An Investigation into the impacts of the Lochaber Hydrological Scheme upon the native fish biodiversity of Loch Laggan.

Elizabeth McMorrine

Acknowledgements

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Abstract

With hundreds of lakes and rivers being managed worldwide the possible implications upon natural fish biodiversity are of great global concern. It is important that the relevant research is undertaken in order to determine whether this management is detrimental to the health of such valuable ecosystems. Previous studies suggest that where a 5m or more fluctuation in water level is present invertebrate populations and spawning zones can be damaged. The combination of this damage and the impact of invasive species can greatly disturb native fish populations. This study explores the possible impacts of the Lochaber Hydrological Scheme on Loch Laggan's fish biodiversity. Loch Laggan experiences an 8.15m annual fluctuation in water levels and is invaded by non-native Pike (*Esox Lucius)*. Shoreline invertebrate populations were examined and fish populations surveyed throughout the various depth zones. Due to lack of data on Loch Laggan prior to the hydrological scheme's construction the findings on Loch Laggan are compared to those on two other lochs. Loch Treig, part of the same hydrological scheme but with much higher water level fluctuations (13.88m) is the second study site. Loch Na-H-Earba, a smaller loch which is part of the same system as Laggan and relatively unmanaged (around 1m fluctuation) is the third study site and one which acts as the control. Results revealed a reduction in both invertebrate and fish population numbers with increased water level fluctuations. The native fish biodiversity of Loch Laggan was noted to have been dramatically reduced with the invasive species currently dominating the system. A comparison of Loch Laggan's results with those of Loch Na-H-Earba highlighted very clearly how serious the impact of management had been on Laggan. Loch Treig gave some indication of what could occur if Laggan was to be further exploited.

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Chapter 1 Introduction

1.1 Rationale

Environmental awareness grew dramatically in the twentieth century and with this came the realisation of the possible environmental benefits of generating power through hydroelectricity (Reid et al, 2005). With deep concerns over the impact of greenhouse gas emissions on our climate UK policy aims to reduce carbon dioxide emissions by 60% before 2050. Reductions such as this rely heavily on the use of renewable energy sources including hydrological schemes (Reid et al, 2005). As a consequence human management of the world's fresh water bodies is currently extensive with there being hundreds of hydrological schemes harnessing the power of Earth's rivers and lakes. It has been noted that very few of the world's largest lakes have yet to be managed by humans (Degerman et al, 2001). Additionally, given the future water shortages predicted in some areas of the world, what are currently natural lakes may not be spared exploitation and the onset of drastic water level fluctuations for much longer (Zohary and Ostrovsky, 2011). Due to the global nature of freshwater management there is concern for the health of our valuable ecosystems. If the systems are in any way being jeopardised by our exploitation of them it is important that we address the issues (Degerman et al, 2001), particularly making sure that we are not blinded by the benefits of renewable energy sources (Reid et al, 2005). This study proposes to investigate the possible effects of the Lochaber Hydrological Scheme on the native fish biodiversity of Loch Laggan, in the Scottish Highlands. By examining the invertebrate populations and fish species present in the Loch a comparison can be made to Loch Treig which has seen a great deal more alteration due to management and to Loch Na-H-Earba which has largely seen no management and thus will act as a control. These comparisons will allow an evaluation of the health of Loch Laggan's native fish biodiversity to be made and, if necessary, possible means to prevent further damage occurring to be determined.

1.2 Background

The Lochaber Hydrological Scheme (now run by Rio Tinto Alcan) was built in three phases between 1924 and 1944 to provide energy for the Fort William Aluminium Smelter. It harnesses the power of the Rivers Mashie, Pattack, Spean, Spey and Treig. The scheme comprises numerous constructions including the Spey Dam and Reservoir, a canal link through to Loch Crunachdan, a tunnel converting water to Loch Laggan from the Spey and the Laggan Reservoir which is also linked by tunnel to Loch Treig and its reservoir (Greer, 1995). This system is much like the majority of Scottish hydroelectric schemes and is what is called a linked series of reservoirs, dams and generating stations, in this case by developing existing lochs (Reid et al, 2005). Due to the fact that the scheme involves numerous fresh water bodies there is a distinct possibility that the native fish life of some, if not all, of the lakes and rivers could have been altered; this has been a noted issue with many human-managed lakes and rivers on a global scale (Degerman et al, 2001). The native fish fauna of Scottish freshwaters is largely comprised of 12 Boreo-Arctic species; this includes the Arctic Charr (*Salvelinus alpinus*), Brown Trout (*Salmo trutta*) and Ferox Trout (*Salmo ferox*) which are all naturally dominant in Loch Laggan (Greer, 2000).

1.2a Arctic Charr (*Salvelinus alpinus*)

The Arctic Charr is a northern, circumpolar, palearctic salmoniod (Johnson, 1980) and a species considered to be of high conservational importance. In Scotland Charr occur in over 150 (Maitland et al, 1984) lochs in their landlocked freshwater forms. Although this means that they do not migrate seawards they do often undertake specific habitat shifts from season to season (Craig, 1978). Unfortunately very little is known about the biology or genetics of Scottish Charr populations. It is thought that within their habitats they can often be separated into pelagic and benthic morphs (Walker et al, 1998) which are thought to be reproductively isolated due to their genetic differences (Hartley et al, 1992). There is evidence to suggest that Charr populations are divided into two genetic types, A and B, with Scottish Charr falling into the latter category of B. This genetic form of Charr has ancestral ties to the first Charr to enter Scotland after the last Ice Age. Type A Charr of a subsequent post-glacial invasion have largely replaced type B which are now restricted to isolated Scottish lochs of high altitudes where it is assumed type A failed to invade (Hartley et al, 1992). Loch Laggan's population is thought to be comprised of type B Charr, landlocked, glacial relics that arrived there due to the cold spell 'The Loch Lomond Stadial' causing a glacial re-advance in the highlands (Peacock et al, 2004). This glaciation dammed lakes in the valleys causing Charr to be among the first fish to re-enter Scottish freshwaters including some of those lochs that form the Lochaber Hydrological Scheme. Since this natural re-introduction into the Scottish Highlands Charr have remained relatively unmanaged and unexploited. They thus maintain a long and undisturbed natural history, making them one of Scotland's most important reserves of native biodiversity (Greer, 2004).

1.2b Brown trout (*Salmo trutta*) and Ferox trout (*Salmo ferox*)

Originally a Palearctic fish, the Brown Trout is a carnivore which thrives in unpolluted and well-oxygenated streams, rivers and lakes. It is now widespread globally due to its polytypic nature although it is largely native only to Europe (Elliot, 1994). The diet of Brown Trout largely consists of macro-invertebrates with some smaller fish prey being consumed in certain situations. Brown Trout have various different life cycles. In some cases the trout stay in their native streams or rivers and remain small whereas in other cases only juveniles do this whilst the adults migrate to the nearest lake or estuary (Elliot, 1994). Many systems contain two, even three or more morphologically and behaviourally distinct forms of the species which are reproductively isolated and genetically different. (Greer, 2000). Unfortunately many of these genetically unique populations have been lost over the past century. This means there is now a great need for classification and conservation of the remains of this diverse and irreplaceable species (Ferguson, 2006).Ferox Trout are one of the numerous sub species of Brown Trout, and one which is the subject of constant confusion and debate. It has not yet been clarified that the Ferox is actually a genetically distinct strand or is just an exceptionally large and long-lived Brown Trout which due to sheer size switches over to a predominately fish based diet (Campbell, 1979). Ferox are thought to be present in large, deep glacier-formed lakes containing Arctic Charr or Whitefish (*Coregonusspp*) thus making Loch Laggan a viable habitat (Greer, 2000). Ferox 85, a group of fishermen and biologists have measured and recorded the importance of Arctic Charr to the diet of Ferox Trout through the examination of stomach contents and concluded that they are the main prey of the trout (Greer, 1995). This finding is supported by the idea that Charr are so highly integral to the diet of Ferox that they greatly influence the distribution of the Trout (Campbell, 1979). Ferox are thought to spend most of their time in the littoral zone, in waters less than 10 metres deep, although they have been recorded at a depth of up to 30 metres where they can catch the deeper dwelling Arctic Charr. As Ferox are not ambush predators they instead make dives to the deeper water where they then pursue their Charr prey (MacDonald and Thorne, 2000). Brown Trout and the larger Ferox are very popular sport amongst the angling community. However, much like Charr, the greatest threat to their survival is the introduction of exotic, alien species. Over and above this hydrological schemes can have negative impacts on inflow and outflow spawning zones (Greer, 1995).

1.2c Pike (*Esox lucius)*

It is thought that Pike *(Esox lucius)* have, since the construction of The Lochaber Hydrological Scheme in 1924, invaded Loch Laggan and become dominant over the endemic species. They are believed to have entered the loch through one of the scheme's tunnels which connects the Spey to Loch Laggan. In 1748 the famous fisherman Colonel Thomas Thornton made a tour of Britain which included a visit to Loch Laggan. He noted the rich abundance of Trout, including Ferox in the Loch but made no mention of Pike being present in the system. The Loch's rich biodiversity inspired his words; "Around her northern and western shores, Throng'd with the finny race, Loch Laggan roars" (Thornton, 1804). In 1959, several years after the initial construction of the hydrological scheme, Michael Brander followed Thornton's journey. Reflecting on his travels Brander wrote; "The North British Aluminium Company have now reduced the loch to nothing more than a reservoir and it was interesting to note the various levels showing on the banks. This must have affected the fishing very considerably." (Brander, 1961). It is clear, even from these initial observations that the system has been greatly affected by the hydrological scheme and its introduction of Pike. This is backed up by the records held by local fishermen who have noticed a steady decline in Trout along with the appearance and increase in abundance of Pike. One fisherman and local resident has recorded catches of 30 Ferox Trout and 4 Pike between 1980 and 1990, 8 Ferox and 30 Pike between 1990 and 2000 and 4 Ferox and 39 Pike since 2000 (Alasdair McMorrine, pers. comm.).

The introduction of a species into an area outwith its natural occurrence can cause serious ecological and genetic changes to the host community (Middleton, 2003). This is due to the increased food competition, predation, hybridization and inbreeding depression caused by the invasive species, such as Pike (Greer and Hammar, 2004). Invasive Pike populations are notoriously hard to get rid of. In both Europe and North America there have been numerous attempts to control and exterminate them but these efforts have largely failed (Svärdson, 1964).Pike is a key and flexible piscivore and the top aquatic predator in many fresh waters of the northern temperate zone. It is not, however, native to northern Scotland (Lefevre 1999). Despite this they are now present in many Lochs in the Scottish Highlands where they have become invasive species. It is thought that anglers have long been stocking them for sport, an issue amplified by the linking together of various systems for hydroelectric schemes. They are successful invaders as they can tolerate a wide range of environmental conditions and are rapid colonisers (Harvey, 2009). The diet of Pike often consists of salmanoids. In Lake Windermere 6637 Pike were examined and were found to have consumed 4436 fish prey with 94% of this being Arctic Charr and Brown Trout (Winfield et al, 2011). Pike have long been noted to be an extremely voracious species, capable of consuming impressive quantities of prey. They use an ambush style of predation, relying on camouflage amongst aquatic vegetation. They are opportunistic feeders, meaning that they will switch to eating invertebrates or even their own young if needs be (Casselman, 1995). Due to their reliance on aquatic vegetation for camouflage the highest densities of Pike are often found in the shallow waters. The impact of Pike on native salmanoids and littoral macro-invertebrates can be remarkable and thus their presence in Loch Laggan, as a result at least partly of the hydrological scheme, must be taken seriously.

1.3 Study Aim

To investigate and evaluate the extent to which the native fish biodiversity of Loch Laggan has been affected by The Lochaber Hydrological Scheme. This investigation will be carried out by way of comparison with Loch Na-H-Earba, a relatively unmanaged control site and Loch Treig which is a heavily exploited loch and also part of The Lochaber Hydrological System.

1.4 Basic Hypothesis

Basic Hypothesis of the Study: As a result of the hydrological scheme Loch Laggan's Native fish population will be much reduced. This will most likely be clear when compared to the fish population of Loch Na-H-Earba. However, it is anticipated that Loch Treig's fish population will be even smaller than Laggan's. Invertebrate populations will echo the fish populations of each loch and it is expected that the invasive species of Pike will dominate Loch Laggan.

1.5 Study Objectives

- Sample shoreline invertebrates to establish population sizes and structures of Loch Laggan, Treig and Na-H-Earba.
- Investigate how these population numbers correlate to the water level fluctuations of each loch.
- Measure the fish populations of the three lochs in order to determine if the amount of prey available (in the form of invertebrates) has had any significant effect and if the invasive species are dominant.
- Examine the stomach contents of a sample of fish caught in order to confirm that invertebrate populations sampled in the littoral zone are of relevance to the diets of the native fish.
- Determine possible means of rectifying any damage of the native fish biodiversity.

Chapter 2 Literature Review

Hydrological schemes such as the Lochaber scheme regulate the water levels of the lakes and rivers that they harness; a factor which can greatly alter fish biodiversity. The natural diet of Loch Laggan's Brown Trout is thought to consist of Gammarous Shrimp, Water-Snails, shallow water and terrestrial insects, worms, Minnows and even the young of their own species (Pentelow, 1932). The available diet can be greatly affected by hydrological schemes. This is because it is a general scientific consensus that rapid and continued fluctuations in flow regime lead to a dramatic change in habitat for the freshwater biota. This makes flow a major factor in determining biotic composition, and means that the maintenance of natural patterns is fundamental in ensuring the viability of a species (Bunn and Arthington, 2002). However, when hydrological schemes are created they cause dramatic changes to run-off and flow regime. Water is often stored in reservoirs during times of peak precipitation such as when snow melt is occurring. This water is then used to produce electricity when precipitation levels are low again. With the annual water level fluctuation being altered in this way the changes are often most noticeable on the shorelines of systems involved. The shorelines often become dry and frozen during the winter months and then submerged, even turbid, in the summer (Aass et al, 2004). Due to this studies have suggested that any water level fluctuation above 5m will begin to negatively impact upon a systems invertebrate population, greatly reducing the prey available for fish (Smith et al, 1987). Without sufficient food smaller fish will become the prey of larger ones and, over time, the number of different species able to survive will drop considerably. This is supported by research undertaken on the River Nidelva, Norway, which suggested that large losses of Atlantic Salmon and Brown Trout were due to the reduced biodiversity of macroinvertebrtates. The river previously had a very rich bottom fauna but the loss of this is now attributed to the fluctuations of water level caused by hydrological peaking (Hvidsten, 1985).

Lakes in the Highlands are populated with native fish species very similar to those in Nordic Lakes, many of which were land-locked over 10,000 years ago after the last continental glaciation ended (Tammi et al, 2003). An impressive body of the research into the effects of hydrological schemes on fish biodiversity has been carried out on Nordic lakes and the similarities in native fish populations lend themselves well to comparison. The four largest lakes in Sweden, the Vanern, Vattern, Malaren and Hjalmaren are extremely important host sites of commercial fisheries which include both Charr and

Trout amongst other species. Despite their importance these ecosystems have been subject to almost constant management since the 12th century when industrialization increased and hydropower was used to provide for the country's vast mining industry which developed around the four lakes (Degerman et al, 2001). The native biodiversity of these four lakes has been damaged by the construction of dams, ship canals, overexploitation and eutrophication (a process which removes oxygen from marine environments thus killing living organisms). As is often the case, the dams built to control the waters have prevented the natural migration of fish and so stopped them from accessing their spawning grounds (Degerman et al, 2001). Due to dams effectively trapping and isolating fish populations, preventing them from interacting with others, inbreeding often occurs. Reduced birth rates are caused by limited access to spawning zones and inbreeding leads to genetic depression (Meffe and Carroll, 1997). These factors have caused the loss of three different strains of landlocked salmon in Lake Vanern and many strains of Brown Trout in Vattern and Malaren. In the 1800s the Trollhate Ship Canal and its sluices were built to allow ships to reach Lake Vanern for trade. Unfortunately this also allowed eels to enter the lake where they had not been present for an estimated 9,000 years. This invasive species have gained dominance of Lake Vanern, causing the native Crayfish to decline dramatically, so much so that they are now largely considered to be locally extinct (Degerman et al, 2001). These issues have not been echoed in the other lakes as they have fewer canal connections to the sea. However, where they do connect, the fauna of both environments is similar enough so that no negative impacts of invasive species have been noted. Additionally, due to the surrounding areas of all four lakes being densely populated, agricultural practices have greatly intensified. The chemicals involved in these practices have caused a marked increase in eutrophication during the twentieth century but the direct impact of this upon fish populations is yet to be determined. Over fishing is thought to be another contributing factor to fish biodiversity decline in the lakes. Alongside catch numbers being too high to be viable in the long term females were often caught that were 35cm in length. The length of 50cm was noted as the average size a female needed to be in order to spawn and thus, by catching fish smaller than this, birth rates were being dramatically reduced by preventing many fish from spawning (Degerman et al, 2001). What is surprising is how little has been done to rectify the damage caused to Sweden's native fish biodiversity. National legislation allows live Crayfish to be imported from any other country in the world despite warnings from biologists that this could be detrimental. Ships are allowed to empty ballast water wherever they please regardless of the invasive species they may release. Perhaps most shockingly Salmon are stocked to compensate the loss of Brown Trout. This is despite the fact that Salmon are a species capable of outcompeting the IUCN Red Listed (IUCN, 2012) Arctic Charr, a species on the cusp of overexploitation. Mistakes seem set to be repeated and even furthered (Degerman et al, 2001).

Similar discoveries were made in Lao, PDR when the effect of the Nam Theun-Hinboun Hydrological Scheme on fish biodiversity was investigated. Due to lack of past scientific data a highly subjective method was used, this relied on the local community's knowledge of past fish populations. This data was used to compare with current populations measured using CPUE (Catch per Unit Effort) after gillnetting, which shows the abundance of species and their migratory patterns. When catch statistics were compared to the data collected from the locals a significant reduction in the general population was apparent, a decline which was considered to be largely human-induced. Wet-season spawning and migration has been blocked in the upstream of the Theun since 1988 due to numerous dam constructions as part of the hydrological scheme (Warren, 2001). It has been noted that even if fish passes are created not all aquatic species will be able to migrate past the dam as they naturally would. Changes to habitat and water flow, both above and below a dam, will affect the entire flora and fauna in the ecosystem. This includes the macroinvertebrtates which fish populations so heavily rely on. Alongside these impacts dams can also dramatically alter the morphology of the system they are constructed in, the transport of sediment, the oxygen levels and the temperature of water within the system. (Reid et al, 2005). In Lao the natural rapids have also been submerged by increased water levels thus causing dramatic changes to environmental conditions. Additionally water quality of both rivers has been reduced by chemicals and eutrophication and many exotic species are thought to have been introduced due to the hydrological scheme construction although examination of the impacts of these is yet to be undertaken (Warren, 2001).

The River Taieri Drainage System in South Island, New Zealand, provides a demonstration of the disruption that invasive species, in this case Brown Trout, can cause to their host environment. In a study of 198 sites across 8 catchments the native species, Galaxias Vulgaris, only occurred in areas such as those above waterfalls which are impossible for the trout to access. It was concluded that the Trout's high breeding rates and cannibalistic nature provide competition for food that is far too great for the native Galaxias Vulgaris to survive and coexist in most areas populated by the invasive species (Townsend and Crowl, 1991). Additionally there were distinct behavioural changes amongst invertebrate populations as a result of the alien species increasing selection pressures. It was estimated that Trout consume the entirety of the annual production of invertebrates, Galaxiids consuming none. With invertebrate populations being dramatically reduced algal biomass increased correspondingly. Due to this agal primary productivity is around six times greater in streams populated by Trout compared to those populated by Galaxiids and the algal species composition also differs considerably between the two (Townsend, 2003). These profound ecosystem changes may not have been anticipated but most certainly need to now be considered seriously by managers and conservationists. The need for more in-depth understanding of invasive species in order to devise appropriate management strategies is most apparent. This should be the basis for making decisions over which species it is safe to introduce and, for those which have colonised accidentally, which ones require immediate intervention and whose eradication should take priority (Townsend, 1991).

Alien species are also a notorious problem in the UK, with hydrological schemes considered to be one of the causes of their invasion. In all of the UK's largest lakes (Loch Lomond, Lough Neagh, Llyn Tegid and Lake Windermere) introductions of non-native species have taken place, some of which have established successfully and now have abundant populations. In these cases alien fish species have been released as live-bait for anglers. None of the releases were approved by the relevant authorities and therefore no assessments of the possible effects were carried out. What is worrying is the wealth of research which suggests that prevention is the only truly effective management method of invasive species (Winfield et al 2001). If Loch Laggan's invasive Pike population is revealed to be detrimental to the health of the native biodiversity rectifying the damage could be difficult.

Many studies note that there are considerable data gaps when it comes to recording past fish population numbers. This is a particular problem in Scotland where in many cases studies were not carried out before the numerous hydrological schemes were built (Greer, 2000). In the case of Loch Laggan there is no scientific data on the native fish biodiversity from before the construction of The Lochaber Hydrological Scheme. We do, as previously mentioned have Colonel Thornton's observations recorded (Thornton, 1804). Due to this being a widespread issue many studies, like that discussed in Lao, PDR (Warren, 2001), do resort to using other methods to come to a conclusion as to whether management has had a negative impact on fish life. Data gaps mean this study of Loch Laggan is not a straightforward before and after comparison. It is rather, by necessity, a study of three different lochs. As previously mentioned Loch Laggan is the main study site with the lower Loch Na-H-Earba acting as the control site as its fluctuation is well under 5m. Loch Treig acts as the third study, site due to it being part of the same hydrological scheme and being even further exploited than Laggan.

Chapter 3 Study Site

The three Lochs included in this study are situated in the Western Scottish Highlands, in the Fort William and Lochaber area, and are detailed individually within this chapter.

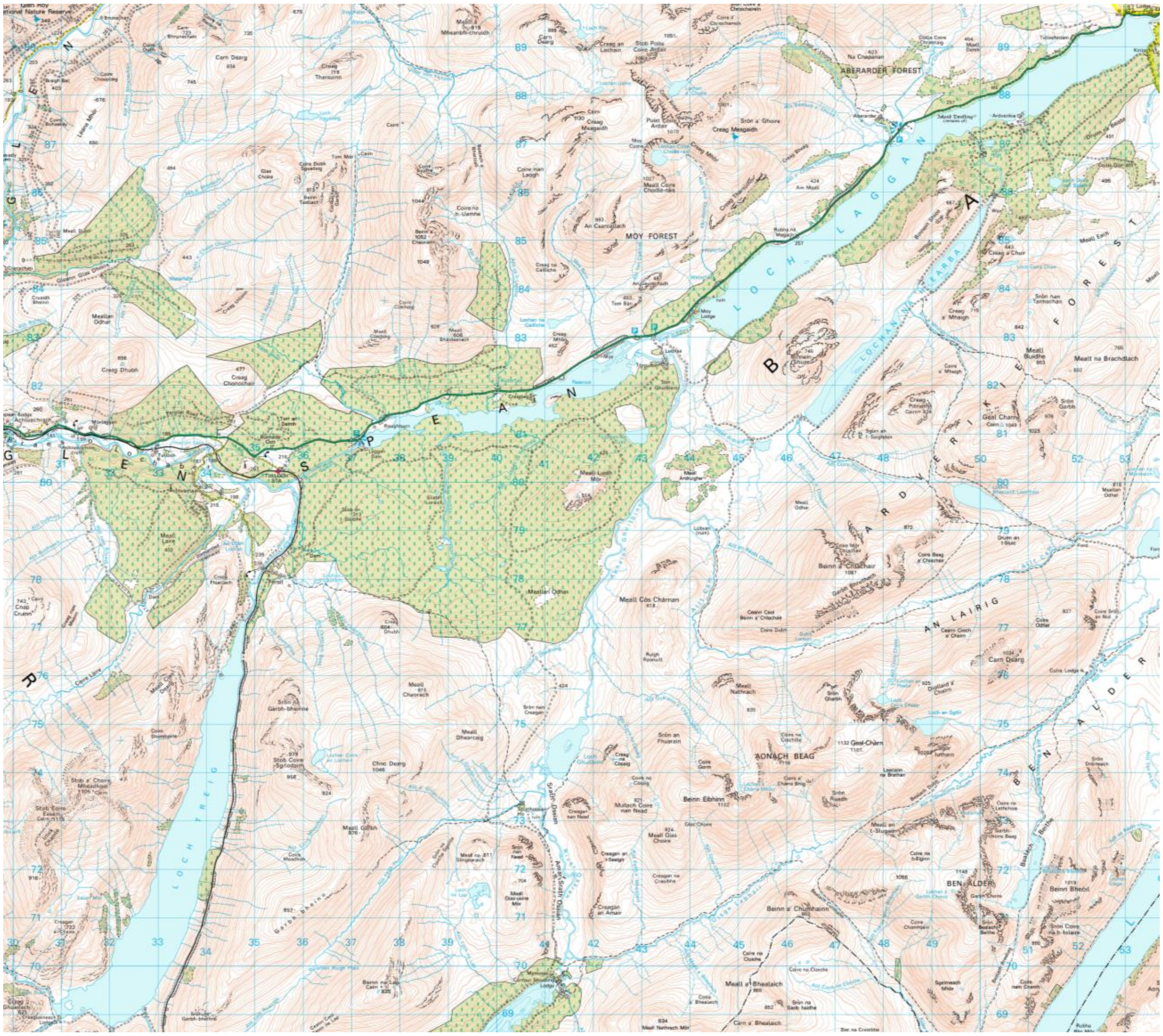


Figure 1: Map of Study Sites: ©Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service, Scale 1:50,000. Features Loch Laggan in the North Eastern corner. The two Loch Na-H-Earbas run parralel, directley south of it,(the southern Loch is involved in this study). Loch Treig is in the South Western corner.

Loch	Max. Depth (m)	Mean Depth (m)	Area (km²)	Annual Water Level Fluctuation (m)
Na-H-Earba	24.6	10.8	1.1	1-2
Laggan	53	20.7	7.6	8.15
Treig	133	63	8.21	13.88

Table 1: Bathymetrical details of each Loch involved in the study. (Richard Hearnden, pers. comm.)

3.1 Loch Laggan

The central focus of this study is Loch Laggan, a fairly large, glacial formed system of around 7.6km² in area as detailed in Table 1. The max depth of the system is 53m which, along with the glacial origins of the Loch, make it a suitable environment for successful invasions of Pike. These alien invaders, as previously explained, have established themselves alongside the native Arctic Charr, Brown Tout and Ferox Trout. The hydrological scheme causes an average annual water level fluctuation of around 8.15m, well above the marker of 5m where any further fluctuation then becomes detrimental (Smith, et al, 1987).

Figure 2: Loch Laggan (taken August 2012) looking towards the northern-eastern end and the Adverikie estate.

As shown in Figure 2 Loch Laggan still appears to look like a relatively natural system. There is some vegetation on the shoreline which is a good indicator of the health of an ecosystem. However, some of the shore has been steepened by the increased water level fluctuations as can be seen on the western side of the Loch, on the left of the photograph. This was also noted by Brander (1961).

3.2 Loch Treig

Loch Treig is the second study site of this investigation and at 8.21km² (taken from table 1) is a loch of a similar area to Loch Laggan and with the same species make-up, thus providing a good comparison. Despite being of similar size to Loch Laggan Loch Treig is much further exploited, with an average annual water level fluctuation of around 13.88 metres.

Figure 3: Loch Treig (taken in August 2012) at the very northern shore, looking south

As shown in figure 3 Loch Treig looks completely different to Loch Laggan. There is, worryingly, no vegetation on the shore, only on the higher ground. The shore, instead of being populated by vegetation, consists of very angular rocks; both building materials from the scheme constructions and natural rocks blasted from the earth to make way for said constructions. As can be seen in the photograph artificial concrete sides have even been built which can have an impact upon invertebrates and on the spawning sites of fish (Reid et al, 2005).

3.3 Loch Na-H-Earba

The southern Loch Na-H-Earba acts as the control site for this study as it is not a part of The Lochaber Hydrological Scheme and thus remains relatively unmanaged. There is a small scale private hydrological Scheme that powers Adverikie estate but, as this draws largely upon the northern loch, the southern one experiences average annual water level fluctuations of only 1-2m. As this is well below the 5m marker set by Smith et al (1987) the Loch remains a valid control site. This study is the first of its kind on Loch Na-H-Earba with netting never having been undertaken on the Loch before. It therefore clears up some of the uncertainty that previously surrounded the native fish biodiversity. As Loch Na-H-Earba feeds into Loch Laggan (via the Stream, Allt Labhrach) it was suspected that it has a similar species composition to that of Laggan prior to the construction of The Lochaber Hydrological Scheme, thus having populations of Trout and possibly Charr. However it was unknown if the Loch had an Arctic Charr population although it was thought that they did not manage to populate the loch after the last glacial period due to the presence of Binnein Shuas and Binnein Shios between Loch Laggan and Loch Na-H-Earba (Ron Greer, pers. comm.). The netting carried out for this study confirmed the presence of Brown Trout in the system with a few fish identified that could probably be Ferox Trout. As had been anticipated Charr were not present in the system and invasive Pike had also not colonised. This is a very positive discovery and one which the Adverikie estate was very pleased to learn of as they had some minor concerns regarding alien invasions due to the popularity of the Loch with anglers.

Figure 4: Loch Na-H-Earba (taken in August 2012) looking down to the northern end of the loch (left) and showing the abundant Water Lobelia (*Lobelia dortmanna)* in the system (top right and bottom right).

Loch Na-H-Earba is practically untouched by man. The shoreline is abundantly colonised with Water Lobelia, a species often taken as a positive sign of good water quality for Salmonids (Ron Greer, pers. comm.). With no artificial or steepened sides the control site is a stark contrast to Loch Treig.

Chapter 4 Materials and Methods

4.1 Invertebrate Populations

Often in larger systems such as Loch Laggan and Loch Treig it is only the littoral zones that change visibly due to the increased water level fluctuations. The deeper water is much harder to test, with changes taking longer to manifest (Zohary and Ostrovsky, 2011). For this reason only the littoral zone of each loch was sampled for invertebrates. The littoral zone is generally defined as the belt of shallow water along the shoreline of a lake. It extends to the maximum depth at which light still reaches the bottom sediments, allowing macrophytic growth. This depth varies depending on the system but is usually considered to be about 1–5 m (Schmieder et al, 2006). Therefore, invertebrate populations were sampled at 20 sites along the shorelines of each loch in the 1-5m depth zone. These sites were chosen initially by map in order to try and scatter them evenly around the shorelines and to attempt to avoid bias. However, when on the lochs, some of the sampling sites were altered due to accessibility issues or in order to get a full range of substrate types in case this had a bearing on invertebrate populations. At each site a kick sample was conducted for one minute. This involved dragging a heel firmly through the bed of the loch, underneath any rocks in the chosen path. Whilst doing this a bottom fauna net was held in the wake and pulled along through the current created (Frost et al, 1971). After one minute the net was then emptied into a basin and analysed on site, anything unable to be identified on site was labelled in a storage tube and kept to then be analysed by microscope back at base.

4.2 Fish Populations

Multiple mesh size gillnets, distributed throughout the various depth zones, were used to survey the lochs. The gillnets, made of monofilament nylon, each comprised of different mesh sizes following a geometric series with a ratio between mesh-sizes of about 1.25. The benthic gillnets were all 30m long and 1.5m deep, each with 12 different mesh sizes ranging from 5 to 55mm knot to knot (Greer and Hammar, 2004). These were set in each depth zone (0-3m, 3-6m, 6-12m etc.) where they would fall to the bottom due to lead lining in the lower net. Whilst setting these benthic nets the depth was continually checked using a depth torch in order to ensure the correct zone was being selected. The set nets were then marked with buoys at each end and their location noted. A pelagic net was also set; this net is very similar in design to the benthic nets although it lacks the 5mm section and so only includes 11 different mesh sizes. The net is 27.5m long and 6m deep giving it a far greater surface area than a benthic net. The net is divided into two separate halves and so is treated as two net efforts. It was set in the same fashion as the benthic nets although pelagic nets are always anchored so that the bottom of the net sits above the bed whilst benthic nets sit directly on it. When anchored in place the pelagic net provides a survey of the 0-3m and 3-6m zones in the deeper water. The nets were set in accordance with the size of each system (see table 2 below) with Loch Treig only being sampled in the 0-3m zone. The full netting on Loch Treig was, unfortunately, unable to be completed due to adverse weather conditions which continued for four months. Due to the vast management of the loch the sides are severely eroded making them extremely steep and this, along with the poor weather conditions, made it impossible to safely launch a boat. As netting of the other two Lochs went smoothly and an abundance of data had been collected the study was not jeopardised. A comparison can be made between all three lochs in the 0-3m zone and an avenue for further research is open, one encompassing a full netting of Treig.

Loch	0-3m	3-6m	6-12m	12-20m	20-35m	35-50m	Pelagic	Total Net Effort
Na-H-Earba	2	2	2	1	1	X	2	12
Laggan	2	2	2	4	4	4	2	20
Treig	2	X	X	X	X	X	X	2

Table 2: Net efforts throughout the various depth zones of each loch. (N.B. Loch Na-H-Earba has a maximum depth of 24.6m thus netting the 35-50m zone was impossible)

On each loch the nets were set in the late afternoon, left overnight and then collected the next morning. Each net was transported back to base where it was then emptied and the contents noted with species type, weight and length being recorded. Additionally a sub-sample covering the various species in each loch was selected for further stomach analysis. The selection of these fish was somewhat biased as attempts were made to select those with full stomachs whilst also getting a range of species.

4.3 Stomach Analysis

A total of 10 stomachs from Loch Na-H-Earba, 10 from Loch Laggan and 5 from Loch Treig (to relate to the size of catch) were selected from the fish survey. These were opened, their contents emptied and added to a small amount of water and then examined under a microscope in order to accurately identify the contents. They were then graded in terms of stomach fullness using the subjective points system which was first employed by Swynnerton & Worthington (1940) and then fully discussed and adapted by Hynes (1950). This method involves the contents of the stomach being awarded points which are proportional to its contribution to the total stomach volume, estimated and judged roughly by eye. The size of food is taken into account so one large organism can be equal to many small ones. This method was chosen as it is rapid and easy, requiring no complicated equipment but still giving a good level of analysis. It must be noted that this is a highly subjective method and not the most accurate. However in the case of this study where stomach analysis serves to back up other data, it was the most appropriate (Hyslop, 1980).

Chapter 5 Results

In this chapter the results of the field work undertaken are presented and analysed whilst keeping in mind the basic hypothesis.

Basic Hypothesis of the Study: As a result of the hydrological scheme Loch Laggan's Native fish population will be much reduced. This will most likely be clear when compared to the fish population of Loch Na-H-Earba. However, it is anticipated that Loch Treig's fish population will be even smaller than Laggan's. Invertebrate populations will echo the fish populations of each loch and it is expected that the invasive species of Pike will dominate Loch Laggan.

5.1 Invertebrate Data

With invertebrates being integral to the diet of Loch Laggan's native fish and as a good indicator of the health of an ecosystem their populations were tested on each loch. Populations were tested by kick sampling the shorelines at 20 sites for each loch, making the findings highly comparable. In this section the results are presented and further explored.

	Mayfly Nymph	Gammarous Shrimp	Diving Beetle	True Worm	Water Mite	Cranefly Larva	Non-Biting Midge Pupa	Meniscus Midge Pupa	Water Flea	Caddis Fly	Stonefly Nymph	Total
Na-H-Earba	30	51	12	50	25	6	25	9	40	10	14	272
Laggan	7	29	6	9	0	4	15	0	0	0	3	73
Treig	0	0	0	0	0	0	0	0	0	0	0	0
Total	37	80	18	59	25	10	40	9	40	10	17	345

Table 3: Invertebrate species and population totals of each of the three lochs.

The above Table 3 simply highlights the invertebrate totals in terms of species type and overall population for each loch. The results are rather striking and are explored further in the succeeding figures.

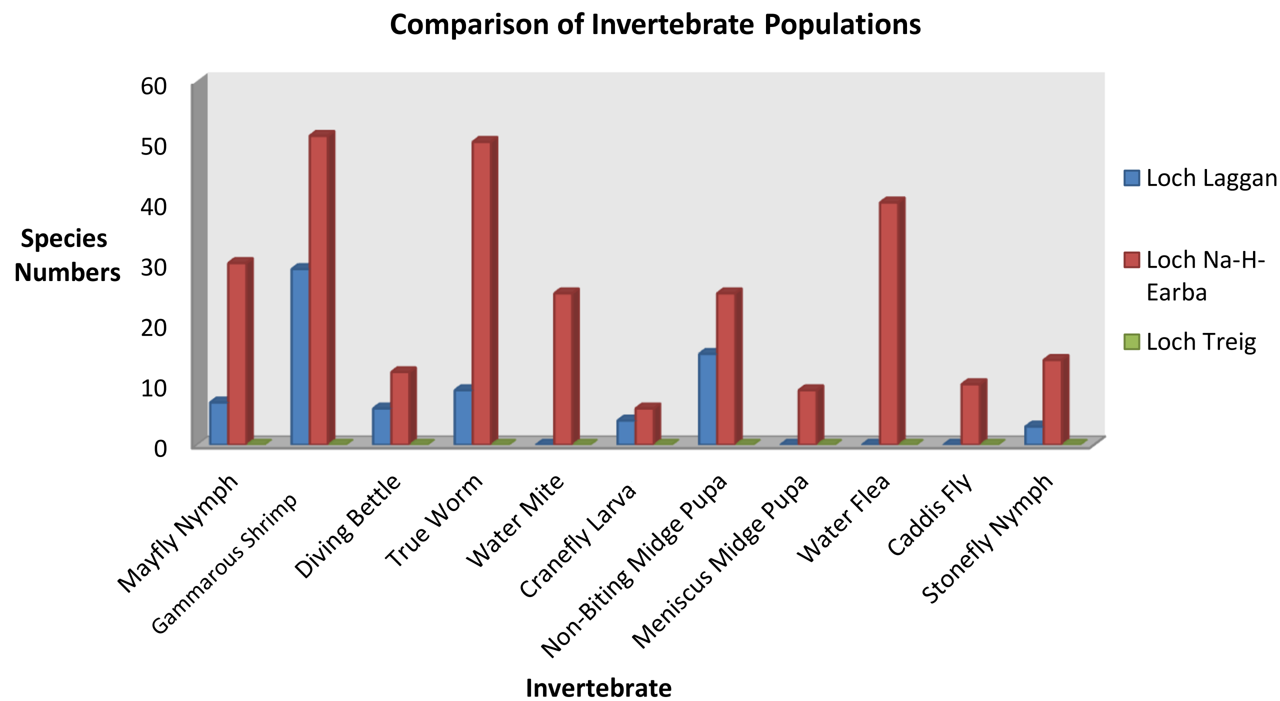


Figure 5: Total populations of invertebrates in each species across all three lochs.

Invertebrate population numbers ranged greatly between each of the lochs. Loch Na-H-Earba had by far the largest populations across all the species found with a total of 272 individuals. Loch Laggan had notably fewer individuals having a population, nearly four times smaller, of 73. These individuals were not evenly distributed across the sites as they were in Loch Na-H-Earba but instead occurred at only 7 of the 20 sites sampled. What was most remarkable was the absence of any invertebrates on Loch Treig.

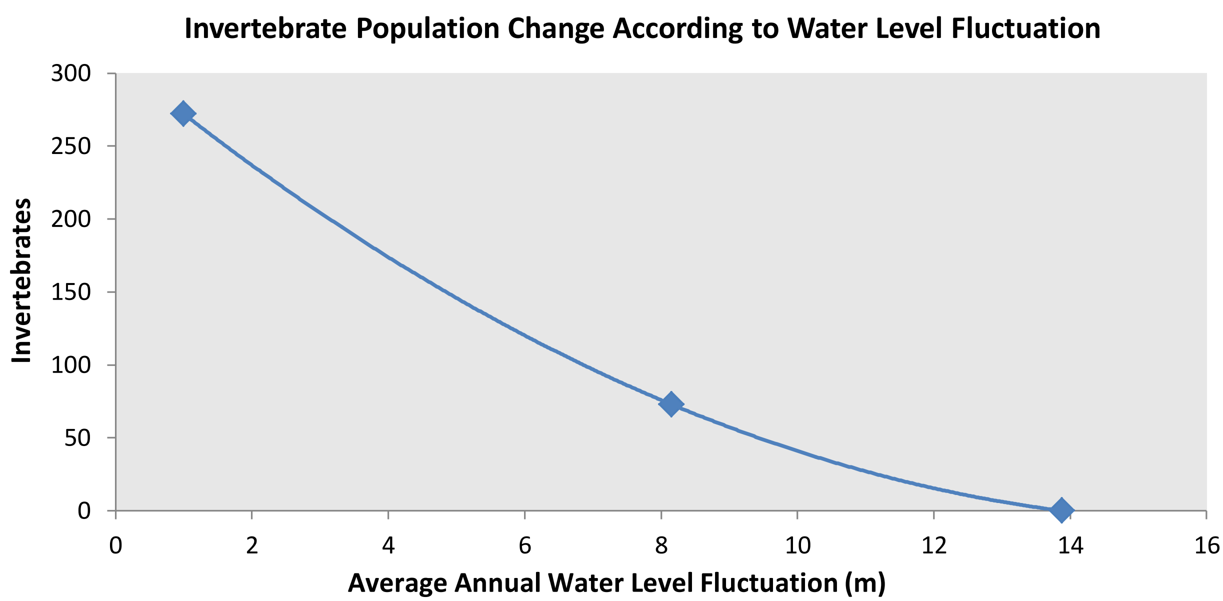


Figure 6: Relationship between shoreline invertebrate population size and average annual water level fluctuation level. (Loch Na-H-Earba = 1m, Loch Laggan = 8.14m and Loch Treig = 13.88m)

When compared to the average annual water level fluctuations the total invertebrate population numbers recorded at each loch shows a very clear trend. There appears to be a strong negative correlation between the two variables, whereby, as water level fluctuation increases invertebrate numbers decrease.

Statistical Correlation Tests

Correlations

		Invertebrate Numbers	Water Level
Invertebrate Numbers	Pearson Correlation	1	-.980
	Sig. (1-tailed)		.063
	N	3	3
Water Level	Pearson Correlation	-.980	1
	Sig. (1-tailed)	.063	
	N	3	3

Table 4: Bivariate one tailed Correlation tests between all three lochs

Whilst the test shows a strong negative correlation between invertebrate numbers and water level fluctuation the value of 0.063 shows the variables are not significantly different. This is because a value of ≤0.05 is required for there to be a significant difference. Due to the results of the first test a second Bivariate test was carried out, this time eliminating Loch Na-H-Earba, thus focusing on the two managed Lochs.

Correlations

			ivlevel	waterlevel
Spearman's rho	ivlevel	Correlation Coefficient	1.000	-1.000
		Sig. (1-tailed)	.	.
		N	2	2
	waterlevel	Correlation Coefficient	-1.000**	1.000
		Sig. (1-tailed)	.	.
		N	2	2

**. Correlation is significant at the 0.01 level (1-tailed).

Table 5: Bivariate one tailed Correlation tests between Loch Laggan and Loch Treig, the two managed lochs.

With the control site no longer included in the tests the results showed a highly significant difference between the variables (0.00). This proved that water level fluctuations do influence the number of invertebrates within the managed systems.

5.2 Fish Survey Data

Catch results of Loch Na-H-Earba and Laggan as whole systems are plotted and compared within this section whereas Loch Treig is only brought in when discussing the littoral level (0-3m depth zone). For ease only Brown Trout are referred to in this section. There were a small number of unusually large Trout in both Loch Na-H-Earba and Loch Laggan. These individuals, due to their exceptionally large size, may well be Ferox Trout but, without further in-depth analysis, it would be difficult to state this with total certainty. They are therefore included in the totals for Brown Trout throughout the study. Biomass of each species is used to demonstrate results in this section. This is calculated by dividing the cumulative weight by the number of net efforts carried out (Greer and Hammar, 2004).

Loch	Brown Trout	Pike	Arctic Charr	Minnow	Stickleback	Total
Na-H-Earba	285	0	0	7	0	292
Laggan	20	5	58	9	0	92
Treig	7	0	0	56	2	65
Total	312	5	58	72	2	449

Table 6: Showing the species and total numbers of fish caught on Loch Na-H-Earba, Loch Laggan and Loch Treig using Nordic survey gillnets during August 2012.

Table 6 highlights the fish population numbers of each loch in terms of both species type and by the total of individuals. Brown Trout were overall the most abundant of all species found. This was most notable in Loch Na-H-Earba where 285 individuals were found. In Loch Laggan only 20 Trout were found. Especially considering the fact that a net effort double that of Na-H-Earba was carried out this is quite a low total. The invasive species of Pike was only found in Loch Laggan and even in this system the total number of individuals was low. The relative abundance of Minnows in Loch Treig, with 56 individuals being sampled, is an interesting result and will be further investigated in the next chapter. As a result of the netting Sticklebacks were only found in Loch Treig, however they were found in the stomachs of fish caught in Laggan and thus their presence in this system should still be noted.

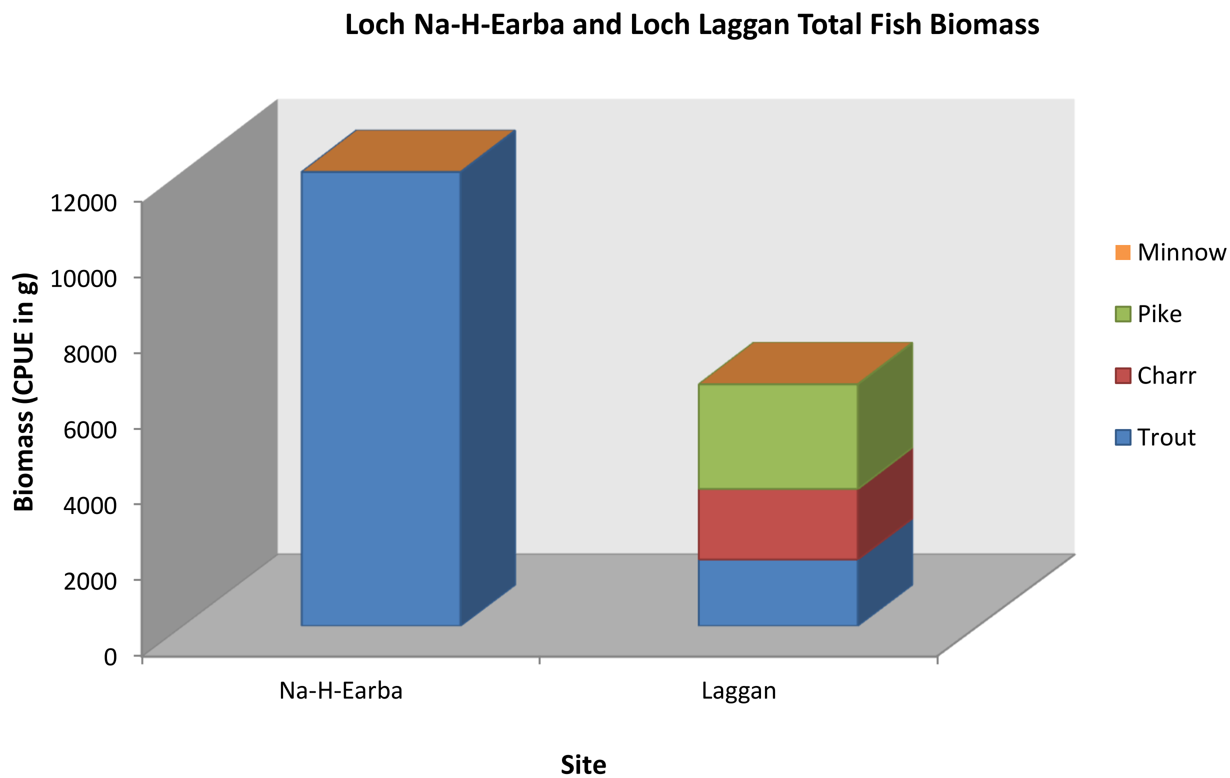


Figure 7: Comparison of species biomass in catches on Loch Na-H-Earba and Loch Laggan measured as Catch Per Unit Effort (CPUE) in weight per gillnet set at all depths.

The drastic difference in total fish biomass between Loch Na-H-Earba and Loch Laggan is detailed in figure 7. In the control site of Loch Na-H-Earba biomass is at 11991g, nearly double that of Loch Laggan which is only 6406g. Despite this the species diversity is much lower in Loch Na-H-Earba, with the ecosystem being much less complex than that of Loch Laggan. In order to demonstrate this, the Shannon-Weaver Diversity Index was calculated for each system. Using the calculation $H = - \Sigma\, p_i \ln p_i$ Loch Na-H-Earba was revealed to have a diversity index of 1.12 whilst Loch Laggan's was much higher at 2.74. The higher diversity index of Loch Laggan is most likely to be largely down to the invasive Pike in the system. In Laggan the distribution of biomass is relatively even between the species with the obvious exception of Minnow which have a biomass of only 11g. The non-native Pike do dominate the system in terms of biomass despite being low in terms of individual numbers (as shown in Table 6, located at the beginning of 5.2).

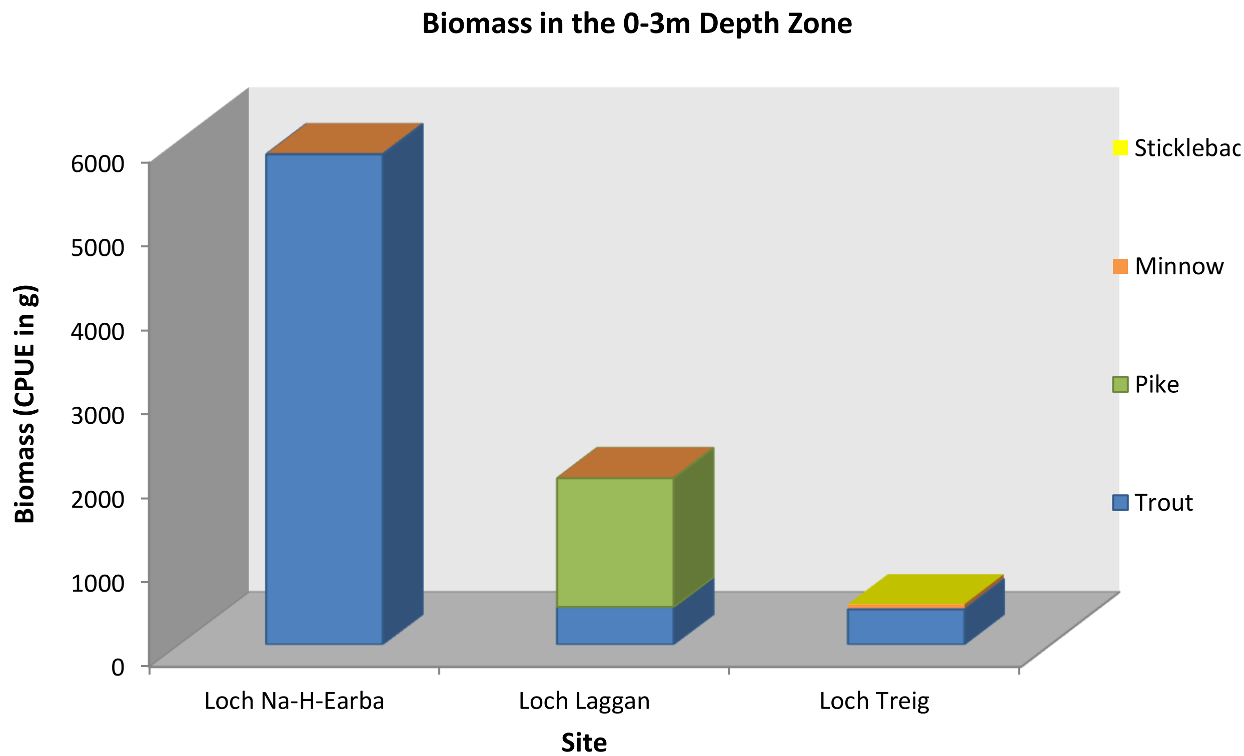
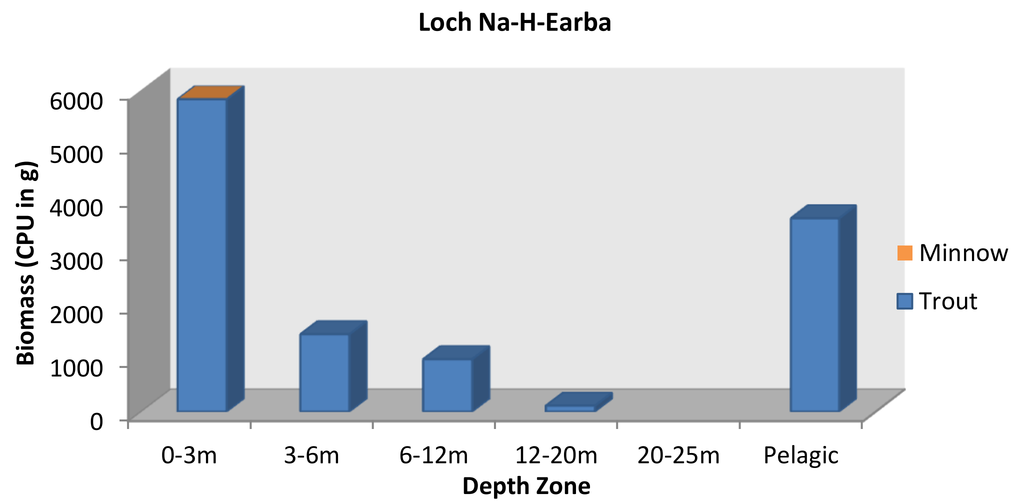


Figure 8: Comparison of biomass in the 0-3m depth zone of each loch measured as Catch Per Unit Effort (CPUE) in weight per gillnet set at this depth.

The total fish biomass for the littoral level, the 0-3m depth zone, of each Loch is illustrated in figure 8. Here we see a distinct reduction in biomass the more managed the study site is. Loch Na-H-Earba has a biomass total of 5841g, this then reducing nearly 3 times to 1997g in Loch Laggan and dropping further to 426g in Loch Treig. Loch Na-H-Earba is, unsurprisingly, dominated by Trout whilst it is the invasive Pike that again dominate in Loch Laggan, even more prominently in this littoral zone than as shown in Figure 7 for the entire loch. In Loch Treig, despite the high numbers of individual Minnow (as shown in Table 6) the small fish do not dominate this depth zone; here it is the Trout which have distinctly the greatest biomass.

Comparison of Biomass Distribution throughout the depth zones.



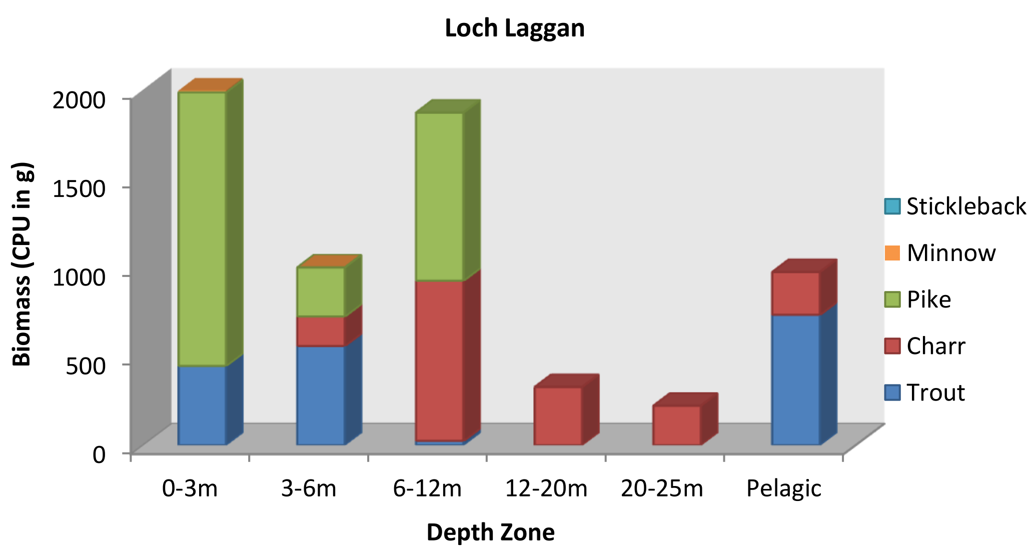


Figure 9: The biomass of different species of fish shown as catch per unit effort (CPUE) in weight per gillnet set at different depths on the two lochs.

When comparing the two systems the simplicity of Loch Na-H-Earba is evident; Trout dominate all depth zones although biomass is lower in the deeper waters. In both study sites biomass is greatest in the littoral level, the 0-3m depth zone, although in Loch Laggan it is the invasive Pike that dominate. Interestingly in Loch Laggan the second greatest portion of biomass is located in the 6-12m zone where again Pike dominate but Charr are also in abundance. Charr continue to occur in the deeper zones of Loch Laggan and in the pelagic zone where Trout biomass dominates, Pike being notably absent. Trout biomass in Loch Na-H-Earba is also in abundance in the pelagic zone despite the lack of Charr prey. Notable similarities can be drawn between the two systems and some picture gained of what biomass distribution throughout the depth zones may have been like in Loch Laggan before the invasion of Pike.

5.3 Stomach Contents Data

The stomach contents of fish from each loch were examined in order to support the data acquired from shoreline kick sampling. By examining the stomachs it can be determined if the kick sampling method provided data on invertebrates that is truly relevant to the diet of the fish. For ease of reference the relevant section of table 3, which details shoreline invertebrate numbers on each loch, is provided above each chart of stomach contents.

	Mayfly Nymph	Gammarous Shrimp	Diving Beetle	True Worm	Water Mite	Cranefly Larva	Non-Biting Midge Pupa	Meniscus Midge Pupa	Water Flea	Caddis Fly	Stonefly Nymph	Total
Na-H-Earba	30	51	12	50	25	6	25	9	40	10	14	272

Taken from: Table 3: Invertebrate species and population totals of each of the three lochs.

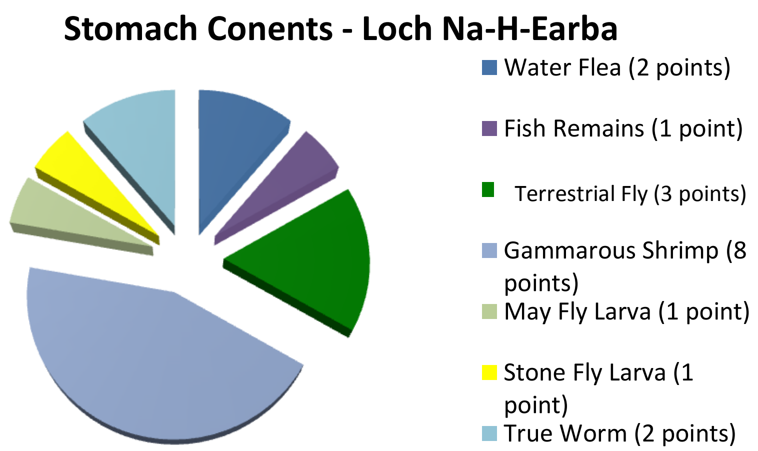


Figure 10: Stomach contents of 10 Trout caught in Loch Na-H-Earba.

The data shown in figure 10 reveals that Gammarous Shrimp make up the largest proportion of the stomach contents of the sample. As the shrimp were the most abundant shoreline invertebrates, with 51 individuals being found, their abundance in the stomachs also backs up their importance to the fish. True Worms and Water Flea were also found in large numbers on the shoreline and again make up a significant proportion of the stomach contents. Additionally the abundance of Terrestrial Flies in the stomachs must be noted. This highlights an avenue for further research into the importance of terrestrial insects to the fish populations and how they are impacted upon by hydrological schemes.

	Mayfly Nymph	Gammarous Shrimp	Diving Beetle	True Worm	Water Mite	Cranefly Larva	Non-Biting Midge Pupa	Meniscus Midge Pupa	Water Flea	Caddis Fly	Stonefly Nymph	Total
Laggan	7	29	6	9	0	4	15	0	0	0	3	73

Taken from: Table 3: Invertebrate species and population totals of each of the three lochs.

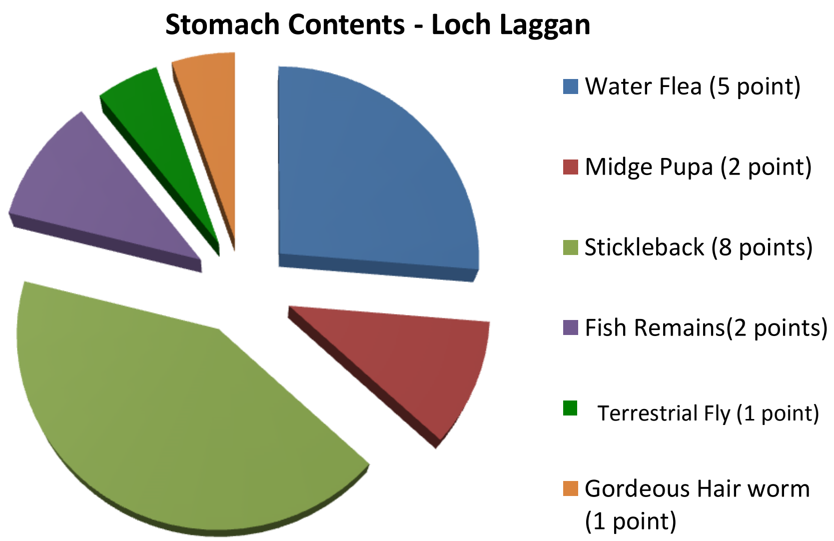


Figure 11: Stomach contents of 10 fish caught in Loch Laggan, including Pike, Brown Trout, Charr and Ferox Trout.

In figure 11, the Loch Laggan sample, the data revealed that Terrestrial Flies made up the largest proportion of the stomach contents with Water Fleas making up the second largest section despite none being found in the shoreline survey. Midge Pupae made up a significant segment and did occur relatively abundantly along the shoreline. It should be noted also that fish remains made up a significant section of the stomach contents. The results of this analysis do highlight some of the issues with this method as many of the stomachs selected were in fact empty and some of the contents too far digested to even identify, therefore some of the contents may have been overlooked.

	Mayfly Nymph	Gammarous Shrimp	Diving Beetle	True Worm	Water Mite	Cranefly Larva	Non-Biting Midge Pupa	Meniscus Midge Pupa	Water Flea	Caddis Fly	Stonefly Nymph	Total
Treig	0	0	0	0	0	0	0	0	0	0	0	0

Taken from: Table 3: Invertebrate species and population totals of each of the three lochs.

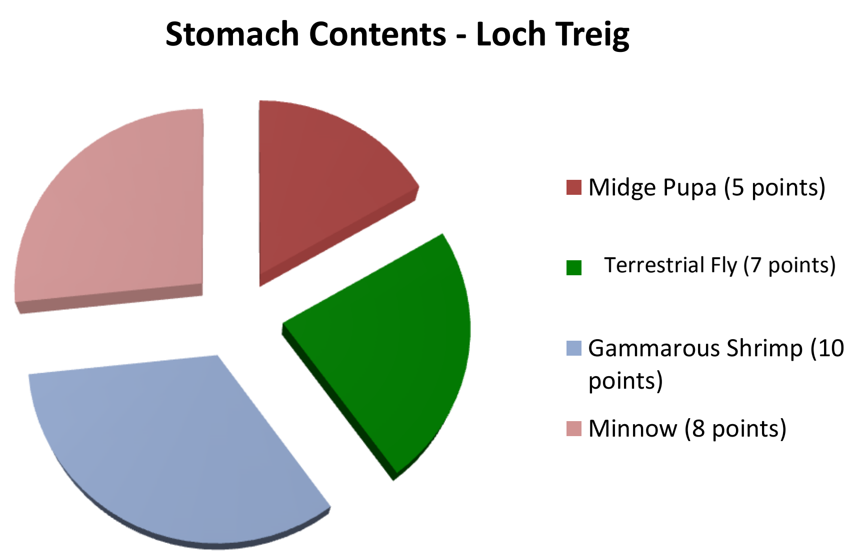


Figure 12: Stomach contents of 5 fish from Loch Treig, taken only from Trout.

With no invertebrates at all being found when conducting the kick sampling on Loch Treig it is encouraging to see that, as figure 12 shows, Gammarous Shrimp make up the largest proportion of the stomach contents. Minnows and Terrestrial Flies make up the next largest segments, perhaps due to an overall lack of invertebrates, although Midge Pupae was also present in the stomachs showing that invertebrate populations do exist in the system.

Chapter 6 Interpretation

6.1 Invertebrates

The results in terms of shoreline invertebrate populations show very clear trends and are, therefore, fairly conclusive. The invertebrate population of the control site, Loch Na-H-Earba, which has an annual average water level fluctuation of around 1m, far exceeds that of Loch Laggan. Invertebrate numbers were not only higher at every site sampled but also throughout every species found. Loch Na-H-Earba's invertebrate populations are almost 4 times that of Loch Laggan's, where water level fluctuation is an annual average of 8.14m. It is interesting to then compare these results to those from Loch Treig. Loch Treig has an annual average water level fluctuation of 13.88m and, as anticipated, the shoreline invertebrate population seems to be greatly disturbed by this. With not a single invertebrate being found at any of the 20 kick sample sites along Loch Treig's shoreline, the difference between the three systems is very striking. However, on examination of the Loch Treig stomach contents invertebrates were found to be present. Due to this discovery it is evident that invertebrates are not entirely absent from the highly managed system but that the population is most certainly severely damaged. Figure 6 demonstrates how these results correlate to the according water level fluctuations, so that a clear and highly negative correlation between the two variables can be concluded.

The most commonly occurring invertebrate in both Loch Na-H-Earba and Laggan was the Freshwater Gammerous Shrimp, an organism which is known to make up a large proportion of the diet of salmanoids (Greer, 2004). This idea was justified by the analysis of stomach contents which revealed it to be a large component of the stomachs of Trout. One species which was in great abundance in Loch Na-H-Earba, where 50 individuals were found, was the True Worm. However in Loch Laggan only 9 were sampled, over 5 times fewer, a fact which could possibly hint at a susceptibility of the species to higher water level fluctuations.

6.2 Fish Populations

The impact upon Loch Laggan's overall native fish biodiversity appears to be fairly severe with the total number of fish surveyed being 92, around three times less than the 292 found in Loch Na-H-Earba. This is a rather striking result and one which can be linked to the amount of invertebrate prey available, which also reduced from Loch Na-H-Earba to Loch Laggan. Bringing Loch Treig into the comparison, as in Figure 8, which gives results for the shallow littoral zone of 0-3m, the same trend continues. As anticipated the biomass of total fish caught reduces in relation to both the severity of the water level fluctuations and the decrease in invertebrates. Whilst this general trend is quite clear the number of fish caught in Loch Treig must be acknowledged. In Treig's highly managed system a total of 65 fish were caught. Considering that only two nets were set and, when compared to Loch Laggan's total netting yielding only 92 individuals, this catch seems very high. However, 56 of the 65 individuals caught in Loch Treig were Minnows, a prey species of both Trout and Pike. The abundance of this prey species could hint that the predators are in decline, their populations severely reduced by the high water level fluctuations and lack of invertebrates. This hypothesis cannot be confirmed until it is possible to survey the whole loch, an extremely exciting avenue for further research when access becomes possible.

In Loch Laggan, the invasive species of Pike dominates in terms of biomass throughout all the depth zones, most obviously in the littoral zone at the shallow depths of 0-3 and 6-12m.This is the zone with the greatest abundance of prey for the Pike, an ambush style predator (Casselman 1995), to consume. Invertebrate populations are concentrated here and thus Brown Trout and Ferox also use it to source food. However, due to the Pike dominance in terms of biomass, it would seem that the Trout are being out-competed in this zone. As shown in Figure 9, in the previous chapter, the distribution of Charr in Loch Laggan is largely in the deeper or more pelagic waters, the area they would naturally occupy (Hartley et al, 1992). The species is relatively abundant in terms of individual numbers. This could be because the Pike, as ambush predators, do not tend to go as deep (Casselman 1995), although both species are present together in the 6-12m depth zone. Without direct Pike predation in the deeper waters and with the bottom-dwelling invertebrates left for them to consume, the Charr population seems to be sustained. Figure 9, showing the distribution of Laggan's Trout, demonstrates that they occur in greater numbers in the deeper zones than they do in Loch Na-H-Earba. This shift reveals the impact an invasive species can have on an ecosystem's hierarchy (Meffe and Carroll, 1997). It would seem that due to the dominance of Pike in Loch Laggan the Trout are forced into these deeper waters to pursue their Charr prey.

6.3 Stomach Contents

The stomach contents analysis of all three lochs' fish clearly backed up the shoreline invertebrate sampling, proving it to be a relevant sampling method. It is suggested that in a natural system the Brown Trout and their larger relatives the Ferox Trout dominate the upper littoral zone (Greer, 2004). They feed predominantly on shallow-water insects and larvae with Freshwater Gammerous Shrimps making up the largest proportion of their diets. As members of the Salmonid family, Charr have a very similar diet to Trout (Greer, 2004). Figures 10 and 12 confirm this to be the case, showing that in both Loch Na-H-Earba and Treig the Trouts' stomachs were largely filled with Freshwater Gammerous Shrimp. Despite Trout and Charr naturally having a similar diet it is suggested that two or more species cannot usually exist in the same niche (Nilsson, 1965). This is why Charr are often found in large shoals in the deeper or more pelagic water where they largely feed on animal plankton. Despite this some degree of overlap in diet can be expected (Nilsson, 1965). Unfortunately the stomachs of Laggan's Charr were largely empty and what was present was digested to such an extent that identification was impossible; meaning no comparison to similar studies could be made. All the figures in section 5.3 (figures 10, 11 and 12), showing overall stomach contents for each loch, illustrate a very interesting trend. It appears that the more managed the system is the less complex the diet of the fish becomes. For Loch Na-H-Earba a total of 7 different organisms were found in the stomachs. In Loch Laggan there were 6 organisms found whilst in Loch Treig only 4 were present. This shows that a definite limitation of prey availability and species richness arises with increased management of a system. In this study the stomach contents were primarily analysed in order to justify and prove the validity of the chosen method of sampling invertebrate populations. Therefore the stomach sample sets analysed were very small; 10 from both Lochs Na-H-Earba and Laggan and 5 from Loch Treig. Sample numbers would need to be larger if, in a different study, any strong conclusions were required to be drawn from the contents. A number of limitations came to light when carrying out stomach contents analysis which can provide valuable information to carry forward into other studies of this kind. A large number of stomachs analysed were discovered to be empty. This could be due to fish not feeding prior to netting, the netting process causing them to empty their stomachs or due to digestion being complete. In some full stomachs the contents were too digested to identify correctly and so some prey may have been overlooked (Hynes, 1950). These limitations may have influenced the overall results gained and therefore, apart from justifying the sampling method and backing up its findings, no firm conclusions can be drawn from the results of this section.

Chapter 7 Discussion and Conclusion

7.1 Reduced Invertebrate Population

The results show a clear reduction in invertebrate populations in the littoral zones of both Loch Laggan and Treig, given the increased water level fluctuations induced by the Lochaber Hydrological Scheme. Bearing in mind Loch Na-H-Earba's thriving shoreline invertebrate population it is most apparent that Loch Laggan has been negatively affected by its human management. Loch Na-H-Earba's invertebrates have evolved in order to suit their life cycles to the natural water fluctuations of the ecosystem. In Loch Laggan invertebrates will have done the same, adjusting over time to the natural fluctuations which are an important feature of any lake and essential to the survival of many species (Zohary and Ostrovsky, 2011). However, due to the hydrological scheme, Loch Laggan's water level now fluctuates 10.18m annually. This is an amplitude far greater than that of any natural fluctuation. Alongside this increased amplitude, the exploitation of lakes for hydroelectric power production often means the timing of minimum and maximum water level will change each year. These continuous changes do not allow invertebrates to adapt and become tolerant of their new environmental conditions (Wantzen et al, 2008).

The stress caused by increased water level fluctuation to the invertebrates in the littoral zone has been noted to cause shorelines to become barren in numerous Scottish Lochs. With the extreme fluctuations and annual changes in peak and trough water level invertebrates will have very low chances of survival (Smith et al, 1987). Smith et al's (1987) concept, derived from examination of many Scottish lochs, appears to be strongly supported by the data collected from the three lochs involved in this study. Loch Treig's invertebrate population is almost completely absent. This is the result of the water level fluctuation being the highest of all three lochs. The low invertebrate numbers could also be due to the creation of vertical concrete walls, tarred surfaces and other false shores which are sadly abundant in the system. The use of these artificial surfaces removes plant material from the shoreline, reducing the food sources available to the littoral-dwelling invertebrates (Zohary and Ostrovsky, 2011). Additionally, the man-made shoreline surfaces greatly reduce the littoral habitat complexity. With habitat complexity providing the existence of sand, clay, boulders and pebbles all in the same zone, many species are able to thrive. Without this complexity significant losses in invertebrates, as found in Loch Laggan and Loch Treig, can be expected.

The reduced species richness in Loch Laggan when compared to the control site, Loch Na-H-Eabra, is possibly due to toleration capabilities. In Loch Laggan the invertebrates that remain are those most capable of surviving the tough conditions caused by the hydrological scheme. With extreme water level fluctuations littoral faunae often become depressed and restricted in terms of the number of different species (Zohary and Ostrovsky, 2011). The low invertebrate numbers in Loch Treig hint that Loch Laggan's remaining species may not be able to tolerate further increased water level fluctuations. Similar reductions in the number of different species present in the littoral zone were found in Finnish Lakes. This is a useful and valid comparison due to these being Nordic lakes which are similar environmentally and biologically to Scottish lochs. The Species richness was assessed in a mixture of regulated and unregulated systems in Finland and the conclusion made that greater richness was due to natural amplitudes of water level fluctuation (Aroviita and Hamalainen, 2008).

The varied invertebrate population results of each Loch involved in this study relate very clearly to the findings demonstrated by the wider literature detailed above. The reduction in populations in Loch Laggan and Loch Treig can be largely attributed to the increased water level fluctuations. Loch Laggan's population is most certainly already damaged but Loch Treig provides a glimpse of possible future degradation if further exploitation occurred. Given Laggan's damaged littoral invertebrate population, a clear mark of the health of an ecosystem, the knock-on effects on fish population must be further examined.

7.2 Reduced Native Fish Population

Given the evident impact that the increased water level fluctuations have had on Loch Laggan's invertebrate population it is unsurprising that the native fish population also seems to be in decline. With water level fluctuations in Loch Laggan greatly increased by the hydrological scheme the native fish lose valuable habitat when the littoral zone is undermined. The shallow water zone provides not only prey for the fish but also refuge from other predators and spawning sites amongst the vegetation (Gafny et al. 1992). Loch Laggan's native Trout population will naturally use the littoral zone at spawning time and throughout their juvenile stage. Most certainly in these stages, and often throughout their life cycle, they rely on the resources in the littoral zone for survival. The water level fluctuations could easily interfere with their initial spawning and even with egg incubation (Winfried, 2004). This reduced reproduction success could, even on its own, cause decline in native Trout and Charr populations.

Loch Leven, Kinross, provides an example of another Scottish Loch where changes to water levels have negatively impacted the native fish biodiversity. Prior to the dramatic lowering of the Loch in 1830, which reduced it by a quarter of its area, the Arctic Charr population was known by many to be abundant (Maitland, 2010). Charr of large sizes were often caught by anglers; Pennant (1769) noted "the length of the Loch Leven charr at two and a half feet". Since the vast changes to the water level of the Loch the Charr is thought to have entirely disappeared from the system, none being caught in over 100 years (Burns-Begg, 1934).

In Lake Limingen, a hydroelectric reservoir in Norway, the effects of amplified water level fluctuations on the Brown Trout and Arctic Charr were studied from 1953 to 1995. The system's water level is thought to fluctuate around 8.7 metres, severely damaging the littoral zone (Aass et al, 2004). This level of fluctuation, alongside the species make-up of the Lake, makes it a very similar system to Loch Laggan, thus a valid comparison. The benthic fish community of the Lake was sampled using standardised gill nets during July to August over the numerous years. This surveying revealed that both Brown Trout and Arctic Charr populations were reduced from their estimated sizes prior to construction of the hydrological scheme. Additionally the populations of both species continued to decline throughout the three years of netting (Aass et al, 2004). The population decline was largely due to the reduced reproduction success caused both by the degradation of the littoral zone and the continually fluctuating water levels. Both Trout and Charr spawn in late autumn when the water level is high, making the spawning areas accessible. However, the Lake's water level is then greatly reduced in the winter for a prolonged period of time causing many of the eggs to fail. This causes the fish populations to stay at critically low numbers (Aass et al, 2004).

The Norwegian Lake Mårvann has also undergone years of management and regulation. Currently the lake has an annual water level fluctuation of around 21 metres (Bórgstom, 1973). With Trout being the only fish present in the system it provides a valuable insight into the effects hydrological schemes can have on the species. Bórgstom (1973) carried out gill netting of Lake Mårvann over two years. Due to a lack of pre-management data the results were compared to local knowledge of previous Trout catches. The conclusion was that there had been a massive reduction in the Trout population since the management of the lake began. Many nets, even in September which was the time locals thought best for fishing, were found completely empty. Prior to the amplified water level fluctuations locals had caught around 350kg of fish and now catches were almost at zero (Bórgstom, 1973). The huge changes in water level were thought to have degraded the littoral zone to such a great extent that the invertebrate population was almost destroyed. The decline in Trout numbers was seen as a direct result of this, with many fish in the Lake having been noted to be dying of starvation (Reimers, 1957).

Water level fluctuation is, however, not the only factor Loch Laggan's native fish populations have to contend with. The data from this study shows both reduced invertebrate populations and a dominance of Pike in the littoral zone. Although it is greatly degraded the invasive colonisers preferentially occupy the shallow water which is the most abundant zone for feeding. The Pike therefore provide great competition for the Trout and Charr in terms of feeding on the now reduced shoreline invertebrate population (Winfried, 2004). This competition and the threat of predation of Pike upon the native fish have caused a shift of Trout to the deeper or more pelagic waters. This in turn could then have huge implications for the rest of the ecosystem as the Trout are forced to exploit other resources such as the Charr population and the deep water invertebrates (Gasith et al. 1996). Studies of fourteen different Lakes in Northern Sweden revealed the impact upon the native fish of both a reduction in prey availability and an increase in competition for food (Nilsson, 1960). Trout were observed to switch from one type of food to another when scarcity or competition made it necessary, much as they have been forced to do in Loch Laggan. A further consideration is that Pike are often mass consumers and thus they can act as environmental degraders. The Pike's dominance of the littoral zone, which is most certainly an already damaged area, may well lead it to even further decline.

7.3 Possible Mitigation Measures

Managing the effects of hydrological schemes upon natural water bodies is a very tough challenge. Many studies have investigated ways in which to mitigate the issues that are linked with amplified water level fluctuations. However it often appears that much of the damage is considered to be so extensive and prolonged that it is deemed to be irreversible. It is strongly advised that wherever possible water level fluctuation increase must be avoided (Zohary and Ostrovsky, 2011). With a rapidly increasing human population and a great strain on resources this is not always possible. In the case of Loch Laggan, as with many other systems, it is too late to completely undo all the damage.

Loch Laggan's native fish biodiversity could possibly be salvaged through various different management techniques. The heavily-damaged littoral zone is perhaps the best focus for this mitigation. The replacement of natural spawning substrata where it is now lost or degraded, the planting of natural vegetation or the use of artificial habitats could increase native breeding success (Winifred, 2004). Alongside this, the dominance of the invasive Pike must be controlled if the native fish biodiversity is to be increased. This could be achieved with the participation of the Lochaber Hydrological Scheme managers, Rio Tinto. If water levels were reduced in April each year when Pike spawn, and maintained in October when both the native Trout and Charr spawn, vital access to the littoral zone could be managed. This would not only maintain the native fish biodiversity but also control the invasive Pike population, thus reducing competition and predation threats (Winifred, 2004).

With the obvious impacts that current exploitation has had on Loch Laggan there is a great need for caution and attention to be paid before any further manipulation of the ecosystem is sanctioned. The severely damaged Loch Treig, almost devoid of littoral invertebrates, can provide a valuable snapshot of Loch Laggan's possible future if this further management is allowed.

7.4 Conclusion

The basic hypothesis of the study was most certainly proved to be correct. The hydrological scheme has greatly reduced Loch Laggan's native fish population, a fact which is most strikingly clear when compared to the abundantly populated Loch Na-H-Earba. It seems that Loch Treig's population is damaged to a much greater extent than Loch Laggan however a full netting survey is required to determine this with total certainty. There was a direct link between the health of the invertebrate populations of each loch and their fish numbers; when one was reduced so was the other. The fact that Loch Laggan's shoreline invertebrates are severely affected by the increased water level fluctuations most certainly is reducing the native fish biodiversity of the system. Additionally the invasive species of Pike appears to have very successfully colonised so that it is now dominant in Loch Laggan. This invasion, which most likely occurred as a result of the Lochaber Hydrological Scheme's tunnel from the Spey to Laggan, and the increased water level fluctuations are creating environmental conditions that are extremely difficult for the native species to tolerate. Without effective mitigation measures and prevention of further exploitation the valuable ecosystem of Loch Laggan and its native fish biodiversity could well be even further eroded, perhaps to the extent that Loch Treig has been.

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