (16 fold since 1993, (P=0.002)), although the CPUE of brown trout remains stable for the period. Only 7 Arctic charr were caught in Lake Ellidavatn in 2005. Similar results were found in Lake Vifilstadavatn where Arctic charr had reduced 3.1 fold (P<0.001) while brown trout had stayed in similar numbers. In Lake Hafravatn brown trout increased 8.8 fold (P<0.001) while Arctic charr had reduced in numbers (Fig. 3).

The length at certain age for Arctic charr and brown trout indicated that growth has changed in all the lakes. In Lake Ellidavatn average length at age for younger (2-3 year old) Arctic charr has decreased, while 5 year old fish have increased from 1993. The growth curve estimated for 2005 was steeper than the one in 1993. Average length at certain age remained similar for brown trout, indicating similar growth rates in both periods (Fig. 4). In Lake Hafravatn a significant decrease in growth rate for 5 and 6 year old Arctic charr was observed, while the opposite was observed for 4, 5 and 6 year old brown trout (Fig. 5). There was a significant increase in growth rate of Arctic charr in Lake Vifilstadavatn, while brown trout showed similar growth rate between these two periods (Fig. 6).

The length distribution had changed both for Arctic charr and brown trout since 1993 and 1998. Arctic charr showed an increase in number of smaller fish in Lake Hafravatn, while in Lake Vifilstadavatn there was an increase of larger fishes (Fig. 6). Brown trout showed an increase in number of larger fish in Lake Ellidavatn, while in Lake Hafravatn there was an overall increase and Lake Vifilstadavatn showed increase of smaller fish (Fig. 7).

The condition factor for Arctic charr in Lake Ellidavatn had not decreased since 1993. There was, however, a significant increase in body condition factor of larger brown trout (length group 35-50 cm) (Fig. 8). In Lake Hafravatn the condition factor for Arctic charr increased for the smaller charr (length group 10-30 cm). Brown trout showed also an increase among the smaller trout (length group 11-20 cm) (Fig. 9). In Lake Vifilstadavatn, Arctic charr showed a small increase in the length group 21-35 cm, while brown trout showed further increase, in length group 26-35 cm (Fig. 10).

Stomach analysis

Stomach analysis in 1993 and 2005 showed an overlap in diet between Arctic charr and brown trout in Lake Ellidavatn, where *Lymnaea peregra* was the main prey species (Table 2). Low sample size of Arctic charr (7 stomachs), should be taken into account. In Lake Hafravatn and Lake Vifilstadavatn there was no overlap in the diet between Arctic charr and brown trout. However, the main prey species changed since 1998 in Lake Hafravatn, both for Arctic charr and brown trout. Arctic charr had shifted from Chironomidae to Crustacea and brown trout from three-spined sticklebacks, *Gasterosteus aculeatus* to Trichoptera larvae. No changes in main prey species was found in Lake Vifilstadavatn. Crustaceans were the main prey species for Arctic charr both periods and three-spined stickleback for brown trout (Table 2).

Invertebrates

The abundance of bottom invertebrates differed between the two time periods. In all the lakes cladocerans had increased in number, while Oligochaeta had decreased and copepods increased in Lake Ellidavatn and Lake Hafravatn. Despite these changes, no significant difference was found in the abundance between 1993 and 2005 in Lake Ellidavatn nor between 1998 and 2005 in Lake Hafravatn and Lake Vifilstadavatn (Table 3). In Lake Ellidavatn, there was no significant difference in zooplankton abundance, but Chironomidae was a new addition to the samples from 1993. In Lake Hafravatn the ratio between cladocerans and copepods was 50/50 in 1998, but 2005 sample showed 4/96 ratio. This apparent decrease of cladocerans was not significant. There was a significant increase ($P=0.002$) in the average number of species in 10 liters in Lake Vifilstadavatn from 1998. The ratio of cladocera and copepods was the opposite as in Lake

Vifilstadavatn for Lake Hafravatn, where in 1998 it was 38/62 (Cladocera/Copepoda), but in 2005 it was 96/4 (Table 4).

Discussion

The sparse freshwater fish fauna in Iceland makes monitoring changes in the structure and abundance of fish populations within lakes easier, compared to other countries with more complex fauna (Aass et al. 2004). Arctic charr and brown trout have both shown changes in stock size in all the lakes in this study. Arctic charr have decreased in abundance, while brown trout has increased or been stable.

“The growth performance of most fish species is indeterminate and flexible, and may be affected by several biotic and abiotic factors” (Amundsen et al. 2007). The most evident change of growth rate was in Lake Vifilstadavatn, where Arctic charr showed a significant increase. It has been shown that with high densities of Arctic charr or other salmonid fish, the mean specific growth rate of Arctic charr will decrease (Amundsen et al. 2007). Increased growth rate of Arctic charr in Lake Vifilstadavatn is therefore anticipated with decrease of Arctic charr and similar stock size of brown trout. This may indicate reduced competition from Arctic charr. Little changes in growth rate of Arctic charr in Lake Ellidavatn are on the other hand unexpected, but also indicate little interspecific competition. In Lake Hafravatn growth rate of Arctic charr is decreasing which correlates with increased stock size of brown trout. This suggests that brown trout is utilizing habitat previously inhabited by Arctic charr.

A long-term study on variation in Arctic charr and brown trout in Lake Limingen (Norway) showed a reduction of CPUE with time for both species. The annual

fluctuations in water level, due to hydropower development, were linked to these changes in population sizes; this was mainly due to fluctuations in the water level causing the shoreline from being submerged or dry and, frozen during winter and turbid water in the summer, which have presumably caused stress for the salmonid populations. In addition food availability changed and egg survival/year class strength showed a negative relationship with minimum and maximum water levels. Despite reduced CPUE, mass-at-length (condition) increased with time, which suggests limited intra- and interspecific competition. Flexible feeding behaviour enables them to cope with lower diversity and availability of food (Aass et al. 2004).

Length distribution for both Arctic charr and brown trout had changed in all three Icelandic lakes since 1993 and 1998, except in Lake Ellidavatn for Arctic charr, its length distribution spanned from 14 cm to 38 cm, which was similar to 1993. In Lake Hafravatn the number of smaller Arctic charr was higher, while the opposite was the case in Lake Vifilstadavatn. The number of larger brown trout has been increasing in Lake Ellidavatn while the opposite has happened in Lake Vifilstadavatn. There was an overall increase of both small and large brown trout in Lake Hafravatn.

Body condition for both Arctic charr and brown trout had not deteriorated since 1993 (Lake Ellidavatn) and 1998 (Lake Hafravatn and Lake Vifilstadavatn), despite changes in stock size. Arctic charr's increased condition suggests reduced intraspecific competition. This conflicts with brown trout, whereas condition and CPUE increased or was stable. With these changes it would be expected that condition would deteriorate. Decreased interspecific competition, due to decreased stock size of Arctic charr could be the cause.

Stomach analyses are complex, as food intake is variable within season as well as from year to year. In addition both Arctic charr and brown trout are rather flexible in their diet, and some prey species digest faster than others and consequently are not present in the sample (Windell & Bowen 1978, Johnson 1980, Aass et al. 2004). The results from Lake Ellidavatn could though be a sign of competition for food between Arctic charr and brown trout. Further research on stomach content, over longer continuous time period, would give a better conclusion. Arctic charr's changes in main prey species from Chironomidae to Crustacea in Lake Hafravatn could be connected to the increase of copepods, which was in an agreement to the zooplankton samples collected. The increase of copepods could be explained by less grazing because of the decrease of Arctic charr, which is known to feed on zooplankton especially when in sympatry with brown trout (Johnson 1980, Klemetsen 2003 & Aass et al. 2004). The changes in zooplankton in Lake Hafravatn were however not significant. In Lake Vifilstadavatn there was on the other hand a significant increase of zooplankton where cladocerans increased. This could be caused by a decrease of Arctic charr. A study from 10 Norwegian lakes revealed that Arctic charr selected cladocerans above copepods (Klemetsen et al. 2003).

The results from this study, compared with previous studies show changes in stock size of both Arctic charr and brown trout, whereas Arctic charr is decreasing while brown trout is increasing. Changes in growth rate and condition show that the Arctic charr found are in good condition and growth rate is similar or faster than before. There are little changes in food availability except in Lake Hafravatn. Less grazing from Arctic charr and the increase of brown trout due to lower interspecific competition could be the cause. These changes in stock size of both Arctic charr and brown trout are presumably

not reflected in growth rate, body condition or diet at adult stages and no signs are of pollutants, or other stress factors.

The reasons for the observed changes in Arctic charr can not be fully explained, but suggests lower recruitment or lower survival during the first life stages. The effects of global warming, with higher air temperatures during the summer for the past 18 years have been suggested as the reason for stock changes of Arctic charr in Lake Ellidavatn (Ingvarsson et al. 2006). Temperature changes are known to influence both growth rate and routine activities like feeding for Arctic charr. Its northern distribution makes it therefore likely to respond sooner to global changes (Lyytikainen & Jobling 1998). Research has shown that at high temperatures both feeding and growth can cease for 0+ Arctic charr and changes in temperature can also lower feeding rates (Thyrel et al. 1999, Lyytikainen & Jobling 1998). There is little information available for the early stages of Arctic charr, when the yolk is finished and feeding has begun. The development of young Arctic charr is also slow and there is a long time that they are unprotected (Johnson 1980). Further research on spawning and the first life stages is therefore needed to determine the reasons for low recruitment.

Generally it is believed that changes in the environment are becoming more apparent in recent years. Stock compositions are changing, where some species are declining and even becoming extinct, while other species are increasing. The effects from anthropogenic impact are often the cause, from various developments and pollution to global warming that is causing severe changes both in terrestrial and aquatic ecosystems.

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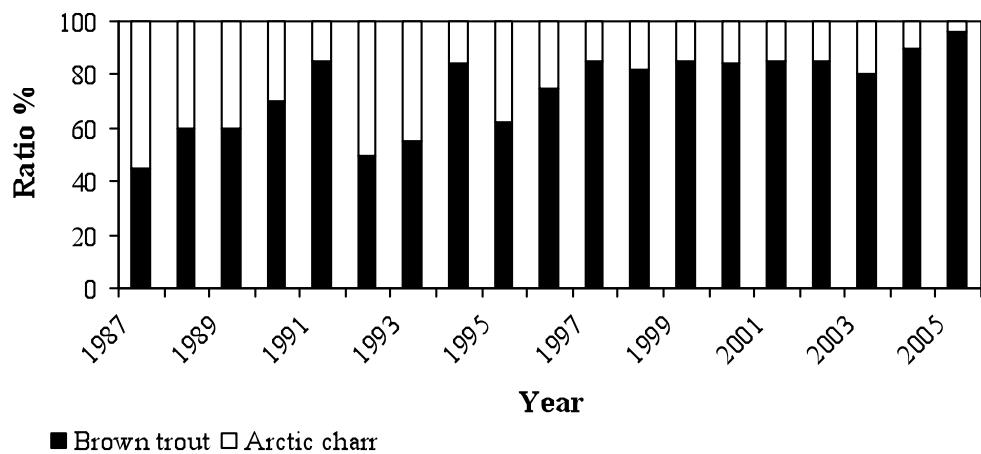


Figure 1. The ratio of Arctic charr to brown trout catches in annual monitoring of the fish stocks in Lake Ellidavatn 1987-2005 (from Antonsson et al. 2005).

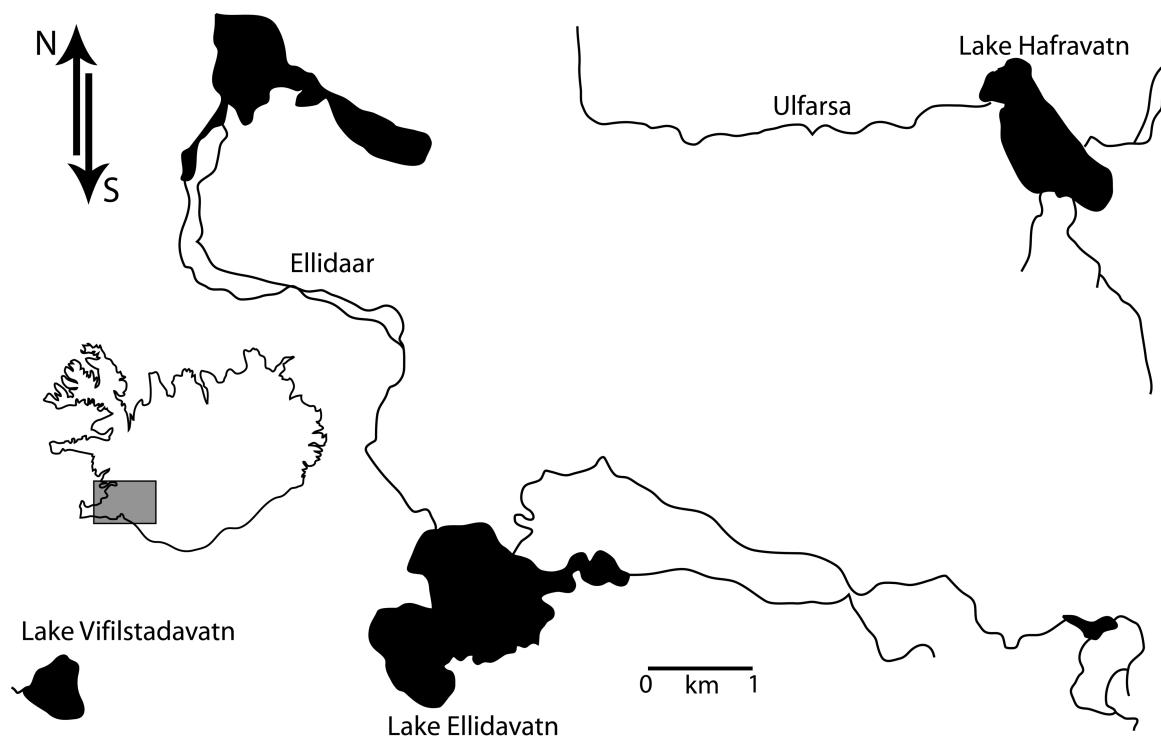


Figure 2. Location of Lake Ellidavatn, Lake Hafnavatn and Lake Vifilstadavatn, SW-Iceland.

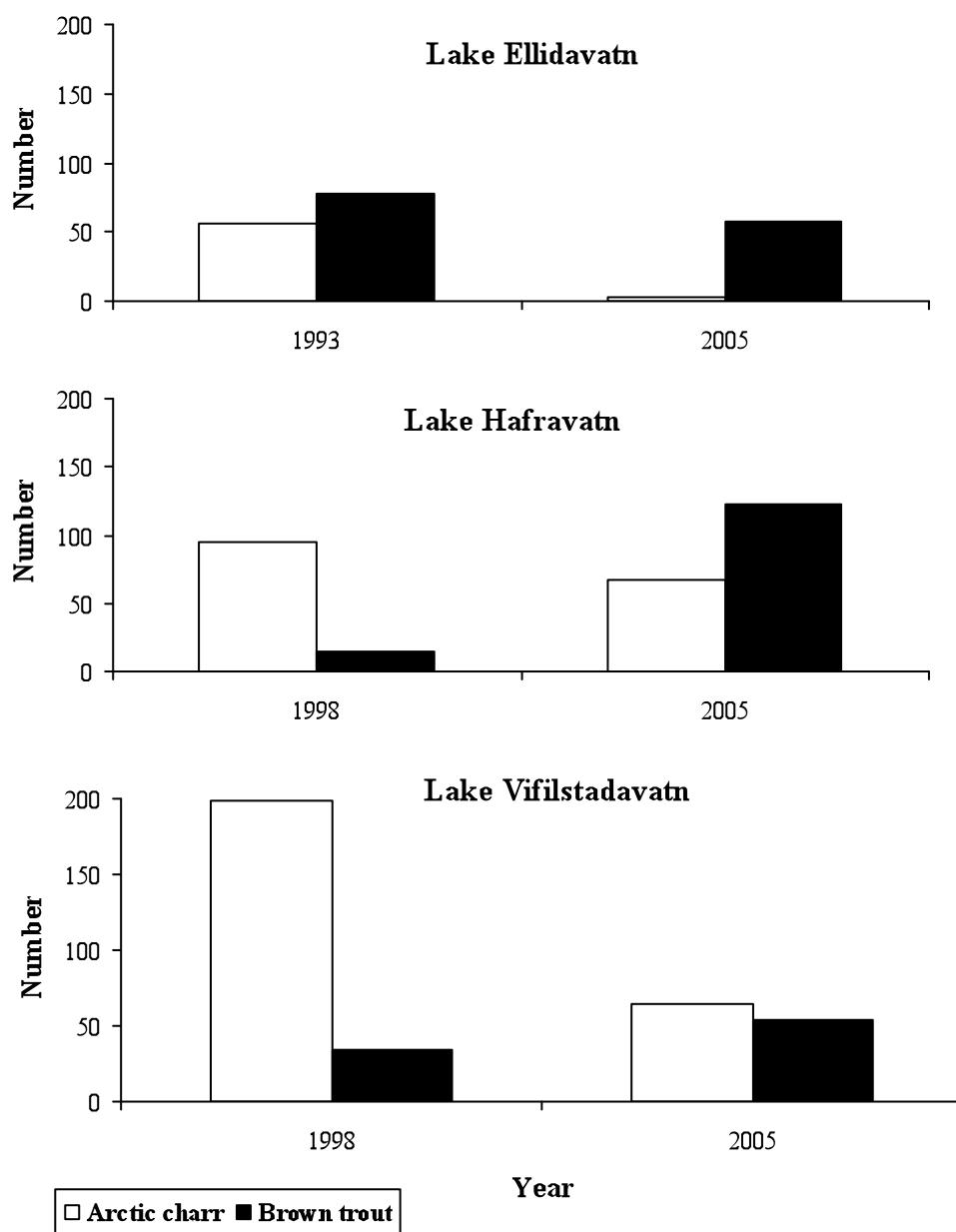


Figure 3. Catch of Arctic charr and brown trout from one gillnet series in Lake Ellidavatn 1993 and 2005 and 1998 and 2005 for Lake Hafrvatn and Lake Vifilstadavatn.

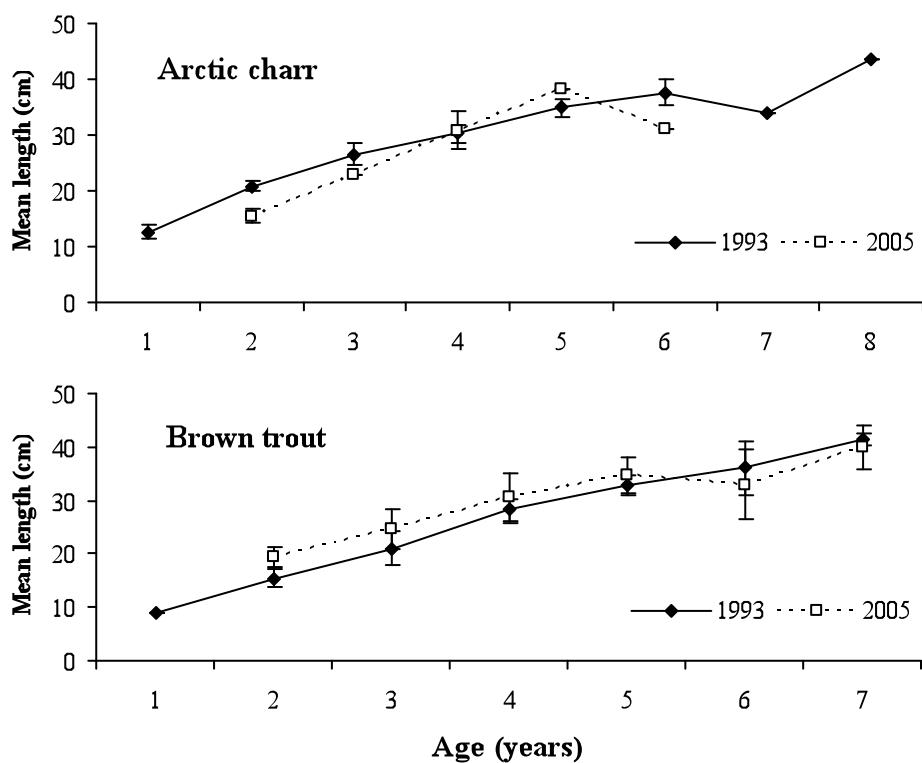


Figure 4. The average length by age of Arctic charr and brown trout, in Lake Ellidavatn 1993 and 2005, with standard deviation.

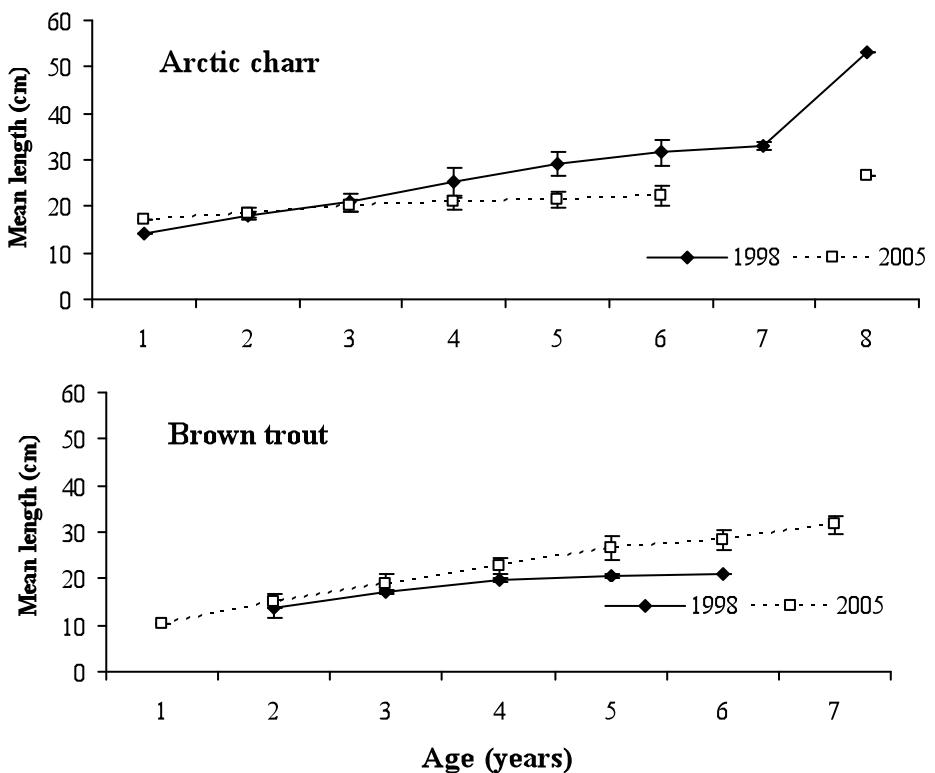


Figure 5. The average length by age of Arctic charr and brown trout in Lake Hafrevatn 1998 and 2005, with standard deviation.

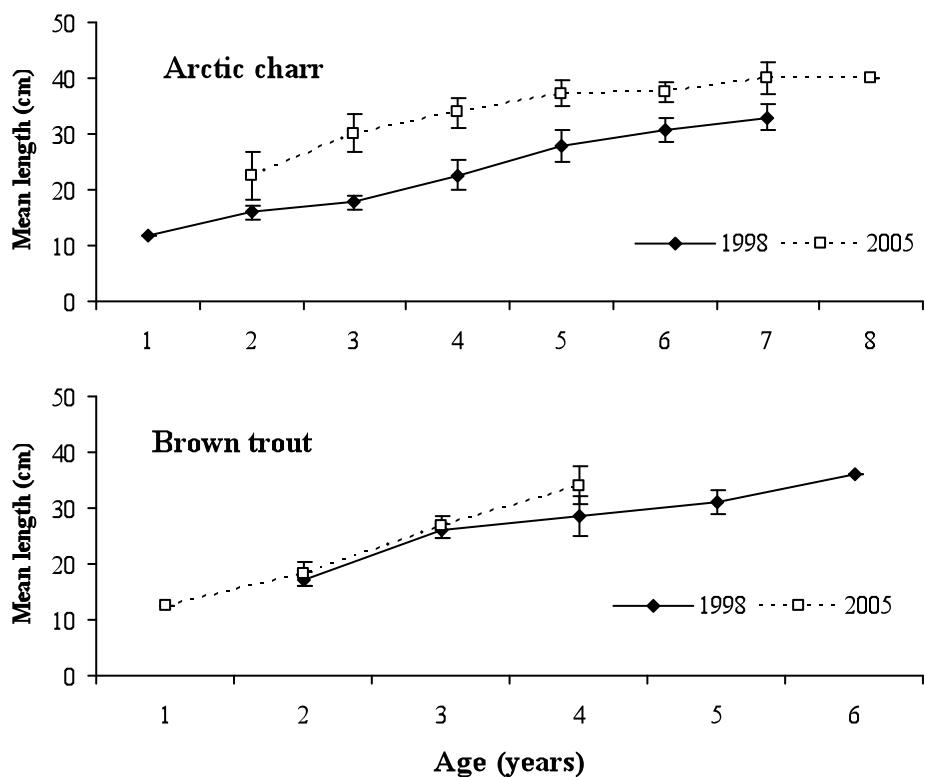


Figure 6. The average length by age of Arctic charr and brown trout in Lake Vifilstadavatn 1998 and 2005, with standard deviation.

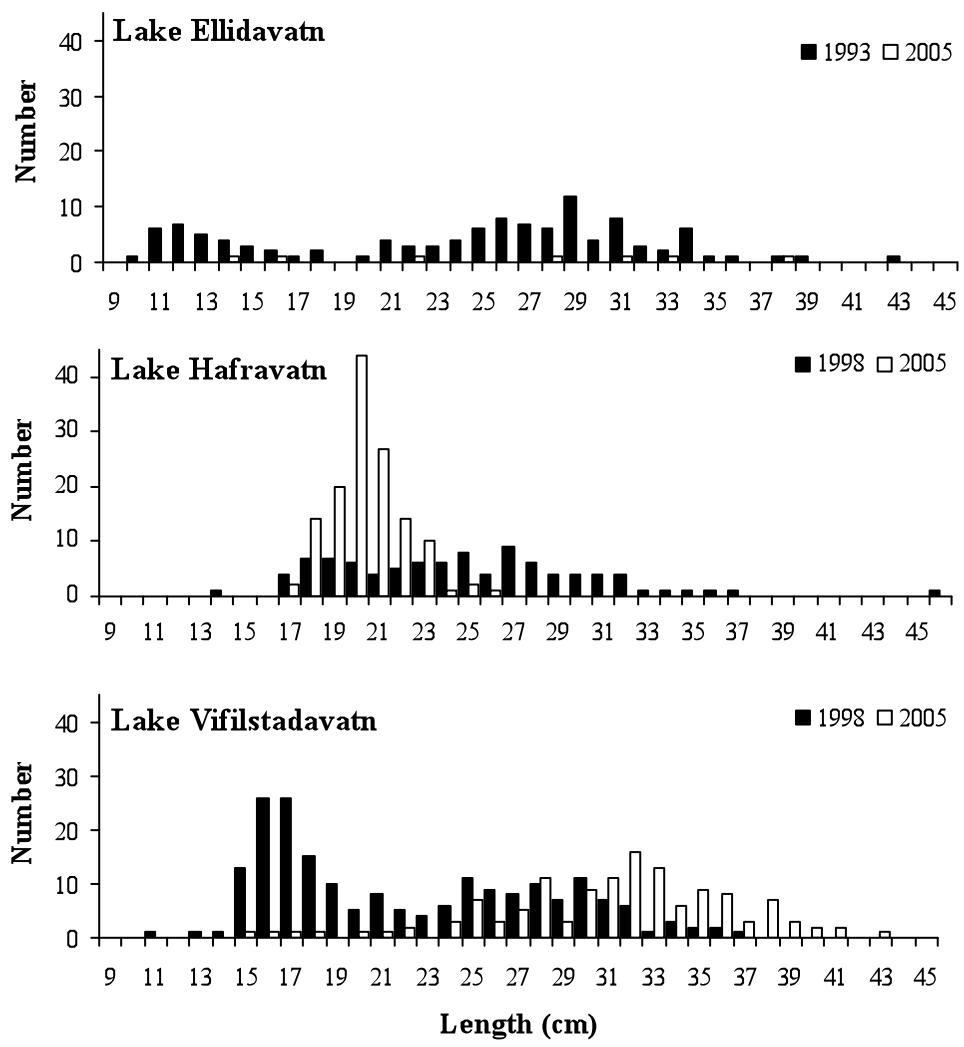


Figure 6. The length distributions of Arctic charr in one gillnet series in Lake Ellidavatn 1993 and 2005, and 1998 and 2005 in Lake Hafravatn and Lake Vifilstadavatn.

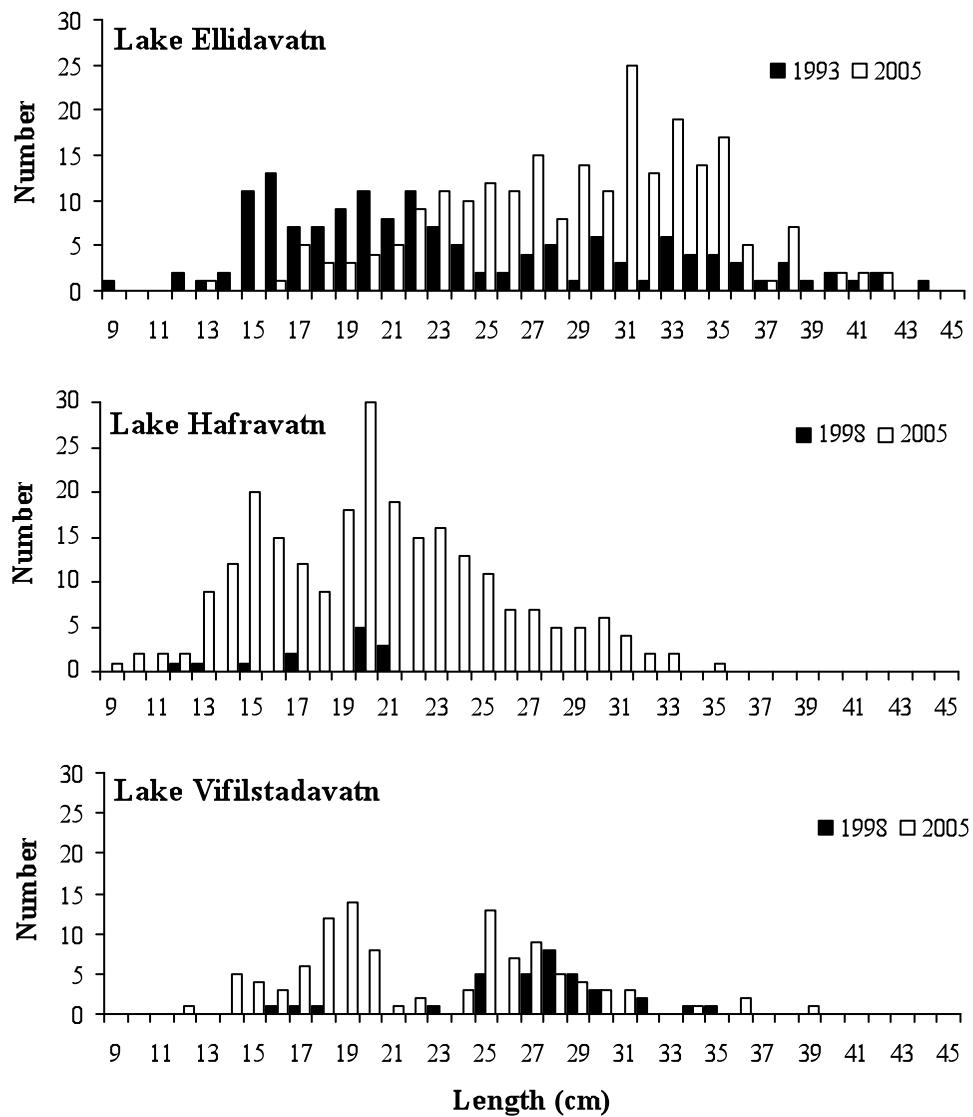


Figure 7. The length distributions of brown trout in one gillnet series in Lake Ellidavatn 1993 and 2005, and 1998 and 2005 in Lake Hafravatn and Lake Vifilstadavatn.

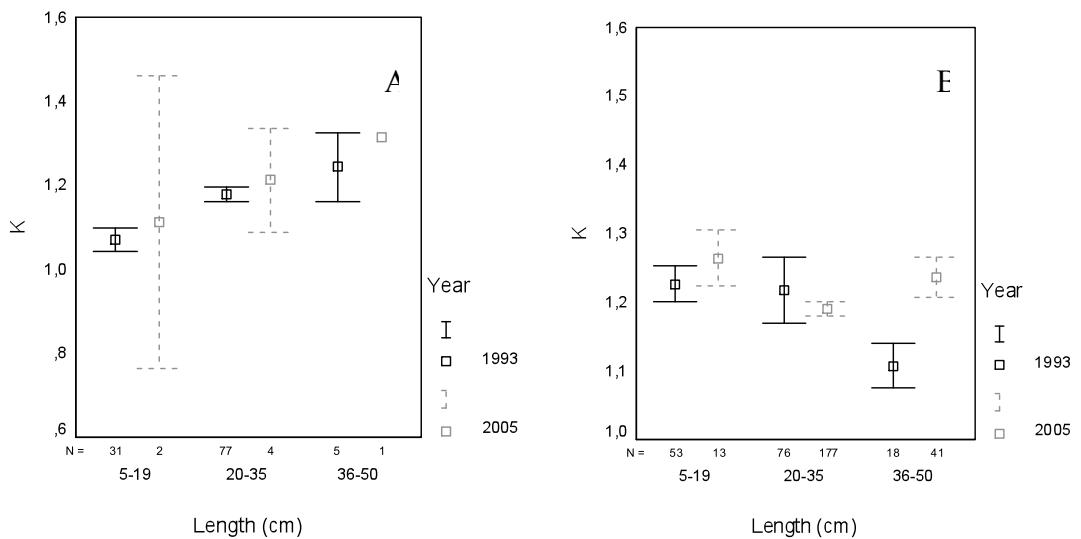


Figure 8. The condition factor (K) of Arctic charr (A) and brown trout (B) in Lake Ellidavatn.

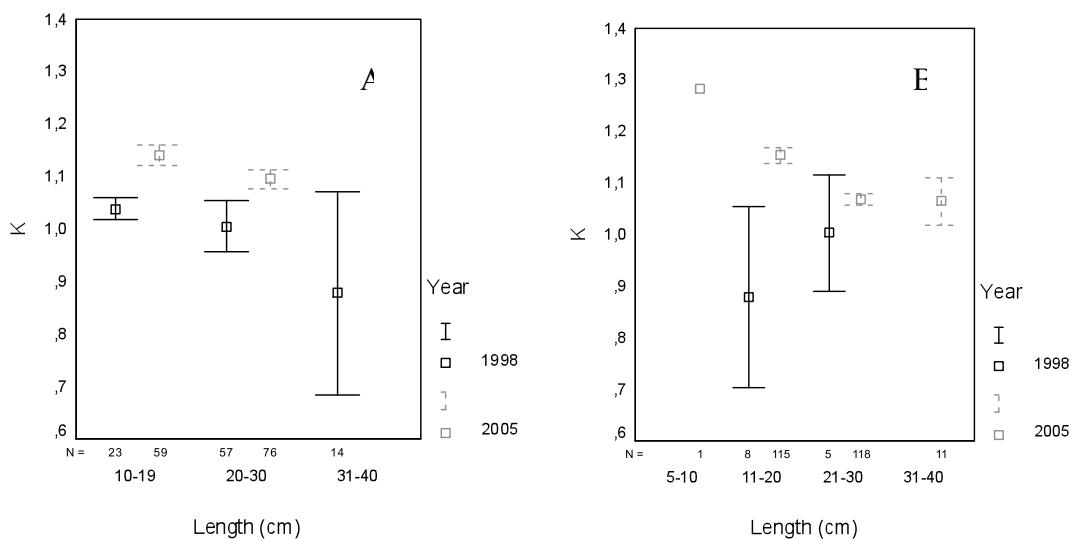


Figure 9. The condition factor (K) of Arctic charr (A) and brown trout (B) in Lake Hafravatn.

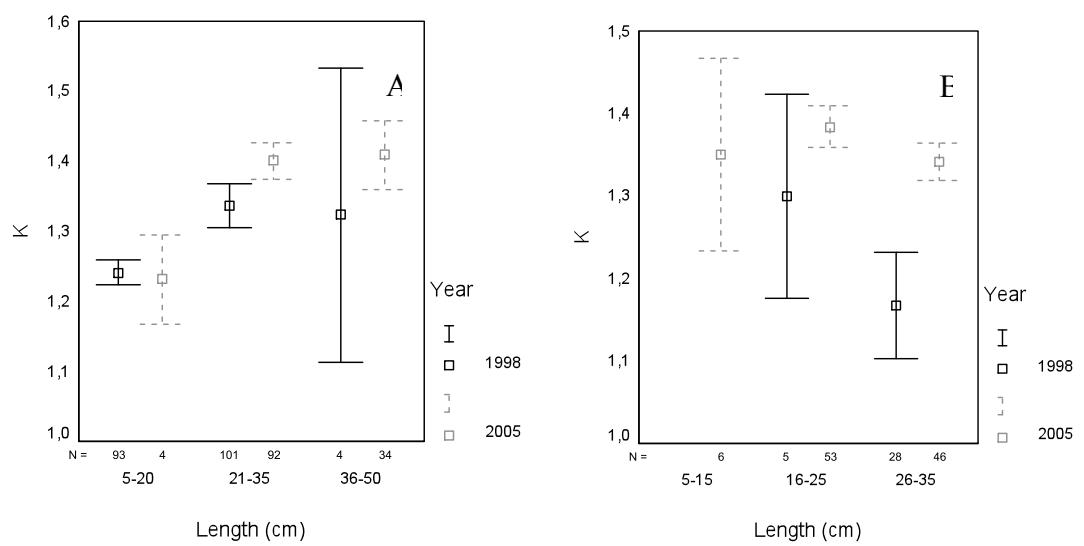


Figure 10. The condition factor (K) of Arctic charr (A) and brown trout (B) in Lake Vifilstadavatn.

Table 1. Physical characteristic of Lake Ellidavatn, Lake Hafravatn and Lake Vifilstadavatn.

Lake	Area/km ²	Alt. (m)	Max depth (m)	Mean depth (m)	Characteristic
Ellidavatn	1,80	73	3	2	inflow/outflow spring-fed
Hafravatn	1,02	76	28	8	inflow/outflow
Vifilstadavatn	0,25	39	1	0,5	outflow spring-fed

Table 2. Main prey species in Lake Ellidavatn 1993 and 2005, Lake Hafravatn and Lake Vifilstadavatn in 1998 and 2005.

Lake	Arctic charr		Ratio %		Brown trout		Ratio %	
	Prey species	1993/1998	2005	Prey species	1993/1998	2005	Prey species	1993/1998
Ellidavatn	<i>Lymnaea peregrina</i>	75	73	<i>Lymnaea peregrina</i>	45	63	<i>Gasterosteus aculeatus</i>	29
	<i>Pisidium</i>	3	18	<i>Gasterosteus aculeatus</i>			<i>Trichoptera larvae</i>	9
	<i>Chironomidae</i>	11	9	<i>Trichoptera larvae</i>			<i>Other</i> ²	17
	<i>Other</i> ¹	11	0	<i>Other</i> ²				24
Hafravatn	<i>Chironomidae</i>	87	1	<i>Gasterosteus aculeatus</i>	77	14	<i>Trichoptera larvae</i>	8
	<i>Crustacea</i>	8	21	<i>Trichoptera larvae</i>			<i>Other</i> ⁴	36
	<i>Other</i> ³	6	78	<i>Other</i> ⁴				15
Vifilstadavatn	<i>Crustacea</i>	89	82	<i>Gasterosteus aculeatus</i>	74	67	<i>Crustacea</i>	23
	<i>Chironomidae</i>	7	5	<i>Crustacea</i>			<i>Other</i> ⁶	14
	<i>Other</i> ³	3	13	<i>Other</i> ⁶				4

¹Trichoptera larvae and Crustacea ('98).

²Chironomidae ('98), Unidentified* ('05).

³Lymnaea peregrina and Pisidium ('98 & '05), Unidentified and many empty stomachs ('05).

⁴Lymnaea peregrina, Pisidium, Crustacea ('98 & '05), Unidentified ('05), Chironomidae ('98).

⁵Lymnaea peregrina and Pisidium ('98 & '05), Unidentified ('05).

⁶Chironomidae ('98), Unidentified and Pisidium ('05).

*Prey species that were digested and not identifiable.

Table 3. The number of invertebrates in Kajak bottom samples in Lake Ellidavatn 1993 and 2005, Lake Hafravatn and Lake Vifilstadavatn 1998 and 2005.

Lake	Ellidavatn		Hafravatn		Vifilstadavatn	
Year	Number		Number		Number	
	1993	2005	1998	2005	1998	2005
Cladocera	503	454	184	606	2704	4451
Copepoda	164	186	296	510	766	1922
Oligochaeta	510	95	376	59	3373	418
Chironomidae	399	63	37	104	333	260
Ostracoda	58	82	437	181	179	301
Total per m ²	64,918	46,294	69,060	79,755	379,476	200,509
M -W test	$P = 0.174$		$P = 0.610$		$P = 0.427$	

Table 4. The number of zooplankton invertebrates in Lake Ellidavatn 1993 and 2005, Lake Hafravatn and Lake Vifilstadavatn 1998 and 2005.

Lake	Ellidavatn		Hafravatn		Vifilstadavatn	
Year	Number		Number		Number	
	1993	2005	1998	2005	1998	2005
Cladocera	318	346	20,834	1,408	146	1,575
Copepoda	76	82	33,173	26,176	381	55
Other ¹		24				
Average per 10 L	10,0	10,2	93,5	101,7	17,1	72,9
M-W test	$P = 0.860$		$P = 0.818$		$P = 0.002$	

¹Chironomidae, Hydra and Hydracarina