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Loch Grannoch Arctic charr re-introduction feasibility project

For Galloway Glens Landscape Partnership

For further information on this report please contact:

Name of GFT Project Manager – J Graham
Galloway Fisheries Trust
Fisheries House
Station Industrial Estate
Newton Stewart
DG8 6ND
Telephone: 01671 403011
E-mail: jackie@gallowayfisheriestrust.org

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Summary

Final report for the Arctic charr translocation to Loch Grannoch feasibility study

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Keywords

Arctic charr; Loch Grannoch; south west Scotland; Kirkcudbrightshire Dee; species re-introduction; translocation; acidification.

Background

Arctic charr (*Salvelinus alpinus L.*) is a species of freshwater fish that was historically present in two freshwater lochs in south west Scotland: Loch Grannoch and Loch Dungeon. Both Lochs are part of the Kirkcudbrightshire Dee river system. This report concentrates on Loch Grannoch.

The Arctic charr population in Loch Grannoch died out because of acidification. At this time, research showed that there was also a severe impact upon the trout, however they were able to survive. In recent years it is known that the water quality has improved and the trout population appears to have recovered significantly. There has been desire locally to introduce charr back into the loch however the exact status of the water quality was not known. This feasibility study, supported by the Galloway Glens Landscape Partnership through the Heritage Lottery Fund Development Funding, aimed to ascertain whether the loch was suitable for sustaining a re-introduced population of Arctic charr, and, if it was, the next stage of the work would be to carry out a full re-introduction of the species into the loch.

Main findings

- An event was held and attended by experts in the field of Arctic charr and other stakeholders. All who attended the event supported the re-introduction of charr into Loch Grannoch, if deemed feasible.
- Spawning substrate around the perimeter of Loch Grannoch was completed and concluded that there is ample spawning material which an introduced population of charr could use for spawning.
- Water quality monitoring was carried out in the loch and two main inflowing tributaries. A multi-parameter sonde was installed in the loch which continually recorded the pH of

the water over three months. Results from the water quality monitoring showed that the water in Loch Grannoch was below pH 5, except on one occasion. pH of ranged from 4.80 to 5.01.

- The necessary licenses required for the re-introduction of Arctic charr to Loch Grannoch was explored via discussion with Marine Scotland Science. Discussions were held with SNH regarding the Scottish Code for Conservation Translocations.
- The suitability of the loch to support a population of Arctic charr was investigated and it was concluded that only the pH of the loch is the limiting factor. Expert opinion was sought and the consensus was that since the loch water was almost consistently below pH 5, then it was unfortunately still too early in the recovery of the loch to re-introduce Arctic charr.
- GFT does believe that the loch will continue to recover and the information contained within this report can be used as a basis for future introduction work.

For further information on this project contact:
Name of Project Manager – J Graham
Telephone No. of Project Manager – 01671 403011

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1 INTRODUCTION AND AIMS

Under Heritage Lottery Fund Development Funding, the Galloway Fisheries Trust (GFT) was contracted by the Galloway Glens Landscape Partnership to undertake a study into the feasibility of re-introducing Arctic charr to Loch Grannoch.

This project had the following aims:

- Engage with relevant stakeholders, including agencies and landowners, to build support and buy-in for a Loch Grannoch Arctic charr translocation project;
- Establish the environmental parameters that a population of Arctic charr requires;
- Examine and map habitats to ascertain whether suitable and sufficient spawning materials are present and accessible;
- Research and determine whether the water (loch and inflowing tributaries) is of adequate quality to sustain Arctic charr eggs and alevins. Establish a water quality data baseline across the Arctic charr spawning period to hatch time;
- Determine the suitability of the loch to support a juvenile and adult Arctic charr population (e.g. other species interactions, potential impacts, predator/prey interactions);
- Investigate other relevant Arctic charr work such as re-introductions and rearing programmes; engage with experts in the field, potentially establish a level of partnership working and/or research opportunities;
- Investigate and identify practical methods of undertaking the Arctic charr reintroduction work including assessing access issues;
- Investigate and identify potential suitable source (donor) populations of Arctic charr with consideration given to genetics;
- Identify the necessary licences and engage with relevant licencing agencies and environmental bodies including the Scottish Government, with reference to the Scottish Code for Translocations and corresponding Translocation Project Form;
- Determine and describe, with evidence, whether the Arctic charr translocation project is deemed feasible at Loch Grannoch.

2 ACKNOWLEDGEMENTS

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3 ENGAGE WITH RELEVANT STAKEHOLDERS, INCLUDING AGENCIES AND LANDOWNERS TO BUILD SUPPORT AND BUY IN FOR A LOCH GRANNOCH ARCTIC CHARR TRANSLOCATION PROJECT

3.1 Stakeholder engagement

Stakeholder engagement began early with identifying known experts in the Arctic charr field in Scotland, namely Professor Colin Adams (University of Glasgow), Professor Colin Bean (Scottish Natural Heritage (SNH)) and Professor Peter Maitland (Fish Conservation Centre). Through discussion with these people, other experts and those involved in Arctic charr and fish conservation were identified from across the UK. Further to this work, landowners and the licencing authorities were also identified. In addition to this it was important to identify individuals involved in water quality analysis and licensing (which would be required prior to any re-introduction work).

A stakeholder meeting was held in November 2016 which experts in the field and interested parties attended to discuss the project, provide their views on the potential re-introduction of charr to Loch Grannoch and to tease out additional thoughts and information, as well as gaining a consensus on which parameters the project should focus on.

The meeting was well attended (see Appendix 1 for attendees and meeting note) and the discussions provided useful information. Within the meeting it was of particular importance to gain the support of Scottish Natural Heritage for the re-introduction of charr to Loch Grannoch. All meeting attendees) agreed with the principle aims of the project and supported the re-introduction of charr to Loch Grannoch (if deemed feasible).

Other individuals and organisations were contacted throughout the length of the project, especially associated with water quality analysis.

4 ESTABLISH THE ENVIRONMENTAL PARAMETERS THAT A POPULATION OF ARCTIC CHARR REQUIRES

4.1 Background on Arctic charr

Arctic charr *(Salvelinus alpinus L.)* is a salmonid fish species and is believed to be one of the first fish to have re-entered the freshwater environment after the last ice age ended and the ice cap retreated (FRS, 2004; Maitland & Campbell, 1992; Maitland, 2007).

The charr is a Holarctic species occurring around the northern hemisphere (Maitland & Campbell, 1992) and is the only species with a circumpolar distribution (Klemetsen *et al*, 2003). Charr can be both freshwater or sea-water residents and can inhabit lakes or rivers. However, in Scotland all species of charr reside in freshwater lochs. These are generally large, deep, oligotrophic still waters with glaciated basins (Maitland & Campbell, 1992). Scotland is host to 258 separate populations of charr (SNH, 2013[1]), moreover in some lochs up to three genetically and morphologically different forms can be found. Each of these may exhibit different patterns of habitat use, spawning location and the timing of reproductive behaviour (SNH, 2013).

Figure 1: Loch Grannoch, November 2016

4.2 Environmental parameters that Arctic charr requires

4.2.1 Water temperature and depth

Optimum temperature for Charr growth appears to be 12-16˚C which is the same as brown trout. Although thought to be one of the most resistant salmonids to low temperatures, there are conflicting beliefs in the tolerance of charr to high water temperatures. Jobling *et al* (1998) mention that charr appears to be amongst the least resistant to high temperatures. However, Maitland and Campbell (1992) note that in North America, Arctic charr are known to live at summer water temperatures of 20˚C and in swift running water even as high as 23.8˚C. In regards to spawning temperatures, as different populations can spawn at varying times, winter spawning is seen at around 6 to 9˚C and in spring it is between 4 and 6˚C.

[1] http://www.snh.gov.uk/about-scotlands-nature/species/fish/freshwater-fish/charr/

In the British Isles, Arctic charr have the reputation of being found only in large deep oligotrophic lakes lying in glaciated basins. Although this is usually the case, many populations are also found in shallow, biologically rich habitats. Charr are not limited in their distribution to particularly cold lakes and appear to thrive in the same upper ranges as brown trout. Maitland and Campbell (1992) suggest that the pelagic behaviour of charr in lakes is probably due more to having to compete with the more aggressive Brown trout, other competitors and predator species than having to find deep cool water. However there is evidence that they are able to thrive relatively better than other salmonids in very cold conditions.

4.2.2 pH

The pH of the water in Loch Grannoch is a crucial factor to consider as it is widely accepted that acidification of the loch was the primary reason behind the loss of the original population of Arctic charr. The pH balance in the water is essential for fish metabolism. Stability of pH is critical because changes in pH initiate complex water quality changes which could cause harm to the fish, in particular their gills (Sæther & Siikavuopio[2]). Most salmonids can tolerate pH within the range of 5 to 9 and maximum productivity occurs between pH 6.5 and 8.5 (Jobling, 1994).

Jones *et al* (1987) investigated the response of charr to acid stress. Fish were exposed to pH 4.5 (Hydrogen Chloride) for two weeks and then returned to control conditions of pH 7.8. Reaction to the acid was evident: the charr were initially hyperactive but became hypoactive with continued exposure to the low pH conditions. Furthermore, feeding intensity and attraction to food extract were depressed throughout the exposure, but periods of partial recovery occurred (Jones *et al*, 1987).

After a review of literature, it appears that the tolerance of Arctic charr to low pH is incredibly variable between populations so genetic testing would be required to find suitable populations for the proposed translocation if the pH of Loch Grannoch was still low.

One of the most characteristic effects of acidification on fish populations is the failure of recruitment of new age classes into the population (Rosseland *et al*, 1980; Harvey, 1982). Early life stages of fish are more sensitive to acidification therefore there is a higher mortality rate in younger fish (Baker *et al,* 1996; Baker & Schofield, 1981). Being unable to increase the population size due to increased mortality at a young age is thought to be an important factor contributing to the extinction of fish populations (Jeffries *et al,* 2003) and indeed this is likely to have been the cause of the previous die out in Loch Grannoch. A shift in the age and size structure of a population is a resulting effect of decreased population which occurs when acidification increases the mortality of eggs and larvae. Populations suffering as a result of acidification are seen to have larger and older fish: older due to the recruitment failure of young and larger in size due to less competition for the available food (Lochhart & Lutz, 1977).

It has also been suggested that the reduced number of young fish could be the result of a reduction in egg deposition. This can result from disruption to the spawning behaviour or the reproductive physiology of maturing adults (Schofield, 1976). Sub lethal acid stress can also inhibit the growth and development of embryos and can cause malformation.

Although extinction of fish species due to fish mortality is normally linked to the younger stages of fish life, mortality in adults can also occur. When these cases have been

[2] https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjHwqqO6IXUAhWrAsAKHRmdABwQFggmMAA&url=http%3A%2F%2Fwww.northernperiphery.eu%2Ffiles%2Farchive%2FDownloads%2FProject_Publications%2F4%2FArctic%2520charr%2520%2520water%2520production%2520standard.doc&usg=AFQjCNGMI0y2Djp4iYpBqXkmoIjUg3MzSA

observed, they have been linked with the episodic changes in water quality during spring snow melt or heavy autumn rain. An indirect observation of this occurrence can be seen when there is a lack of older fish in the population being observed.

Aluminium concentration in water is inversely related to the pH, i.e. the concentration of aluminium increases as the pH of the water decreases (Sharma, 2003). Low pH, particularly below pH 4.5 (Walker *et al*., 2001) increases the solubility of metals and therefore leads to increased levels of toxic forms of aluminium (labile aluminium) being absorbed by fish. Salmonids are known to be highly sensitive to elevated levels of labile Al which affects gill function and ionic regulation (Kernan *et al*, 2010). This becomes the most important factor responsible for the death of fish in acidified areas (Walker *et al*, 2001). Baker and Schofield (1982) showed that Labile aluminium concentrations of 0.2 mg/L and higher resulted in reduced survival of young stages of brook trout at all pHs.

4.2.3 Dissolved oxygen

Arctic charr are amongst the most tolerant of salmonids to low oxygen levels, tolerating oxygen levels of 1.8 to 2.4 mg per litre (Baroudy, 1995; Baroudy & Elliott 1994) depending on temperature. The egg and alevins stages of the lifecycle are the least tolerant and the older life stages of parr and adults are more tolerant.

4.2.4 Spawning habitat

Arctic charr become sexually mature relativity early. Maturation is generally at 2+ (over two years old) for males and 3+ (over three years old) for females. It has been suggested that a fish of 250 g might be expected to produce 400-600 eggs. The eggs are amber in colour and comparatively large compared to eggs of other salmonids.

The spawning period of Arctic charr is variable and depends on the population. Spawning generally takes place in the autumn and early winter months between September and December (Walker, 2007). Other charr are known to spawn in the spring, e.g. Lake Windermere. Different populations in the same water body have been known to spawn at different times, e.g. in Lake Windermere, there are three different strains in the charr population which spawn in different locations and different depths. One strain migrates up an inflowing river and spawns in November and December, a second strain spawns in autumn in the shallow waters around the perimeter of the lake around 1-3 m deep and a third strain spawns in the spring (February to March) using much deeper water at some 20-30 m deep (Maitland & Campbell, 1992).

Reference material on the absolute requirements for charr spawning was limited however Maitland and Campbell (1992) suggest that spawning takes place over gravel and stones in fairly shallow water near the shore or on a submerged reef. Frost (1965) goes further to suggest that in shallow water spawning areas in Lake Windermere substrates were hard, with a range of particle sizes ranging from sand through to large stones or small boulders up to 25 cm in diameter. There is a consensus that spawning grounds may range from sand to small boulders and they generally would contain a lower percentage of fine sediments (silt). In practice it is difficult to identify exactly where charr will spawn as they will generally spawn where they are able to in a range of substrates.

4.2.5 Feeding

Arctic charr have a similar diet to brown trout, however when the two species occur together they tend to alter their feeding habits. Brown trout will prefer shallow water insect larvae and freshwater shrimp, while the Arctic charr will feed on zooplankton, small mussels and midge larvae (Maitland & Campbell, 1992). In a study of Loch Doon charr gut contents, Maitland *et al* (1991) found that prey items changed from benthic material in October,

February and April/May to almost 100% zooplankton in July. It was found that the benthic material consumed in October was of Planktonic origin.

Arctic charr often exclusively feed on zooplankton and are equipped to do so having well-developed gill rakers. These allow rapid feeding on plankton where it is abundant and easily taken in. Trout however need to use more energy to consume the plankter individually. This could be one reason behind Arctic charr outnumbering trout where they co-exist.

Certain populations of charr can be piscivorous (fish eating), and are known to eat Three-spined sticklebacks and their eggs. In one of the few sites in the British Isles where charr exist without trout, the charr are known to behave like trout, completely ignoring the plankton (Maitland, 2007).

5 EXAMINE AND MAP HABITATS TO ASCERTAIN WHETHER SUITABLE AND SUFFICIENT SPAWNING MATERIALS ARE PRESENT AND ACCESSIBLE

5.1 Historical spawning at Loch Grannoch

Charr spawn in areas where there are smaller substrates (see Section 4.2.4). As well as a relatively large area of shoreline, Loch Grannoch has three significant inflowing tributaries along the western shore: the Cuttie Shallow Burn, the Cuttiemore Burn and an un-named burn at Loch Grannoch Lodge. It is possible that the historical charr population may have used some or all of these areas for spawning. In factual terms almost nothing is known about the historical spawning at Loch Grannoch, the only information that was sourced is the quote below:

"…charrs of the deep Galloway lochs, which could only be secured in sufficient quantity for potting purposes when they came to the margins of gravel in the autumn months" (Service, 1902).

This comment would appear to suggest that charr in Galloway were probably autumn spawners and spawned along the shoreline in gravels and pebbles.

The consensus of experts at the Stakeholder meeting was that as the majority of charr populations are 'lake spawners' rather than 'river spawners', the Loch Grannoch population would indeed most likely have spawned in the shallows around the loch shore. Thus the habitat assessment work was concentrated around the perimeter of the loch as opposed to concentrating on the inflowing tributaries.

5.2 Present status of spawning material at Loch Grannoch

In early March 2017, GFT undertook a spawning habitat assessment around the shore of the loch to assess whether there would be sufficient good quality spawning substrates for any introduced charr to spawn in (see Section 4.2.4 for information on charr spawning habitat). The habitat surveys evaluated spawning habitats through looking at sediment sizes (based on the Wentworth (1922) scale and modified by the Scottish Fisheries Co-ordination Centre[3]) and using GFT experience of surveying other salmonid spawning habitat. Kayaks and a boat were used (Figure 2) to gain easier access the perimeter of the loch. Bathyscopes were used to assist in viewing substrates.

[3] http://www.sfcc.co.uk/assets/files/SFCC%20Habitat%20Training%20Manual.pdf

Figure 2: Setting off on the kayaks to carry out the spawning substrate survey

Results of the survey are presented in Figure 4. The majority of spawning material was located in the west and south of the margins of the loch where inflowing tributaries have created deltas and there are more bays compared to the east and north banks. Figure 3 shows an area of spawning material near the Cuttiemore Burn inflow. The eastern shore of the loch does have some areas where charr may spawn but in general the quantity of the spawning sized gravels is lower than that available on the western shore.

Figure 3: An area of spawning gravels near the Cuttiemore Burn inflow

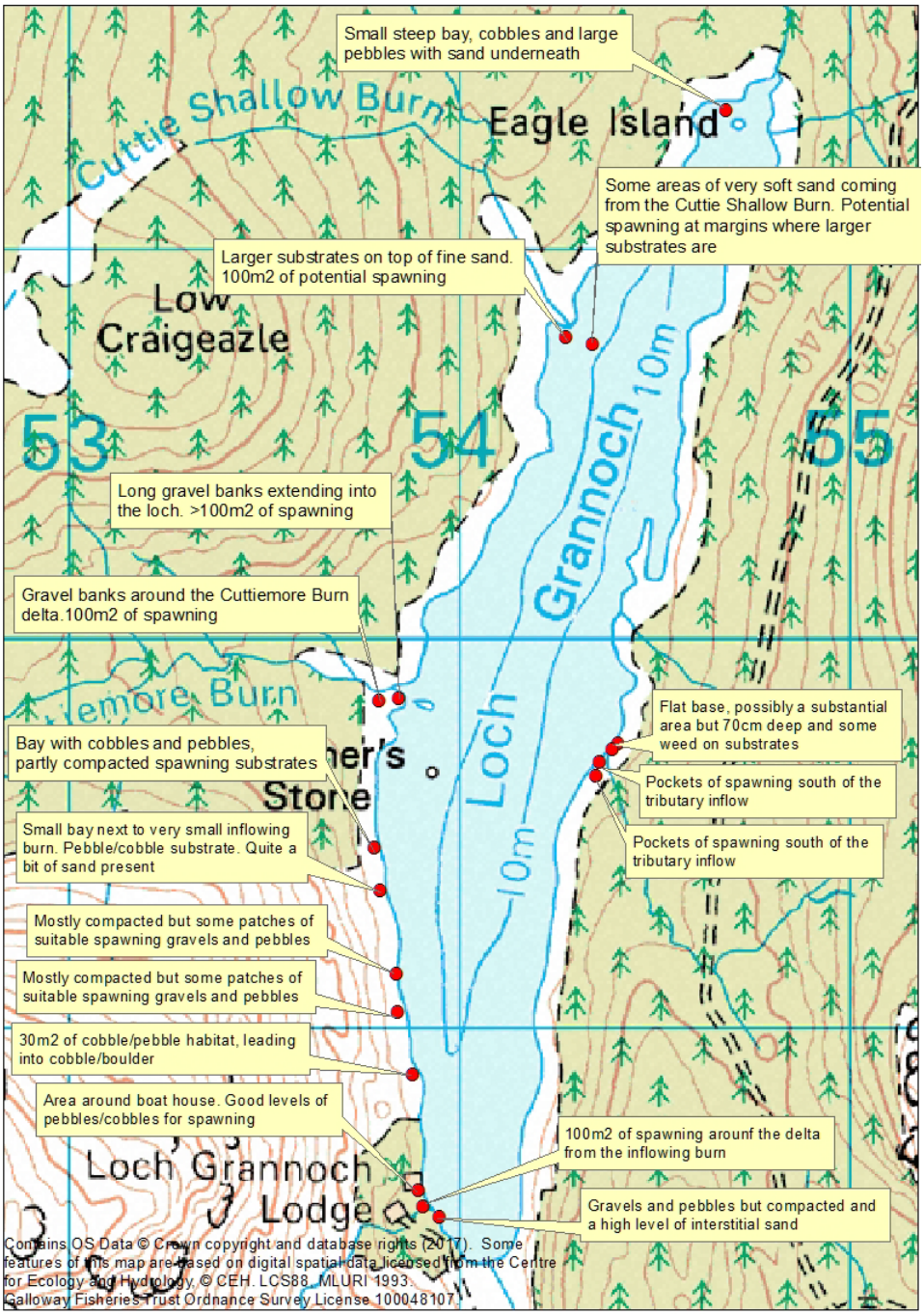

Figure 4: Showing the spawning areas recorded in the survey

Following the survey it was concluded that there are adequate areas of spawning habitat around Loch Grannoch although some areas are currently compacted. This is likely to be due to the amount of granite sand within the substrates that has been washed into the loch from the surrounding tributaries. This siltation may have worsened following the conifer afforestation of the basin surrounding the loch which required extensive drainage. It may also be that spawning beds were less compacted in the past because of the annual digging of redds by spawning charr.

In conclusion a lack of spawning material is not considered to be a limiting factor for any re-introduced population of charr.

6 RESEARCH AND DETERMINE WHETHER THE WATER (LOCH AND INFLOWING TRIBUTARIES) IS OF ADEQUATE QUALITY TO SUSTAIN ACRTIC CHARR EGGS AND ALEVINS. ESTABLISH A WATER QUALITY DATA BASELINE ACROSS THE ARCTIC CHARR SPAWNING PERIOD TO HATCH TIME

6.1 Researching water quality in Loch Grannoch and tributaries

Due to the importance of water quality in the survival of Arctic charr, the current status of the water quality at Loch Grannoch and its main tributaries needed to be assessed to determine whether the pH and labile aluminium levels were at acceptable levels.

Two different sampling techniques were used:

- Periodic spot sampling for detailed analysis of pH and labile aluminium, and
- Continual pH monitoring of the loch water over the spawning period.

6.1.1 Spot sampling

Periodic sampling work was undertaken which encompassed collecting water samples from the two main inflowing tributaries (Cuttiemore Burn and Cuttie Shallow Burn) and from the loch itself. After discussion at the Stakeholder meeting and with Marine Scotland Science the sampling strategy was agreed:

- Samples were to be taken monthly for a period of four months over the winter months, covering the time that charr eggs would be present in the gravels,
- Water samples would be taken at pre-existing historical sampling locations on the tributaries
- In the loch, a water sample would be taken from near the surface and one from >15 m deep. A specialised depth sampler was borrowed from Marine Scotland Science to complete this task.

As charr are known to dwell in deeper waters, particularly when cohabiting with a trout population, it was important to assess any differences there may be in deeper water as opposed to at the surface.

Figure 5: Taking a water sample and measuring the pH of the Cuttiemore Burn

A boat was launched each sampling day from the south bay near Loch Grannoch Lodge to

collect the following samples:

- Cuttiemore Burn
- Cuttie Shallow Burn
- Loch Grannoch c. 20 m deep - a depth gauge was used to locate the deepest part of the loch (c. 20.5 m in depth) where the depth water sampler (Figure 6) was deployed to collect a water sample from c.20 m depth
- Loch Grannoch at the surface

All samples were decanted into clean sample bottles. These four samples were sent monthly to the Marine Scotland Freshwater Fisheries Laboratory where they were fully analysed. Results are presented in Section 6.2.

Figure 6: The depth water sampler used to collect water from c.20 m deep for analysis

6.1.2 Establishing a water quality baseline

In order to obtain a true picture of the pH of the loch over the winter when it is likely to be at its lowest, a multi-parameter sonde (Figure 7) was used to constantly monitor the pH of the loch (this also collected the dissolved oxygen content of the water over the same timescale). To install the sonde a boat was used. A depth gauge was used to locate an area of water greater than 10 m deep where the sonde could be installed at a depth of 8 m. The sonde was tethered to the surface via two buoys and secured in location using a concrete block as an anchor.

The sonde constantly took readings of the water at 15 minute intervals and was installed from 09/12/2016 to 09/03/2017. Results are presented in Section 6.2.

Figure 7: The multi-parameter sonde

Figure 8: The sonde being installed at 8 m depth in Loch Grannoch

6.2 Results

6.2.1 Spot sampling results

The pH of the loch at the surface and at ~20 m depth are shown in Figure 9. It can be seen that on only one occasion was the pH of the loch water above pH 5, at 5.01 (December 2016). All other readings from the loch (surface and ~20 m depth) were below pH 5, with

pH 4.80 the lowest recorded.

The Cuttie Shallow and Cuttiemore Burns had pHs over 5, all towards the end of 2016. The highest pH recorded was in the Cuttiemore Burn in November 2016 where a pH of 5.59 was recorded. Readings in both burns in 2017 were all lower than pH 5, with the lowest recorded in the Cuttie Shallow Burn (pH 4.1) in January 2017.

In general it can be seen that the pH of the tributaries fluctuates more significantly than that of the loch where it is more stable.

The labile aluminium results show that the loch has much lower levels than those recorded in the 1980s and 90s (see Section 7.4) which was encouraging.

Sample location	Date	pH	Labile Aluminium (µgL)
Surface of Loch	09/12/16	5.01	54
Surface of Loch	10/01/17	4.92	32
Surface of Loch	07/02/17	4.80	45
Surface of Loch	09/03/17	4.81	54
Loch at ~20 m depth	09/12/16	4.97	40
Loch at ~20 m depth	10/01/17	4.89	31
Loch at ~20 m depth	07/02/17	4.81	44
Loch at ~20 m depth	09/03/17	4.86	67
Cuttie Shallow Burn	14/11/16	5.31	16
Cuttie Shallow Burn	09/12/16	4.90	11
Cuttie Shallow Burn	10/01/17	4.17	10
Cuttie Shallow Burn	07/02/17	4.26	6
Cuttie Shallow Burn	09/03/17	4.48	2
Cuttiemore Burn	14/11/16	5.59	31
Cuttiemore Burn	09/12/16	5.07	87
Cuttiemore Burn	10/01/17	4.60	52
Cuttiemore Burn	07/02/17	4.62	38
Cuttiemore Burn	09/03/17	4.86	47

Figure 9: Showing results of the spot sampling of Loch Grannoch and two main tributaries

6.2.2 Constant monitoring results from Loch Grannoch

Results from the sonde in Loch Grannoch over a three month period (Figure 10) showed a relatively stable loch pH. The lowest pH recorded was pH 4.57 on 13/12/16 whilst the highest was 4.9 on 07/02/17.

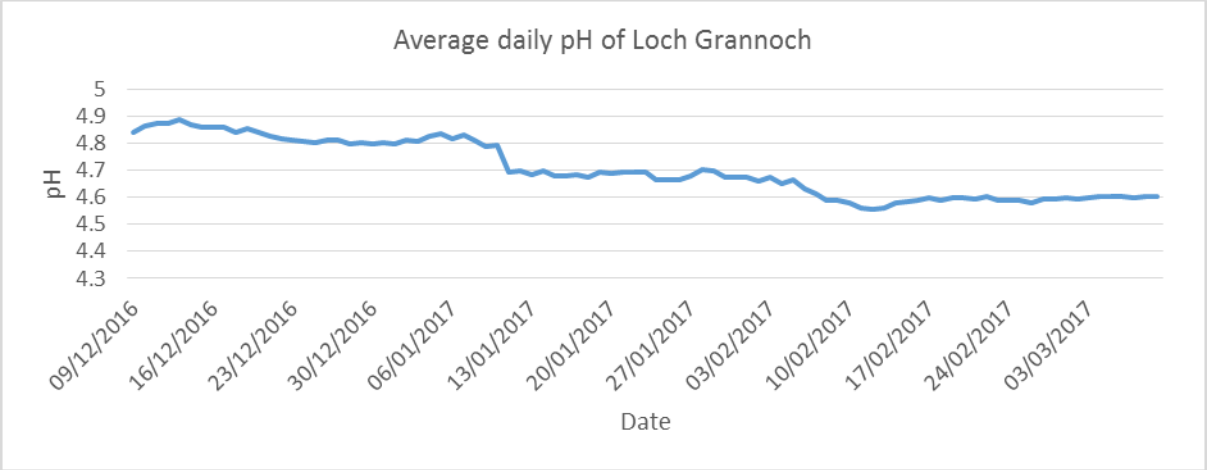

Figure 10: The average daily pH of Loch Grannoch between 09/12/2016 and 09/03/2017 at 8 m deep

6.2.3 Dissolved oxygen results

The sonde deployed in Loch Grannoch collected dissolved oxygen (DO) information as well as pH. Results presented in Figure 11 shows that the daily average DO in the loch ranged from 94.9 % saturation on 06/03/17 to 100.6 % saturation on 21/02/17 showing that there was sufficient oxygen available for adult charr in the water column. DO could not be collected from a depth greater than 10 m due to pressure constraints of the sonde.

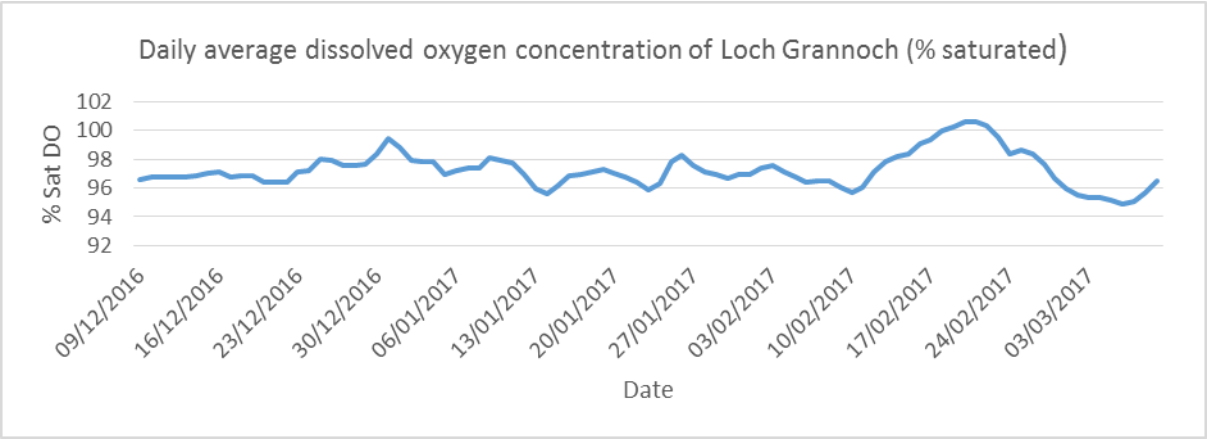

Figure 11: The pH of Loch Grannoch between 09/12/2016 and 09/03/2017

7 DETERMINE THE SUITABILITY OF THE LOCH TO SUPPORT A JUVENILE AND ADULT ARCTIC CHARR POPULATION

7.1 Other species and interactions

Arctic charr are known to show adverse effects if living in low densities. In several low productivity lakes in Iceland it has been found that introducing charr has reduced trout numbers (A. Ferguson, *pers. comm*.). However as charr are usually found cohabiting waterbodies with trout it has been suggested by experts that there is not likely to be a major impact on a healthy population of brown trout.

In the initial project specification it was planned to undertake plankton sampling in order to gauge if there was sufficient prey items in the loch to sustain a population of both charr and trout. After discussion with charr and trout experts it was decided that this would not significantly add to our knowledge or assist in any application made to re-introduce charr because a) there appears to be a relatively healthy population of trout in the loch, and b) charr and trout living together prey on different food items, thus there would be little competition for the food resource. Indeed the feeding habits of charr and brown trout in waterbodies containing only one of these fish species was shown by Nilsson (1963) to be very similar – prey items include Gammarus, Limnaea, Ephemeroptera nymphs, Trichoptera larvae, terrestrial insects, and small crustacean (Nilsson, 1963). However, when trout and charr occur together, which is common in the UK, trout typically occupy the littoral zone and feed on benthic invertebrates and surface insect whereas charr are predominantly zooplanktivorous and utilise the habitat between the profundal and littoral zones (Jensen *et al*, 2017).

7.2 Potential impacts

Maitland *et al* (2007) explained that the greatest threats to charr are pollution, eutrophication, acidification, afforestation, engineering, exploitation, aquaculture, climate change (particularly in lakes already affected by fish introductions and eutrophication) and the introduction of alien species.

In the case of a re-introduced charr population in Loch Grannoch, apart from acidification, few of the above threats would be likely to have an impact. Although unlikely, there is potential for the catchment to become more afforested in the future which would include new ground preparation and tree planting. The current main land use in the catchment of the loch is commercial forestry (mainly Sitka spruce plantations) but there are a range of ages and thus felling years. There is some open space and long term retention forestry within the catchment and it is anticipated that future replanting will include higher environmental standards such as larger riparian buffer zones which would imply that the impact of forestry activities in the future is likely to be lower than it has been.

7.3 Predator/prey interactions

There are few piscivorous birds based at Loch Grannoch therefore the likelihood of the re-introduced population being impacted by birds is low. Furthermore, charr are known to live at depth and therefore only diving birds would be likely to interact with a re-introduced charr population.

Loch Grannoch is not heavily fished by anglers. Usually Forest Enterprise holds up to six open angling days per year on the loch between July and September, and the anglers are usually concentrated around the south end, fishing in the shallower waters of the south bay. These anglers are targeting the abundant brown trout which appear to have flourished in the loch since numbers had been depressed by acidification in the 1970s and 80s. On

average 25 anglers per day attend these fishing events and catch, on average, 134 fish per angling day (between 2012 and 2016) (Archie McNellie *pers. comm*.). Angling is therefore unlikely to have a significant effect on an introduced charr population in the loch. In time, introduced charr could become a resource for angling, particularly specialised charr anglers, if the population was determined to be healthy enough.

7.4 Determine the suitability of the loch to support a juvenile and adult arctic charr population

Figure 12: Loch Grannoch looking north from the south

The labile aluminium results obtained during the spot sampling work show that levels are much lower than those recorded as part of the UK Upland Waters Monitoring Network in the 1980s and90s which is encouraging. Kernan *et al* (2010) has suggested that there is a more muted recovery of acidified waterbodies in afforested sites which is likely to be a reflection of the more acidic starting conditions. This appears to have been the case at Loch Grannoch.

The main chemical response to falling acid deposition is Loch Grannoch has been falling Labile Aluminum rather than rising pH (Kernen at al, 2010). Results from the spot samples show that the labile aluminium levels are much reduced from those observed in the 1980s. Labile aluminium levels in Loch Grannoch are shown in Figure 13 (taken from The United Kingdom Upland Waters Monitoring Network Data Report 2014-2015).

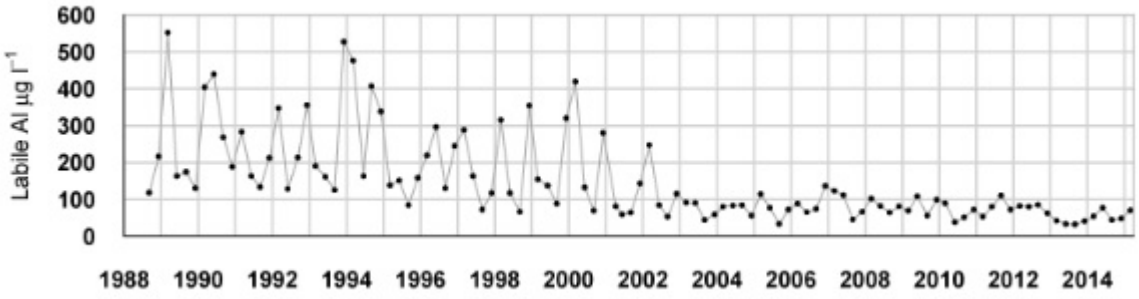

Figure 13: Labile aluminium levels in Loch Grannoch from 1988 to 2015 (taken from The

United Kingdom Upland Waters Monitoring Network Data Report 2014-2015)

In terms of pH, the results obtained from the spot sampling work show that levels are somewhat improved than those recorded as part of the UK Upland Waters Monitoring Network in the 1980s and 90s (Figure 14). Although the results since 1988 show an improving trend, the pH has not recovered as quickly as was hoped. All but one result from the spot sampling recorded a loch pH of below pH 5.

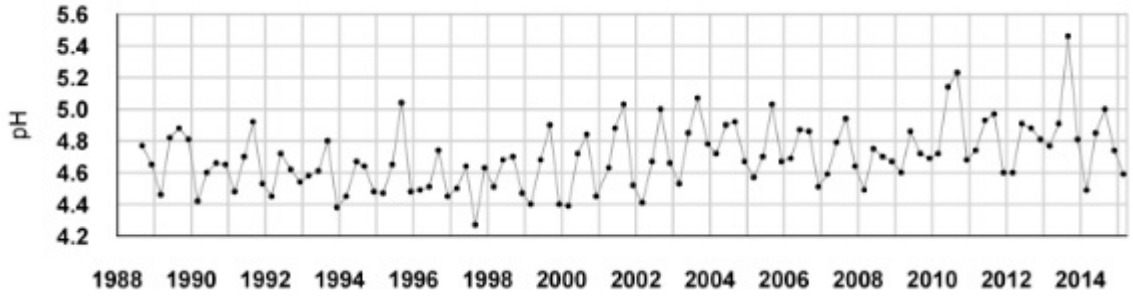

Figure 14: The pH of in Loch Grannoch from 1988 to 2015 (taken from The United Kingdom Upland Waters Monitoring Network Data Report 2014-2015)

After discussion with experts it was concluded that the loch could support charr in physical terms but the pH of the water is not yet suitable for the re-introduction of charr. Maitland (2003) suggested that the water should be consistently above pH 5 before reintroduction was considered.

8 INVESTIGATE OTHER RELEVANT ARCTIC CHARR WORK SUCH AS RE-INTRODUCTIONS AND REARING PROGRAMMES; ENGAGE WITH EXPERTS IN THE FIELD, POTENTIALLY ESTABLISHING A LEVEL OF PARTNERSHIP WORKING AND/OR RESEARCH OPPORTUNITIES

8.1 Other Arctic charr re-introductions

Charr were translocated from Loch Doon to the Talla and Megget Reservoirs (River Tweed catchment) in the early 1990s in order to establish genetic refuge sites because Loch Doon charr were, and potentially still are, threatened by acidification. The translocation involved rearing of eggs stripped from adult fish the previous year. A survey carried out in 2010 found that the translocated charr populations had established at these sites (SNH, 2011).

There was a recent attempt at translocating charr from Lake Windermere to Grimwith Reservoir in Yorkshire. Eggs were stripped from an autumn spawning population in the south basin and were incubated in a hatchery and introduced as fingerings between 1989 and 1991. Gill netting afterwards suggested reasonable initial survival however no further monitoring was carried out. Following a sharp decline in a population of river spawning charr in Ennerdale Water in the Lake District, because of forestry and acidification impacts, charr were raised at Kielder hatchery and stocked into Kielder Reservoir by the Environment Agency. This now an 'ark site' for the Ennerdale population. Due to a lack of resources, there hasn't been a follow up survey to assess the success of this programme (Richard Bond, *pers. comm*.)

Wales has seen a number of translocations of Arctic charr. Between 1977 and 1982 Arctic charr were translocated to lake Ffynnon Llugwy primarily from the charr population in Llyn Pardarn. Surveys conducted in 1982 found a spawning population had become established. Further surveys in 2004 showed a healthy spawning population still present in the lake. In Lake Llyn Diwaunedd a spawning population of charr was discovered in the early 1990s however it is thought that charr were not native to this lake. This indicated a translocation may have taken place however the timing and the source of fish are uncertain (Maitland, *et al* 2007).

Accidental translocations have occurred in the past due to connections created by hydropower schemes. For example, charr were pumped up several hundred meters from Loch Awe into Cruachan Reservoir (Maitland, *et al* 2007).

8.2 Engage with experts in the field

From the beginning of this project GFT has been in touch with experts in the charr field, indeed the principal researchers were all invited to the Stakeholder meeting (i.e. Professor Peter Maitland, Alexander Lyle, Professor Colin Adams and Professor Colin Bean). Since we do not currently have charr in Dumfries and Galloway, GFT was keen to engage with these experts in order to gain knowledge on charr prior to any re-introduction work. GFT was also eager to hear their views on the aims of the project and gain their support for the re-introduction work, if it was deemed feasible.

Due to charr being 'poor cousins' of the most recognisable salmonids, the salmon and the trout, there is much less information available on distinct populations of charr in Scotland. Since we were most concerned with water quality and charr, we had to seek out those who held any information on water quality in locations which also held extant populations of charr.

In terms of research, the University of Glasgow, Professor Colin Adams in particular, carry out various research on charr at different times. It is likely that if charr are re-introduced to

Loch Grannoch then there would be research opportunities, perhaps as post graduate projects. Professor Paulo Prodohl and Queen's University, in conjunction with Professor Andy Ferguson, have indicated that they would be very interested in the genetic evolution of an introduced charr population.

9 INVESTIGATE AND IDENTIFY PRACTICAL METHODS OF UNDERTAKING THE ARCTIC CHARR RE-INTRODUCTION WORK INCLUDING ASSESSING ACCESS ISSUES

One of the most positive areas of management for endangered stocks of fish lies in the establishment of new populations – either to replace those which have become extinct or to provide an additional safeguard for valuable stocks in threatened waters (Maitland, 1985).

Stock may be transferred as eggs, fry, juveniles or adults. Adult translocation, if the health of the donor stock allowed this (Maitland *et al*, 1991), would allow nature to take its course. However the removal of adults could pose a threat to the parent stock (Maitland *et al,* 2007) so the health of the donor population would have to be assessed if unknown. It would be very difficult to get a wide range of genetic populations without carrying out several translocations from different populations across the UK. Transferring eggs, fry or juveniles does allow increased choice from a wide range of charr populations. These would be chosen for their genetic characteristics by sampling known populations which have shown a tolerance to acidic waters to ensure the best possible chance at survival in Loch Grannoch.

With regards to eggs there are questions surrounding the best method of rearing to give the greatest survival. One method would be to raise eggs and feed the alevins past their most sensitive stages before releasing them. However by feeding on the alevins you risk dampening their natural feeding instinct and increasing their domestication. It also reduces their predator avoidance as they will be attuned to feeding at the surface which is not natural. Alternatively they could be released straight after hatching, however this exposes the alevins to acidic water at a particularly sensitive life stage. Adult broodstock could either be returned safely to their original waterbody to spawn in future years however depending on the parent stock, adults can also be moved (Maitland *et al*, 1991).

Creating redds in suitable spawning locations and transferring fertilised eggs is another method which could be monitored and this would provide an insight into the ability of the charr to become a spawning population.

Alevins and adult charr sourced from Loch Doon have been successfully translocated into Megget and Talla Reservoirs (Maitland *et al*, 1991; Maitland & Lyle, 2003). It is therefore considered that a transfer of both adult and juvenile charr into Loch Grannoch would be most appropriate. This would avoid the transfer of eggs and alevins which are the most sensitive life stages. Stocking should be carried out over a period of at least two years. It has been suggested by Maitland and Lyle (2003) that around 30 female and 30 male adult charr should be transferred along with 50 to 100 juvenile charr.

Obtaining the stock to transfer would entail netting adult charr in shallow water from the source waterbody(ies) during the spawning period. Juvenile fish may be harder to source, depending on which donor populations were selected, however rearing eggs stripped from adults and rearing them through to the juvenile stage would be an option.

10 INVESTIGATE AND IDENTIFY POTENTIAL SUITABLE SOURCE (DONOR) POPULATIONS OF ARCTIC CHARR WITH CONSIDERATION GIVEN TO GENETICS

In order to identify suitable donor population/s of charr it was required to look at the genetics of potentially suitable populations. After consultation with experts it was decided that because of the historical low pH of Loch Grannoch, it was required to identify charr populations in other waterbodies which also had a lower pH. After this was done it would be necessary to ascertain whether those charr populations were in a favourable state, i.e. healthy enough to remove charr for the translocation work.

10.1 Potential donor populations of charr

In order to establish which charr containing waterbodies were of lower pH, numerous people were contacted to obtain water quality data and charr population information. It proved to be extremely difficult to obtain up to date pH data from most waterbodies supporting charr, as many of these lochs and lakes are not periodically monitored. Certainly in Scotland, many charr bearing lochs are relatively inaccessible and are not monitored for either the pH or the current status of their charr population.

SEPA were able to provide recent water quality information on some lochs that had been provisionally identified by experts as likely candidates for having a low pH. In addition, some recent water quality information was obtained from researchers involved in the UK Upland Waters Monitoring Network[4]. The SNH Standing Waters Database[5] was queried using information supplied by Professor Colin Adams on charr holding lochs and this gave some pH data collected from between 25 to 30 years ago. Data available is shown in Figure 15 below.

Charr loch	pH	Date of sampling
Loch Suainabheal	6.2	Recent SEPA reading
Loch nan Geireann	6.4	Recent SEPA reading
Loch Naver	6.48	Recent SEPA reading
Loch Awe	6.779	Recent SEPA reading
Loch Lubnaig	6.83	Recent SEPA reading
Loch Tarff	6.856	Recent SEPA reading
Loch an t-Seilich	7.08	1995
Loch Einich	6.42	Recent SEPA reading
Loch Lee	6.67	Recent SEPA reading
Loch an Duin	6.99	2002
Loch an t-Seilich	6.89	Recent SEPA reading
Loch Avon	5.42	Average of 6 readings from 1979 to 1993
Loch Bhrodainn	6.91	Average of 2 readings from 1990 to 2002
Loch Builg	7.21	Average of 3 readings from 1980 to 2002
Loch Callater	6.74	Average of 6 readings from 1980 to 1993
Loch Einich	6.32	Average of 7 readings from 1955 to 1993
Loch Bhrodainn	6.61	1990
Loch Callater	6.83	1988

[4] http://awmn.defra.gov.uk/

[5] http://gateway.snh.gov.uk/pls/apex_cagdb2/f?p=111:1000::::::

Loch Avon	6.3	1996
Loch An Duin	6.74	1995
Loch An Duin, Lewis	7	1995
Loch an Duin	6.71	1995
Loch Bhrodain	6.82	1995
Lochan a Choire	4.7	1987
Loch a Mhuilinn	6.6	1989
Lochan Dubh	4.8	1987
Loch Uaine	6.27	1993
Dubh Loch	4.58	1898
Loch a Chroisg	6.15	1990
Loch an Easain Uaine	8.7	1988
Loch a Choire	4.7	1988
Lochan na Seilg	6.76	1988
Loch Scamadal	5.1	1989
Lochan Uaine	5.55	1988
Loch an Duin	6.74	1995
Loch nan Ealachan	5.53	1990
Loch Fada	7.02	1990
Loch na Dail	5.81	1990
Loch Uidh Tarrraigean	6.49	1990
Loch Bad a Ghaill	6.39	1990
Loch Eilenach	7.06	1988

Figure 15: Showing available pH data from some known charr lochs in Scotland

It was concluded that there are not many known low pH lochs with a population of Arctic charr present. Indeed much of the available data is almost 30 years old so does not provide an accurate picture of the pH of these (likely extant) charr waterbodies.

10.2 Considering genetics

At the same time as looking into potential donor populations of charr, it was required to ascertain from which populations existing genetic samples were available for analysis.

The analysis was to be carried out by Professor Paulo Prodohl at Queen's University Belfast using Arctic charr mitochondrial DNA markers already held by the University. To attempt to answer the question of which donor population(s) would be the most suitable for translocation there needed to be >20 specimens from as many waterbodies as possible. This initial screening would identify potential donor populations however a Risk Assessment would also be required to assess whether the source(s) were healthy enough to act as donors. In order to make this assessment between 30 to 50 individual samples from potential source populations would need to be screened to identify how viable they were in terms of genetic diversity. It is desirable to ensure maximum genetic diversity of donor population/s of charr that are introduced into Loch Grannoch because over time natural selection will act on genetic variation so the best genes for coping with the Loch Grannoch environment are retained in the reintroduced population. This differs from previous practices which advised to simply use the geographically closest population, but which may not provide the most suitable genetic characteristics for the local environment.

For this screening to take place it was required to identify individuals and organisations that

held physical samples of charr genetic material and which of these were available for analysis.

All fisheries trusts in Scotland were contacted and asked if they held any charr genetic material. Charr experts were also contacted as well as Marine Scotland Science, the Centre of Ecology and Hydrology, the University of the Highlands and Islands and the Environment Agency. Glasgow University held the greatest number of samples from different populations, with Marine Scotland Science and the University of the Highlands and Islands also holding material from several populations of interest (see Figure 14). Agreement was reached and permission was granted from these three organisations to provide their samples for genetic analysis.

In early spring 2017 Queen's University provided information on what was needed in terms of samples and how long analysis would take. Genetic analysis of these samples did not actually take place because discussion on the final pH analysis of the loch water had taken precedence.

Funds allocated to cover this important genetic analysis were therefore reallocated within the Galloway Glens project.

11 IDENTIFY THE NECESSARY LICENCES AND ENGAGE WITH RELEVANT LICENCING AGENCIES AND ENVIRONMENTAL BODIES INCLUDING THE SCOTTISH GOVERNMENT, WITH REFERENCE TO THE SCOTTISH CODE FOR TRANSLOCATIONS AND CORRESPONDING TRANSLOCATION PROJECT FORM

In order to protect native biodiversity from the consequences of introductions of non-native species of fish, legislation came into force on August 2008 regulating the introduction (i.e. stocking) of all species of freshwater fish within Scotland. The legislation makes it an offence for any person to intentionally introduce any live fish or spawn of any fish into inland waters, or possess such with the intention of introduction without previous written agreement (i.e. a licence) from the appropriate authority[6].

In addition to licencing requirements, GFT was advised by SNH to refer to and fill in a 'Translocation Project Form'. This form is part of the Scottish Code for Conservation Translocations which provides best practice guidelines for conservation translocations[7]. A conservation translocation is the deliberate movement and release of living organisms for conservation purposes which includes: reinforcement (adding to an existing population), reintroduction (restoring a species to parts of its natural range from which it has been lost), and conservation introduction (establishing new populations of a species out with its natural range).

The Translocation Project Form was partially completed with information gained whilst the project was running. If the outcome of the project was favourable and Loch Grannoch had been suitable for the introduction of Arctic charr then the fully complete Translocation Project Form would have been submitted to SNH for approval.

[6] http://www.gov.scot/Topics/marine/Licensing/fishintros

[7] http://www.snh.org.uk/pdfs/publications/wildlife/CodeTranslocationsGuidelines.pdf

12 DETERMINE AND DESCRIBE, WITH EVIDENCE, WHETHER THE ARCTIC CHARR TRANSLOCATION PROJECT IS DEEMED FEASIBLE AT LOCH GRANNOCH

12.1 Is it appropriate to re-introduce Arctic charr into Loch Grannoch?

With consideration to all information and data collected over the course of this project, along with full consideration of expert opinion, unfortunately Loch Grannoch was deemed unsuitable for the re-introduction of Arctic charr at this time.

12.2 Reasoning for the decision

The reasons for the decision not to re-introduce Arctic charr into Loch Grannoch at this time are:

- The pH of the loch was still more acidic than had been anticipated. Because of the apparent healthy populations of trout in the loch and the recovery of other upland lochs in Galloway it had been assumed that the pH was likely to have recovered to levels over pH 5. Unfortunately when measured over the sensitive winter and early spring period when charr eggs would be in gravels, the pH of the loch remained just below 5.
- The historical Loch Grannoch charr population is widely accepted to have died out because of the effects of acidification. Expert opinion has strongly suggested that because the pH of the loch has still not reached acceptable levels for the re-introduction of charr it is, at the moment, too low for there to be a realistic chance of successful survival of a re-introduced population.

GFT does believe that the loch will continue to recover. The lowest pHs recorded in the spot sampling are not too far away from what might be considered acceptable (pH 5). When the pH of the loch consistently recorded above 5 then the information contained within this report can be used as a basis for future introduction work.

13 APPENDIX 1: STAKEHOLDER MEETING ATTENDEES, PRESENTATION AND MAIN OUTCOMES

13.1 Invitees

Alexander Lyle, Alex Lyle Projects
Alisdair MacDonald, Marine Scotland Science
Alison Bell, SEPA
Alistair McCartney, Marine Scotland Science
Andrew Jarrott, Forest Enterprise
Andy Gowans, Environment Agency
Archie McNellie, Forest Enterprise
Duncan Baillie, local angler
Emily Taylor, Crichton Carbon Centre/Biosphere
Ian Winfield, CEH
James Ingall, Kirkcudbrightshire Dee District Salmon Fishery Board
John Gorman, SEPA
Karen Morley, Dumfries and Galloway Council/Galloway Glens
McNabb Laurie, Dumfries and Galloway Council/Galloway Glens
Peter Norman, Dumfries and Galloway Council Biodiversity Officer
Professor Andy Ferguson, Queen's University Belfast
Professor Colin Adams, University of Glasgow
Professor Colin Bean, SNH
Professor Paulo Prodohl, Queen's University Belfast
Professor Peter Maitland, Fish Conservation Centre
Robin Ade, local angler
Stuart Ferns, Scottish Power

13.2 Attendees

Alisdair MacDonald, Marine Scotland Science
Alison Bell, SEPA
Alistair McCartney, Marine Scotland Science
Duncan Baillie, local angler
Emily Taylor, Crichton Carbon Centre/Biosphere
Ian Winfield, CEH
Jackie Graham, GFT
John Gorman, SEPA
Karen Morley, Dumfries and Galloway Council/Galloway Glens
Peter Norman, Dumfries and Galloway Council Biodiversity Officer
Professor Andy Ferguson, Queen's University Belfast
Professor Colin Adams, University of Glasgow
Professor Colin Bean, SNH
Professor Paulo Prodohl, Queen's University Belfast
Victoria Semple, GFT

13.3 Main outcomes of meeting

- Water quality is important, however habitat quality is also important in order to sustain a population of charr. Water quality of the loch itself is key. Tributaries are important but the loch is more so as this is where the charr are most likely to spawn and live all the time. Access to water quality data was discussed and data sharing from Ian Winfield, Colin Bean, Colin Adams, Alistair McCartney and Alison Bell was agreed.

- The reason for the charr extinction was discussed – the consensus and the same as the widely accepted reason –they died out because of acidification. A discussion was held surrounding time frames of extinction and reasons. It was agreed that habitat must be assessed as it may be more important than previously thought.

- It was discussed and agreed that any future donor populations should be selected from lochs of similar conditions and pH ranges. These areas needed to be identified as well as individuals/organisations with which to engage with.

- An intermediate study using egg boxes to determine the survival of charr at its most sensitive life stage was suggested. Important that this is explored further.

- Eggs or adults to be used for re-introduction was discussed.

- Logistics and resources would need to be considered when determining donor populations as spawning times can vary widely between charr waterbodies.

- Future monitoring post re-introduction was discussed. The need for identifying future partnerships/collaborations/research work was highlighted and this may fit into the project legacy. University researchers/PhDs to carry out monitoring was suggested.

- The historical population of charr in Loch Dungeon was discussed – relatively recent anecdotal evidence had suggested there may still be a remnant population of charr there. If this population is confirmed then could these be a potential donor or would numbers be too sparse? Using eDNA to determine presence/absence in Loch Dungeon was discussed.

- Environmental matching most suitable way of determining which donor population to use. We have nothing to use for genetic matching at Loch Grannoch and common ancestry is not always reliable.

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