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ASSESSMENT OF THE VENDACE POPULATION OF BASSENTHWAITE LAKE INCLUDING OBSERVATIONS ON VENDACE SPAWNING GROUNDS

FINAL REPORT

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EXECUTIVE SUMMARY

1. Previous studies and a current monitoring programme have shown that the status of the vendace (*Coregonus albula*) in Bassenthwaite Lake in north-west England has now been poor for at least two decades. This is in contrast to the condition of the only other surviving native U.K. population of this rare fish in nearby Derwent Water, which remains acceptable. Furthermore, at Bassenthwaite Lake a survey gill-netting component of the monitoring programme has not recorded any biological specimens of vendace since 2000, although four individuals were recorded in 2001 during broodstock collection for a successful translocation programme. Such survey gill netting is undertaken at a relatively low level of effort because of its destructive nature and the fact that it catches appreciable numbers of several other fish species. Given this situation, it is now highly desirable to use other means to acquire a robust assessment of the continued presence or otherwise of the vendace in Bassenthwaite Lake.

2. The primary objective of the present project was to attempt to produce unequivocal evidence of the continued presence of vendace in Bassenthwaite Lake by the use of underwater video and high-frequency hydroacoustics observations on a previously-used vendace spawning ground, and by the deployment of a high sampling effort of custom-built gill nets in offshore areas. In addition, a secondary objective was to develop bottom-typing and associated macrophyte analyses of hydroacoustic recordings recently made in Bassenthwaite Lake and Derwent Water in order to improve the assessment of their ecological conditions. During the course of the project, a further objective was added to look for vendace eggs in the gut contents of ruffe (*Gymnocephalus cernuus*) caught during the above netting.

3. An underwater video system with colour and infra-red cameras and integral lights was deployed on a previously-used vendace spawning ground near Beck Wythop in Bassenthwaite Lake on the evenings of 22 November, 6 December and 12 December 2007, and for comparative purposes on a known vendace spawning ground near Calf Close Bay in Derwent Water on 11 December 2007. Using the infra-red camera and integral light, no vendace were observed at either site although ruffe were frequently observed at Bassenthwaite Lake. The only fish seen at Derwent Water was a single minnow (*Phoxinus phoxinus*). In addition, a high-frequency (1.1 and 1.8 MHz) hydroacoustics DIDSON system was deployed during the underwater video observations of 6 December 2007 at Bassenthwaite Lake. However, this system also did not reveal any vendace. Thus, both types of observations failed to produce any sightings of vendace in Bassenthwaite Lake.

4. Using custom-built gill nets designed to sample adult vendace and set in areas of Bassenthwaite Lake most likely to be inhabited by such individuals, over three dates in early 2008 a total of 294 fish was sampled comprising 8 brown trout (*Salmo trutta*), 40 perch (*Perca fluviatilis*), 7 pike (*Esox lucius*), 32 roach (*Rutilus rutilus*) and 207 ruffe but no vendace.

5. The diets of 68 of the above ruffe (ranging in length and weight from 66 to 142 mm and 4 to 42 g, respectively) from a site nearest to the previously-used vendace spawning ground of Beck Wythop sampled on 11 February 2008 were examined for the presence of vendace eggs. None were found, with the diet instead appearing to be composed exclusively of chironomid larvae.

6. Hydroacoustics recordings made previously on vendace spawning grounds and elsewhere in Bassenthwaite Lake and Derwent Water were explored with the developers of the analytical softwares VBT and EcoSAV, which are appropriate for bottom typing and macrophyte mapping, respectively. Unfortunately, such dialogue revealed that the collection of further ground-truthing data is necessary to complete the bottom typing of the recorded survey data using VBT, which was not possible within the resources of the present project. Discussions and data explorations in this general field were also held with the developers of the analytical software Sonar5-Pro, for which potential developments may prove to be extremely useful for the characterisation and mapping of vendace spawning grounds.

7. In summary, while it is inherently impossible to prove a negative, a hypothesis of a recent extinction of the vendace from Bassenthwaite Lake was supported by three independent lines of evidence, i.e. no observations of vendace on a previously-used spawning ground were produced by infra-red underwater video and high-frequency hydroacoustics systems, no vendace were sampled by the extensive use of custom-built gill nets designed to sample adult vendace and used at a sampling effort an order of magnitude greater than that used during routine vendace monitoring, and no vendace eggs were present in the diets of ruffe sampled from a site nearest to the above previously-used vendace spawning ground during the egg incubation period.

8. Five areas of continuing or new work were identified and recommended. Firstly, it is recommended that further effort is directed towards completing analysis of the hydroacoustic surveys of vendace spawning grounds in Bassenthwaite Lake and Derwent Water. Secondly,

further macrophyte monitoring by hydroacoustics and underwater video recording is recommended in both lakes, with a particular emphasis on the introduced New Zealand pygmy weed (*Crassula helmsii*). Thirdly, it is recommended that a basic population model for vendace is developed to guide future management options. Fourthly, it is recommended that a scoping study is undertaken of the reintroduction of vendace to Bassenthwaite Lake from a refuge population established in Loch Skeen, south-west Scotland. Fifthly, it is recommended that efforts are continued to increase public awareness of the need for vendace conservation through the development of improved vendace signage, leaflet production, internet presence and live exhibits in appropriate public aquaria.

CHAPTER 1 INTRODUCTION

1.1 Background

The vendace (*Coregonus albula*) is the U.K.'s rarest freshwater fish species and is accordingly protected by its inclusion on Schedule 5 of the Wildlife and Countryside Act of 1981. It is also included on the List of Priority Species of the U.K. Biodiversity Action Plan (www.ukbap.org.uk). Following the loss of two populations from south-west Scotland during the previous century, the only remaining native populations occur in Bassenthwaite Lake and nearby Derwent Water in north-west England (Winfield *et al.*, 2004).

However, previous studies (Mubamba, 1989; Winfield *et al.*, 1994a) and a current monitoring programme (Winfield *et al.*, 2008a) have shown that the status of the vendace in Bassenthwaite Lake has now been poor for at least two decades, in contrast to that of Derwent Water which remains acceptable. Furthermore, at Bassenthwaite Lake a survey gill-netting component of the monitoring programme of Winfield *et al.* (2008a) has not recorded any biological specimens of vendace since 2000, although four individuals were recorded in 2001 during broodstock collection for a translocation programme. Although such survey gill netting is undertaken at a relatively low level of effort because of its destructive nature and the fact that it catches appreciable numbers of several other fish species, the recent persistent absence of vendace suggests that this species may now be locally extinct in Bassenthwaite Lake.

The above vendace population faces a number of environmental threats including species introductions, eutrophication, climate change and sedimentation on its spawning grounds (Winfield *et al.*, 2004), but the latter problem currently appears to be the most severe. Extensive surveys of known and potential vendace spawning grounds in Bassenthwaite Lake and Derwent Water have observed widespread deposits of fine sediments in the former but not the latter lake (Winfield *et al.*, 1998a; Winfield *et al.*, 2007). In anticipation of the potential consequences of the deteriorating environmental conditions in Bassenthwaite Lake, a refuge population of vendace originating from this water body has been established in Loch Skeen in south-west Scotland (Lyle *et al.*, 1999; Maitland *et al.*, 2003) and has recently been assessed and found to be in favourable condition (Winfield *et al.*, 2008b). This new population forms a potential source of vendace for future restocking into a restored Bassenthwaite Lake.

Given the above situation, it is now highly desirable to acquire a more robust assessment of the continued presence or otherwise of the vendace in Bassenthwaite Lake. Although the vendace monitoring programme described above continues, its biological sampling effort cannot be feasibly increased significantly due to its by-catch of other fish species. As a result, it is unlikely to record any vendace unless the local population increases significantly in abundance. At extremely low population densities, alternative sampling approaches are required in order to detect vendace unequivocally. Conversely, although it is impossible to prove a negative, if such techniques again fail to record vendace then this would add further weight to a hypothesis of local extinction.

1.2 Objectives

The primary objective of the present project was to attempt to produce unequivocal evidence of the continued presence of vendace in Bassenthwaite Lake by the use of underwater video and high-frequency hydroacoustics observations on a previously-used vendace spawning ground, and by the deployment of a high sampling effort of custom-built gill nets in deep water. In addition, a secondary objective was to develop bottom-typing and macrophyte analyses of hydroacoustic recordings made previously on vendace spawning grounds and elsewhere in Bassenthwaite Lake and Derwent Water in order to improve the assessment of their ecological conditions. During the course of the project, a further objective was added to look for vendace eggs in the gut contents of ruffe (*Gymnocephalus cernuus*) caught during the above netting.

CHAPTER 2 UNDERWATER OBSERVATIONS ON VENDACE SPAWNING GROUNDS

2.1 Introduction

Although vendace populations spend most of the year in deep-water habitats where they are relatively dispersed and so difficult to observe by techniques capable of unequivocally identifying them to species, during November and December they temporarily migrate after dark onto inshore spawning grounds of depth less than 4 m (Winfield *et al.*, 1994a; Winfield *et al.*, 1994b) where they are much more amenable to observation. This natural concentration effect is likely to be particularly beneficial for the observation of populations which are at best scarce, as is the case at Bassenthwaite Lake.

For the specific case of Bassenthwaite Lake, a previously-used vendace spawning ground near Beck Wythop offers a particularly appropriate site for an attempt to detect vendace by this approach. Following successful sampling for spawning vendace at this site in the early 1990s by Winfield *et al.* (1994a), its habitat features have been described in detail by Winfield *et al.* (1998a) and Winfield *et al.* (2007), while it was also used as a source of vendace eggs for a translocation programme in the late 1990s by Lyle *et al.* (1999). It also has the advantage of being readily accessible by road and a short track.

Although Winfield *et al.* (2007) were able to observe *Coregonus lavaretus* with the naked eye after dark at an inshore spawning site in Hallstättersee, Austria, by a remarkable combination of clear water and street lighting, such an approach is clearly unsuited to the turbid, unlit waters of Bassenthwaite Lake. However, underwater video recording combined with infra-red lighting offers an alternative and unobtrusive means of short-range observation. In addition, the use of the high-frequency hydroacoustics DIDSON system can produce high-resolution moving images in turbid water with no requirement for light and at a much greater range (see Moursunda *et al.* (2003)).

The objective of this part of the present project was to attempt to produce unequivocal evidence of the continued presence of vendace in Bassenthwaite Lake by the use of underwater video and high-frequency hydroacoustics observations on a previously-used vendace spawning ground.

2.2 Methods

A SeaViewer Underwater Video System with colour and infra-red cameras and integral lights (SeaViewer Cameras, Inc., Tampa, U.S.A., www.seaviewer.com) mounted to a static platform and recording digitally to an ARCHOS 604 Portable Multimedia Player (ARCHOS, Igny, France, www.archos.com) was used as the primary method of underwater observation (Fig. 1).

In Bassenthwaite Lake, this system was deployed on the previously-used vendace spawning ground near Beck Wythop (54°, 38.840’ North, 3°, 13.127’ West) on the evenings of 22 November (16.30 to 19.00 hours), 6 December (16.00 to 18.30 hours) and 12 December (16.00 to 18.30 hours) 2007 (Fig. 2). For comparative purposes, a similar deployment was made on a vendace spawning ground near Calf Close Bay in Derwent Water (54°, 34.780’

North, 3°, 7.964’ West) on 11 December 2007 (16.00 to 18.30 hours). On each occasion, live observations were made continuously over the survey period using the infra-red camera and integral light of the system, with 5 minute segments also recorded at 30 minute intervals for later review in the laboratory on a larger viewing screen. Surface water temperature was also recorded on each occasion.

In addition, a high-frequency (1.1 and 1.8 MHz) hydroacoustics DIDSON system (Sound Metrics Corp., Washington, U.S.A., www.soundmetrics.com) owned and operated by the Environment Agency was deployed in a horizontal orientation throughout the underwater video observations of 6 December at Bassenthwaite Lake. Moving images produced at approximately 6 frames per second to a range of 10 m were viewed live in the field and all data were recorded for subsequent review and further analysis in the laboratory. The latter was performed using the hydroacoustic software Sonar5-Pro Version 5.9.7 (24.09.2007) (Lindem Data Acquisition, Oslo, Norway, www.fys.uio.no/~hbalk/sonar4_5) and included on-screen measurements of individual fish lengths.

2.3 Results

Surface water temperature at Bassenthwaite Lake on 22 November, 6 December and 12 December 2007 was 6.8, 7.7 and 6.0 ºC, respectively. At Derwent Water on 11 December 2007 it was 6.0 ºC.

Using the underwater video system, no vendace were observed at either site although ruffe were frequently observed at Bassenthwaite Lake (Fig. 3). The only fish seen at Derwent Water was a single minnow (*Phoxinus phoxinus*).

The high-frequency hydroacoustics DIDSON system also did not reveal any vendace during live observations at Bassenthwaite Lake. Fish subsequently observed on the recordings reviewed in the laboratory comprised two large individuals of approximately 800 and 1000 mm in length, which on the basis of their size and swimming motions were both probably Atlantic salmon (*Salmo salar*), together with 10 small individuals of between approximately 40 and 130 mm in length, which were probably ruffe (Fig. 4). Thus, no fish of the size range of adult vendace (approximately 200 to 280 mm) were observed and none showed any movements typical of spawning behaviour.

2.4 Discussion

Extensive underwater video observations over three evenings, augmented on one occasion by high-frequency hydroacoustics, spanning the vendace spawning season on a previously-used vendace spawning ground in Bassenthwaite Lake failed to produce any records of this species. Although disappointing, this finding does not itself constitute definitive evidence of the local extinction of vendace as evidenced by the failure of underwater video to observe specimens during a more limited deployment in Derwent Water, where the population is known to persist (Winfield *et al.*, 2008a).

CHAPTER 3 CUSTOM-BUILT GILL NETTING IN DEEP WATER

3.1 Introduction

As noted in the introduction, the survey gill-netting component of the monitoring programme of Winfield *et al.* (2008a) has not recorded any vendace in Bassenthwaite Lake since 2000, although four individuals were sampled in 2001 during broodstock collection for a translocation programme (Winfield & Fletcher, 2002). While such survey gill netting is routinely undertaken at a relatively low level of effort because of its destructive nature and its capture of appreciable numbers of several other fish species, Winfield *et al.* (2006) recommended that the importance of resolving the apparent local extinction of vendace from Bassenthwaite Lake was now such that greatly increased gill-net sampling effort outside the monitoring programme was warranted.

The scale of the vendace reduction observed in Bassenthwaite Lake in recent years has been such that an appropriate increase in sampling effort would have to be very substantial. For example, outside the monitoring programme of Winfield *et al.* (2008a), the setting of 22 nets in 1997 (Lyle *et al.*, 1998a), 48 nets in 1998 (Lyle *et al.*, 1998b), 9 nets in 2000 (Winfield & Fletcher, 2002) and 25 nets in 2001 (Winfield & Fletcher, 2002) resulted in the captures of just 5, 35, 0 and 4 vendace, respectively. This netting inevitably produced an extremely high by-catch of other fish species which is highly undesirable not only on ethical grounds, but also on logistical grounds given the appreciable amount of time required to clear a gill net of species such as ruffe and perch (*Perca fluviatilis*). However, such by-catch can be minimised by the use of gill nets of mesh sizes optimal for sampling only fish of the length of adult vendace and by their placement in areas most likely to be inhabited by vendace and less by other fish species.

The objective of this part of the present project was to attempt to produce unequivocal evidence of the continued presence of vendace in Bassenthwaite Lake by the use of a high sampling effort of custom-built gill nets in offshore areas.

3.2 Methods

Based on the mesh panels of the Norden survey gill net (Appelberg, 2000) which are most likely to catch fish of the size of adult vendace (approximately 200 to 280 mm), bottom-set and surface-set custom-built gill nets were designed by the authors and then constructed by a scientific supplier (Lundgrens Fiskredskap, Stockholm, Sweden, www.lundgrensfiske.com). The bottom-set custom-built gill net was of a monofilament design measuring approximately 1.5 m deep and 30 m long with 4 panels of equal length of bar mesh sizes 15.5, 19.5, 24.0 and 29.0 mm. The surface-set custom-built gill net was of the same material, mesh sizes and length, but had a depth of 6.0 m. For sampling adult vendace, each of the custom-built gill nets thus had a sampling power three times greater than that of its Norden survey gill net counterpart.

On 11 February 2008, single bottom-set and surface-set custom-built gill nets were set overnight at a deep-water site of approximately 20 m water depth off the previously-used vendace spawning ground of Beck Wythop (Fig. 2, Table 1). Here this site is referred to as Site 1, but it is the same location as Site 3 of the monitoring programme of Winfield *et al.*

(2008a). The same procedure was repeated on 12 February 2008 at two further sites (Sites 2 and 3) of similar water depth (Fig. 2, Table 1). Finally, on 8 April 2008 single surface-set custom-built gill nets were again set at Sites 1, 2 and 3.

With the exception of large pike (*Esox lucius*) in good condition which were released alive, all captured fish were taken directly to the laboratory where they were frozen at -20 °C to await future processing. At a later date, after being partially thawed all fish were enumerated, measured (fork length, mm) and weighed (total wet, g). In addition, the gut contents of 68 of the ruffe were examined for the presence of vendace eggs as described below in Chapter 4.

With a total of nine custom-built gill nets, each with a sampling power for adult vendace three times greater than that of its Norden survey gill net counterpart, used over the three sampling dates of early 2008, for the purposes of detecting adult vendace the present exercise had a sampling effort 13.5 times greater than that of the monitoring programme of Winfield *et al.* (2008a) which uses two Norden survey gill nets (one bottom-set and one surface-set).

3.3 Results

A total of 294 fish (Table 2) was sampled comprising 8 brown trout (*Salmo trutta*) (ranging in length and weight from 170 to 237 mm and 52 to 153 g, respectively), 40 perch (ranging in length and weight from 106 to 263 mm and 14 to 292 g, respectively), 7 pike (ranging in length and weight from 574 to 685 mm and 2151 to 4116 g, respectively (5 individuals were immediately released unmeasured and unweighed)), 32 roach (*Rutilus rutilus*, ranging in length and weight from 110 to 224 mm and 17 to 200 g, respectively) and 207 ruffe (ranging in length and weight from 66 to 142 mm and 4 to 42 g, respectively).

3.4 Discussion

Using gill nets designed to sample adult vendace and set in areas of Bassenthwaite Lake most likely to be inhabited, extensive sampling over three dates in early 2008 failed to produce any records of this species. Such a negative result cannot constitute definitive evidence of the local extinction of vendace, as exemplified by the fact that recent gill-net monitoring in the lake by Winfield *et al.* (2008a) has failed to record dace (*Leuciscus leuciscus*) even though this cyprinid is known to persist in anglers' catches (first author, personal observations). However, such a negative result is strongly supportive of a hypothesis that the vendace has indeed been lost from Bassenthwaite Lake. It is also notable that during the 2007 monitoring of vendace in Derwent Water, both bottom-set and surface-set nets recorded vendace with an effective sampling effort approximately an order of magnitude lower than that of the present study (Winfield *et al.*, 2008a).

CHAPTER 4 DIET OF RUFFE DURING THE VENDACE EGG INCUBATION PERIOD

4.1 Introduction

Given evidence from elsewhere in the U.K. of the ability of introduced ruffe to consume large numbers of coregonid eggs (e.g. Adams & Tippett, 1991), the introduction and subsequent population expansion of this species in Bassenthwaite Lake have been studied in detail as reviewed by Winfield *et al.* (2004). Studies in the mid 1990s did not find vendace eggs in the diet of ruffe during the winter of 1995/1996 (Winfield *et al.*, 1998b), but did find them in the following winter of 1996/1997 (Winfield *et al.*, 1998c). Subsequently, vendace eggs were again found in the diet of this introduced percid in the winter of 2001/2002 (Winfield & Fletcher, 2002).

While this propensity of ruffe to eat coregonid eggs is usually considered an undesirable feature, it could in theory also be exploited in a positive sense to provide evidence for the local presence of a coregonid population. For the specific case of Bassenthwaite Lake, the occurrence of vendace eggs in the winter diet of ruffe, which would be readily identifiable given the lack of any other comparable eggs in the environment at this time of year, would provide evidence for the continued survival of this coregonid even if it was so scarce as to be practically undetectable by more direct means.

The objective of this part of the present project was to look for vendace eggs in the gut contents of ruffe caught in the winter of 2007/2008 during the netting exercise described in Chapter 3.

4.2 Methods

Ruffe to be examined for the presence of vendace eggs in their diet should ideally be sampled at the time of vendace spawning and on the vendace spawning ground. However, this specific objective had not been adopted within the present project at the time of the vendace spawning period of late 2007, nor did it have any dedicated sampling resources. Consequently, a sample of ruffe was instead obtained from the netting exercise described in Chapter 3 at the earliest date sampled during the subsequent vendace egg incubation period and at the sampling site nearest to the previously-used vendace spawning ground of Beck Wythop.

A total of 68 ruffe ranging in length and weight from 66 to 142 mm and 4 to 42 g, respectively, was available from the sampling at Site 1 (Fig. 2, Table 1) on 11 February 2008 as described in full in Chapter 3. All individuals had all been sampled by the bottom-set net. Immediately after the laboratory examination described in Chapter 3, the gut contents of each individual were transferred to a Petri dish and examined under a low power magnification for the presence of vendace eggs. Casual non-quantitative observations were also made of other gut contents.

4.3 Results

No vendace eggs were found in the gut contents of any ruffe. Instead, diet composition appeared to be composed exclusively of chironomid larvae, although it is possible that smaller prey or other broken larger prey were not detected by the present rapid examination procedure.

4.4 Discussion

The use of ruffe as a biological detector of vendace eggs, and thus as an indicator of a surviving vendace population in Bassenthwaite Lake, is clearly not infallible as evidenced by the fact that no eggs were found in the diet of ruffe during the winter of 1995/1996 (Winfield *et al.*, 1998b) but they were detected in the following winter of 1996/1997 (Winfield *et al.*, 1998c). Furthermore, the present sampling of ruffe was limited both temporally and spatially, being conducted both after spawning (although during egg incubation) and not on a spawning ground (although ruffe may move into such areas to feed during the evening and then retreat to deeper waters). In addition, heavy siltation frequently occurs in the inshore areas of Bassenthwaite Lake during the winter months (Winfield *et al.*, 2007) and could make it difficult for foraging ruffe to locate any vendace eggs that had been laid in the preceding weeks.

Although the above limitations must be borne in mind, the present finding of no vendace eggs in the diet of ruffe during the winter of 2007/2008 is another observation which is consistent with the hypothesis of a recent local extinction of vendace from Bassenthwaite Lake.

CHAPTER 5 ECOLOGICAL CONDITIONS OF VENDACE SPAWNING GROUNDS

5.1 Introduction

The following description of typical vendace spawning grounds is taken from the extensive review of European literature on coregonid ecology by Winfield *et al.* (1994b) and serves as a useful reminder of the conditions that were presumably once present in Bassenthwaite Lake and still persist in Derwent Water (Winfield *et al.*, 2007). The spawning grounds of late autumn-spawning populations of this species, which include the populations of both Bassenthwaite Lake and Derwent Water, are located on the steep or gentle slopes of shorelines and islands, in the regions of underwater wells, or in river mouths. The sites used in a given lake are remarkably consistent from year to year, and are generally at depths of less than 10 m. The substratum is usually hard, often with stones or gravel and thus largely devoid of fine sediments, and sometimes has macrophytes present.

Using the above background information as a guide, Winfield *et al.* (1998a) used air-lift sampling and kick sampling for vendace eggs together with underwater video observations to describe site conditions at Bassenthwaite Lake and Derwent Water during 1997 and 1998. In addition, information on the locations of spawning vendace in Bassenthwaite Lake in 1996 and in both lakes in 1997 subsequently reported by Lyle *et al.* (1998a) and Lyle *et al.* (1998b) was also taken into consideration. At Bassenthwaite Lake, this resulted in the location and description of three actual spawning grounds in very poor condition, no potential spawning grounds and 17 unsuitable spawning grounds. All sites examined were heavily laden with fine sediments. Moreover, in addition to being sediment-laden, all three spawning grounds supported no macrophytes or only sparse growths in the form of isoetids. At Derwent Water, six actual spawning grounds in good condition were located and described, together with 14 potential spawning grounds and six unsuitable spawning grounds. Conditions for spawning vendace were much more appropriate, with far less or no fine sediments at many sites and frequently extensive macrophyte growths in the form of isoetids or elodeids. Further investigations at Derwent Water during a vendace translocation effort in late 2004 revealed the presence of large amounts of the invasive macrophyte New Zealand pygmy weed (*Crassula helmsii*) on inshore areas previously used by spawning vendace (Lyle *et al.*, 2005), but further studies using underwater video and hydroacoustic techniques during the spawning season of 2005 showed that all sites remained suitable for vendace spawning and incubation (Winfield *et al.*, 2006). More recent underwater video and hydroacoustic surveys of macrophytes at Bassenthwaite Lake and Derwent Water during the vendace egg incubation period of early 2007 showed that their relative conditions had persisted, with further deterioration at Bassenthwaite Lake and no significant loss of spawning habitat in Derwent Water (Winfield *et al.*, 2007). Similar conclusions were reached by Coyle & Adams (2008) on the basis of more extensive and more rigorous underwater video observations during July 2007 using a remotely operated vehicle.

In addition to the above macrophyte surveys at Bassenthwaite Lake and Derwent Water, the project reported by Winfield *et al.* (2007) also had a secondary objective of using the same and additional hydroacoustic data in conjunction with developing hydroacoustic bottom-typing techniques to produce more extensive maps of substrate types in Bassenthwaite Lake. However, this objective could not be pursued by Winfield *et al.* (2007) beyond initial extensive data collection during April 2007 due to resource constraints.

The objective of this part of the present project was to address these postponed bottom-typing and associated macrophyte analyses of hydroacoustic recordings made in Bassenthwaite Lake, together with some consideration of corresponding data from Derwent Water for comparative purposes, in order to improve the assessment of their ecological conditions.

5.2 Methods

Hydroacoustics and associated underwater video recordings made on vendace spawning grounds and other areas in Bassenthwaite Lake on 10 and 11 April 2007 and in Derwent Water on 12 April 2007 by Winfield *et al.* (2007) were explored during a visit (funded from outside the present project) during October 2007 to the developers (BioSonics Inc, Seattle, U.S.A., www.biosonicsinc.com) of the hydroacoustics analytical softwares VBT and EcoSAV, which are appropriate for bottom typing and macrophyte mapping, respectively.

In addition, during December 2007 discussions and data explorations in this general field were held during a visit (again funded from outside the present project) to the developers (Lindem Data Acquisition, Oslo, Norway, www.fys.uio.no/~hbalk/sonar4_5) of the analytical software Sonar5-Pro. Although this software was initially developed exclusively for the analysis of hydroacoustics data for fish, it now also contains a macrophyte analysis module and the rapidly developing nature of this software had suggested that further developments may be possible.

5.3 Results

Discussions and data explorations in relation to VBT indicated that the collection of further ground-truthing data is necessary to complete the bottom typing of the recorded survey data using this analytical software, which unfortunately was not possible within the time resources of the present project.

Discussions and data explorations in relation to Sonar5-Pro indicated that this analytical software may well be further developed in the near future to include bottom-typing analyses of the kind required within the present study.

5.4 Discussion

Although this part of the project did not produce any definitive results due to limited time resources, it did precipitate useful direct dialogue with two of the leading developers of software for the analysis of hydroacoustic data from lake habitats. In particular, potential developments in the analytical software Sonar5-Pro in the near- to medium-term future may prove to be extremely useful for the characterisation and mapping of vendace spawning grounds.

CHAPTER 6 GENERAL DISCUSSION AND RECOMMENDATIONS

6.1 General discussion

The findings of the various components of this project have already been discussed within their specific chapters. However, a very brief general discussion is warranted here to bring together these elements of evidence relating to the present status of the vendace in Bassenthwaite Lake.

While it is inherently impossible to prove a negative, the hypothesis of a recent extinction of vendace from Bassenthwaite Lake was supported by three independent lines of evidence, i.e. no observations of vendace on a previously-used spawning ground were produced by infra-red underwater video and high-frequency hydroacoustics systems (Chapter 2), no vendace were sampled by the extensive use of custom-built gill nets designed to sample adult vendace and used at a sampling effort an order of magnitude greater than that used during routine vendace monitoring (Chapter 3), and no vendace eggs were present in the diets of ruffe sampled from a site nearest to the above previously-used vendace spawning ground during the egg incubation period (Chapter 4).

6.2 Recommendations

Against the background of previous research at Bassenthwaite Lake and Derwent Water and with the results of the present project in mind, a total of five areas of continuing or new work is identified and recommended here. These will be presented with the first two relating to the further investigation of environmental conditions in Bassenthwaite Lake, the next two concerning the direct conservation management of the vendace and the final one addressing the wider issue of public awareness of vendace conservation.

Firstly, to improve knowledge of the distribution of substrates in Bassenthwaite Lake it is recommended that further effort is directed towards the hydroacoustic survey of the lake bottom which was an initial secondary objective of the present project, together with limited comparisons with data from Derwent Water. Although such investigation was not completed here due to resource constraints, the future application of bottom-typing techniques to already-collected data would be informative.

Secondly, given a further reduction in macrophyte distribution in Bassenthwaite Lake and changes in macrophyte, including New Zealand pygmy weed (*Crassula helmsii*), distribution in Derwent Water observed by Winfield *et al.* (2007), further macrophyte monitoring by hydroacoustics and underwater video recording is recommended. Having established appropriate series of transects in both lakes, such assessments can now be made with a minimum amount of time in the field and also require relatively little time in the laboratory for subsequent data analyses.

Thirdly, despite the lack of significant progress achieved by Winfield *et al.* (2007), a basic population model for vendace remains very desirable. Such a tool would be useful to guide future management options, including for example the potential reintroduction of vendace to Bassenthwaite Lake. Given the increasing likelihood of such a reintroduction ultimately being carried out, further endeavour in this area is consequently recommended.

Fourthly, given that the development of an effective artificial spawning substrate system for free-swimming vendace now looks unachievable in the immediate future in Bassenthwaite Lake (Winfield *et al.*, 2007) and would be futile if the local population is indeed now extinct, it is recommended that a scoping study is undertaken of the sustained reintroduction of vendace over a number of years in the form of eggs stripped from the refuge population established in Loch Skeen. Such activity should include contacts with the international vendace research community. Many members of the latter have considerable experience and expertise with vendace stocking for fisheries purposes, much of which is likely to be directly transferable to such a reintroduction programme. Recent recommendations made by Thompson *et al.* (2008) concerning genetics aspects of vendace stocking programmes should also be taken into consideration.

Fifthly and finally, the issue of vendace conservation remains relatively little known amongst the general public of the U.K. This situation in part reflects the lower public interest held by fish when compared, for example, with birds or mammals. However, it also results in part from the near-impossibility of seeing a vendace in its natural habitat. In this context, it is recommended that the development of improved vendace signage, leaflet production, internet presence and live exhibits in appropriate public aquaria would play an important role within continued efforts to increase public awareness of the need for vendace conservation.

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Table 1. Locations of three gill-netting sites used in Bassenthwaite Lake in early 2008. Locations are given in degrees and decimal minutes.

Site	Latitude (North)	Longitude (West)
1	54, 38.927	3, 12.937
2	54, 39.217	3, 13.136
3	54, 39.372	3, 13.354

Table 2. Numbers of fish individuals recorded in the gill-net surveys of Bassenthwaite Lake in early 2008.

Date	Site	Net type	Perch	Pike	Roach	Ruffe	Trout	Total
11 February 2008	1	Bottom	24	2	21	68	0	115
11 February 2008	1	Surface	0	0	2	0	2	4
12 February 2008	2	Bottom	11	3	3	63	0	80
12 February 2008	2	Surface	0	0	2	0	0	2
12 February 2008	3	Bottom	5	2	0	76	0	83
12 February 2008	3	Surface	0	0	3	0	1	4
8 April 2008	1	Surface	0	0	0	0	3	3
8 April 2008	2	Surface	0	0	0	0	1	1
8 April 2008	3	Surface	0	0	1	0	1	2
Total			40	7	32	207	8	294

Fig. 1. The SeaViewer Underwater Video System with colour and infra-red cameras and integral lights mounted to a static platform as used on vendace spawning grounds in Bassenthwaite Lake and Derwent Water in late 2007.

Fig. 2. Locations in Bassenthwaite Lake of the vendace spawning ground near Beck Wythop surveyed by underwater video and high-frequency hydroacoustics in late 2007 (open circle) and three gill-netting sites (closed circles) used in early 2008. Latitudes and longitudes of sites are given in Table 1. Redrawn with permission from Ramsbottom (1976).

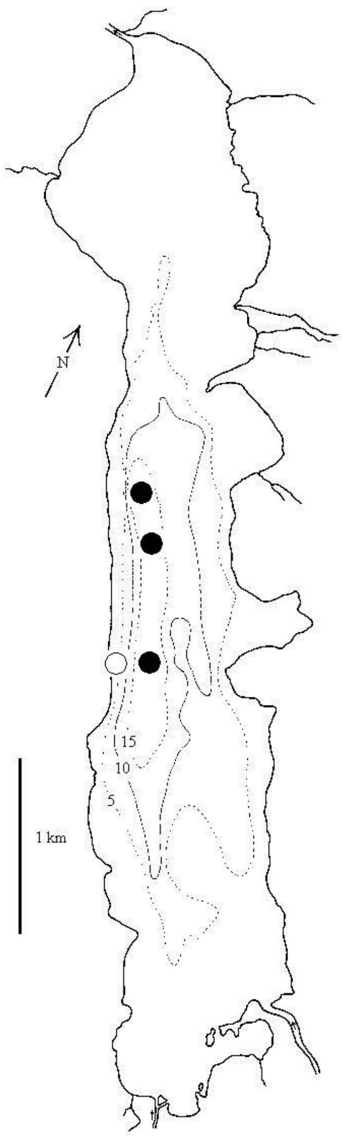

Fig. 3. Representative images taken from infra-red underwater video recordings made on the vendace spawning ground near Beck Wythop in Bassenthwaite Lake on 22 November 2007. A ruffe can be seen approaching (upper image, visible as a pair of highly reflective eyes within the white square) and then turning to the left (lower image, visible as a single eye and side of body within the white rectangle). Note that time and date are given as Greenwich Mean Time and month-day-year format, respectively.

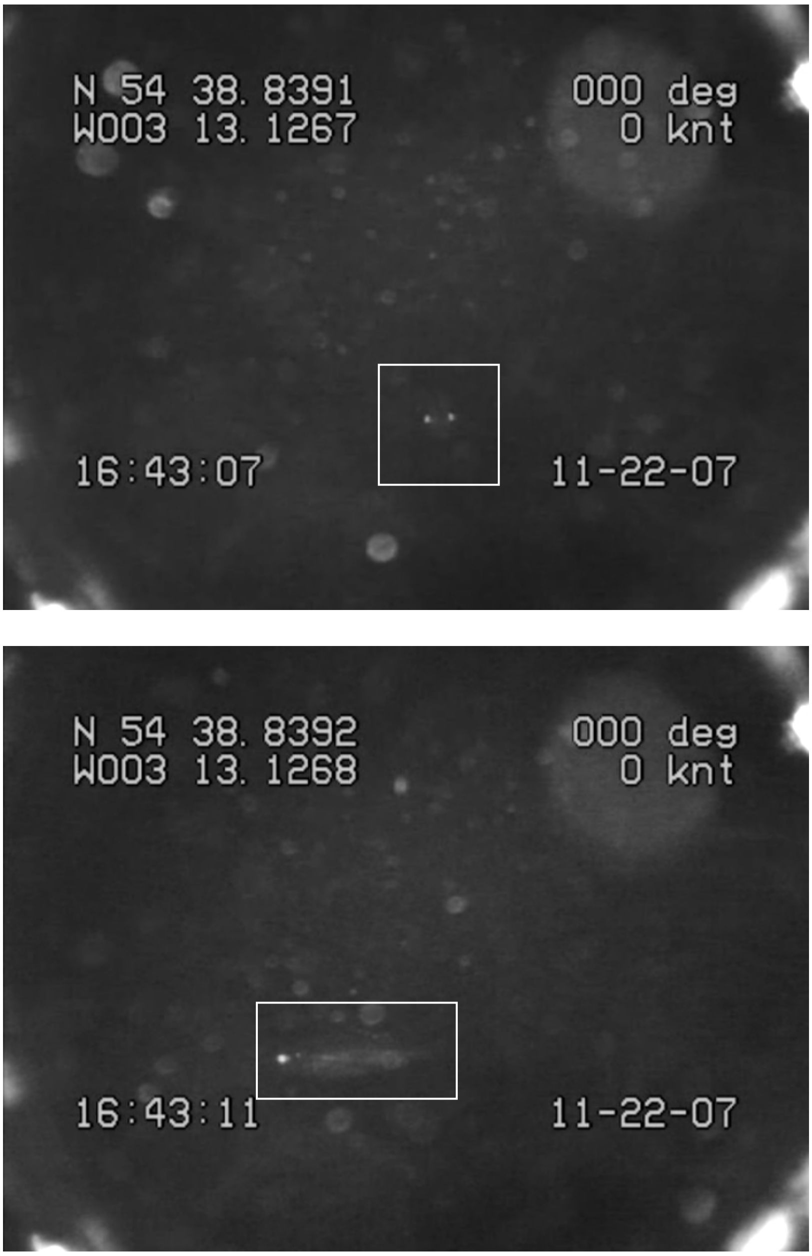

Fig. 4. A representative image taken from high-frequency hydroacoustics DIDSON recordings made on the vendace spawning ground near Beck Wythop in Bassenthwaite Lake on 6 December 2007. Although not apparent in this still image, a small fish of approximately 60 mm in length, probably a ruffe, is present at a range of approximately 5 m (see range scale at the right of the image) from the transducer at the top of the image.