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FEASIBILITY STUDY FOR THE ASSESSMENT OF ARCTIC CHARR SPAWNING GROUNDS IN WINDERMERE

FINAL REPORT

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EXECUTIVE SUMMARY

1. The Arctic charr (*Salvelinus alpinus*) is widely recognised as a fish species of extremely high biodiversity conservation value in the U.K. and has recently been added to the U.K. List of Priority Species and Habitats of the U.K. Biodiversity Action Plan. However, since the early 1990s concerns have been expressed for the autumn- and spring-spawning populations of this environmentally intolerant species in the north and south basins of Windermere, which are also lightly exploited by a high profile, semi-commercial fishery. Significant local pressures include eutrophication, which in addition to generating deepwater anoxia is also known to influence habitat conditions in the littoral zone where some Arctic charr spawn, lake warming, and a fundamentally changed fish community in which the introduced roach (*Rutilus rutilus*) is now abundant in both inshore and offshore habitats. Furthermore, symptoms of eutrophication have recently increased again in the south basin of the lake and this development has been accompanied by recent and marked Arctic charr declines in both basins.

2. The objectives of the present project were to conduct a feasibility study for the assessment of the current locations and characteristics of Arctic charr spawning grounds in Windermere and to assist the Environment Agency in the development of an appropriate project plan with which to pursue funding.

3. Extensive searching confirmed that the only published account of the spawning grounds of Arctic charr in Windermere with any level of detail is that of Frost (1965), although even this publication only contains information on only three of the 13 known or assumed spawning

grounds. Although more relevant information may exist within Frost's unpublished notebooks held within unpublished Freshwater Biological Association information holdings, the volume of this material was found to be such that its examination was far beyond the resources of the present feasibility study.

4. Literature searches and national and international dialogues revealed a range of potential approaches to the investigation of Arctic charr spawning grounds in Windermere including biological (netting, egg collecting), visual (underwater video cameras deployed on a Remotely Operated Vehicle, motion-triggered underwater still cameras), tracking, and hydroacoustic (standard fish split-beam, DIDSON acoustic camera, single-beam, multi-beam) techniques.

5. A recommended project plan, with an indicative total cost of £125k over a variable number of years, was proposed for use by the Environment Agency as a basis from which to pursue funding. This recommended project plan incorporates explicit or implicit involvement by a number of bodies including Centre for Ecology & Hydrology, Durham University, Environment Agency, Freshwater Biological Association, Lancaster University and National Oceanography Centre Southampton. Each of these organisations can make unique contributions to the overall body of work. It is emphasised here that overall project management of such a diverse range of activities would be challenging and so should such work proceed it is important that appropriate Environment Agency staff are themselves given sufficient resources to play a full role in the work

CHAPTER 1 INTRODUCTION

1.1 Background

The Arctic charr (*Salvelinus alpinus*) is widely recognised as a fish species of extremely high biodiversity conservation value in the U.K. and has recently been added to the U.K. List of Priority Species and Habitats of the U.K. Biodiversity Action Plan (www.ukbap.org.uk). At the same time, it is one of the very few lake fish species in the U.K. to be exploited on a commercial or semi-commercial basis. In Windermere, where lightly exploited populations of autumn- and spring-spawning Arctic charr exist in both the north and south basins, concerns for this environmentally intolerant species have been expressed since the early 1990s (e.g. Mills *et al.*, 1990). Significant local pressures include eutrophication, which in addition to generating deepwater anoxia is also known to influence habitat conditions in the littoral zone (Parker & Maberly, 2000) where some Arctic charr spawn, lake warming (Winfield *et al.*, 2008a), and a fundamentally changed fish community in which the introduced roach (*Rutilus rutilus*) is now abundant in both inshore and offshore habitats (Winfield *et al.*, 2008b). Furthermore, symptoms of eutrophication have recently increased again in the south basin of the lake (Maberly *et al.*, 2007) and this development has been accompanied by recent and marked Arctic charr declines in both basins (Winfield *et al.*, 2008c).

Environmental conditions for Arctic charr in Windermere have recently been assessed in terms of oxygen availability (Jones *et al.*, 2008), but the conditions of their nine known or assumed autumn- and four known or assumed spring-spawning grounds have not been investigated since three of them in the north basin (Holbeck Point, Low Wray Bay, and Red Nab) were described in detail during the 1960s by Frost (1965). In the meantime, geographical positioning and underwater technology have developed such that examinations of shallow-water spawning grounds of other rare fish populations have been carried out using underwater video and hydroacoustics (e.g. Winfield *et al.*, 2007; Coyle & Adams, 2008).

Given the above situation and a continued development of shoreline areas (jetties, boathouses, etc.), it is now highly desirable to undertake a robust assessment of the current locations and characteristics of Arctic charr spawning grounds in Windermere. Furthermore, the scale, complexity and sometimes considerable water depths involved in these issues are such that a feasibility study is an appropriate first step.

1.2 Objectives

To conduct a feasibility study for the assessment of the current locations and characteristics of Arctic charr spawning grounds in Windermere and to assist the Environment Agency in the development of an appropriate project plan with which to pursue funding.

CHAPTER 2 REVIEW OF EXISTING INFORMATION SPECIFIC TO WINDERMERE

2.1 Introduction

The Arctic charr populations of Windermere have been studied with varying intensity since the 1940s, resulting in the production of numerous scientific publications and reports. However, the majority of these investigations have apparently focussed on aspects of population biology as summarised in Winfield *et al.* (2008b) and Winfield *et al.* (2008c) and so are of limited relevance to the present project. Only very limited studies have been made on the nine known or assumed autumn- and four known or assumed spring-spawning grounds originally described by Frost (1965).

The objective of this part of the present project was to collate and review existing information on Arctic charr spawning grounds in Windermere, including both published and unpublished material.

2.2 Methods

Although the relevant published literature was believed to be already well known to the authors, a literature search using the keywords ‘Salvelinus’ and ‘Windermere’ was performed using ISI Web of Knowledge (http://wok.mimas.ac.uk) during January 2009. The titles and abstracts (where available) of a resulting 21 articles were examined online, with several also read in full.

In addition, unpublished information was pursued by a request on 1 December 2008 to the Director of the Freshwater Biological Association (FBA, www.fba.org.uk) for access to Frost's unpublished notebooks and any other materials which may contain further historical information concerning the spawning grounds of Arctic charr in Windermere. This request was swiftly approved on 2 December 2008 when appropriate metadata were provided on relevant FBA information holdings.

2.3 Results

Detailed reading of the published literature on the Arctic charr populations of Windermere confirmed what was already suspected, i.e. that most historical and recent investigations have focussed on population biology and contain little information on spawning grounds. For example, Kipling (1984) considers a monitoring programme for local long-term population biology and this work has been continued and expanded by Winfield *et al.* (2008b) and aspects of it put into a wider U.K. context by Maitland *et al.* (2007).

In terms of information specifically on spawning Arctic charr, Frost (1963) deals primarily with the homing behaviour of spawners rather than spawning grounds themselves. This leaves Frost (1965) as the only scientific publication which deals in any detail with the locations and characteristics of Arctic charr spawning grounds in Windermere.

Frost (1965) documents nine known or assumed autumn- and four known or assumed spring-spawning grounds for Arctic charr in Windermere. These are shown in Figure 1 of Frost

(1965) which is reproduced here as Fig. 1. A redrawn version of this figure has subsequently appeared in a number of unpublished studies including Baroudy (1993) and Elliott (1993) and is reproduced here as Fig. 2. Although the documentation of these 13 sites is commonly taken to be firm evidence that Arctic charr do indeed spawn at them, the text of Frost (1965) actually states ‘There are several sites in Windermere where it is known or assumed that the autumn and spring spawning charr breed (figure 1), but detailed investigation of the breeding fish and their habits has been confined to three lake sites, all in the north basin of Windermere.’. The text goes on to identify these three investigated lake sites as the autumn sites of Low Wray Bay and Red Nab on the west shore and the spring site of Holbeck Point on the east shore. Sampling was also undertaken at the river autumn site of Purdom’s Dub in the River Brathay of the north basin. Thus, only three of the 13 spawning sites have been identified as such on the basis of scientific sampling, with the rest presumably having been identified exclusively on the basis of indigenous knowledge.

Frost (1965) goes on to describe the key features of the spawning grounds, noting that all of the lake autumn sites are in shallow water of 1 to 3 m and range considerably in size with those at Low Wray Bay and Red Nab being comparatively large with the latter being approximately 90 m by 150 m in extent. The lake bottom is described as being always stony, but including varying proportions of sand, pea-sized (approximately 6 mm) gravel (approximately 25 mm), walnut-sized (approximately 25 by 50 mm) stones, fist-sized (approximately 50 by 100 mm) stones and head-sized (approximately 200 to 250 mm) stones. A brief description is also given of the single river autumn site. In contrast, the lake spring grounds as described as all ‘apparently’ being in deep water, although specific information is only given for Holbeck Point. This site is described as being at a depth of 12 to 30 m at a distance of 35 to 45 m offshore. A ‘tongue’ of gravel 14 to 16 m wide extends from a depth of 9.5 to 28 m and is flanked on one side by grit and on the other by mud. The lake bottom consists mostly of head- and fist-sized stones, pea-sized gravel and some grit. Frost (*op. cit.*) notes that Arctic charr eggs are most commonly found among walnut-sized stones (approximately 25 by 50 mm) and when these are mixed with larger stones, but they are rarely found among pea-sized stones and gravel.

In terms of the unpublished literature, the PhD thesis of Baroudy (1993) contains no further information on spawning grounds over that already known from Frost (1965). However, the more recent PhD thesis of Corrigan (2009) included sampling on a number of spawning grounds and thus gives information on their current use. On the basis of netting undertaken in 2004, 2005 and 2006, Corrigan (2009) found spawning Arctic charr in the north basin at Holbeck Point, High Wray Bay and the previously undocumented site of Rough Holme, while in the south basin she recorded fish at Rawlinson Nab, Grass Holme and Sewage Works. In addition within the unpublished literature, the continuation of the long-term monitoring programme of Kipling (1984) by Elliott (1993) and Winfield *et al.* (2008c) has consistently found spawning Arctic charr at the north basin site of North Thompson Holme.

Although access was swiftly granted to relevant unpublished FBA information holdings, metadata presented in Table 1 revealed that this comprised very substantial amounts of correspondence, papers and records together with approximately 300 notebooks. Examination of this volume of material was far beyond the resources of the present feasibility study and so this activity could not be undertaken as planned.

2.4 Discussion

The present extensive searching has confirmed that the only published account of the spawning grounds of Arctic charr in Windermere with any level of detail is that of Frost (1965), although even this publication only contains information on four of the nine known spawning grounds. Although more relevant information may exist within Frost's unpublished notebooks held within unpublished FBA information holdings, the volume of this material was found to be such that its examination was far beyond the resources of the present feasibility study. It would however be desirable to pursue this potential source of detailed information in a subsequent project because such a course of action may increase our understanding of the significance of changes which have already occurred, or which may occur in the near future.

The present findings do, however, give at least a basis on which to take forward the development of the full project plan. Furthermore, it is also encouraging that of the nine autumn- and four spring-spawning grounds described in the published literature, more recent and currently unpublished studies have found evidence of continued spawning at six of these locations.

CHAPTER 3 REVIEW OF TECHNIQUES FOR THE DESCRIPTION OF SPAWNING GROUNDS

3.1 Introduction

Although as confirmed by the findings of Chapter 2 little research has been undertaken on the spawning grounds of Arctic charr in Windermere in recent years, there has been increasing activity in this field for this and similar species in other large lakes. For example, geographical positioning and underwater technology have developed such that examinations of shallow-water spawning grounds of coregonid populations have been carried out using underwater video and hydroacoustics (e.g. Winfield *et al.*, 2007; Coyle & Adams, 2008).

The objective of this part of the present project was to collate and review techniques previously used or currently in use elsewhere which may be appropriate to the description of Arctic charr spawning grounds in Windermere, including both published and unpublished material.

3.2 Methods

A number of literature searches using combinations of the keywords 'fish', 'ground*', 'lake', 'observation*', 'ROV', 'Salvelinus' and 'spawn*' was performed using ISI Web of Knowledge (http://wok.mimas.ac.uk) during January 2009. The titles and abstracts (where available) of a resulting approximately 1,000 articles were examined online, with several also read in full although few transpired to be of any significant relevance to the present project.

In addition, unpublished information was pursued through dialogues with a number of national and international researchers with current research relevant or potentially relevant to the study of Arctic charr spawning grounds. Within the U.K. these included Colin Adams of the University of Glasgow who has experience of using a Remotely Operated Vehicle (ROV) to study the spawning grounds of vendace (*Coregonus albula*) and powan (*Coregonus lavaretus*), Jonathan Bull of the National Oceanography Centre Southampton who has experience in the use of hydroacoustics for mapping and typing lake bottoms, Peter Clabburn of Environment Agency Wales who has used an ROV to investigate Arctic charr in Llyn Padarn, North Wales, Jon Hateley of Environment Agency who has experience with high-frequency imaging hydroacoustics, and Ian Marshall of Lancaster University who has experience in developing motion-triggered cameras for the monitoring of terrestrial vertebrates.

3.3 Results

A range of potentially appropriate techniques was identified, although only a few of them had a proven track record in specific terms of Arctic charr spawning ecology. Given the twin overall objectives of the present project of locating and characterising spawning grounds in Windermere, these techniques covered studies of lake habitat and actual Arctic charr spawning. Here, these diverse techniques are reviewed using a framework of biological, visual, tracking and hydroacoustic techniques.

Biological techniques

Arguably the most obvious way by which to locate Arctic charr spawning grounds in a large lake such as Windermere is to capture either actively spawning adult fish, or their resulting eggs. The capture of adults was the main approach used by Frost (1965), specifically through the use of seine nets although other fish capture techniques are also likely to have been used in earlier years to produce the indigenous knowledge which Frost (op. cit.) also exploited. In addition, gill nets are used to capture spawning Arctic charr in the long-term monitoring programme reported most recently by Winfield *et al.* (2008b) and Winfield *et al.* (2008c) for one spawning ground in the north basin. Gill nets have also been used more extensively to catch Arctic charr at autumn- and spring-spawning sites by both Baroudy (1993) and Corrigan (2009). Although such gill netting can be largely destructive, if done with care and in appropriate conditions it can result in minimal mortalities.

The collection of Arctic charr eggs has the clear advantage that it does not kill adult spawners and the numbers of any eggs collected, even if they are killed, are unlikely to be significant at the population level. However, the relatively coarse (approximately 25 by 50 mm) and at times very deep (up to 30 m) spawning substrate of Windermere Arctic charr is a difficult medium to sample for such purposes. Techniques such as freeze-coring which have been used extensively for many years to locate and characterise salmonid spawning grounds in gravel beds of streams and rivers (e.g. Crisp & Carling, 1989) would be ineffective and/or impractical.

The published literature did not contain any studies which overcome these sampling problems, but dialogues with international researchers identified the currently unpublished work of Marsden *et al.* (2009) who used an ROV to collect eggs of a closely related salmonid in North America. As part of restoration efforts for lake trout (*Salvelinus namaycush*) spawning in the deep water of Lake Michigan, U.S.A., a suction sampler was mounted on an ROV and used successfully to find spawning habitat and collect eggs from sites as deep as 60 m. Using this equipment, Marsden *et al.* (*op. cit.*) have begun to characterise spawning habitat in deep water, and compare spawning activity between shallow and deep sites.

Visual techniques

Both the location and characterisation of Arctic charr spawning grounds can potentially be addressed using visual techniques, the former objective by locating spawning adults and the latter objective by allowing the detailed inspection of identified sites. Such visual inspections could be conducted manually by divers, although this would be extremely expensive, difficult under cold autumn or spring conditions, difficult due to the depths involved, and potentially disturbing to the fish approach. The use of an underwater video camera displaying to operators at the surface would be much more efficient, although for practical purposes deployment on an ROV would be almost essential. This approach is currently being used by Winfield *et al.* (2009) in a similar study of vendace, schelly (*Coregonus lavaretus*)and gwyniad (*Coregonus lavaretus*), although so far without any success. Limited visibility remains a significant problem, particularly when artificial lighting has to be used at night and at depth. For the location of spawning adults, the use of an ROV fitted not just with an underwater video camera but also with a dedicated sonar may increase the chances of successful location.

National dialogue revealed that the use of motion-triggered underwater still cameras may also be of use for the present purposes. Ian Marshall of Lancaster University is currently working with Centre for Ecology & Hydrology in the development of such systems to monitor the location and relative abundance of terrestrial vertebrates and preliminary discussions have indicated that aquatic versions of such systems may be feasible. If so, a number of such cameras could be left on potential spawning grounds for a period of days before being recovered and their recordings examined. In addition, a system with real-time communication through a radio link may also be technically feasible. This approach would have the great advantage of allowing the simultaneous deployment of cameras at a number of sites during the relatively brief spawning season.

Tracking techniques

The use of more commonly radio- and sometimes acoustic-tracking techniques to follow adult fish to their spawning grounds has been used frequently in recent decades, although usually within river systems for species such as brown trout (*Salmo trutta*) (e.g. Svendsen *et al.*, 2004). D'Amelio *et al.* (2008) have recently also demonstrated the value of this approach for charrs by tracking coaster brook trout (*Salvelinus fontinalis*) to their sources in Nipigon Bay, Lake Superior, U.S.A. Furthermore, Martyn Lucas of Durham University has recently successfully completed a trial tracking programme for Arctic charr in Windermere, although robust tracking of individuals from the relatively deep waters would probably require an acoustic rather than a radio signal (Martyn Lucas, Durham University, *pers. comm.*).

Hydroacoustic techniques

Hydroacoustic techniques have the great advantages of being extremely rapid to deploy in the field and being non-destructive. Furthermore, they can in theory be used both to locate spawning grounds by detecting adults and to characterise spawning grounds by examining their acoustic properties.

Spawning adults can be detected by long-standing, standard fish split-beam hydroacoustics techniques as were used for example by Qiao *et al.* (2006) in a study of the location and abundance of Chinese sturgeon (*Acipenser sinensis*) on their last spawning ground in the Yangtze River, China. However, there are two significant limitations to this approach. Firstly, only relatively small volumes of water can be searched for shallow-water spawning fish such as autumn-spawning Arctic charr in Windermere, although offshore aggregations in deeper water would be more amenable to detection. Secondly, the only information that can be generated for detected individuals in addition to their location is their approximate body size. While this attribute allowed Qiao *et al.* (2006) to differentiate between large Chinese sturgeon and other fish species present, this approach could not be used for Arctic charr in Windermere because of the presence of other similar-sized species.

Both of the above limitations of standard fish hydroacoustics can be over come through the use of the very high frequency DIDSON hydroacoustic system (Sound Metrics Corp., Lake Forest Park, U.S.A., www.soundmetrics.com) which has been described as an acoustic camera. This technique both insonifies a much greater volume of water than does standard hydroacoustics and it produces an effectively imaged output which can be used in some cases to identify individuals to specific species by their ‘appearance’ and behaviour. An example of such an application is given by Moursunda *et al.* (2003) for a fixed site in a river habitat, with Winfield *et al.* (2008d) also deploying it at a fixed site in a lake.

The use of hydroacoustic techniques to characterise spawning habitats relies on the detailed interpretation of the acoustic signature of bottom echoes to give information not only on bottom depth, but also on smoothness and other factors which may be linked to features of importance to successful spawning and egg incubation. The authors’ personal experiences reveals that such information can be gathered using standard fish hydroacoustics single- or split-beam hardware coupled with ‘bottom typing’ software such as VBT (BioSonics Inc, Seattle, U.S.A., www.biosonicsinc.com) and potentially Sonar5-Pro (Lindem Data Acquisition, Oslo, Norway, www.fys.uio.no/~hbalk/sonar4_5) and Echoview (Myriax, Hobart, Australia, www.echoview.com), although successful ground truthing is critical to the outcome of such activities.

Finally, and more efficiently and effectively in terms of the characterisation Arctic charr spawning grounds in Windermere, dedicated multi-beam hardware and software systems as described specifically with respect to Windermere by Bull (2008) would produce a definitive and detailed bathymetry coupled with specific bottom typing for areas of particular interest.

3.4 Discussion

This component of the project has identified a number of approaches for the location and characterisation of Arctic charr spawning grounds in Windermere. Some of them such as gill netting for spawning adults fall within the core activities of fish and fisheries research, while other such as the use of hydroacoustics include approaches at the cutting edge of technology and/or from other research fields. It is clear that no single technique can provide all of the required answers, but when assembled into an appropriate and sustained framework of activities they have the potential to improve greatly our understanding and management of the Arctic charr in Windermere. This important step is discussed in detail in the following project plan.

CHAPTER 4 RECOMMENDED PROJECT PLAN FOR ENVIRONMENT AGENCY

4.1 Introduction

The literature searches and personal dialogues described in Chapters 2 and 3 identified a range of techniques potentially appropriate to the assessment of the current locations and characteristics of Arctic charr spawning grounds in Windermere.

The objective of this part of the present project was to incorporate these findings into a recommended project plan which the Environment Agency could use as a basis from which to pursue funding. Although this plan could be structured by techniques as was Chapter 3, in practical terms it is clearly essential to develop a detailed knowledge of spawning ground locations before they can be robustly characterised. Accordingly, the structure of this recommended project plan follows these twin overall project objectives of spawning ground location and characterisation. Although given the present level of ignorance a valuable first step could be argued to be simply the location of all Arctic charr spawning grounds in Windermere, in practice this activity would itself greatly benefit from some effort also being expended on characterision in order to help the development of location techniques. In addition, such characterisation would also an assessment of how much some of the spawning grounds have changed since the observations of Frost (1965).

4.2 Location of spawning grounds

It is recommended that an extensive gill netting and seine netting programme on all of the now 10 known Arctic charr spawning grounds in Windermere is undertaken to determine their current use during autumn and spring. It is stressed that if done sympathetically, such gill netting leads to very low mortalities and so is acceptable on both scientific and conservation grounds. Furthermore, with appropriate management such activities should also be acceptable to the recreational fishing community. An approximate costing for this activity is £10k.

The above activities should also be supported by a visual approach using underwater video cameras deployed from an ROV, preferably one equipped with dedicated sonar. In addition to increasing sampling effort for spawning adults by a completely non-destructive technique, such activities would also contribute to characterising the spawning grounds. An approximate costing for this activity is £10k, although this assumes that appropriate hardware is already available to the project. Such hardware costs are like to vary between approximately £25k and £50k depending on their exact configuration.

It is also recommended that attempts are made to locate spawning grounds by searching for eggs using an ROV equipped with a suction or other sampler. This approach has the advantages of being effectively non-destructive and deployable in a much longer time window (approximately November to March) than the actual spawning periods (essentially November or February depending on the population). An approximate costing for this activity is £10k, although this assumes that appropriate hardware is already available to the project. Such hardware costs are like to be approximately £25k.

Although with a high risk, consideration should also be given to supporting the development of motion-triggered underwater still cameras which could be deployed on known or potential spawning grounds. A minimum approximate costing for this activity is £20k, although development of a system with real-time communication through a radio link is likely to cost significantly more at approximately £70k.

With much less risk, it is recommended that consideration be given to undertaking a tracking programme for spawning adults. Although some use could be made of individuals caught on shallow and relatively easily sampled spawning grounds, for obvious reasons this approach would also require the capture of fish at greater depths which may pose logistical problems due to depressurisation. However, the local semi-commercial fishery for Arctic charr may be a good source of fish for tagging, although this would of course rely on the co-operation of anglers. An approximate costing for this activity is £30k, although this assumes that some appropriate hardware is already available to or could be loaned to the project.

Finally, the only hydroacoustic technique which can be recommended to have a substantial chance of success for the location of spawning grounds is DIDSON. Even then, this approach would require some novel aspects such as the deployment of the system from a mobile boat or ROV. An approximate costing for this activity is £15k, although this assumes that appropriate hardware is already available to or could be loaned to the project. Such hardware costs are like to be approximately £50k.

4.3 Characteristics of spawning grounds

Although present resources did not allow the examination of relevant unpublished FBA information holdings and these are unlikely to contain any previously unpublished spawning ground locations, it is highly recommended that these materials are examined in the context of determining spawning ground characteristics as an aid to informing the development of procedures for their location. An approximate costing for this activity is £5k.

In terms of collecting new data to characterise the spawning grounds, the ROV activities described above with respect to location will also inevitably contribute to characterisation. However, there is also considerable scope for field work dedicated purely to locating spawning grounds and this would have the benefit of being conductable at any time of the year. An approximate costing for this activity is £10k.

Finally, the only hydroacoustic technique which can be readily recommended to have a substantial chance of success for the characterisation of spawning grounds is multi-beam hydroacoustics. This is already a proven technique and so would be a very low risk activity. While some attempt could be made to use a standard single- or split-beam system towards the same goals, this approach is unproven in the present context and with anything more than a very small coverage would require orders of magnitude more time in the field with consequent implications for costs. An approximate costing for a multi-beam study is between £15k and £75k, depending on the way the activity was configured.

4.4 Project team and management

This recommended project plan incorporates explicit or implicit involvement by a number of bodies including Centre for Ecology & Hydrology, Durham University, Environment Agency, Freshwater Biological Association, Lancaster University and National Oceanography Centre Southampton. Each of these organisations can make unique contributions to the overall body of work. It is emphasised here that overall project management of such a diverse range of activities would be challenging and so should such work proceed it is important that appropriate Environment Agency staff are themselves given sufficient resources to play a full role in the work.

Finally, the costings provided above are only approximate and in many cases can be significantly increased or decreased as a function of changes to specific objectives. Thus a minimum overall figure of £125k must be viewed as a guide at this stage. In addition, it is should be acknowledged that while the spread of such a project over several calendar years is highly desirable to allow optimum use to be made of the relatively short spawning periods of Arctic charr in Windermere, such scheduling would require its own consideration in terms of the inter-dependencies of some areas of work.

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Table 1. Metadata for unpublished information held by the Freshwater Biological Information on Arctic charr in Windermere as supplied on 2 December 2008.

Form	Author/Person assoctd	Date range	Item(s)	Call no	Location	Storage
Unpublished literature	Fletcher, J	1987	"Charr" and inside "Charr project Chris Mills". Experimental notebook.	771	Pearsall B8	Blue notebook and loose papers.
Unpublished literature	Frost, WE		Assorted correspondence and papers on pike and eels	797	Pearsall B8	Papers, files in archive box
Unpublished literature	Frost, WE		Assorted correspondence and papers on pike	798	Pearsall B8	Papers, files in archive box
Unpublished literature	Frost, WE		Assorted correspondence and papers on brown trout (part 1)	799	Pearsall B8	Papers, files in archive box
Unpublished literature	Frost, WE		Assorted correspondence and papers on brown trout (part 2)	800	Pearsall B8	Papers, files in archive box
Unpublished literature	Frost, WE		Assorted correspondence and papers on char (part 1)	801	Pearsall B8	Papers, files in archive box
Unpublished literature	Frost, WE		Assorted correspondence and papers on char (part 2)	802	Pearsall B8	Papers, files in archive box
Unpublished literature	Frost, WE		Assorted correspondence and papers on fish generally, FBA business, lectures (part 1)	803	Pearsall B8	Papers, files in archive box
Unpublished literature	Frost, WE		Assorted correspondence and papers on fish generally, FBA business, lectures (part 2)	804	Pearsall B8	Papers, files in archive box
Unpublished literature	Frost, WE		Assorted correspondence and personal papers	972	Quasimodo	Papers, files, photographs in wooden trunk
Unpublished literature	Various	1950s-70s	Photographs. Reel films. 'The River Must Live' FBA/Shell; charr spawning, Mackereth corer, Tomorrow's World 1979.	832	Pearsall B8	Assorted reels. The Web of Life is a large reel in box UCR?.
Unpublished literature	Frost, WE		Old fish data.	958	Quasimodo	Paper records. Outsize grey box.
Unpublished literature	Frost, WE		Asstd fish records, much from WE Frost.	878	Quasimodo	Paper records. Outsize grey box.
Unpublished literature, specimens	Frost, WE	1948-50	Tagging records. Perch mark/recapture experiments 1948-50. Asstd papers and associated? samples. Old notebooks, including one marked 'Methods' by WE Frost.	872	Quasimodo	Tagging records in box 12x10x8". Notebooks, papers, samples.
Unpublished literature	Macan/Elliott		"Haweswater especially char" Elliott, Frost, Macan, Elliott, 1941-73; "Charr	1001	Pearsall B4	

			1940s-60s" Elliott, WE Frost, Macan, LeCren			
Specimens	Frost, WE	1947-67	Fish scales on microscope slides: 7 boxes trout Scandale 1949, Blagdon, School Knott Tarn 1948, various waters, also 'standard series' 1-1140 (149-570??); 1 box salmon various waters diseased 1966-7, 1 box "Miss RH Lowe eels" (but appears to be loach)	295	Pearsall B4	9 black slide boxes, 100 slides per box
Unpublished literature	Frost, WE	1940s-50s	Logbooks and notebooks, box 1 of 2	710	Quasimodo	c150 notebooks, some correspondence
Unpublished literature	Frost, WE	1940s-50s	Logbooks and notebooks, box 2 of 2	711	Quasimodo	c150 notebooks, some correspondence
Unpublished literature	Frost, WE	1939	River Forss fish studies by WE Frost 1939, notes records and papers.	716	Quasimodo	Papers in brown box
Unpublished literature	Frost, WE	1942-61	Frost and CE Myers, correspondence, includes "Growth of brown trout in Blagdon Reservoir. Scales from fish of known age. 1949-53" and various articles on salmon propagation from the Salmon and Trout Association London Conference 1956	243		
Unpublished literature	Frost, WE	1940-42	Minnow data	245		

Fig. 1. The nine known autumn- and four known spring-spawning grounds of Arctic charr in Windermere first published as Figure 1 of Frost (1965). Autumn- and spring-spawning grounds are depicted by cross-hatched and hatched areas, respectively. Reproduced with kind permission of the Royal Society.

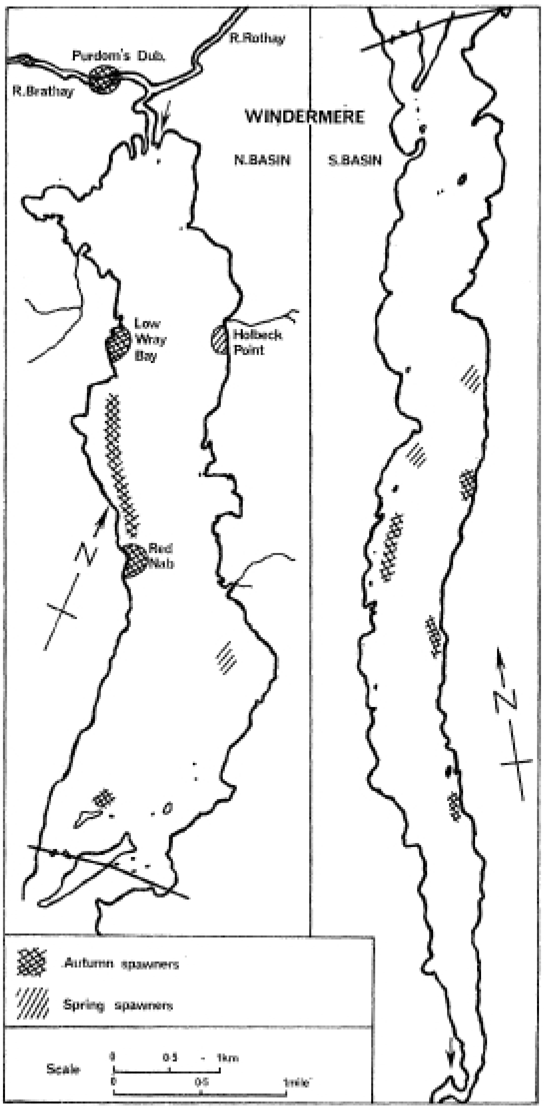

FIGURE 1. Spawning places of charr. Sites of detailed investigation of autumn and spring spawners are named, other places where spawning probably occurs are indicated.

Fig. 2. The nine known autumn- and four known spring-spawning grounds of Arctic charr in Windermere as redrawn from Frost (1965) by Baroudy (1993), Elliott (1993) and others. Autumn- and spring-spawning grounds are depicted by red and green areas, respectively.