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RARE FISH MONITORING

FINAL REPORT

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

Project Leader: Ian J Winfield
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EXECUTIVE SUMMARY

1. Natural England has an obligation to monitor and report on national and European interest features of SSSIs and SACs, which is being undertaken using Common Standards for Monitoring (CSM). The objectives of the present project were, using CSM where possible, to assess Arctic charr (*Salvelinus alpinus*) in Buttermere, Crummock Water, Ennerdale Water and Wastwater, schelly (*Coregonus lavaretus*) in Brotherswater, Red Tarn and Ullswater, and vendace (*Coregonus albula*) in Bassenthwaite Lake and Derwent Water.

2. Following a CSM-compliant combined hydroacoustic and gill-netting survey carried out from 12 to 14 July 2010, the Arctic charr population of Buttermere is considered to be unfavourable (maintained).

3. Following a CSM-compliant combined hydroacoustic and gill-netting survey carried out from 15 to 16 July 2010, the Arctic charr population of Crummock Water is considered to be favourable.

4. Using hydroacoustic and gill-netting data collected outside the present project, combined with a review of appropriate scientific literature and unpublished reports, the Arctic charr population of Ennerdale Water is considered to be unfavourable (recovering).

5. Following a CSM-compliant combined hydroacoustic and gill-netting survey carried out from 9 to 11 August 2010 and the results of a previous survey in August 2005, the Arctic charr population of Wastwater is considered to be unfavourable (declining).

6. Using hydroacoustic and gill-netting data collected outside the present project, combined with a review of appropriate scientific literature and unpublished reports, the schelly population of Brotherswater is considered to be unfavourable (maintained).

7. Using gill-netting data collected outside the present project, combined with a review of appropriate scientific literature and unpublished reports, the schelly population of Red Tarn is considered to be favourable.

8. Using hydroacoustic and gill-netting data collected outside the present project, combined with a review of appropriate scientific literature and unpublished reports, the schelly population of Ullswater is considered to be favourable.

9. Using hydroacoustic and gill-netting data collected outside the present project, combined with a review of appropriate scientific literature and unpublished reports, the vendace population of Bassenthwaite Lake is considered to be destroyed.

10. Using hydroacoustic and gill-netting data collected outside the present project, combined with a review of appropriate scientific literature and unpublished reports, the vendace population of Derwent Water is considered to be favourable.

11. These findings are briefly discussed in a wider context and recommendations made for future activities.

CHAPTER 1 INTRODUCTION

1.1 Background

Within the U.K., the three rare fish species Arctic charr (*Salvelinus alpinus*), schelly (*Coregonus lavaretus*) and vendace (*C. albula*) are interest features of several standing water Sites of Special Scientific Interest (SSSIs) in Cumbria, north-west England. In addition, the vendace is a European interest feature for which Special Areas of Conservation (SACs) must be designated.

Natural England (NE) has an obligation to monitor and report on national and European interest features of SSSIs and SACs, which is being undertaken using Common Standards for Monitoring (CSM) methodologies (Williams, 2006). Such condition assessments are recorded as one of four categories, i.e. favourable, unfavourable (with sub-categories of declining, maintained or recovering), partially destroyed or destroyed. For rare fish in standing water bodies, these methodologies require the use of hydroacoustics and survey gill nets as first developed and described by Scottish Natural Heritage for Arctic charr by Bean (2003a) and for schelly and vendace by Bean (2003b) and subsequently adopted by JNCC (2005) in their Common Standards Monitoring Guidance for Freshwater Fauna. The latter two species are collectively termed whitefish, which also includes the populations of *Coregonus lavaretus* known as gwyniad and powan in Wales and Scotland, respectively. Assessment criteria specified by Bean (2003a) and Bean (2003b) concern population abundance, population demographic structure and the maintenance of habitat quality. After a number of years of use in assessments of Arctic charr, gwyniad and powan (e.g. Winfield *et* *al.*, 2003; Winfield *et al.*, 2006a; Winfield *et al.*, 2009), the hydroacoustic component of the CSM methodology was reviewed for vendace by Winfield *et al.* (2010a). Outside these CSM activities, the combination of hydroacoustics and survey gill nets has been used by the Centre for Ecology & Hydrology (CEH) for the assessment or longer-term monitoring of Arctic charr in Coniston Water (Winfield *et al.*, 2004a), Ennerdale Water (Winfield *et al.*, 2005), Wastwater (Winfield *et al.*, 2006b) and Windermere (Winfield *et al.*, 2011a), schelly in Haweswater (Winfield *et al.*, 2011b) and vendace in Bassenthwaite Lake and Derwent Water (Winfield *et al.*, 2011c). Aspects of this and other work have also been brought together for Arctic charr in Winfield *et al.* (2010b), for schelly in Winfield *et al.* (1996), and for vendace in Winfield *et al.* (1996), Winfield *et al.* (2004b) and Winfield *et al.* (in press). In addition, the Environment Agency (EA) occasionally undertakes hydroacoustic surveys (Jon Hateley, Environment Agency, *pers. comm.*) and gill-net sampling (Andy Gowans, Environment Agency, *pers. comm.*) of Arctic charr or schelly, including annual hydroacoustic surveys at Ennerdale Water (e.g. Hateley, 2010).

With respect to rare fish in Cumbrian standing water bodies, NE thus has an obligation to produce assessments for Arctic charr in Buttermere, Crummock Water, Ennerdale Water and Wastwater, for schelly in Red Tarn and Ullswater, and for vendace in Bassenthwaite Lake and Derwent Water. In addition, an assessment of schelly in Brotherswater was required as a feature of local distinctiveness.

1.2 Objectives

The objectives of the present project were, using CSM methodology as far as possible, to produce condition assessments for Arctic charr in Buttermere, Crummock Water, Ennerdale Water and Wastwater, for schelly in Brotherswater, Red Tarn and Ullswater, and for vendace in Bassenthwaite Lake and Derwent Water.

CHAPTER 2 METHODOLOGY

2.1 Approach

Following a pre-project meeting between CEH, EA and NE, it was agreed that given available resources NE's assessment obligations would be best met by field surveys at Buttermere, Crummock Water and Wastwater, by a re-examination of hydroacoustic and/or gill-netting data recently collected by CEH and EA outside the present project at Bassenthwaite Lake, Brotherswater, Derwent Water, Ennerdale Water, Red Tarn and Ullswater, and by the review of appropriate unpublished reports previously produced by CEH for EA and others.

2.2 Hydroacoustics at Buttermere, Crummock Water and Wastwater

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 2 m from the transducer. 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 each survey.

At each lake, 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 totals of 9 transects for Buttermere (Table 1), 15 transects for Crummock Water (Table 2), and 15 transects for Wastwater (Table 3). The Wastwater survey thus repeated exactly a survey previously performed in 2005 by Winfield *et al.* (2006b). Surveys were run in the general direction of from the south to the north (Buttermere, Wastwater) or north to the south (Crummock Water) of each lake, began at least two hours after sunset and were of approximately 60 (Buttermere) or 90 (Crummock Water, Wastwater) minutes duration. This gave ratios of coverage (length of surveys : square root of research area) of 4.2:1, 5.5:1 and 4.7:1 for Buttermere, Crummock Water and Wastwater, respectively.

Surveys as described above were carried out at Buttermere, Crummock Water and Wastwater on 12 July, 15 July and 9 August 2010, respectively.

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 previously during the studies of Winfield *et al.* (2006a), Winfield *et al.* (2006b), Winfield *et al.* (2009), Winfield *et al.* (2010a), Winfield *et al.* (2011a), Winfield *et al.* (2011b) and Winfield *et al.* (2011c) 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).

Finally, the mean with 95% confidence limits percentage contribution by small (assumed to be 0+/1+ age class) individuals to the total Arctic charr population was calculated for each site using arcsine-transformed data from each transect on which fish were recorded.

2.3 Gill netting at Buttermere, Crummock Water and Wastwater

2.3.1 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.

At each lake, 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 Tables 1, 2 and 3 for Buttermere, Crummock Water and Wastwater, respectively. Water depth at the inshore habitats was approximately 3 to 4 m, while in the offshore habitats it was approximately 15 to 20 m. Nets were set during the evening and lifted during the morning of the following day and all fish, with the exception of any large salmonids still in good condition which were measured (fork length, mm) before being released alive, 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 Wastwater survey thus repeated exactly a survey previously performed in 2005 by Winfield *et al.* (2006b).

Surveys as described above were carried out at Buttermere, Crummock Water and Wastwater on 13 July, 15 July and 10 August 2010, respectively.

2.3.2 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, all individuals were 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 condition of individual Arctic charr was subsequently 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).

Sample sizes of Arctic charr available for each of the above examinations varied slightly within sites due to variations in the level of pre-lift damage sustained by a few individuals.

2.4 Other data sources for Ennerdale Water, Brotherswater, Red Tarn, Ullswater, Bassenthwaite Lake and Derwent Water

For sites where field surveys were not undertaken within the present project, appropriate information was gathered from the scientific literature, unpublished data and unpublished reports held by CEH and EA. Specific such sources are given in the assessments of each site. Finally, information was also sourced from a number of secondary and semi-popular articles including Horne & Horne (1985), Frost (1989), Talling (1999) and Armsby (2011).

2.5 Condition assessment

Criteria to be used to assess the condition of each Arctic charr, schelly or vendace population specified by Bean (2003a) and Bean (2003b), and subsequently adopted by JNCC (2005) in their Common Standards Monitoring Guidance for Freshwater Fauna, were based on abundance, population demographic structure and maintenance of habitat quality.

For Arctic charr (Bean, 2003a), abundance in an oligotrophic site was considered to be in unfavourable condition if it was below a level of 37 fish ha^{-1}. For a mesotrophic site, the equivalent figure was 520 fish ha^{-1}. Each Arctic charr site was assigned to its appropriate trophic category on the basis of SSSI Citations provided by NE and, where available, the scientific literature or other information sources. This approach classified Buttermere, Crummock Water, Ennerdale Water and Wastwater as oligotrophic (Maberly *et al.*, 2006). Statistical significance of each site's assessment was performed by t tests on log(x+1)-transformed data of Arctic charr abundance from night-time transects, against expected values taken as the above criteria. For population demographic structure, to achieve favourable condition an Arctic charr population required 70% of individuals to be in the 0+/1+ age class, corresponding to individuals in the small length class of 40 to 99 mm. Statistical significance of each site's assessment was performed, where appropriate and possible, by t tests on arcsine-transformed data of Arctic charr population percentage composition from night-time transects on which fish were recorded, against an expected value taken as the above criterion.

For schelly and vendace, the protocol of Bean (2003b) does not set abundance criteria because it considers that the differing ecological status of each site means that reference values must be calculated which are unique for each site. However, it does note that abundance may be used as an indicator of population status. Each schelly and vendace site was assigned to its appropriate trophic category on the basis of SSSI Citations provided by NE and, where available, the scientific literature or other information sources. This approach classified Brotherswater as meso-oligotrophic (Maberly *et al.*, 2006), Red Tarn as oligotrophic (Carrick & Sutcliffe, 1982), Ullswater as mesotrophic (Maberly *et al.*, 2006), Bassenthwaite Lake as meso-eutrophic (Maberly *et al.*, 2006), and Derwent Water as mesotrophic (Maberly *et al.*, 2006). For population demographic structure, to achieve favourable condition a schelly or vendace population required 90% of individuals to be in the 0+/1+ age class, largely corresponding to individuals in the small length class of 40 to 99 mm. Statistical significance of each site's assessment was performed by t tests on arcsine-transformed data of powan population percentage composition from night-time transects on which fish were recorded, against an expected value taken as the above criterion.

For maintenance of habitat quality, to achieve favourable condition an Arctic charr, schelly or vendace site must not have suffered changes in habitat quality through nutrient enrichment, siltation, gravel exposure, or loss of spawning substrate (Bean, 2003a; Bean, 2003b). This habitat aspect of condition assessment was addressed as far as it can be in the field by a brief visual inspection of the site and its immediate catchment, supplemented where possible by reference to the scientific literature or other information sources. In addition, the protocol of Bean (2003b) notes that in order for sites containing schelly or vendace to achieve favourable condition they must not contain established introduced populations of species such as ruffe (*Gymnocephalus cernuus*), although under the condition assessment of JNCC (2005) the presence of such species is only a discretionary attribute. Finally, it is relevant to note that in a recent review of the application of Bean (2003b) to vendace populations it was recommended by Winfield *et al.* (2010a) that the population demographic structure of 90% of individuals in the 0+/1+ age class should be relaxed to 70%, and that even this figure should not be expected to be attained every year due to the inherently variable recruitment of this species. A similar argument could be applied to the application of Bean (2003b) to schelly populations.

Finally, where appropriate and possible, earlier information on the conditions of the Arctic charr, schelly and vendace populations was taken from the scientific literature, unpublished data and unpublished reports held by CEH and EA. Specific such sources are given in the assessments of each site.

CHAPTER 3 ARCTIC CHARR

3.1 Buttermere

The population density recorded by hydroacoustics of all fish had a geometric mean of 1.4 fish ha^{-1} with lower and upper 95% confidence limits of 0.7 and 3.1 fish ha^{-1}, respectively. A breakdown into small (length 40 to 99 mm, likely to contain all young Arctic charr), medium (100 to 249 mm) and large (250 mm and greater) individuals is given in Table 4. Note that the extremely low abundances of fish recorded during the survey resulted in the x+1 transformation performed during the calculation of geometric means having an effect on the summary data, e.g. small fish were not actually recorded on any transect.

Based on a combination of the 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. The contribution of individuals in the 0+/1+ age class to the Arctic charr population was 0%.

A total of 108 fish of five species was sampled by gill netting, comprising 1 Arctic charr, 11 brown trout (*Salmo trutta*), 4 minnow (*Phoxinus phoxinus*), 90 perch (*Perca fluviatilis*) and 2 pike (*Esox lucius*) (Table 5). The single Arctic charr was 224 mm in length, 161 g in weight, aged 4 years, male and had a condition index of 1.43.

For Arctic charr abundance, the observed abundance was clearly below (t test, $t = 24.810$, $df = 8$, $p < 0.001$) the minimum required for favourable condition and so this criterion was failed. Similarly, although the data were such that a statistical assessment was impossible, the contribution of individuals in the 0+/1+ age class to the Arctic charr population was below the required level and so this criterion was also failed. In terms of habitat quality, none of the adverse changes specified by Bean (2003a) were apparent at a significant level and Maberly *et al.* (2006) found no major water quality problems at the lake in 2005. Consequently, the habitat quality criterion was passed.

Unfortunately, it is difficult to put the present Arctic charr observations into a robust temporal context because of the scarcity of previous fish studies at Buttermere. Very early, but subsequently updated, general texts on the English Lake District such as Pearsall & Pennington (1989) give no relevant quantitative information for Arctic charr. Furthermore, a bibliography of Lake District research complied by Horne & Horne (1985) similarly contains no references to any relevant studies with quantitative data, although it does document very brief accounts of Arctic charr in Buttermere given by Frost (1955) and Frost (1965). However, a subsequent primarily genetic and biometric study of Arctic charr from 10 U.K. lakes by Partington & Mills (1988) contains some limited Arctic charr population data from this lake. Although gill-net sampling effort was not reported and so no assessment can be made of even relative abundance at the time of sampling in the mid 1980s, a total of 33 Arctic charr aged from 2 to 10 years was recorded and the authors noted a relatively fast growth rate although they also conceded that some of the older individuals may have been under-aged by their methodology.

On the basis of the above results and background, the overall CSM assessment of Arctic charr in Buttermere is considered to be unfavourable. Given that the present observations cannot be put into a detailed longer-term context and there is no evidence that the population is currently declining or recovering, the most parsimonious sub-category is unfavourable (maintained).

3.2 Crummock Water

The population density recorded by hydroacoustics of all fish had a geometric mean of 43.8 fish ha^{-1} with lower and upper 95% confidence limits of 20.0 and 95.8 fish ha^{-1}, respectively. A breakdown into small (length 40 to 99 mm, likely to contain all young Arctic charr), medium (100 to 249 mm) and large (250 mm and greater) individuals is given in Table 6.

Based on a combination of the hydroacoustic and gill-netting data (see below), the population abundance of Arctic charr was estimated to be 35.2 fish ha^{-1} with lower and upper 95% confidence limits of 16.1 and 77.0 fish ha^{-1}, respectively. The contribution of individuals in the 0+/1+ age class to the Arctic charr population was 60% with lower and upper 95% confidence limits of 40 and 78%, respectively

A total of 112 fish of three species was sampled by gill netting, comprising 41 Arctic charr, 10 brown trout and 61 perch (Table 7). The Arctic charr ranged from 95 to 205 mm in length, 8 to 121 g in weight, 2 to 4 years in age and comprised 18 males, 10 females and 13 immature individuals of indeterminable sex. The overall male : female sex ratio for Arctic charr was thus 1.8:1 and condition index ranged from 0.77 to 1.40, with an overall mean of 0.98 with lower and upper 95% confidence limits of 0.94 and 1.03, respectively. Fig. 1 presents the length frequency distribution and age frequency distribution for Arctic charr.

For Arctic charr abundance, the observed abundance was close to and not significantly below (t test, $t = 0.165$, $df = 14$, $p > 0.10$) the minimum required for favourable condition and so this criterion was passed. Similarly, the contribution of individuals in the 0+/1+ age class to the Arctic charr population was close to and not significantly different from (t test, $t = 1.632$, $df = 13$, $p > 0.10$) the required level and so this criterion was also passed. In terms of habitat quality, none of the adverse changes specified by Bean (2003a) were apparent at a significant level and Maberly *et al.* (2006) found no major water quality problems at the lake in 2005. Consequently, the habitat quality criterion was passed.

It is difficult to put the present Arctic charr observations into a robust temporal context because of the scarcity of previous fish studies at Crummock Water. Very early, but subsequently updated, general texts on the English Lake District such as Pearsall & Pennington (1989) give no relevant quantitative information for Arctic charr. Furthermore, a bibliography of Lake District research complied by Horne & Horne (1985) similarly contains no references to any relevant studies with quantitative data, although it does document very brief accounts of Arctic charr in Crummock Water given by Frost (1955), Frost (1965) and Frost (1977) and some observations on the perch of this lake by Le Cren (1955). 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 Crummock Water. Although gill-net sampling effort was not reported and so no assessment can be made of even relative abundance at the time of sampling in the mid 1980s, a total of 45 Arctic charr aged from 3 to 9 years was recorded. An unreported hydroacoustic survey was performed at Crummock Water in 1996 and although it had some technical limitations and operational difficulties (Jon Hateley, Environment Agency, *pers. comm.*), further analysis of the resulting data may allow some limited comparison with fish abundance observed in 2010.

On the basis of the above results and background, the overall CSM assessment of Arctic charr in Crummock Water is considered to be favourable.

3.3 Ennerdale Water

Assessment of the Arctic charr population of Ennerdale water was undertaken by a re-examination of hydroacoustic and gill-netting data collected by CEH and EA outside the present project, combined with a review of the appropriate scientific literature and appropriate unpublished reports previously produced by CEH.

Very early, but subsequently updated, general texts on the English Lake District such as Pearsall & Pennington (1989) give no relevant quantitative information for Arctic charr. Furthermore, a bibliography of Lake District research complied by Horne & Horne (1985) similarly contains no references to any relevant studies with quantitative data, although it does document very brief accounts of or references to Arctic charr in Ennerdale Water given by Friend (1959), Frost (1965), Frost (1977), Child (1980) and Fryer (1981). Most notably, Frost (1965) records that, somewhat unusually for this species, the population present in Ennerdale Water spawns apparently exclusively in the inflowing River Liza. 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 Ennerdale Water. Although gill-net sampling effort was not reported and so no assessment can be made of even relative abundance at the time of sampling in the mid 1980s, a total of 86 Arctic charr aged from 5 to 10 years was recorded and showed a relatively fast growth rate.

Subsequent to the study by Partington & Mills (1988), the numbers of Arctic charr spawning in the inflowing River Liza declined dramatically (Ben Bayliss, Environment Agency, *pers. comm.*). This development led to the undertaking of a single hydroacoustic survey by EA in 1997, which was subsequently repeated in 2003 and thereafter at annual intervals to the present (Hateley, 2010), and the commissioning of a review and assessment of Arctic charr and brown trout stocks in Ennerdale Water by Winfield *et al.* (2005).

Hateley (2010) provides an estimate of the size of the spawning stock of Arctic charr in Ennerdale Water for 1997 and then annually from 2003 to 2010 as reproduced in Fig. 2. This figure, supported by more detailed analysis of the hydroacoustic time series (Jon Hateley, Environment Agency, *pers. comm.*), suggests that the numbers of adult Arctic charr have shown some increase in recent years. This apparent recovery may have been aided by a recent enhancement programme in which EA stripped eggs from adult Arctic charr in the River Liza and then incubated them in a hatchery before returning the resulting young to the lake itself (Ben Bayliss, Environment Agency, *pers. comm.*). This course of action was itself prompted by the conclusion by Winfield *et al.* (2005) that the decline of Arctic charr observed in Ennerdale Water had been caused by intermittent adverse pH conditions on the riverine spawning grounds.

Winfield *et al.* (2005) also undertook a hydroacoustic survey at Ennerdale Water in 2004 which was technically similar to those reported elsewhere in this report for Buttermere, Crummock Water and Wastwater, although it was undertaken in September rather than in the CSM-compliant months of July and August. This September survey recorded a total fish abundance of 314.9 fish ha^{-1} with lower and upper 95% confidence limits of 209.8 and 472.4 fish ha^{-1}, respectively, which when combined with near-simultaneous gill-netting data collected in September and October 2004 produced an estimate of Arctic charr abundance of 78.7 fish ha^{-1} with lower and upper 95% confidence limits of 52.4 and 118.1 fish ha^{-1}, respectively. It also indicated that the contribution of individuals in the 0+/1+ age class to the Arctic charr population was 95% with 95% confidence limits of 87 and 100%, respectively. However, these abundance and demographic parameters cannot be robustly interpreted in CSM-terms because the survey was not undertaken during the prescribed months of July or August, and Arctic charr population abundance varies significantly with season (Winfield *et al.*, 2007), and because the gill-netting data indicated that most of the detected echoes from small fish probably originated from three-spined stickleback (*Gasterosteus aculeatus*). The gill netting of September and October 2004 reported by Winfield *et al.* (2005) recorded a total of 40 fish comprising three species, i.e. 7 Arctic charr, 17 brown trout and 16 three-spined stickleback. The Arctic charr ranged from 68 to 355 mm in length, 2 to 733 g in weight, 0 to 8 years in age and comprised 2 males, 2 females and 3 immature individuals of indeterminable sex.

In terms of habitat quality, with the possible exception of periodic effective losses of spawning substrate due to low pH as discussed by Winfield *et al.* (2005), none of the adverse changes specified by Bean (2003a) were apparent at a significant level at Ennerdale Water and Maberly *et al.* (2006) found no major water quality problems at the lake in 2005.

On the basis of the above results and background, the overall CSM assessment of Arctic charr in Ennerdale Water is considered to be unfavourable (recovering).

3.4 Wastwater

The population density recorded by hydroacoustics of all fish had a geometric mean of 15.9 fish ha^{-1} with lower and upper 95% confidence limits of 7.0 and 35.9 fish ha^{-1}, respectively. A breakdown into small (length 40 to 99 mm, likely to contain all young Arctic charr), medium (100 to 249 mm) and large (250 mm and greater) individuals is given in Table 8.

Based on a combination of the hydroacoustic and gill-netting data (see below), the population abundance of Arctic charr was estimated to be 3.2 fish ha^{-1} with lower and upper 95% confidence limits of 1.4 and 7.2 fish ha^{-1}, respectively. The contribution of individuals in the 0+/1+ age class to the Arctic charr population was 85% with lower and upper 95% confidence limits of 60 and 100%, respectively.

A total of 52 fish of four species was sampled by gill netting, comprising 4 Arctic charr, 26 brown trout, 4 minnow and 18 three-spined stickleback (Table 9). The Arctic charr ranged from 78 to 151 mm in length, 3 to 32 g in weight, 2 to 4 years in age and comprised 1 male, 1 female and 2 immature individuals of indeterminable sex. The overall male : female sex ratio for Arctic charr was thus 1.0:1 and condition index ranged from 0.59 to 0.93, with an overall mean of 0.77 with lower and upper 95% confidence limits of 0.54 and 1.01, respectively. Fig. 3 presents the length frequency distribution and age frequency distribution for Arctic charr.

For Arctic charr abundance, the observed abundance was significantly below (t test, $t = 7.695$, $df = 14$, $p < 0.001$) the minimum required for favourable condition and so this criterion was failed. In contrast, the contribution of individuals in the 0+/1+ age class to the Arctic charr population was close to and just not significantly different from (t test, $t = 2.076$, $df = 12$, $0.10 > p > 0.05$) the required level and so this criterion was also passed. In terms of habitat quality, none of the adverse changes specified by Bean (2003a) were apparent at a significant level and Maberly *et al.* (2006) found no major water quality problems at the lake in 2005. Consequently, the habitat quality criterion was passed.

It is difficult to put the present Arctic charr observations into a robust temporal context because of the scarcity of previous fish studies at Wastwater. Very early, but subsequently updated, general texts on the English Lake District such as Pearsall & Pennington (1989) give no relevant quantitative information for Arctic charr. Furthermore, a bibliography of Lake District research complied by Horne & Horne (1985) similarly contains no references to any relevant studies with quantitative data, although it does document a very brief account of Arctic charr in Wastwater given by Frost (1977). 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 Wastwater. Although gill-net sampling effort was not reported and so no assessment can be made of even relative abundance at the time of sampling in the mid 1980s, a total of 45 Arctic charr aged from 2 to 6 years was recorded. More recently, a hydroacoustic and gill-netting survey of Wastwater undertaken in August 2005 by Winfield *et al.* (2006b) used exactly the same methodology as the present study and so allows a direct comparison with the current Arctic charr population and fish community of

Wastwater. In 2005, 19 Arctic charr ranged in length from 73 to 253 mm, in weight from 4 to 182 g, comprised 36% of the total fish catch, and if the hydroacoustic and gill-netting data are combined as in the present study they had an abundance of 6.3 fish ha^{-1} with lower and upper 95% confidence limits of 3.2 and 12.7 fish ha^{-1}, respectively. When these two directly comparable data sets are compared, over the last 5 years the Arctic charr population of Wastwater has reduced in its length and weight ranges, its contribution to the sampled fish community has declined by approximately 80% and its absolute abundance has declined by approximately 50%.

On the basis of the above results and background, the overall CSM assessment of Arctic charr in Wastwater is considered to be unfavourable (declining).

CHAPTER 4 SCHELLY

4.1 Brotherswater

Assessment of the schelly population of Brotherswater was undertaken by a re-examination of hydroacoustic and gill-netting data collected by CEH and EA outside the present project, combined with a review of the appropriate scientific literature and appropriate unpublished reports previously produced by CEH.

Very early, but subsequently updated, general texts on the English Lake District such as Pearsall & Pennington (1989) give no relevant quantitative information for schelly in Brotherswater and only note that it is 'possibly' present in this lake. Furthermore, a bibliography of Lake District research complied by Horne & Horne (1985) similarly contains no references to any relevant studies with quantitative data, and in fact contains no references at all to fish research at Brotherswater. The first published account of schelly presence in this location is that of Ellison (1966a), although this only comprised the observation of a single schelly being found dead on the lake's shoreline in 1963.

The first scientific study of schelly in Brotherswater was made within a wider rare fish study undertaken by Winfield *et al.* (1994) and reported specifically by Winfield *et al.* (1993). On a first visit to this lake on 10 August 1992, a survey gill net set overnight on the lake bottom at a depth of 15 m near the lake's maximum depth caught no fish, while one set on the bottom at 5 m caught 5 brown trout and 11 perch and one set on the bottom at 10 m caught 16 schelly. During a second visit on 17 August 1992, two survey gill nets set again at the 10 m site caught a further 11 schelly. The total sample of 27 schelly ranged in length from 247 to 289 mm and in age from 3 to 9 years. Very limited hydroacoustic survey during the afternoon of 10 August 1992 also recorded very few small fish, although this may have reflected their spatial distribution during daylight, and temperature and oxygen profiles showed that the lake was strongly stratified with dissolved oxygen levels less than 1 mg L^{-1} below 12 m. Winfield *et al.* (1993) concluded that in 1992 the schelly population of Brotherswater was dominated by old individuals due to poor recent recruitment.

A second and most recent scientific sampling of schelly in Brotherswater was undertaken by EA using survey gill nets on 3 July 2008 as part of a wider whitefish study collecting material for genetic and morphometric analysis (Andy Gowans, Environment Agency, *pers. comm.*). Survey gill nets were set at one shallow (2 to 5 m) and one deep (3 to 7 m) site in Brotherswater and resulted in the capture of 8 brown trout, 1 perch and 13 schelly at the former site and 8 brown trout, 1 perch and 6 schelly at the latter site. The total sample of 19 schelly ranged in length from 290 to 384 mm.

In addition, night-time hydroacoustic surveys of Brotherswater have been undertaken by EA on 15 August 1996 and 1 August 2000 (Hateley, 2000). Mean single target density estimates with 95% confidence limits were 1.91 ± 0.60 fish 1000 m^{-3} and 2.45 ± 1.25 fish 1000 m^{-3} for 1996 and 2000, respectively.

These gill-netting observations can be reasonably robustly interpreted in CSM-terms because the surveys were undertaken during the prescribed months of July or August, but the hydroacoustic data cannot be used to assess the population demographic criterion because the survey of Winfield *et al.* (1993) was restricted to a single transect during the daytime and those of Hateley (2000) used a recording threshold incompatible with the CSM analysis described by Bean (2003b).

In terms of habitat quality, with the possible exception of the low oxygen availability at depth observed by Winfield *et al.* (2003) which certainly constitutes poor habitat quality and may be due to nutrient enrichment, none of the adverse changes specified by Bean (2003b) were apparent at a significant level at Brotherswater. Maberly *et al.* (2006) found that this oxygen problem persisted at the lake in 2005.

On the basis of the above results and background, the overall CSM assessment of schelly in Brotherswater is considered to be unfavourable (maintained).

4.2 Red Tarn

Assessment of the schelly population of Red Tarn was undertaken by a re-examination of gill-netting data collected by CEH and EA outside the present project, combined with a review of the appropriate scientific literature and appropriate unpublished reports previously produced by CEH. Note that due to logistical problems arising from its remote and high altitude location near the summit of Helvellyn, no quantitative hydroacoustic surveys have ever been carried out at this site.

Very early, but subsequently updated, general texts on the English Lake District such as Pearsall & Pennington (1989) give no relevant quantitative information for schelly in Red

Tarn and only note that it is present in this lake. Furthermore, a bibliography of Lake District research complied by Horne & Horne (1985) similarly contains no references to any relevant studies with quantitative data, and in fact its only reference to fish in Red Tarn is through the brief note of Ellison (1966a).

The first scientific study of schelly in Red Tarn was undertaken by Maitland *et al.* (1990) who surveyed the fish community of this water body using qualitative hydroacoustics and survey gill nets, and also catalogued earlier largely angler-reported observations of schelly in this remote site. On 31 May 1989, five survey gill nets were set overnight at depths from 3 m to over 15 m and resulted in the capture of 22 brown trout and 15 schelly, with three-spined sticklebacks seen but not caught. Individual lengths and ages were not reported for the schelly, but they were all mature fish of a similar size with a maximum age of 7 years.

A second scientific study of schelly in Red Tarn was made within a wider rare fish study undertaken by Winfield *et al.* (1994). On a first visit to this lake on 25 July 1991, a survey gill net set overnight on the lake bottom at a depth of 18 to 20 m near its maximum depth caught 1 brown trout and 8 schelly, while one set on the bottom at 3 to 5 m caught 4 brown trout and 9 schelly. During a second visit on 2 July 1992, further gill nets set at deep sites caught a further 3 schelly while further gill nets set at shallow sites caught a further 14 brown trout and 10 schelly. The total sample of 27 schelly ranged in length from 219 to 323 mm and in age from 5 to 14 years.

A third and most recent scientific sampling of schelly in Red Tarn was undertaken by EA using survey gill nets in 2008 as part of a wider whitefish study collecting material for genetic and morphometric analysis (Andy Gowans, Environment Agency, *pers. comm.*). Survey gill nets were set at one shallow (1 to 5 m) and one deep (2 to 17 m) site in Red Tarn on 14 August 2008 and resulted in the capture of 3 brown trout and 2 schelly at the former site and 6 brown trout and 7 schelly at the latter site. A second visit on 4 September 2008 with survey gill nets set at 1 to 17 m, 1 to 18 m and 4 to 20 m sampled a further 11 brown trout and 13 schelly. The total sample of 22 schelly ranged in length from 100 to 290 mm.

These gill-netting observations can be reasonably robustly interpreted in CSM-terms because the surveys were undertaken predominantly during the prescribed months of July or August, but note that no hydroacoustic data are available for consideration.

In terms of habitat quality, none of the adverse changes specified by Bean (2003b) were apparent at a significant level at Red Tarn.

On the basis of the above results and background, the overall CSM assessment of schelly in Red Tarn is considered to be favourable.

4.3 Ullswater

Assessment of the schelly population of Ullswater was undertaken by a re-examination of hydroacoustic and gill-netting data collected by CEH and EA outside the present project, combined with a review of the appropriate scientific literature and appropriate unpublished reports previously produced by CEH.

Very early, but subsequently updated, general texts on the English Lake District such as Pearsall & Pennington (1989) give no relevant quantitative information for schelly in Ullswater, but do note that the species was once the subject of a local fishery and that Arctic charr were also present until about the mid-nineteenth century. A bibliography of Lake District research complied by Horne & Horne (1985) contains references to early primarily qualitative schelly observations by Regan (1908), Dottrens (1959), Ellison (1966a), Ellison (1966b), Ellison & Cooper (1967) and Bagenal (1966), together with a more recent and rigorous investigation of the population by Bagenal (1970). In addition, it also documents accounts of local fisheries by Anon. (1884), eel (*Anguilla anguilla*) by Lowe (1952) and perch by Le Cren (1955), McCormack (1965) and Kelso & Bagenal (1977).

The first detailed scientific study of schelly in Ullswater was thus made by Bagenal (1970) in which a number of relatively large mesh (38 to 102 mm), non-survey gill nets was set at ‘inshore’, ‘middle’ and ‘offshore’ locations on 6 January 1965, 19 January 1965, 16 December 1965 and 11 January 1966 and resulted in the capture of totals of 35 brown trout and 437 schelly. The schelly ranged in length from approximately (only length classes were reported for only some of the catches) 200 to 440 mm and in age from 2 to 8 years.

A second and more limited study of the schelly of Ullswater was undertaken by Mubamba (1989) in a wider investigation of most of the whitefish populations of Cumbria. 5 overnight sets of survey gill nets during December 1986, March 1987, June 1987, September 1987 and November 1987 resulted in the capture of 25 brown trout, 16 perch, 276 schelly and 2 three-spined stickleback. The schelly ranged in length from 83 to 309 mm and in age from 1 to 16 years.

A third scientific study of this schelly population was made within a wider rare fish study undertaken by Winfield *et al.* (1994). Survey gill nets set at inshore (water depth 3 to 5 m), offshore bottom (water depth 18 to 20 m) and offshore surface (above water depth 18 to 20 m) sites on 14 May 1991, 30 May 1991, 11 July 1991 and 17 September 1991 resulted in the capture of 11 brown trout, 1 eel, 10 minnow, 80 perch, 49 schelly and 5 three-spined stickleback. The schelly ranged in length from 223 to 349 mm and in age from 2 to 13 years.

A fourth and most recent scientific biological sampling of schelly in Ullswater was undertaken by EA using survey gill nets in 2008 as part of a wider whitefish study collecting material for genetic and morphometric analysis (Andy Gowans, Environment Agency, *pers. comm.*). Survey gill nets were set overnight at two sites at water depths of 2 to 10 m in Ullswater on 3 August 2008 resulted in the capture of 4 brown trout and 3 schelly. A second visit on 14 August 2008 with survey gill nets set at four sites at water depths of 2 to 21 m sampled a further 1 brown trout, 406 perch and 6 schelly. A third visit on 19 August 2008 with survey gill nets set at six sites at water depths of 3 to 22 m sampled a further 4 brown trout, 309 perch and 12 schelly. A fourth visit on 11 September 2008 with survey gill nets set at six sites at water depths of 20 to 30 m sampled a further 106 perch and 8 schelly. The total sample of 29 schelly ranged in length from 271 to 398 mm.

Finally, a night-time hydroacoustic survey of Ullswater undertaken by EA on 16 October 2008 (Jon Hateley, Environment Agency, *pers. comm.*) recorded a total fish abundance of 95.7 fish ha^{-1} with lower and upper 95% confidence limits of 60.1 and 116.5 fish ha^{-1}. 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 10.

These gill-netting observations can be reasonably robustly interpreted in CSM-terms because the surveys were undertaken in large part during the prescribed months of July or August, but the hydroacoustic data cannot be used to assess the population demographic criterion because the sampling was undertaken outside this period in October by which time younger and older schelly are likely to have changed significantly in their relative abundances.

In terms of habitat quality, none of the adverse changes specified by Bean (2003b) were apparent at a significant level at Ullswater and Maberly *et al.* (2006) found no major water quality problems at the lake in 2005.

On the basis of the above results and background, the overall CSM assessment of schelly in Ullswater is considered to be favourable.

CHAPTER 5 VENDACE

5.1 Bassenthwaite Lake

Assessment of the vendace population of Bassenthwaite Lake was undertaken by a re-examination of hydroacoustic and gill-netting data collected by CEH outside the present project, combined with a review of the appropriate scientific literature and appropriate unpublished reports previously produced by CEH.

Very early, but subsequently updated, general texts on the English Lake District such as Pearsall & Pennington (1989) give no relevant quantitative information for vendace in Bassenthwaite Lake, although they do note its local presence. A bibliography of Lake District research complied by Horne & Horne (1985) contains references to early primarily qualitative vendace observations by Regan (1906), Regan (1908) and Segerstråle (1957), together with a more recent and rigorous investigation of the population by Maitland (1966). In addition, it also documents a brief reference to the lake's perch population by Le Cren (1955).

Based on samples collected in 1965, Maitland (1966) described the vendace population of Bassenthwaite Lake as 'thriving', i.e. of good status. Limited data given subsequently by Broughton (1972) from sampling in 1972 also indicated a good population status, but by 1987 further and more extensive sampling carried out by Mubamba (1989) showed that the status of the population had become poor due to inconsistent recruitment and also documented the arrival of roach (*Rutilus rutilus*) in the lake in 1986. This situation persisted into the early 1990s when the first record of ruffe was made at Bassenthwaite Lake in 1991 (Winfield *et al.*, 1994; Winfield *et al.*, 1996), after which the local status of vendace declined even further with continued inconsistent recruitment and reduced population abundance (Winfield *et al.*, 2004b).

From 1995 onwards the fish community of Bassenthwaite Lake has been monitored by CEH in partnership with EA using a combination of hydroacoustics and survey gill nets as reported in full most recently for 2010 by Winfield *et al.* (2011c) and described in part up to 2010 by Winfield *et al.* (in press), during which time the first local record of dace (*Leuciscus leuciscus*) was made in 1996. Vendace were last recorded in this monitoring programme in 2000 (Fig. 4) and subsequent additional efforts to detect the species have failed, with the result that the population is now considered to be extinct Winfield *et al.* (in press).

On 2 September 2010 within the monitoring programme of Winfield *et al.* (2011c), a total of 491 fish of five species was sampled by gill netting at six sites in Bassenthwaite Lake and comprised 1 brown trout, 384 perch, 7 pike, 43 roach and 56 ruffe.

In terms of habitat quality, among the adverse changes specified by Bean (2003b) those of nutrient enrichment and siltation and thus loss of spawning substrate have been apparent at a significant level at Bassenthwaite Lake for many years. In addition, the lake now contains well established and significant populations of introduced roach and ruffe. Maberly *et al.* (2006) found no major water quality problems at the lake in 2005, although the lake has been subject to some eutrophication.

On the basis of the above results and background, the overall CSM assessment of vendace in Bassenthwaite Lake is considered to be destroyed.

5.2 Derwent Water

Assessment of the vendace population of Derwent Water was undertaken by a re-examination of hydroacoustic and gill-netting data collected by CEH outside the present project, combined with a review of the appropriate scientific literature and appropriate unpublished reports previously produced by CEH.

Very early, but subsequently updated, general texts on the English Lake District such as Pearsall & Pennington (1989) give no relevant quantitative information for vendace in Derwent Water, although they do note its local presence. A bibliography of Lake District research complied by Horne & Horne (1985) contains references to early primarily qualitative vendace observations by Regan (1906), Regan (1908) and Segerstråle (1957), together with a more recent and rigorous investigation of the population by Maitland (1966).

Based on samples collected in 1965, Maitland (1966) described the vendace population of Derwent Water as 'thriving'. This good status persisted through 1987 (Mubamba, 1989) and the early 1990s (Winfield *et al.*, 1994; Winfield *et al.*, 1996), although the latter period also included the first record in this lake of roach in 1991. Subsequently, both dace and ruffe were first recorded in Derwent Water in 1999 and 2001, respectively (Winfield *et al.*, 2004).

From 1998 onwards the fish community of Derwent Water has been monitored by CEH in partnership with EA using a combination of hydroacoustics and survey gill nets as reported in full most recently for 2010 by Winfield *et al.* (2011c) and described in part up to 2010 by Winfield *et al.* (in press). Although showing variations in population abundance typical of this species, vendace have persisted in Derwent Water to the present (Fig. 5).

Fig. 5 taken from Winfield *et al.* (in press) presents hydroacoustic data for the adult component of the vendace population of Derwent Water recorded in September 2010, but the monitoring programme of Winfield *et al.* (2011c) from which this figure was derived also includes a July hydroacoustic survey which can be subjected to a CSM-compliant analysis as follows. On 27 July 2010, the population density of all fish had a geometric mean of 191.5 fish ha^{-1} with lower and upper 95% confidence limits of 116.8 and 313.9 fish ha^{-1}, respectively. A breakdown into small (length 40 to 99 mm, likely to contain all young vendace), medium (100 to 249 mm) and large (250 mm and greater) individuals is given in Table 11.

Based on a combination of the 27 July 2010 hydroacoustic and 20 September 2010 gill-netting data (see below) following the methodology of the CSM implementation of Winfield *et al.* (2009), the population abundance of vendace was estimated to be 127.7 fish ha^{-1} with lower and upper 95% confidence limits of 77.9 and 209.3 fish ha^{-1}, respectively. Similarly following the methodology of the CSM implementation of Winfield *et al.* (2009), the contribution of individuals in the 0+/1+ age class to the vendace population was 51% with lower and upper 95% confidence limits of 27.8 and 74.8%, respectively.

On 20 September 2010 within the monitoring programme of Winfield *et al.* (2011c), a total of 120 fish of six species was sampled by gill netting at six sites in Derwent Water and comprised 1 brown trout, 58 perch, 5 pike, 30 roach, 18 ruffe and 8 vendace. The vendace ranged from 141 to 182 mm in length, 27 to 52 g in weight, 2 to 3 years in age and comprised 3 males, 3 females and 2 individuals of indeterminable sex.

For vendace abundance, the whitefish protocol of Bean (2003b) does not give a specific criterion and so a statistical test of this feature of the vendace population of Derwent Water cannot be made. The contribution of individuals in the 0+/1+ age class to the vendace population was significantly below (t test, $t = 6.798$, $df = 4$, $p < 0.01$) the required level of 90% and so this criterion was failed. However, it was just not significantly different (t test, $t = 2.771$, $df = 4$, $0.10 > p > 0.05$) from the criterion of 70% proposed by the review of the CSM hydroacoustic analysis for this species proposed by Winfield *et al.* (2010a). In terms of habitat quality, none of the adverse changes specified by Bean (2003a) were apparent at a demonstrably significant level although following the unprecedented floods in the Derwent Water area of November 2009, Winfield *et al.* (2010c) noticed extensive deposits of fine sediments in inshore areas of the lake in addition to extensive growths of New Zealand pygmy weed (*Crassula helmsii*). Maberly *et al.* (2006) found no major water quality problems at the lake in 2005. Consequently, the habitat quality criterion was passed.

In terms of habitat quality, among the adverse changes specified by Bean (2003b) evidence has recently been found for the possible loss of spawning substrate at Derwent Water by the expansion of introduced New Zealand pygmy weed over vendace spawning gravels (Winfield *et al.*, 2010c). In addition, the lake now contains well established and significant populations of introduced roach and ruffe. Maberly *et al.* (2006) found no major water quality problems at the lake in 2005, although quite substantial oxygen depletion was noted in its deepest water layers.

On the basis of the above results and background, the overall CSM assessment of vendace in Derwent Water is considered to be favourable.

CHAPTER 6 GENERAL DISCUSSION AND RECOMMENDATIONS

6.1 General discussion

A study of this nature, in which the overall objective was simply to apply the protocols of Bean (2003a), Bean (2003b) and JNCC (2005) to produce condition assessments for populations of Arctic charr, schelly and vendace in nine sites in Cumbria, requires relatively little discussion. Consequently, this section will be brief but it will attempt to put the present findings into a wider context than given in the earlier site-specific accounts.

Four of the assessed populations, i.e. those of Arctic charr in Crummock Water, schelly in Red Tarn and Ullswater, and vendace in Derwent Water, were found to be in favourable condition. This equates to 44% of the assessed populations.

Less encouragingly, one (or 11%) of the assessed populations, i.e. that of vendace in Bassenthwaite Lake, was found to be destroyed. However, the demise of this species in this lake had been detected and, before it became locally extinct, a proactive project was successfully undertaken to establish a refuge population in Loch Skeen (or Skene) in south-west Scotland (Winfield *et al.*, in press). Although this established population could potentially be used to restock a restored Bassenthwaite Lake, the lake is likely to respond only slowly to current active management of its environmental problems (Winfield *et al.*, in press). Furthermore, a recent modelling investigation has indicated that temperature increases arising from climate change are likely to reduce Bassnehtwaite Lake’s future suitability as a habitat for vendace (Elliott & Bell, 2010).

It is also of concern that four (or 44%) of the assessed populations, i.e. those of Arctic charr in Buttermere, Ennerdale Water and Wastwater, and schelly in Brotherswater, were found to be in unfavourable condition. Encouragingly, the Arctic charr population of Ennerdale Water appears to be responding positively to a recent enhancement programme carried out by EA and so was more specifically classified as recovering. With no evidence to indicate otherwise, the Artic charr population of Buttermere and the schelly population of Brotherswater were specifically classified as maintained, although both classifications were somewhat tentative. Most alarmingly, on the basis of the present and a previous assessment (Winfield *et al.*, 2006b), the Arctic charr population of Wastwater was specifically classified as declining.

Moreover, although when all three species were considered only 44% of the assessed populations were concluded to be in favourable condition, for Arctic charr specifically this figure is only 25%, i.e. only one out of the four assessed Cumbrian populations. A similar decline has recently been reported for this species at the U.K. level by Winfield *et al.* (2010b), who also noted a significant positive relationship between the observed population decline ranking and a vulnerability to climate change ranking based on water body latitude, altitude and mean depth.

6.2 Recommendations

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

Firstly, it is strongly recommended that the CSM programme is continued. Although a higher frequency of such surveys is highly desirable, it is appreciated that the level of current and probable future funding available to NE is insufficient to allow significant expansion within the programme itself.

Secondly, and related to the funding limitations noted above, it is strongly recommended that dialogues are continued between NE, CEH and EA to explore and deliver mutually beneficial collaborations between the monitoring and research programmes of these three bodies.

Thirdly, it is recommended that investigations are undertaken to identify and address the factors which have led to the unfavourable conditions of Arctic charr in Buttermere and Wastwater and schelly in Brotherswater (that of Arctic charr in Ennerdale Water and the destruction of vendace in Bassenthwaite Lake are already understood). Such studies should address both local and global, i.e. climate change, factors. Again, collaboration is recommended between NE, CEH, EA and other directly and indirectly appropriate bodies such as Countryside Council for Wales, Scottish Natural Heritage and United Utilities.

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Table 1. GPS locations for nine hydroacoustic transects and nine gill-netting sites used at Buttermere in July 2010. 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 degrees and decimal minutes.

Event	Latitude (North)	Longitude (West)
Transect 1 start	54, 31.433	3, 15.411
Transect 1 end	54, 31.675	3, 15.123
Transect 2 start	54, 31.735	3, 15.341
Transect 2 end	54, 31.538	3, 15.569
Transect 3 start	54, 31.646	3, 15.759
Transect 3 end	54, 31.787	3, 15.578
Transect 4 start	54, 31.916	3, 15.686
Transect 4 end	54, 31.730	3, 15.932
Transect 5 start	54, 31.806	3, 16.088
Transect 5 end	54, 32.004	3, 15.815
Transect 6 start	54, 32.091	3, 15.965
Transect 6 end	54, 31.886	3, 16.241
Transect 7 start	54, 31.949	3, 16.391
Transect 7 end	54, 32.159	3, 16.160
Transect 8 start	54, 32.195	3, 16.308
Transect 8 end	54, 31.999	3, 16.545
Transect 9 start	54, 32.057	3, 16.667
Transect 9 end	54, 32.182	3, 16.500
I1	54, 31.721	3, 15.275
I2	54, 31.813	3, 16.087
I3	54, 32.160	3, 16.313
OB1	54, 31.708	3, 15.360
OB2	54, 31.870	3, 15.979
OB3	54, 32.046	3, 16.474
OS1	54, 31.717	3, 15.359
OS2	54, 31.864	3, 16.030
OS3	54, 32.065	3, 16.453

Table 2. GPS locations for 15 hydroacoustic transects and nine gill-netting sites used at Crummock Water in July 2010. 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 degrees and decimal minutes.

Event	Latitude (North)	Longitude (West)
Transect 1 start	54, 34.384	3, 18.793
Transect 1 end	54, 34.427	3, 18.602
Transect 2 start	54, 34.310	3, 18.535
Transect 2 end	54, 34.251	3, 18.819
Transect 3 start	54, 34.158	3, 18.814
Transect 3 end	54, 34.241	3, 18.379
Transect 4 start	54, 34.136	3, 18.295
Transect 4 end	54, 34.029	3, 18.998
Transect 5 start	54, 33.916	3, 18.909
Transect 5 end	54, 34.042	3, 18.108
Transect 6 start	54, 33.916	3, 18.016
Transect 6 end	54, 33.809	3, 18.786
Transect 7 start	54, 33.683	3, 18.646
Transect 7 end	54, 33.786	3, 17.961
Transect 8 start	54, 33.667	3, 17.913
Transect 8 end	54, 33.554	3, 18.568
Transect 9 start	54, 33.437	3, 18.510
Transect 9 end	54, 33.521	3, 17.868
Transect 10 start	54, 33.378	3, 17.935
Transect 10 end	54, 33.299	3, 18.429
Transect 11 start	54, 33.182	3, 18.250
Transect 11 end	54, 33.269	3, 17.882
Transect 12 start	54, 33.104	3, 17.902
Transect 12 end	54, 32.993	3, 18.295
Transect 13 start	54, 32.875	3, 18.102
Transect 13 end	54, 32.991	3, 17.779
Transect 14 start	54, 32.910	3, 17.522
Transect 14 end	54, 32.737	3, 17.943
Transect 15 start	54, 32.646	3, 17.731
Transect 15 end	54, 32.782	3, 17.433
I1	54, 33.515	3, 17.858
I2	54, 33.297	3, 17.901
I3	54, 32.905	3, 17.453
OB1	54, 33.539	3, 17.891
OB2	54, 33.311	3, 17.939
OB3	54, 32.889	3, 17.480
OS1	54, 33.548	3, 17.906
OS2	54, 33.340	3, 17.942
OS3	54, 32.884	3, 17.461

Table 3. GPS locations for 15 hydroacoustic transects and nine gill-netting sites used at Wastwater in August 2010. 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 degrees and decimal minutes.

Event	Latitude (North)	Longitude (West)
Transect 1 start	54, 25.615	3, 18.784
Transect 1 end	54, 25.731	3, 19.033
Transect 2 start	54, 25.862	3, 18.898
Transect 2 end	54, 25.719	3, 18.621
Transect 3 start	54, 25.840	3, 18.435
Transect 3 end	54, 25.990	3, 18.736
Transect 4 start	54, 26.135	3, 18.569
Transect 4 end	54, 25.955	3, 18.226
Transect 5 start	54, 26.068	3, 18.049
Transect 5 end	54, 26.269	3, 18.407
Transect 6 start	54, 26.405	3, 18.236
Transect 6 end	54, 26.183	3, 17.817
Transect 7 start	54, 26.307	3, 17.622
Transect 7 end	54, 26.516	3, 17.980
Transect 8 start	54, 26.663	3, 17.837
Transect 8 end	54, 26.417	3, 17.422
Transect 9 start	54, 26.524	3, 17.226
Transect 9 end	54, 26.784	3, 17.618
Transect 10 start	54, 26.884	3, 17.395
Transect 10 end	54, 26.629	3, 17.031
Transect 11 start	54, 26.728	3, 16.849
Transect 11 end	54, 26.938	3, 17.123
Transect 12 start	54, 27.039	3, 16.942
Transect 12 end	54, 26.786	3, 16.647
Transect 13 start	54, 26.840	3, 16.385
Transect 13 end	54, 27.123	3, 16.717
Transect 14 start	54, 27.190	3, 16.479
Transect 14 end	54, 26.921	3, 16.147
Transect 15 start	54, 27.068	3, 15.994
Transect 15 end	54, 27.255	3, 16.226
I1	54, 25.722	3, 19.049
I2	54, 26.777	3, 17.724
I3	54, 27.271	3, 16.219
OB1	54, 25.660	3, 18.804
OB2	54, 26.739	3, 17.739
OB3	54, 27.214	3, 16.319
OS1	54, 25.673	3, 18.740
OS2	54, 26.746	3, 17.722
OS3	54, 27.206	3, 16.410

Table 4. 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 hydroacoustic survey of Buttermere on 12 July 2010.

Small fish (fish ha^{-1})	Medium fish (fish ha^{-1})	Large fish (fish ha^{-1})	All fish (fish ha^{-1})
1.0 (1.0, 1.0)	1.4 (0.7, 2.6)	1.3 (0.7, 2.4)	1.4 (0.7, 3.1)

Table 5. Numbers of fish individuals recorded in the gill-net survey of Buttermere on 13 July 2010. Sites are identified as inshore (I), offshore bottom (OB) or offshore surface (OS) with individual numbering from 1 to 3.

Site	Arctic charr	Brown trout	Minnow	Perch	Pike	Total
I1	0	0	3	6	0	9
I2	0	1	0	58	2	61
I3	0	1	1	25	0	27
OB1	0	0	0	1	0	1
OB2	1	0	0	0	0	1
OB3	0	0	0	0	0	0
OS1	0	2	0	0	0	2
OS2	0	5	0	0	0	5
OS3	0	2	0	0	0	2
Total	1	11	4	90	2	108

Table 6. 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 hydroacoustic survey of Crummock Water on 15 July 2010.

Small fish (fish ha^{-1})	Medium fish (fish ha^{-1})	Large fish (fish ha^{-1})	All fish (fish ha^{-1})
23.1 (8.7, 61.1)	11.7 (6.2, 22.1)	3.5 (1.6, 7.7)	43.8 (20.0, 95.8)

Table 7. Numbers of fish individuals recorded in the gill-net survey of Crummock Water on 15 July 2010. Sites are identified as inshore (I), offshore bottom (OB) or offshore surface (OS) with individual numbering from 1 to 3.

Site	Arctic charr	Brown trout	Perch	Total
I1	0	0	14	14
I2	0	1	9	10
I3	0	0	37	37
OB1	13	2	1	16
OB2	7	0	0	7
OB3	21	0	0	21
OS1	0	0	0	0
OS2	0	1	0	1
OS3	0	6	0	6
Total	41	10	61	112

Table 8. 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 hydroacoustic survey of Wastwater on 9 August 2010.

Small fish (fish ha^{-1})	Medium fish (fish ha^{-1})	Large fish (fish ha^{-1})	All fish (fish ha^{-1})
12.7 (5.9, 27.3)	3.5 (1.6, 7.6)	1.4 (0.9, 2.2)	15.9 (7.0, 35.9)

Table 9. Numbers of fish individuals recorded in the gill-net survey of Wastwater on 10 August 2010. Sites are identified as inshore (I), offshore bottom (OB) or offshore surface (OS) with individual numbering from 1 to 3.

Site	Arctic charr	Brown trout	Minnow	Three-spined stickleback	Total
I1	0	2	1	0	3
I2	0	7	1	7	15
I3	0	3	2	9	14
OB1	2	0	0	2	4
OB2	1	1	0	0	2
OB3	1	1	0	0	2
OS1	0	5	0	0	5
OS2	0	4	0	0	4
OS3	0	3	0	0	3
Total	4	26	4	18	52

Table 10. 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 hydroacoustic survey of Ullswater on 16 October 2008 (Data from Jon Hateley, Environment Agency (*pers. comm.*)).

Small fish (fish ha^{-1})	Medium fish (fish ha^{-1})	Large fish (fish ha^{-1})	All fish (fish ha^{-1})
36.0 (26.3, 57.6)	38.9 (28.1, 77.0)	8.2 (6.0, 18.8)	95.7 (60.1, 116.5)

Table 11. 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 hydroacoustic survey of Derwent Water on 27 July 2010 (Data from Winfield *et al.* (2011c)).

Small fish (fish ha^{-1})	Medium fish (fish ha^{-1})	Large fish (fish ha^{-1})	All fish (fish ha^{-1})
93.5 (65.3, 133.9)	83.9 (36.2, 194.7)	7.0 (1.6, 29.9)	191.5 (116.8, 313.9)

Fig. 1. Length frequency distribution (N = 41 fish) and age frequency distribution (N = 40 fish) of Arctic charr recorded in the gill-net survey of Crummock Water on 15 July 2010.

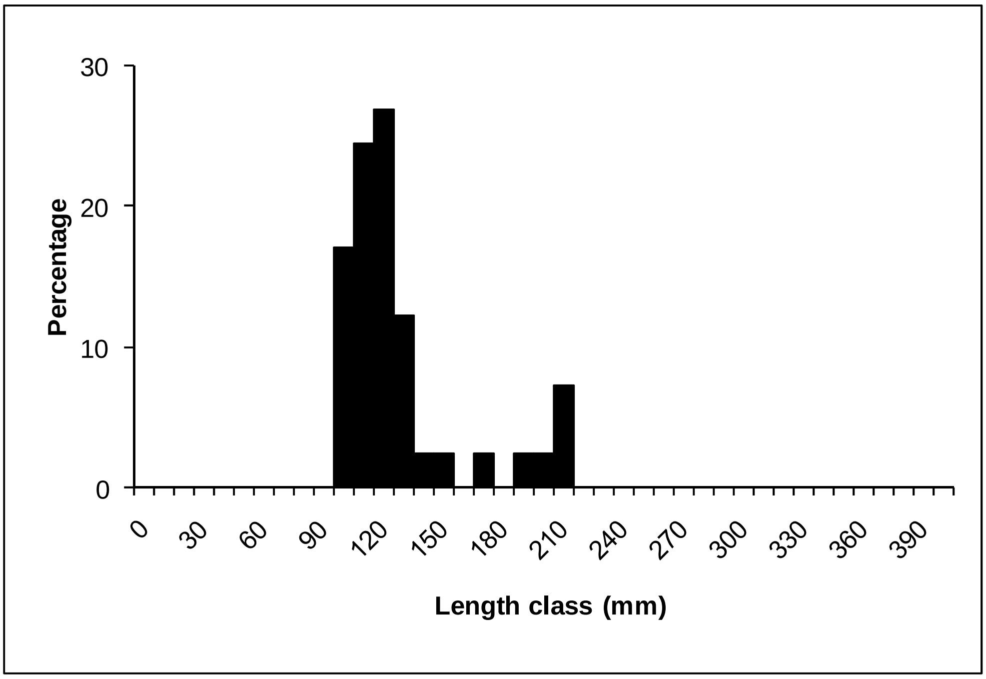

Fig. 2. Annual estimates (given as means with lower and upper 95% confidence limits) of the size of the spawning stock (numbers of individuals greater than 160 mm in length) of Arctic charr in Ennerdale for 1997 and from 2003 to 2010 (Redrawn from Hateley (2010)).

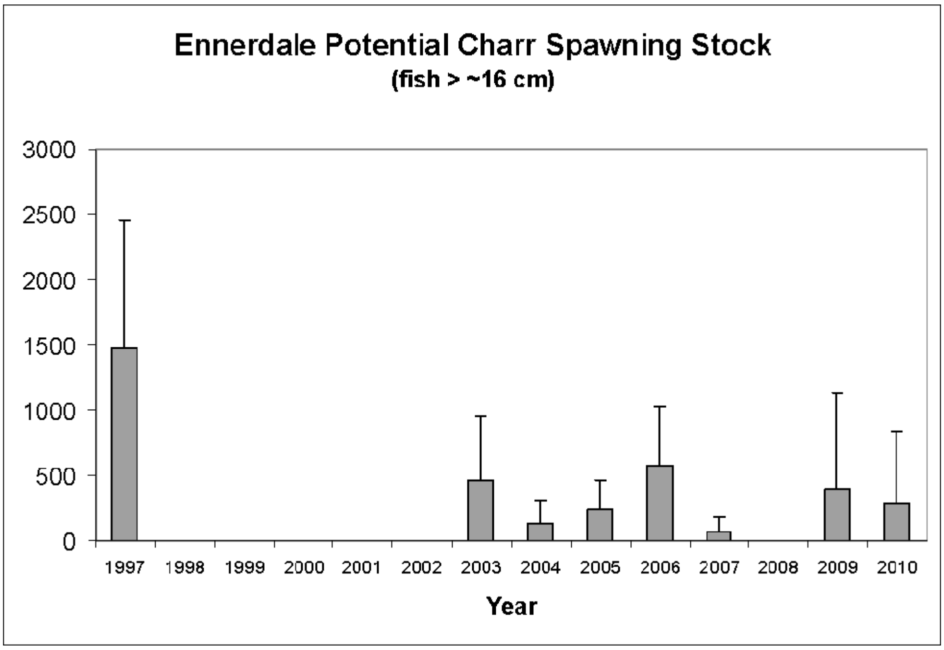

Fig. 3. Length frequency distribution (N = 4 fish) and age frequency distribution (N = 4 fish) of Arctic charr recorded in the gill-net survey of Wastwater on 10 August 2010.

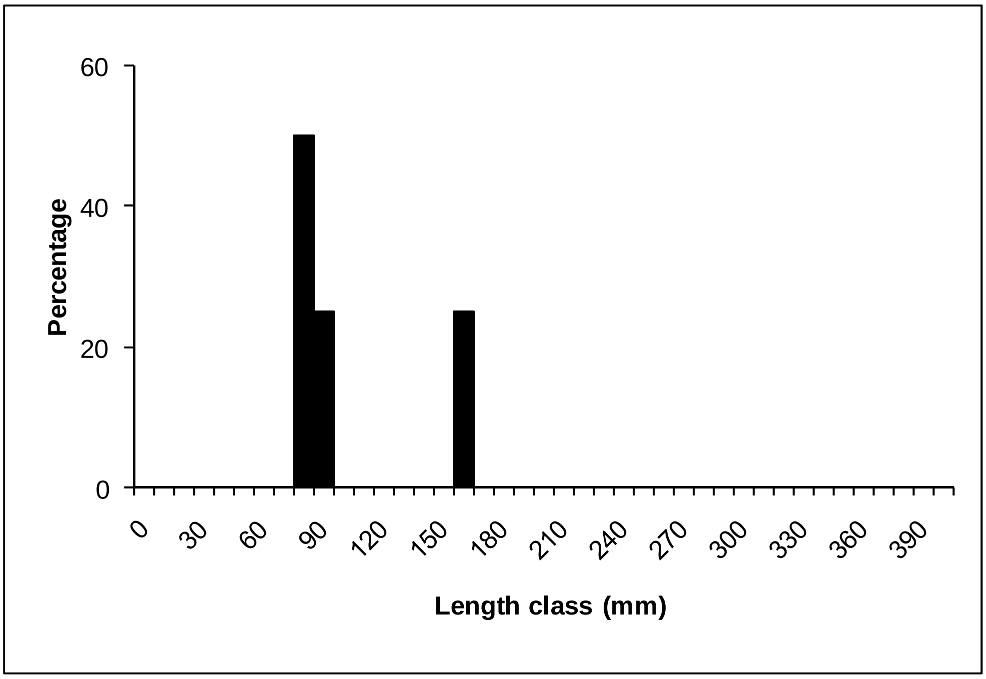

Fig. 4. Species composition by numbers of the total (upper figure) and deep-water (middle figure) fish communities (total sample size 5,924 individuals), and the abundance of vendace (lower figure, geometric means with 95% confidence limits) at Bassenthwaite Lake from 1995 to 2010. For clarity within the figure, Atlantic salmon (*Salmo salar*) and brown trout are referred to by their short common names (Data from Winfield *et al.* (2011c)).

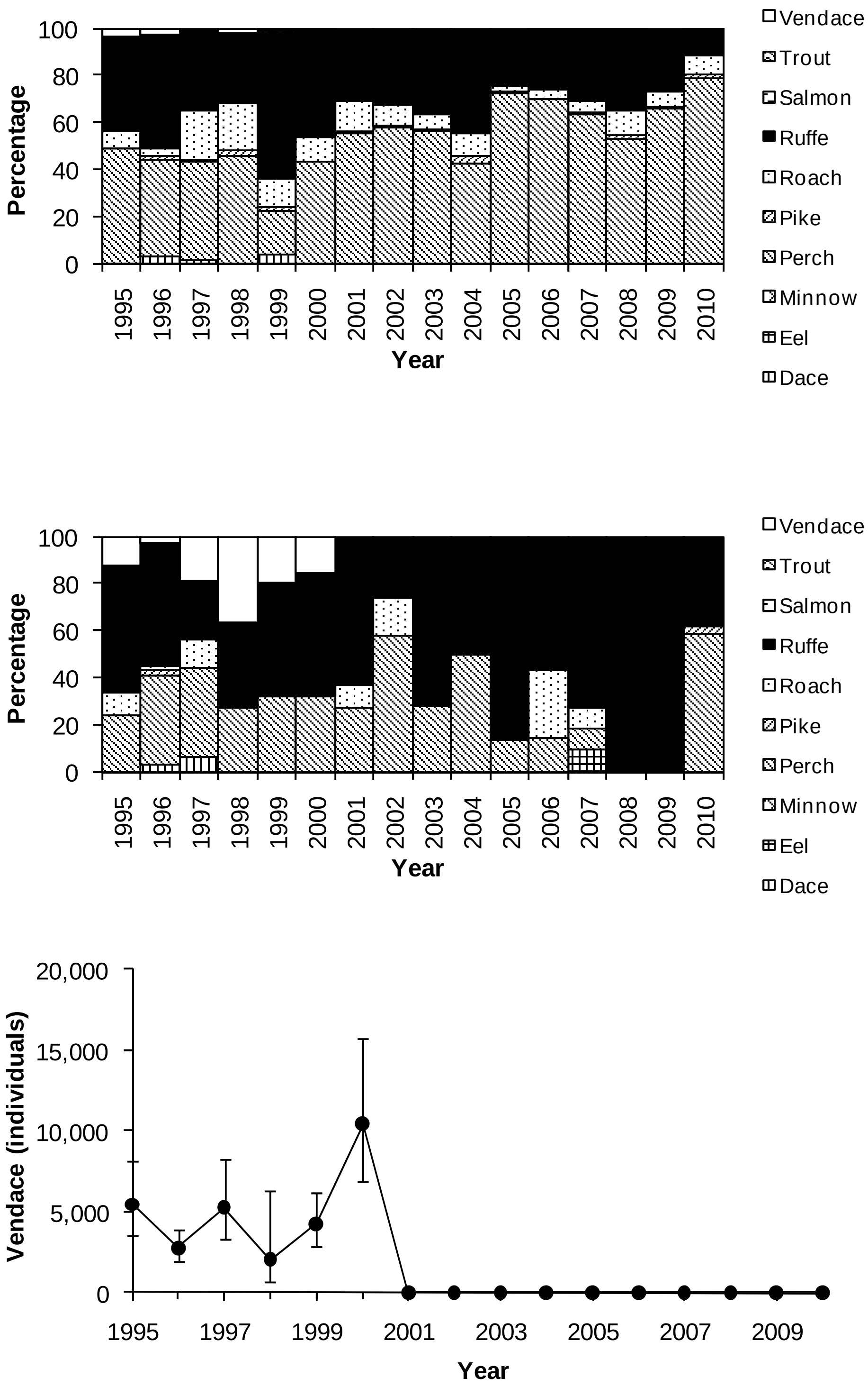

Fig. 5. Species composition by numbers of the total (upper figure) and deep-water (middle figure) fish communities (total sample size 2,974 individuals), and the abundance of vendace (lower figure, geometric means with 95% confidence limits) at Derwent Water from 1998 to 2010. For clarity within the figure, Atlantic salmon and brown trout are referred to by their short common names (Data from Winfield *et al.* (2011c)).