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ASSESSMENT OF THE FISH COMMUNITY OF THIRLMERE

FINAL REPORT

Prepared by Ian J Winfield BSc, PhD, CEnv, FIFM, FSB
Janice M Fletcher BSc
J Ben James

Project Leader: Ian J Winfield
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EXECUTIVE SUMMARY

1. The Arctic charr (*Salvelinus alpinus*) is of high conservation value in the U.K., with native populations in England being restricted to eight Lake District water bodies including Thirlmere. Variations in the water level of this reservoir may have adverse effects on the status of the populations of Arctic charr and other fish species. The objectives of the present project were to assess the fish community of Thirlmere, with a particular emphasis on the abundance, population structure, spawning season and spawning location of Arctic charr. These issues were addressed using a combination of hydroacoustics, gill netting and the examination of fish entrapped in the lake's water abstraction system.

2. A hydroacoustic survey was carried out on 4 July 2011. The population density recorded by night-time hydroacoustics of all fish had a geometric mean of 4.3 fish ha^{-1} with lower and upper 95% confidence limits of 2.1 and 9.0 fish ha^{-1}, respectively. Based on a combination of these hydroacoustic and associated gill-netting data (see below), the population abundance of Arctic charr was estimated to be 0.1 fish ha^{-1} with lower and upper 95% confidence limits of 0.1 and 0.3 fish ha^{-1}, respectively. Both of these abundance estimates are low in a wider U.K. context.

3. A gill-netting survey was carried out on 5 July 2011. A total of 169 fish of four species was sampled, comprising 1 Arctic charr (length 138 mm, weight 31 g, male, age 2 years, condition index 1.18, apparent benthic morph), 4 brown trout (*Salmo trutta*), 148 perch (*Perca fluviatilis*) and 16 ruffe (*Gymnocephalus cernuus*). This relative numerical contribution of Arctic charr to the total fish community of Thirlmere was lower than

corresponding values recently observed at Buttermere, Crummock Water and Wastwater using an identical sampling protocol. In addition, this was the first record of ruffe for Thirlmere and follows the recent appearance of this species in a number of other Cumbrian lakes at which live-baiting for pike (*Esox lucius*) is or has been practised. The failure of the present gill-netting to record any pike is probably due to the limited sampling effort deployed and the relative scarcity of this piscivore.

4. Fish entrapped between 1 April 2011 and 31 March 2012 were collected and examined. A total of 413 fish of five species was sampled, comprising 1 Arctic charr (length 247 mm, weight 169 g, male, age 4 years, condition index 1.12, apparent pelagic morph), 1 brown trout, 221 perch, 189 ruffe and 1 river lamprey. This single Arctic charr may be compared with a much greater number of 96 Arctic charr entrapped at Haweswater over a similar but slightly shorter time period.

5. Given the very low abundance of Arctic charr observed during the hydroacoustic and gill-net and surveys, plans for further gill netting in the autumn and early spring to determine the local spawning time of this species were not progressed. Instead, the gut contents of entrapped ruffe were examined for Arctic charr eggs although none were found.

7. These findings are briefly discussed in a wider context and recommendations made for future activities in terms of both monitoring and research.

CHAPTER 1 INTRODUCTION

1.1 Background

The Arctic charr (*Salvelinus alpinus*) is of high conservation value in the U.K. and has recently become listed as a UKBAP species, with native populations in England being restricted to the eight Lake District water bodies of Buttermere, Coniston Water, Crummock Water, Ennerdale Water, Haweswater, Thirlmere, Wastwater and Windermere (Maitland *et al.*, 2007). In extensive studies of this species elsewhere in Europe, population status has been found to be strongly influenced by local eutrophication and marked variations in lake levels (Maitland, 1995). Within the English Lake District, these two factors have been found to impact the Arctic charr populations of Windermere (Winfield *et al.*, 2008) and probably Haweswater (Winfield *et al.*, 2011a), respectively. Although eutrophication is extremely unlikely ever to become a cause for concern at Thirlmere, variations in water level may have adverse effects on the status of the populations of Arctic charr and other fish species of this lake, which are believed to include brown trout (*Salmo trutta*), perch (*Perca fluviatilis*) and pike (*Esox lucius*) (Frost, 1989).

However, the ecology of the Arctic charr population of Thirlmere remains essentially unstudied, as indeed does that of the lake's other fish species, with the only known data available for this population originating from limited samples taken in June 1986 within a study of Arctic charr biometrics and genetics (Partington & Mills, 1988). As a result, even basic characteristics of the Arctic charr population such as whether spawning occurs in autumn or spring, or both, and whether more than one morph is present, remain undescribed.

Consequently, the implications for this population of any changes in the lake’s water level regime cannot presently be anticipated with any degree of confidence.

1.2 Objectives

The objectives of the present project were to assess the fish community of Thirlmere, with a particular emphasis on the abundance, population structure, spawning season and spawning location of Arctic charr. These issues were addressed using a combination of hydroacoustics, gill netting and the examination of fish entrapped in the lake’s water abstraction system.

CHAPTER 2 HYDROACOUSTICS

2.1 Introduction

The use of hydroacoustics for the study of Arctic charr populations in the English Lake District and elsewhere now has a substantial history, with Winfield *et al.* (2009), Winfield *et al.* (2011b) and Winfield *et al.* (2011c) providing detailed examples of such applications. In terms of the standardisation of methodologies for the specific assessment of such populations, an assessment protocol developed by Bean (2003), subsequently adopted for Common Standards for Monitoring (CSM) by JNCC (2005), gives specific details for appropriate hydroacoustic surveys.

The objective of this part of the present project was to undertake a hydroacoustic survey of the Arctic charr and other fish populations of Thirlmere compliant with the protocol of Bean (2003).

2.2 Methods

2.2.1 Field work

Hydroacoustic surveys were carried out using a BioSonics DT-X echo sounder with a 200 kHz split-beam vertical transducer of beam angle 6.5° operating under the controlling software Visual Acquisition Version 6.0.1.4318 (BioSonics Inc, Seattle, U.S.A.). Throughout the surveys, data threshold was set at -130 dB, pulse rate at 5 pulses s^{-1}, pulse width at 0.4 ms, and data recorded from a range of 0 m from the transducer face. In addition to the real-time production of an echogram through a colour display on a laptop computer, data were also recorded to hard disc. The system was deployed from a 4.8 m inflatable dinghy powered by a 25 horse power petrol outboard engine and moving at a speed of approximately 2 m s^{-1}, depending on wind conditions. The transducer was positioned approximately 0.5 m below the surface of the water. Navigation was accomplished using a Garmin GPSMAP 60CSx GPS (Global Positioning System) (www.garmin.com) with accuracy to less than 10 m, while a JRC Model DGPS212 GPS (www.jrc.co.jp) with accuracy to less than 5 m inputted location data directly to the hydroacoustic system where they were incorporated into the recorded hydroacoustic data files. Prior to the surveys, the hydroacoustic system had been calibrated using a tungsten carbide sphere of target strength (TS) -39.5 dB at a sound velocity of 1470 m s^{-1} and surface water temperature was recorded immediately before the surveys.

Hydroacoustic surveys were undertaken once during day-time and once during night-time. A discrete systematic parallel survey design was employed covering areas of depth in excess of approximately 5 m and incorporated a total of 19 transects (Table 1). Surveys were run in the general direction of from the south to the north of the lake, were of approximately 90 minutes duration, and the night-time survey began at least two hours after sunset. This gave a ratio of coverage (length of surveys : square root of research area) of 5.8:1.

The above surveys were carried out on 4 July 2011.

2.2.2 Laboratory examination and analysis

Subsequent data analysis in the laboratory was performed by trace formation, also known as fish tracking, using SonarData Echoview Version 3.40.47.1551 (Myriax, Hobart, Australia, www.echoview.com) with a target threshold of -70 dB and all other tracing parameters set to default values. This process was applied individually to each transect of the night-time surveys, with data from the day-time surveys not used in the present analysis.

Further data analysis was similar to that carried out during earlier studies of Arctic charr populations such as those reported by Winfield *et al.* (2009) and Winfield *et al.* (2011b), with the water column of each transect divided into 1 m deep strata from a depth of 2 m below the transducer down to the lake bottom. Fish counts were converted to fish population densities expressed as individuals per hectare of lake surface area for each transect by the use of a spreadsheet incorporating the insonification volume for each depth stratum. Following Jurvelius (1991) and Baroudy & Elliott (1993), the average density of fish during each survey was calculated as the geometric mean with 95% confidence limits of the component transects.

Estimates of target strengths produced by Echoview were converted to fish lengths using the relationship described by Love (1971),

$$TS = (19.1 \log L) – (0.9 \log F) – 62.0$$

where TS is target strength in dB, L is fish length in cm, and F is frequency in kHz. Targets were then pooled into three length classes of small (i.e. -52 to -45 dB, length 40 to 99 mm), medium (-44 to -37 dB, length 100 to 249 mm) and large (greater than -37 dB, length greater than 250 mm) fish and the above calculations of fish population densities repeated for small, medium and large fish.

Estimates of the abundance of all species were converted to estimates for Arctic charr using offshore (i.e. simple unweighted pooling of offshore bottom and offshore surface) community composition data from the gill-netting surveys (see below) following the established methodology of the earlier CSM implementation of Winfield *et al.* (2009). However, due to the rarity of Arctic charr in the gill-net samples (see below), the mean with 95% confidence limits percentage contribution by small (assumed to be 0+/1+ age class) individuals to the total Arctic charr population, as required in the protocol described by Bean (2003) and implemented elsewhere by Winfield *et al.* (2009), was not calculated for the present hydroacoustic data.

2.3 Results

The population density recorded by hydroacoustics of all fish had a geometric mean of 4.3 fish ha^{-1} with lower and upper 95% confidence limits of 2.1 and 9.0 fish ha^{-1}, respectively. A breakdown into small (length 40 to 99 mm), medium (100 to 249 mm) and large (250 mm and greater) individuals is given in Table 2.

Based on a combination of these hydroacoustic and gill-netting data (see below), the population abundance of Arctic charr was estimated to be 0.1 fish ha^{-1} with lower and upper 95% confidence limits of 0.1 and 0.3 fish ha^{-1}, respectively.

2.4 Discussion

The total fish population density of 4.3 fish ha^{-1} recorded by the hydroacoustic survey at Thirlmere was relatively low in the context of levels observed by Winfield *et al.* (in press) for 17 Arctic charr or coregonid dominated lakes elsewhere in the U.K., which ranged in mean values from 5.5 to 476.9 fish ha^{-1}. In more specific terms, the observed population density of Arctic charr of 0.1 fish ha^{-1} at Thirlmere was also very low in the context of other U.K. estimates for this species previously made using an identical approach to that used here. For example, Winfield *et al.* (2009) reported a range in mean values of from 1.6 to 457.8 fish ha^{-1} from five lochs in Scotland between 2003 and 2005. For Arctic charr populations within Cumbria in 2010, Winfield *et al.* (2011b) reported mean values of 0.1, 35.2 and 3.2 fish ha^{-1} in Buttermere, Crummock Water and Wastwater, respectively, while in the same year Hateley (2010) used a slightly different form of hydroacoustic survey to produce an estimate for Arctic charr abundance in Ennerdale Water of 31.3 fish ha^{-1}.

While the absence of any previous hydroacoustic surveys at Thirlmere precludes any discussion of temporal trends in Arctic charr local abundance, the present observations clearly indicate that in 2011 the population is present at a very low abundance. Indeed, the present abundance of this species is so low that the hydroacoustic data analysis component of the CSM assessment protocol of Bean (2003) cannot be robustly applied in full.

CHAPTER 3 GILL NETTING

3.1 Introduction

The use of gill netting for the study of Arctic charr populations in the English Lake District and elsewhere has, like hydroacoustics, a substantial history with Winfield *et al.* (2009) and Winfield *et al.* (2011b) again providing detailed examples of such applications. In terms of standardisation of methodologies for the specific assessment of such populations, the CSM-compliant assessment protocol developed by Bean (2003) for Arctic charr also gives specific details for appropriate gill-netting surveys.

The objective of this part of the present project was to undertake a gill-netting survey of the Arctic charr and other fish populations of Thirlmere compliant with the protocol of Bean (2003).

3.2 Methods

3.2.1 Field work

Gill netting was undertaken using basic and pelagic versions of the Norden survey gill net, which was formerly known as the Nordic survey gill net (Appelberg, 2000). The basic version of this net, which is set on the lake bottom, is approximately 1.5 m deep and 30 m long, with 12 panels of equal length of bar mesh sizes 5, 6.25, 8, 10, 12.5, 15.5, 19.5, 24, 29, 35, 43 and 55 mm, while the pelagic version, which is set floating from the lake surface, is approximately 6.0 m deep and 27.5 m long, with 11 panels of equal length of bar mesh sizes 6.25, 8, 10, 12.5, 15.5, 19.5, 24, 29, 35, 43 and 55 mm. Locations of gill-net sets were recorded using a Garmin GPSMAP 60CSx GPS (Global Positioning System) (www.garmin.com) with accuracy to less than 10 m.

Three basic nets were set in the inshore habitat, three basic nets were set in the offshore bottom habitat and three pelagic nets were set in the offshore surface habit in the locations specified in Table 1. Water depth at the inshore habitats was approximately 3 to 4 m, while in the offshore habitats it was approximately 20 to 25 m. Nets were set during the early evening and lifted during the early morning of the following day and all fish were removed from the nets and killed, where practical by overdose with 2-phenoxy-ethanol. All fish were then frozen at -20 °C to await future processing in the laboratory.

The above survey was carried out on 5 July 2011.

3.2.2 Laboratory examination and analysis

After being partially thawed from storage at -20 °C, all fish were enumerated, measured (fork length, mm), and weighed (total wet, g). For Arctic charr, the single individual sampled (see below) was also sexed (male, female or indeterminate) before otoliths and a sample of scales were removed for subsequent age determination, although only the former were processed further within this project by examination under a binocular microscope.

The single Arctic charr sampled was also photographed to facilitate its classification by the first author as an apparent benthic or pelagic morph on the basis of Fig. 2 and Table 2 of Walker *et al.* (1988). Its condition was also assessed using the condition index (CI),

$$CI = 10^5 \, W / L^3$$

where W is total body weight (g) and L is fork length (mm).

3.3 Results

A total of 169 fish of four species was sampled by the gill netting, comprising 1 Arctic charr (length 138 mm, weight 31 g, male, age 2 years, condition index 1.18, apparent benthic morph (Fig. 1)), 4 brown trout (length range 276 to 372 mm, weight range 258 to 588 g), 148 perch (length range 75 to 288 mm, weight range 4 to 319 g) and 16 ruffe (*Gymnocephalus cernuus*, length range 42 to 135 mm, weight range 1 to 36 g) (Table 3).

3.4 Discussion

The present gill-netting survey represents the first systematic biological sampling of the Thirlmere fish community. Very early, but subsequently updated, general texts on the English Lake District such as Pearsall & Pennington (1989) incorporating Frost (1989) give no quantitative information for any fish species of this lake. Furthermore, a bibliography of Lake District research complied by Horne & Horne (1985) only refers to studies of the Thirlmere perch and Arctic charr populations by Le Cren (1955) and Frost (1977), respectively. However, both of these studies are extremely limited in terms of information presented on the Thirlmere populations and offer nothing or very little to the interpretation of the present gill-net data. For example, Le Cren (1955) is concerned with a wider perspective on perch year class strengths and Frost (1977) in concerned primarily with the diet of Arctic charr in Windermere. However, a subsequent primarily genetic and biometric study of Arctic charr from 10 U.K. lakes by Partington & Mills (1988) contains some limited population data from Thirlmere. Although gill-net sampling effort was not reported in detail and so no robust assessment can be made of relative abundance at the time of sampling in the mid 1980s, a total of 49 Arctic charr aged from 2 to 12 years was recorded which suggests at least a moderate abundance of this species at that time.

In the context of the above earlier gill-netting observations at Thirlmere, the present gill-netting results were somewhat surprising although not entirely unexpected given the hydroacoustic observations of the present project. The total sample size of 169 fish from the inshore, offshore bottom and offshore surface habitats of Thirlmere was relatively large in the context of corresponding numbers of 108, 112 and 52 fish sampled by the same design of gill-netting survey carried out in 2010 at Buttermere, Crummock Water and Wastwater, respectively, by Winfield *et al.* (2011b). However, the numerical contribution of Arctic charr to the total fish community of Thirlmere of 0.6% was lower than the corresponding values of 0.9, 36.6 and 7.7% observed at Buttermere, Crummock Water and Wastwater, respectively. The fish community composition of Thirlmere was also remarkable in that it is the only Arctic charr lake in Cumbria in which ruffe have also been recorded. Indeed, the present observation constitutes the first record of ruffe for Thirlmere and follows the recent appearance of this species in a number of other Cumbrian and U.K. lakes at which live-baiting for pike is or has been practised, with the obvious implication that its arrival is associated with this practice (Winfield *et al.*, 2010a; Winfield *et al.*, 2011d). The failure of the present gill-netting to record any pike at Thirlmere is not completely unexpected given the limited sampling effort deployed and the fact that this piscivore is likely to be present at only relatively low abundance due to its trophic position in the lake's food chain.

The spatial distribution of the four fish species between the inshore, offshore bottom and offshore surface habitats was typical for a U.K. lake. Outside the spawning season, Arctic charr are usually restricted to offshore areas and so the recording of the single individual from the offshore bottom was compliant with the general pattern observed elsewhere in Cumbria by Winfield *et al.* (2011b). Similarly, the brown trout and perch showed the inshore and offshore surface distributions typical for these species in Cumbria. In contrast, the ruffe were restricted exclusively to the inshore habitats of Thirlmere, even though elsewhere in Cumbria introduced populations of this species in Bassenthwaite Lake and Derwent Water are frequently recorded in both inshore and offshore bottom habitats (Winfield *et al.*, 2012).

Clearly, with only a single individual sampled, little can be concluded from the present gill-netting survey concerning the Arctic charr population of Thirlmere other than that it is present at only a very low level of abundance. The latter was also indicated by the results of the hydroacoustic survey. At the individual level, the single specimen was in a good condition as indicated by its condition index. In addition, it was apparently a benthic morph although the application of this term must be somewhat contentious when only a single specimen was available for examination.

Given the very low abundance of Arctic charr observed during the gill-net and hydroacoustic surveys of Thirlmere, original plans for further gill netting in the autumn and early spring to determine the local spawning time of this species were not progressed for two reasons. Firstly, with such a low abundance of the target species such activities may be detrimental to the population. Secondly, they or any non-destructive netting technique such as fyke netting are unlikely to be productive without a degree of sampling effort far beyond the resources of the present project. Instead, an attempt was made to gather information on the spawning time of Arctic charr in Thirlmere using a novel analysis of material produced by the entrapment study.

CHAPTER 4 ENTRAPMENT

4.1 Introduction

The use of entrapment for the study of Arctic charr populations in the English Lake District has previously been restricted to Haweswater, with Maitland (1985) and Winfield *et al.* (2011a) providing detailed examples of such work. Although monitoring fish populations using this approach has a number of limitations including potential biases related to the location and individual sizes of fish collected, it also has the substantial advantage of typically being operated continuously for long periods of time and so is ideal for investigating issues such as the timing of spawning.

The objective of this part of the present project was to monitor the entrapment of Arctic charr, including the seasonality of gonad development and thus spawning, and other fish species from 1 April 2011 to 31 March 2012. In addition, given the current unproductive results for Arctic charr of gill netting at Thirlmere, a attempt to identify their local spawning time was made by examining the gut contents of entrapped ruffe for the presence of Arctic charr eggs.

4.2 Methods

With the cooperation of United Utilities staff, fish entrapped from a depth of approximately 25 m (when the lake is full) by the abstraction system at Thirlmere were collected and stored in dated plastic bags in a freezer at -20 °C to await collection by CEH staff for standard processing as described below.

Entrapped fish were subsequently returned to the laboratory where at a later date they were thawed, identified, measured (fork length to nearest mm), weighed (wet weight to nearest g), sexed and their reproductive state classified as immature, mature, mature and ripe (hereafter abbreviated to ripe), mature and running (hereafter abbreviated to running), or mature and spent (hereafter abbreviated to spent). Otoliths and scales were removed from Arctic charr and brown trout and opercular bones were removed from perch and ruffe for subsequent ageing, although the remit of the present project only included such processing of material from the former species.

The single Arctic charr sampled (see below) was also photographed to facilitate its classification by the first author as an apparent benthic or pelagic morph on the basis of Fig. 2 and Table 2 of Walker *et al.* (1988). Its condition was also assessed using the condition index (CI),

$$CI = 10^5 \, W / L^3$$

where W is total body weight (g) and L is fork length (mm).

Finally, the gut contents of all ruffe entrapped from 1 October 2011 to 31 March 2012 were examined for the presence of Arctic charr eggs by dissection and examination under a bench magnifying glass at a magnification of x2.

4.3 Results

A total of 413 fish of five species was sampled by the entrapment, comprising 1 Arctic charr (length 247 mm, weight 169 g, male (further reproductive status could not be determined), age 4 years, condition index 1.12, apparent pelagic morph (Fig. 2)), 1 brown trout (length 175 mm, weight 71 g), 221 perch (length range 41 to 237 mm, weight range 1 to 168 g), 189 ruffe (length range 61 to 164 mm, weight range 4 to 82 g) and 1 river lamprey (*Lampetra fluviatilis*, length 1207 mm, weight 3 g).

In terms of seasonal patterns, the single Arctic charr, brown trout and river lamprey were each entrapped on 30 March 2012, 3 August 2011 and 21 December 2011, respectively. However, both perch (1 April 2011 to 26 March 2012) and ruffe (1 April 2011 to 28 March 2012) were entrapped in almost all months of the study as shown in Fig. 3. Perch entrapment peaked in the early autumn, while that of ruffe was less variable with highest numbers in the late winter and spring.

No Arctic charr eggs were found in the gut contents of any ruffe, the composition of which was consistently dominated by benthic macroinvertebrates.

4.4 Discussion

As noted in the introduction, the use of entrapment to study fish populations must acknowledge that this technique is likely to generate significant bias to samples as a result of the location of the abstraction point and physical limitations on the individual sizes of fish retained by the abstraction infrastucture. In terms of the system at Thirlmere which evidently can retain individuals as small as 41 mm in length, such bias is likely to be restricted to the location of the abstraction point. The latter is at a depth of approximately 25 m at full lake, which is very similar to the depth of the abstraction point at Haweswater which is at a depth of 20.6 m at full lake (Winfield *et al.*, 1998).

The present work represents the first systematic examination of entrapment at Thirlmere and so no long-term comparisons are possible with earlier periods. Indeed, the only general comparison that can be made is with entrapment at Haweswater which has been monitored since 1973 (Winfield *et al.*, 2011a). The long-term entrapment study at Haweswater has shown that the numbers of Arctic charr and schelly (*Coregonus lavaretus*) entrapped tend to peak during their late winter spawning times (Winfield *et al.*, 2011a), and so it was anticipated that an equivalent indication of local spawning time would be produced by the collection of entrapment data at Thirlmere.

Unfortunately, the 12 months of entrapment at Thirlmere within the present study resulted in the sampling of just a single Arctic charr, which was itself in a good condition as indicated by its condition index. In addition, it was apparently a benthic morph although, as with the gill-netting results, the application of this term must be somewhat contentious when only a single specimen was available for examination. This single individual may be compared with a much greater number of 96 Arctic charr entrapped at Haweswater over a similar but slightly shorter time period between 1 April 2011 and 12 February 2012 (CEH, unpublished data). Like the hydroacoustic and gill-netting surveys, the entrapment study of Thirlmere indicates an Arctic charr population present at only a very low level of abundance.

In contrast to the rarity of Arctic charr, both perch and ruffe were entrapped in substantial numbers throughout most of the study period, despite the fact that the abstraction point was located in the relatively deep water of the offshore bottom habitat where such species might be expected to be relatively scarce through at least the summer months. For these species, the entrapment record probably reflects an offshore migration of perch in the autumn as well as a persistence of ruffe in this deep habitat throughout the year even though gill netting in this habitat failed to detect them.

Finally, the attempt to generate information on the timing of spawning of Arctic charr in Thirlmere by looking for a seasonal pattern in the consumption of their eggs by ruffe was clearly unsuccessful. Indeed, to the authors' knowledge Thirlmere is the only lake in the U.K. where these two species coexist and so it is not even known if ruffe can and do extract Arctic charr eggs from their redds during the spawning or subsequent incubation periods. The failure to record any Arctic charr eggs in the diet of ruffe over a 6 month period in Thirlmere encompassing the potential autumn and spring spawning times of the former species may be because ruffe cannot in fact consume Arctic charr eggs, that ruffe in the vicinity of the abstraction point do not consume Arctic charr eggs, or that there are extremely few Arctic charr eggs available for consumption in the lake as a whole. Whatever the reason for the absence of such eggs from the local diet of ruffe, this part of the project clearly failed to produce any information on the spawning time of Arctic charr in Thirlmere.

CHAPTER 5 GENERAL DISCUSSION AND RECOMMENDATIONS

5.1 General discussion

The objectives of the present project were to assess the fish community of Thirlmere, with a particular emphasis on the abundance, population structure, spawning season and spawning location of Arctic charr. These issues were addressed using a combination of hydroacoustics, gill netting and the examination of fish entrapped in the lake's water abstraction system. While the work was successful in terms of describing the fish community in a standardised way which facilitated direct comparisons with similar studies elsewhere as presented in the earlier chapters, the evident present scarcity of Arctic charr in Thirlmere made it impossible to draw any robust conclusions concerning its detailed local population biology and spawning ecology. This is a key failing of the present work and suggestions for its remediation are made below.

In the context of the CSM assessment protocols of Bean (2003) and JNCC (2005), when taken together the findings presented in the earlier chapters of the present report clearly lead to the conclusion that the Arctic charr population of Thirlmere is currently in an unfavourable condition. As such, it joins the Arctic charr populations of Buttermere, Ennerdale Water and Wastwater which were recently concluded to be in this state by Winfield *et al.* (2011b). Furthermore, of the seven Cumbrian Arctic charr populations recently assessed by the present project (Thirlmere), Winfield *et al.* (2011a) (Haweswater), Winfield *et al.* (2011b) (Buttermere, Crummock Water, Ennerdale Water and Wastwater) and Winfield *et al.* (2011c) (Windermere), only that of Crummock Water has been found to be in a favourable condition.

A similar decline has recently been reported for this species at the U.K. level by Winfield *et al.* (2010b), who found that 10 out of 11 populations had shown a recent decline.

Fully explaining these various declines in Arctic charr populations, and thus providing a framework for their constructive management, is clearly a major undertaking beyond the scope of the present project. Winfield *et al.* (2010b) have already noted that some of these declines such as those at Ennerdale Water, Haweswater and Windermere have clear and lake-specific potential causes such as acidification of tributary spawning grounds, lake level fluctuations, predation by cormorants, and eutrophication, i.e. environmental problems which are relatively tractable and in some cases are already being addressed. However, some such as that at Coniston Water have no obvious local cause. Furthermore it is of concern that within their U.K.-wide observations, Winfield *et al.* (2010b) also noted a significant positive relationship between observed population decline ranking and a vulnerability to climate change ranking based on water body latitude, altitude and mean depth. Clearly, if this empirical relationship is indeed causal it has considerable implications for the long-term management of Arctic charr in Thirlmere and elsewhere in the U.K.

5.2 Recommendations

Four areas of recommendations are made on the basis of the present findings.

Firstly, it is strongly recommended that the Arctic charr population of Thirlmere is continued to be monitored alongside the CSM programme now in operation for some other Cumbrian populations as described by Winfield *et al.* (2011b). Notably, entrapment could play an informative and highly cost-effective role in such monitoring at Thirlmere and may yet provide information on the local spawning time of Arctic charr.

Secondly, given the failure of the present project to identify the timing and location of Arctic charr spawning in Thirlmere it is recommended that further work in these areas is considered. The Arctic charr population currently appears to be present at too low an abundance to facilitate any standard netting-based approach to determining spawning time, although if resources allow an extensive and non-destructive fyke netting programme may produce such information. An alternative and novel option may be to conduct repeated searches for Arctic charr remains brought to shore by otters (*Lutra lutra*) foraging on spawning aggregations, as has recently been demonstrated by Hewitt & Winfield (submitted) to be highly effective for determining the timing and location of schelly spawning grounds in Ullswater. Such work could also be supplemented by the use of underwater video or still photography, potentially deployed from a Remotely Operated Vehicle, to locate suitable spawning habitat as recently used for vendace (*Coregonus albula*) at Derwent Water by Winfield *et al.* (2010c). Limited use of kick sampling for eggs at the appropriate time of year could then be deployed at such areas in an effort to confirm their actual use by Arctic charr.

Thirdly, it is recommended that investigations are undertaken to identify and address the factors which have led to the present unfavourable condition of Arctic charr in Thirlmere. Such studies should address both local, e.g. introduction of ruffe, lake level fluctuations, and global, i.e. climate change, factors. In this context, collaboration is recommended between United Utilities, Centre for Ecology & Hydrology, Environment Agency and Natural

England, together with other directly and indirectly appropriate bodies such as Countryside Council for Wales and Scottish Natural Heritage.

Fourthly, it is strongly recommended that dialogues are also continued at a wider level between United Utilities, Centre for Ecology & Hydrology, Environment Agency and Natural England to explore and deliver mutually beneficial collaborations between the monitoring and research programmes currently in place for Arctic charr populations in Cumbria.

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Table 1. GPS locations for 19 hydroacoustic transects and nine gill-netting sites used at Thirlmere. Gill-netting sites are identified as inshore (I), offshore bottom (OB) or offshore surface (OS) with individual numbering from 1 to 3. Locations are given in decimal degrees.

Event	Latitude (North)	Longitude (West)
Transect 1 start	54.51453	3.05339
Transect 1 end	54.51568	3.04588
Transect 2 start	54.51841	3.04661
Transect 2 end	54.51686	3.05472
Transect 3 start	54.51924	305614.
Transect 3 end	54.52062	3.04797
Transect 4 start	54.52264	3.04941
Transect 4 end	54.52191	3.05739
Transect 5 start	54.52407	3.05778
Transect 5 end	54.52498	3.05019
Transect 6 start	54.52689	3.05077
Transect 6 end	54.52651	3.05726
Transect 7 start	54.52826	3.05814
Transect 7 end	54.52944	3.05245
Transect 8 start	54.53114	3.05319
Transect 8 end	54.52982	3.05821
Transect 9 start	54.53053	3.06332
Transect 9 end	54.53296	3.05543
Transect 10 start	54.53526	3.05770
Transect 10 end	54.53273	3.06619
Transect 11 start	54.53462	3.06892
Transect 11 end	54.53710	3.05973
Transect 12 start	54.53952	3.06229
Transect 12 end	54.53788	3.07185
Transect 13 start	54.54102	3.07119
Transect 13 end	54.54204	3.06329
Transect 14 start	54.54502	3.06421
Transect 14 end	54.54409	3.07350
Transect 15 start	54.54746	3.07597
Transect 15 end	54.54792	3.06473
Transect 16 start	54.55072	3.06408
Transect 16 end	54.55054	3.07465
Transect 17 start	54.55355	3.07348
Transect 17 end	54.55304	3.06287
Transect 18 start	54.55556	3.06447
Transect 18 end	54.55569	3.07163
Transect 19 start	54.55857	3.07410
Transect 19 end	54.55898	3.06740
I1	54.53504	3.05825
I2	54.54795	3.06508
I3	54.55383	3.06374
OB1	54.53455	3.05990
OB2	54.54747	3.06725
OB3	54.55374	3.06626
OS1	54.53467	3.05974
OS2	54.54761	3.06680
OS3	54.55371	3.06568

Table 2. Summary data (given as geometric means with lower and upper 95% confidence limits in parentheses) for densities of small (length 40 to 99 mm), medium (100 to 249 mm), large (250 mm and greater) and all fish recorded during the night-time hydroacoustic survey of Thirlmere.

Small fish (fish ha^{-1})	Medium fish (fish ha^{-1})	Large fish (fish ha^{-1})	All fish (fish ha^{-1})
2.3 (1.3, 4.2)	2.2 (1.2, 4.1)	1.5 (0.9, 2.3)	4.3 (2.1, 9.0)

Table 3. Numbers of fish individuals recorded in the gill-net survey of Thirlmere. Sites are also identified as inshore (I), offshore bottom (OB) or offshore surface (OS) with individual numbering from 1 to 3.

Site	Arctic charr	Brown trout	Perch	Ruffe	Total
I1	0	0	26	5	31
I2	0	1	64	6	71
I3	0	1	30	5	36
OB1	1	0	0	0	1
OB2	0	0	0	0	0
OB3	0	0	0	0	0
OS1	0	0	0	0	0
OS2	0	0	0	0	0
OS3	0	2	28	0	30
Total	1	4	148	16	169

Fig. 1. The single Arctic charr sampled by gill netting. See text for further details.

Fig. 2. The single Arctic charr sampled by entrapment. See text for further details.

Fig. 3. The monthly entrapment patterns of perch (closed bars) and ruffe (open bars) from 1 April 2011 to 31 March 2012.