CEH LANCASTER
LANCASTER ENVIRONMENT CENTRE, LIBRARY AVENUE
BAILRIGG, LANCASTER, LANCASHIRE LA1 4AP

MONITORING THE FISH POPULATIONS OF BASSENTHWAITE LAKE AND DERWENT WATER, 2010

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

Project Leader: Ian J Winfield
Contract Start Date: 1 April 2007
Report Date: 31 March 2011
Report To: Environment Agency (North West Region)
CEH Project No: NEC03461
CEH Report Ref No: LA/NEC03461/7

INTELLECTUAL PROPERTY RIGHTS

CONFIDENTIALITY STATEMENT

CONTENTS **PAGE**

Executive summary			1
Chapter 1	Introduction		3
	1.1	Background	3
	1.2	Objectives	5
Chapter 2	Methods		6
	2.1	Approach	6
	2.2	Hydroacoustics	6
		2.2.1 Field work	6
		2.2.2 Laboratory examination and analysis	8
	2.3	Gill netting	10
		2.3.1 Field work	11
		2.3.2 Laboratory examination and analysis	12
Chapter 3	Results		13
	3.1	Bassenthwaite Lake	13
		3.1.1 Hydroacoustics	13
		3.1.2 Gill netting	13
	3.2	Derwent Water	14
		3.2.1 Hydroacoustics	14
		3.2.2 Gill netting	15
Chapter 4	Discussion		17
	4.1	Introduction	17
	4.2	Bassenthwaite Lake	17
	4.3	Derwent Water	20
	4.4	Closing remarks	24
Acknowledgements			26
References			27

Tables 35

Figures 41

EXECUTIVE SUMMARY

1. The fish populations of Bassenthwaite Lake and Derwent Water were monitored by hydroacoustics and gill netting in 2010, with a particular emphasis on the vendace (*Coregonus albula*) which is the U.K.'s rarest freshwater fish. This constituted the sixteenth year of such monitoring at Bassenthwaite Lake and the thirteenth year at Derwent Water.

2. In Bassenthwaite Lake, the population density of all fish increased from a geometric mean of 6.1 fish ha^{-1} (lower and upper 95% confidence limits of 1.9 and 20.0 fish ha^{-1}) in May to 899.0 fish ha^{-1} (lower and upper 95% confidence limits of 634.6 and 1273.6 fish ha^{-1}) in July, and then decreased to 352.9 fish ha^{-1} (lower and upper 95% confidence limits of 211.1 and 589.8 fish ha^{-1}) in September. However, the complete absence of vendace from gill-net samples (see below) suggested that few, if any, of these fish are likely to be vendace.

3. In Bassenthwaite Lake, gill netting produced a sample of 491 fish comprising 1 brown trout (*Salmo trutta*), 384 perch (*Perca fluviatilis*), 7 pike (*Esox lucius*), 43 roach (*Rutilus rutilus*) and 56 ruffe (*Gymnocephalus cernuus*). Introduced roach and ruffe thus continue to be major components of the fish community, although introduced dace (*Leuciscus leuciscus*) have not increased to the same extent and were not recorded in the present survey.

4. Given that the above monitoring of Bassenthwaite Lake in 2010 failed to catch a single vendace, the local population continues to be considered to be extinct.

5. In Derwent Water, the population density of all fish increased from a geometric mean of 34.8 fish ha^{-1} (lower and upper 95% confidence limits of 8.7 and 138.8 fish ha^{-1}) in May to 191.5 fish ha^{-1} (lower and upper 95% confidence limits of 116.8 and 313.9 fish ha^{-1}) in July, and then increased further to 364.9 fish ha^{-1} (lower and upper 95% confidence limits of 135.5 and 982.9 fish ha^{-1}) in September. The composition of gill-net samples suggested that tentative equivalent figures specific to post-juvenile vendace were 22.8 fish ha^{-1} (lower and upper 95% confidence limits of 6.1 and 84.4 fish ha^{-1}) in May, 62.9 fish ha^{-1} (lower and upper 95% confidence limits of 27.1 and 146.0 fish ha^{-1}) in July and 29.1 fish ha^{-1} (lower and upper 95% confidence limits of 1.9 and 450.6 fish ha^{-1}) in September.

6. In Derwent Water, gill netting produced a sample of 120 fish comprising 1 brown trout, 58 perch, 5 pike, 30 roach, 18 ruffe and 8 vendace. Introduced roach and ruffe thus continue to be important components of the fish community. Introduced dace have not increased to the same extent and were not recorded in the present survey. Biological parameters of the vendace population have remained relatively stable in recent years, with evidence of continued recruitment and recovery from a 2007 low point in the normal variation in population density exhibited by this species.

7. The status of the vendace population of Derwent Water in 2010 is considered to be acceptable, although population abundance is still relatively low and there is concern over introduced populations of roach and ruffe. Potential threats to spawning grounds from introduced New Zealand pygmy weed (*Crassula helmsii*), first raised in 2004, and from elevated levels of fine sediments probably deposited by an extreme flood event in November 2009 appear to have receded.

CHAPTER 1 INTRODUCTION

1.1 Background

Bassenthwaite Lake and Derwent Water in Cumbria contain, or in the case of the former lake at least have contained (Winfield *et al.*, 2008a; Winfield *et al.*, 2008a), the U.K.'s last two native populations of vendace (*Coregonus albula*). This species is the U.K.'s rarest freshwater fish and is protected under the Wildlife and Countryside Act of 1981 and appears on the U.K. List of Priority Species and Habitats of the U.K. Biodiversity Action Plan (www.ukbap.org.uk). The only other previously recorded U.K. native vendace populations were present in two lochs in south-west Scotland, but these are now both believed to be extinct (Maitland, 1990).

At least one of the above two extinctions of vendace was probably due to eutrophication (Maitland, 1990), and indeed this aspect of environmental degradation is considered to be a major threat to vendace populations throughout their distribution range in Europe (Lelek, 1987). The eutrophicated state of Bassenthwaite Lake (Thackeray *et al.*, 2006) thus gives some concern with respect to the local survival of the vendace, concern which is increased by the findings that the status of this vendace population in the late 1980s (Mubamba, 1989) and early 1990s (Winfield *et al.*, 1994a, 1996) was poor, particularly in comparison with that of the nearby population in Derwent Water.   Deoxygenation of the lower water column and siltation of spawning grounds are the major ways in which eutrophication adversely affects vendace populations, although an indirect influence by shifting balances within the fish community may also be important (Winfield, 1992). The latter mechanism may be particularly relevant in Bassenthwaite Lake which has received introductions of roach (*Rutilus rutilus*), ruffe (*Gymnocephalus cernuus*) and more recently dace (*Leuciscus leuciscus*), while Derwent Water has also received introductions of these three species although at later dates (Winfield *et al.*, 2004a). The potential implications of these fish species introductions have been studied (Winfield *et al.*, 1998a), including an interpretation of their impacts at the community level (Winfield *et al.*, 2002). A wider synthesis of these and other conservation issues relating to the conservation of vendace in Bassenthwaite Lake and Derwent Water, including allochthonous siltation on spawning grounds, is provided by Winfield *et al.* (2004a) and Winfield *et al.* (in press).

Although the vendace population of Bassenthwaite Lake has been the subject of both fundamental and applied research for some time, such activities initially did not include a monitoring component. This deficiency was remedied in 1995 by the inception of a monitoring programme based on hydroacoustics and gill netting, reported most recently for 2009 by Winfield *et al.* (2010a) and continued by the present project. Although this monitoring was primarily directed at the vendace, it also addressed the lake's other major fish populations. Activities in the reporting period of 2010 thus constitute the sixteenth year of such monitoring at Bassenthwaite Lake, while the addition of Derwent Water to the programme in 1998 means that they also constitute the thirteenth year of corresponding activities at this second site. Earlier work on Derwent Water has been more limited than at Bassenthwaite Lake, although some relevant population information is given in Mubamba (1989), Winfield *et al.* (1994a), Winfield *et al.* (1996), Winfield *et al.* (1998a), Winfield *et al.* (2004a) and Winfield *et al.* (in press). In addition, two recent studies have focussed on examining the spawning grounds of vendace in Derwent Water (Winfield *et al.*, 2009b;

Winfield *et al.*, 2010b). All of these earlier studies indicated that the status of the vendace population of this mesotrophic lake had been good through the 1980s and early to mid 1990s.

1.2 Objectives

The objectives of this reporting period of the project were to monitor the fish populations of Bassenthwaite Lake and Derwent Water in 2010, with a particular emphasis on the vendace.

CHAPTER 2 METHODS

2.1 Approach

Following previous extensive experience in sampling the vendace of Bassenthwaite Lake and Derwent Water (Winfield *et al.*, 1994a; Winfield *et al.*, 1994b), a monitoring programme was devised which incorporated hydroacoustics to give estimates of fish abundance and gill netting to obtain specimens for detailed biological examination. Combination of these two data streams can be used to give an abundance estimate specific to vendace.

Hydroacoustics was scheduled for early, mid and late summer as a compromise between the scientific ideal of high frequency sampling, e.g. monthly, and the logistical difficulties of undertaking such surveys during the hours of darkness (see below) at distant (from CEH) lakes within the project's resource limits. Gill netting was undertaken only in the autumn in order to sample fish which had completed their annual growth, and to avoid excessive damage of specimens by eel (*Anguilla anguilla*) previously experienced by the authors to be a considerable problem at Bassenthwaite Lake and Derwent Water during the summer months.

2.2 Hydroacoustics

2.2.1 Field work

Echo sounding was 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}.

Hydroacoustic surveys were undertaken after dusk using zig-zag designs incorporating a total of 10 transects across areas of depth in excess of approximately 10 m at Bassenthwaite Lake (Table 1, Fig. 1) and five transects across similar but more limited and less tractable areas of Derwent Water (Table 2, Fig. 2). Post-larval vendace are known to be restricted to such deep areas during the spring, summer and autumn months (see Winfield *et al.*, 1994a, 1994b, 1998a). Both surveys were run in the general direction of from the south to the north of the lake, began at least two hours after sunset, were of approximately one hour duration, and for the area of the lake in excess of approximately 10 m in depth gave ratios of coverage (length of surveys : square root of research area) of 4.6:1 and 4.0:1 for Bassenthwaite Lake and Derwent Water, respectively.

Surveys as described above were carried out at Bassenthwaite Lake on 6 May, 1 July and 2 September 2010, and at Derwent Water on 18 May, 27 July and 20 September 2010.

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.

The approach to data analysis was similar to that carried out previously during the studies of Winfield *et al.* (1994a, 1994b), i.e. with the water column of each transect was 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.

The medium length class has previously been assumed to be largely post-juvenile vendace, i.e. individuals of at least one summer old, and a detailed justification for this assumption was given by Winfield *et al.* (1994b) following extensive hydroacoustics and gill netting at Bassenthwaite Lake in the early 1990s. A similar argument for Derwent Water was supported by the results of Winfield *et al.* (1994a) and Winfield *et al.* (1998a). However, given developments in the introduced fish populations of both lakes (Winfield *et al.*, 2002; Winfield *et al.*, 2004a; Winfield *et al.*, in press), this assumption is no longer applicable.

As explained in detail in Winfield *et al.* (2004b), a quantitative correction factor to convert all fish abundance to vendace abundance is unavailable for either Bassenthwaite Lake or Derwent Water. While such a tool would be extremely useful for the present monitoring programme, it is unfortunately unlikely to be determinable robustly using present technology for a combination of practical and conservation reasons. At the moment, the only way to determine such correction factors is to undertake hydroacoustic surveys with simultaneous extensive gill netting to determine the percentage species composition of the fish community at that time and place, which in the present context would probably result in unacceptably high destructive sampling of vendace and/or other fish species. Given that such additional gill netting cannot be undertaken due to licensing and resource constraints, tentative estimates of post-juvenile vendace population densities for each year of monitoring were calculated by multiplying medium fish population densities by the fraction of the medium fish community composition comprised of vendace at deep sites revealed by gill netting in Bassenthwaite Lake (Site 3, see below) and Derwent Water (Site 4, see below). Note that this procedure is based on only small gill-net sample sizes and so must be viewed with considerable caution.

Finally, the population sizes of post-juvenile vendace were then calculated by multiplying post-juvenile vendace population densities by the surface area of the parts of Bassenthwaite Lake and Derwent Water where water depth exceeds approximately 10 m, i.e. 85.2 ha (Ramsbottom, 1976) and 65.0 ha (CEH unpublished data), respectively. Note that, for brevity, the resulting data are sometimes referred to later in this report simply as estimates of vendace population density or population size, although more specifically they refer only to the post-juvenile components of the populations.

As 2010 was the ninth year in which a BioSonics split-beam echo sounder (DT6000 for 2002 to 2004, DT-X for 2005 to 2010) had been used in the present monitoring as a replacement for an older and less sophisticated Simrad EY 200P portable echo sounder, all fish population densities produced earlier using the older system were converted to values that would have been recorded by the BioSonics machines using a series of inter-calibration relationships determined during 2003 (CEH unpublished data). Only these converted values are presented and considered in this report.

2.3 Gill netting

2.3.1 Field work

A gill-netting survey was carried out on 2 September 2010 at Bassenthwaite Lake using five basic (i.e. bottom set) Norden survey gill nets. This version of the Norden survey gill net is of a monofilament design (measuring 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) and was set singly for approximately 24 hours at five sites (Sites 1 to 5) ranging in depth from approximately 4 to 20 m (Table 1, Fig. 1). This design of net, which was previously known as the Nordic survey gill net, has become widely adopted throughout Europe as a standard survey net (Appelberg, 2000) and so was used in this project for the first time in 2002, replacing a similar but larger net design (monofilament design measuring approximately 1.5 m deep and 60 m long with ten panels of equal length of bar mesh sizes 8, 10, 13, 16, 19, 25, 30, 33, 38 and 45 mm) used from 1999 to 2001. However, the differences between the two types of nets will not result in any significant differences in the characteristics of vendace caught under the conditions of the present monitoring programme, although the reduction of net area by 50% is likely to lead to a reduction in catch of approximately the same degree. Following its first use in 2004, a single pelagic (i.e. surface set) version of the Norden survey gill net was also set for *c.* 24 hours at the deepest site, i.e. Site 3. This version of the Norden survey gill net, which has only recently been developed, measures 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. All captured fish were taken directly to the laboratory where they were frozen to await future processing.

A similar gill-netting survey was carried out on 20 September 2010 at Derwent Water, although in this instance the deepest site was Site 4 and the pelagic net was set at this location (Table 2, Fig. 2).

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). All vendace were then sexed (male, female or indeterminate) by internal examination, had their left opercular bones removed for subsequent age determination following Mubamba (1989), and had condition indices (CI) calculated according to the equation

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

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

Other fish species were processed in a similar way, with sub-sampling where appropriate, although age determinations were not made and condition indices were not calculated.

CHAPTER 3 RESULTS

3.1 Bassenthwaite Lake

3.1.1 Hydroacoustics

The population densities of small, medium, large and all fish recorded at Bassenthwaite Lake during May, July and September 2010 are given in Table 3, while these are put into a longer-term context with equivalent data from 1995 to 2009 in Fig. 3 and Fig. 4. The population density of all fish in 2010 increased from a geometric mean of 6.1 fish ha^{-1} (lower and upper 95% confidence limits of 1.9 and 20.0 fish ha^{-1}) in May to 899.0 fish ha^{-1} (lower and upper 95% confidence limits of 634.6 and 1273.6 fish ha^{-1}) in July, and then decreased to 352.9 fish ha^{-1} (lower and upper 95% confidence limits of 211.1 and 589.8 fish ha^{-1}) in September.

The population density and population size of post-juvenile vendace at Bassenthwaite Lake between 1995 and 2010 are shown in Fig. 5, both of which directly linked parameters have been zero since 2001 even though medium fish have continued to be recorded in large numbers by hydroacoustics. This decline to zero in 2001 results from the absence of vendace from the corresponding gill-net samples of Site 3, which in 2010 was occupied by perch, pike and ruffe (Fig. 6, Fig. 7 and see below). It is stressed again that these estimates of post-juvenile vendace population density and population size are based on only small gill-net sample sizes and so must be viewed with considerable caution.

3.1.2 Gill netting

A total of 491 fish was sampled by gill netting at Bassenthwaite Lake in 2010, comprising 1 brown trout (*Salmo trutta*), 384 perch (*Perca fluviatilis*), 7 pike (*Esox lucius*), 43 roach (*Rutilus rutilus*) and 56 ruffe (*Gymnocephalus cernuus*) (Table 4, Fig. 7). Although observed in at least some earlier years at Bassenthwaite Lake or Derwent Water, no dace, eel, minnow (*Phoxinus phoxinus*), Atlantic salmon (*Salmo salar*) or vendace were recorded.

Although biological specimens of vendace were not available for examination in 2010, as they similarly had not been from 2002 to 2009, median individual length and median individual age between 1995 and 2001 (for the latter of year of which the only available vendace specimens were produced during an attempted stripping programme (Winfield & Fletcher, 2002)) are shown in Fig. 8.

3.2 Derwent Water

3.2.1 Hydroacoustics

The population densities of small, medium, large and all fish recorded at Derwent Water during May, July and September 2010 are given in Table 5, while these are put into a longer-term context with equivalent data from 1995 (using data from Winfield *et al.* (1998a)) to 2009 in Fig. 9 and Fig. 10. The population density of all fish in 2010 increased from a geometric mean of 34.8 fish ha^{-1} (lower and upper 95% confidence limits of 8.7 and 138.8 fish ha^{-1}) in May to 191.5 fish ha^{-1} (lower and upper 95% confidence limits of 116.8 and 313.9 fish ha^{-1}) in July, and then increased further to 364.9 fish ha^{-1} (lower and upper 95%

confidence limits of 135.5 and 982.9 fish ha^{-1}) in September. Equivalent figures specific to post-juvenile vendace were 22.8 fish ha^{-1} (lower and upper 95% confidence limits of 6.1 and 84.4 fish ha^{-1}) in May, 62.9 fish ha^{-1} (lower and upper 95% confidence limits of 27.1 and 146.0 fish ha^{-1}) in July and 29.1 fish ha^{-1} (lower and upper 95% confidence limits of 1.9 and 450.6 fish ha^{-1}) in September.

The population density and population size of post-juvenile vendace at Derwent Water between 1998 (no appropriate gill-net data are available for 1995) and 2010 are shown in Fig. 11, both of which directly-linked parameters were comparable with most values recorded from 2004 to 2006 and from 2008 to 2009. They thus showed some increase over the relatively low values of 2007 and the lowest values on record observed in 2003. Following the low of 2003, post-juvenile vendace had comprised an increasing component of the gill-net samples of Site 4 up to 2006. However, in 2007 this trend was temporarily reversed due to increasing numbers of ruffe before being resumed in 2008 and continued to 2010 (Fig. 12, Fig. 13 and see below). This change in fish community composition of a shift from vendace to ruffe was the major factor responsible for the periodically low estimates of vendace abundance presented above, rather than any marked decrease in total fish abundance recorded by hydroacoustics, although it is stressed again that these estimates of post-juvenile vendace population density and population size are based on only small gill-net sample sizes and so must be viewed with considerable caution.

3.2.2 Gill netting

A total of 120 fish was sampled by gill netting at Derwent Water in 2010, comprising 58 perch, 5 pike, 30 roach, 18 ruffe, 1 brown trout, and 8 vendace (Table 6, Fig. 13). Although recorded in at least some earlier years at Derwent Water or Bassenthwaite Lake, no dace, eel, minnow or Atlantic salmon were recorded.

Five of the eight vendace had been damaged to varying degrees while in the gill net prior to lifting and so not all individuals could be measured, weighed and sexed. However, four individuals could be measured and ranged in length from 141 to 182 mm, three individuals could be weighed and ranged in weight from 27 to 52 g, six individuals could be sexed and comprised 3 males and 3 females, and three individuals could be aged and ranged in age from 2 to 3 years. Condition indices could be calculated for three individuals and ranged from 0.922 to 1.058. Vendace median individual length and median individual age between 1998 and 2010 are shown in Fig. 14.

CHAPTER 4 DISCUSSION

4.1 Introduction

The results of the monitoring programme for 2010 will be discussed firstly for Bassenthwaite Lake, where they constituted the sixteenth year of monitoring, and then for Derwent Water, where they constituted the thirteenth year of monitoring.

4.2 Bassenthwaite Lake

The robust interpretation of hydroacoustic surveys at Bassenthwaite Lake in the context of a vendace monitoring programme has undoubtedly been greatly compromised by recent fish species introductions and subsequent population expansions, particularly those of roach and ruffe. In contrast, the failure in recent years to record any biological specimens of vendace by gill netting or a number of other means (Winfield *et al.*, 2008a) arguably simplifies things by leading to the simple conclusion that the vendace is now locally extinct.

The failure of the gill netting of the present project to produce any biological specimens of vendace in 2010 was not unexpected given similar failures of the monitoring programme from 2001 to 2009. The possibility of a natural recolonisation of Bassenthwaite Lake by vendace arriving from Derwent Water during the extensive and unprecedented flooding experienced at both lakes and the connecting River Derwent in November 2009 (Winfield *et al.*, 2010a) appears not to have happened. Four individuals were, however, sampled in December 2001 during an unsuccessful attempt to collect material for a translocation programme (Winfield & Fletcher, 2002) and upward trends observed from 1995 to 2001 in median individual length and median individual age had indicated poor recruitment. Moreover, the fact that all but one of the vendace sampled in 2001 were of a relatively old age of at least 6 years, with an individual of age 8 years being the oldest ever recorded during the present monitoring programme, also gave cause for concern. Indeed, it is possible that there has now been no or extremely little recruitment at all since the year class of 1998. This suggestion is supported by the results of activities outside the present monitoring programme involving 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) which resulted in the capture of just 5, 35, 0 and 4 vendace, respectively. Furthermore, greatly increased efforts to detect vendace in Bassenthwaite Lake were undertaken using a number of approaches outside the present project in 2007 and 2008 but failed to record a single specimen (Winfield *et al.*, 2008a).

Before the apparent extinction of vendace in Bassenthwaite Lake following the last individuals recorded in December 2001, population densities and thus population sizes observed in the late 1990s and 2000 showed very low levels in May. At this time of year vendace densities are typically at their annual low point following spawning and winter mortality, before rising by September at which time any juveniles will have recruited to the recorded component of the population. However, even during this period vendace population densities in Bassenthwaite Lake still fell towards the very lower end of ranges reported for this species in mainland Europe by Jurvelius *et al.* (1984), Jurvelius *et al.* (1987), Jurvelius *et al.* (1988), Mehner & Schulz (2002), Schmidt *et al.* (2005) and Jurvelius *et al.* (2006). It is stressed again that the Bassenthwaite Lake estimates of vendace population density and population size are based on only small gill-net sample sizes and so must be viewed with considerable caution.

Prior to the capture of the last biological specimens in December 2001, there had been no indication that the relatively high growth rate of vendace observed in Bassenthwaite Lake in the early 1990s (Winfield *et al.*, 1994a) had decreased in subsequent years (Winfield *et al.*, 1997), an observation which is consistent with a scarce vendace population limited not by feeding conditions but by other factors. The latter appear to include the poor condition of the vendace spawning grounds due to the extensive local deposition of fine sediments (Winfield *et al.*, 1998b; Winfield, 1999; Winfield *et al.*, 2004a; Winfield *et al.*, 2006; Winfield *et al.*, 2007; Winfield *et al.*, 2008a), and predation impact from the introduced ruffe population which, although not found to consume vendace eggs during the spawning season of 1995 (Winfield *et al.*, 1998c), was subsequently found to have eaten eggs in the spawning seasons of 1996 (Winfield *et al.*, 1998a) and 2001 (Winfield & Fletcher, 2002).

In terms of the wider fish community of Bassenthwaite Lake, the gill netting of 2010 showed that introduced roach and ruffe continue to be major components of the fish communities of most sites within the lake. In contrast, introduced dace have not increased to the same extent and were not recorded in the present survey. The native perch population, however, continues to be both abundant and diverse in individual size as considered in more detail by Winfield *et al.* (2004c). It has also continued to recruit as suggested by the hydroacoustic monitoring and confirmed by the gill netting.

In conclusion, the 2010 monitoring of the vendace population of Bassenthwaite Lake again resulted in the capture of no biological specimens. Given this observation and the findings of Winfield *et al.* (2008a), the local population continues to be considered to be extinct.

4.3 Derwent Water

Variations between 1998 and 2010 in the population density and thus abundance of vendace in Derwent Water revealed by hydroacoustics are clearly less marked than those observed at Bassenthwaite Lake, although there had been notably low abundances in 2003 and 2007 (Winfield *et al.*, 2008c). However, the scale of these reductions were such that they fell within the normal variation of population density shown by this species and so gave no immediate cause for alarm, although following the 2003 monitoring Winfield *et al.* (2004b) noted that concern would rise if population density did not increase in the near future. Consequently, it was welcome that the hydroacoustic observations of 2004 reported by Winfield *et al.* (2005) showed some increase in vendace abundance. This welcome trend has been continued by subsequent surveys, with the temporary fall in 2007 recovered by 2008 (Winfield *et al.*, 2009a) and continued to 2010. In addition, the vendace population abundance in Derwent Water generally continues to be more stable within each year than was typically observed in Bassenthwaite Lake prior to the local extinction. This stability is due in large part to the absence of a dramatic fall in abundance in May, as was increasingly the case in Bassenthwaite Lake in the late 1990s. This observation may be interpreted as indicating a more robust adult spawning stock in Derwent Water, probably composed of a number of age classes.

The estimates of vendace population density and population size produced for Derwent Water in 2010 may be compared with data published for several lakes in Finland, Norway and Germany. In Lake Paasivesi in Finland, Jurvelius *et al.* (1984) recorded densities of 260 and 530 individuals ha^{-1} in May and August, respectively, and reported similar densities of this species from Lake Toisvesi in Finland and Lake Randsfjorden in Norway. Together with their subsequent publications of Jurvelius *et al.* (1988) and Jurvelius *et al.* (2006), the same authors observed vendace densities of up to approximately eight times higher, i.e. up to 4270 individuals ha^{-1}, in three more oligotrophic (Lakes Karjalan, Kermajärvi and Pyhajärvi) and two more eutrophic (Lakes Oulujarvi and Pyhaselka) lakes in Finland. In a detailed survey of Lake Pyhajarvi in Finland, Jurvelius *et al.* (1987) found vendace densities of between 700 and 16000 individuals ha^{-1} on different transects. Finally, in Germany, Mehner & Schulz (2002) recorded a mean vendace density of 5038 individuals ha^{-1} in the oligrotrophic Lake Stechlin, while Schmidt *et al.* (2005) reported vendace densities of up to approximately 8000 individuals ha^{-1} in the mesotrophic Henne Reservoir. In comparison, after allowing for the sampling error of the present study, the mean densities of vendace recorded in Derwent Water in 2010 generally fall within but towards the lower end of this range of values reported from the European mainland. It is stressed again that the present estimates of vendace population density and population size are based on only small gill-net sample sizes and so must be viewed with considerable caution.

The estimated population sizes of vendace produced by the present project for Derwent Water in 2010 are relatively small when compared with population estimates for Scandinavian populations made by Jurvelius *et al.* (1984) and Jurvelius *et al.* (1987).

However, this is largely due to the relatively small size of the Derwent Water vendace habitat, rather than to an unusually low population density.

Although sample sizes in recent years have been very small, a stability of the biological parameters of the Derwent Water vendace population between 1998 and 2010 is indicated by the lack of any marked and alarming trends in median length and median age. The former parameter has shown remarkable stability, although it is acknowledged that no length data were produced for 2009. Median age has varied within the range typical for the species, with the low abundance years of 2003 and 2007 being followed in the subsequent year by a relatively low median age indicating successful and relatively strong recruitment. Although sample size was only small, the range of individual vendace ages recorded in 2010 indicates a population with a diverse age structure and thus recent recruitment. This sequence of observations supports the earlier conclusion of Winfield *et al.* (2004b) that the small population of 2003, and subsequently that of 2007, was simply showing low population fluctuations typical of the species. The current situation thus remains comparable with the results of more extensive earlier sampling concentrated mainly in 1991 when age ranged from 2 to 8 years and length from 111 to 247 mm (Winfield *et al.*, 1994a).

In terms of the wider fish community of Derwent Water, the gill netting of 2010 showed that introduced roach and ruffe continue to be important components of the fish communities of most sites within the lake. As in Bassenthwaite Lake, introduced dace have not increased to the same extent and were not recorded in the present survey. Again as in Bassenthwaite Lake, the native perch population continues to be both abundant and diverse in individual size. Overall, the fish community of Derwent Water clearly continues to be in a state of considerable flux.

Gill-net sampling by Lyle *et al.* (2005) in 2004 supported the encouraging interpretation of the biological specimens of the present monitoring programme, but also produced findings of concern. Despite extensive sampling efforts on several known spawning grounds, Lyle *et al.* (2005) failed to collect significant numbers of spawning vendace. This was remarkable given the abundance of vendace in deep areas of the lake at the time and the relative ease with which such fish were collected in similar sampling in the late 1990s (Lyle *et al.*, 1998b). However, the gill nets used by Lyle *et al.* (2005) did reveal large amounts of introduced New Zealand pygmy weed (*Crassula helmsii*) on the vendace spawning grounds. Thus, it was suggested by Lyle *et al.* (2005) that vendace spawning grounds in Derwent Water had become extensively colonised by New Zealand pygmy weed to the extent that the normal spawning behaviour of vendace had been disrupted. If correct, this development could have serious adverse implications for future recruitment. Subsequent sampling by Lyle *et al.* (2006) in 2005 was more successful in terms of catching spawning vendace, even though most fish were not caught in precisely the expected locations, while similar work in 2006 produced smaller catches of vendace but did not note New Zealand pygmy weed to be a persisting problem (Lyle & Maitland, 2008). In agreement with this interpretation of a receding threat from this invasive macrophyte, specific surveys of New Zealand pygmy weed in 2005 and 2007 by Winfield *et al.* (2006) and Winfield *et al.* (2007), respectively, revealed only limited coverage on vendace spawning grounds. However, further survey in December 2009 by Winfield *et al.* (2010) revealed a considerable deterioration in spawning conditions due to the combination of another expansion of New Zealand pygmy weed and a marked increase in the amounts of fine sediments present, the latter of which were suggested by Winfield *et al.* (2010) to have been deposited by an extreme flood event in November 2009. No further surveys of spawning grounds were undertaken in late 2010, although casual visual observations on foot of some of the extreme inshore areas of the lake showed that the fine sediments deposited in late 2009 had been removed and that New Zealand pygmy weed was again low in abundance (I.J.W., *pers. obs.*). Also encouragingly, adult vendace were caught in abundance for egg stripping purposes on the one occasion that severe weather conditions allowed fieldwork within another project during late 2010 (A. A. Lyle, *pers. comm.*).

In conclusion, the 2010 monitoring of the vendace population of Derwent Water showed no dramatic change in population characteristics from those reported in previous years of the present monitoring programme and in earlier studies. Absolute population densities of vendace were relatively low in a European context, but after allowing for sampling error were within the range reported for non-eutrophic lakes comparable with Derwent Water. The status of the population is thus considered to be acceptable.

4.4 Closing remarks

Little needs to added to the above discussion, except to emphasise that the apparently last remaining native population of vendace in the U.K. is worthy of continued future monitoring in Derwent Water. In addition, continued monitoring is also justifiable at Bassenthwaite Lake in case vendace should reappear, either from an undetected remnant population or by recolonisation from Derwent Water. The probability of the latter ever occurring is probably very remote, particularly given its apparent failure to occur during the unprecedented extensive and prolonged flooding of late 2009.

Given the apparent loss of vendace in Bassenthwaite Lake, it is fortunate that a refuge population has now been successfully established for it at Loch Skeen in south-west Scotland (Maitland *et al.*, 2003; Winfield *et al.*, 2008b). Continued changes in the fish community at Derwent Water and the relatively low abundance of its vendace population mean that work currently in progress (A. A. Lyle, *pers. comm.*) to establish similar refuge populations at Daer Reservoir and potentially elsewhere in south-west Scotland (Lyle *et al.*, 2005) and Sprinkling Tarn in Cumbria (Lyle *et al.*, 2006) should be continued until successful.

ACKNOWLEDGEMENTS

We thank our former colleague Bernie Simon for providing access to unpublished data on the bathymetry of Derwent Water. We also thank Andy Gowans of the Environment Agency and his recently retired former colleague Cameron Durie for their support for this monitoring programme.

REFERENCES

Appelberg, M. (2000). Swedish standard methods for sampling freshwater fish with multi-mesh gillnets. *Fiskeriverket Information* 2000, 1.

Baroudy, E. & Elliott, J. M. (1993). The effect of large-scale spatial variation of pelagic fish on hydroacoustic estimates of their population density in Windermere (northwest England). *Ecology of Freshwater Fish* 2, 160-166.

Jurvelius, J. (1991). Distribution and density of pelagic fish stocks, especially vendace (*Coregonus albula* (L.)), monitored by hydracoustics in shallow and deep southern boreal lakes. *Finnish Fisheries Research* 12, 45-63.

Jurvelius, J., Lindem, T. & Louhimo, J. (1984). The number of pelagic fish in Lake Paasivesi, Finland, monitored by hydroacoustic methods. *Fisheries Research* 2, 273-283.

Jurvelius, J., Lindem, T. & Louhimo, J. (1987). The number of fish in the pelagic areas of Lake Pyhajarvi (Karelia), monitored by hydroacoustic methods. *Finnish Fisheries Research* 8, 48-52.

Jurvelius, J., Lindem, T. & Heikkinen, T. (1988). The size of a vendace, *Coregonus albula* L., stock in a deep lake basin monitored by hydroacoustic methods. *Journal of Fish Biology* 32, 679-687.

Jurvelius, J., Marjomäki, T. J., Hirvonen, E., Lilja, J. & Riikonen, R. (2006). Vendace (*Coregonus albula*) stock assessment in winter using a mobile echo-survey under ice. *Boreal Environment Research* 11, 415–420.

Lelek, A. (1987). *The Freshwater Fishes of Europe. Volume 9. Threatened Fishes of Europe.* Wiesbaden: AULA-Verlag.

Love, R.G. (1971). Dorsal aspect target strength of an individual fish at any aspect. *Journal of the Acoustic Society of America* 49, 816-823.

Lyle, A. A., Maitland, P. S. & Winfield, I. J. (1998a). Re-introduction of vendace: Phase II. Second Interim Report. *Report to Scottish Natural Heritage*. ED/T11063y7/2. 7 pp.

Lyle, A. A., Maitland, P. S. & Winfield, I. J. (1998b). Re-introduction of vendace: Phase II. Final Report. *Report to Scottish Natural Heritage*. ED/T11063y7/3. 18 pp.

Lyle, A. A., Maitland, P. S., & Winfield, I. J. (2005). Translocation of vendace from Derwentwater to safe refuge locations. *Report to English Nature*. LA/C02620/1. 26 pp.

Lyle, A. A., Maitland, P. S., & Winfield, I. J. (2006). Translocation of vendace from Derwentwater to safe refuge locations (2005/6). Final Report. *Report to Environment Agency, North West Region*. LA/C02852/2. 31 pp.

Lyle, A. A. & Maitland, P. S. (2008). Translocation of vendace from Derwentwater to refuge locations in southwest Scotland (2007/8). *Report by ALP to Scottish Natural Heritage (Scottish Natural Heritage Contract Number 21851. Project R06AC618C).* 22 pp.

Maitland, P. S. (1990). *The Conservation of Rare British Freshwater Fish.* Peterborough: Nature Conservancy Council.

Maitland, P. S., Lyle, A. A. & Winfield, I. J. (2003). Survey of vendace in Daer Reservoir and Loch Skene. *Report by Fish Conservation Centre to English Nature (English Nature Contract No. EIT 34-01-006).* 29 pp.

Mehner, T. & Schulz, M. (2002). Monthly variability of hydroacoustic fish stock estimates in a deep lake and its correlation to gillnet catches. *Journal of Fish Biology* 61, 1109-1121.

Mubamba, R. (1989). The ecology of the coregonid fishes in the English Lake District. *Unpublished Ph.D. Thesis*. University of Wales.

Ramsbottom, A. E. (1976). Depth charts of the Cumbrian lakes. *Freshwater Biological Association Scientific Publication No. 33*.

Schmidt, M. B., Gassner, H. & Meyer, E. I. (2005). Distribution and biomass of an underfished vendace, *Coregonus albula*, population in a mesotrophic German reservoir. *Fisheries Management and Ecology* 12, 169-175.

Thackeray, S. J., Maberly, S. C. & Winfield, I. J. (2006). The ecology of Bassenthwaite

Lake (English Lake District). *Freshwater Forum* 25, 1-80.

Winfield, I. J. (1992). Threats to the lake fish communities of the U.K. arising from eutrophication and species introductions. *Netherlands Journal of Zoology* 42, 233-242.

Winfield, I. J., Fletcher, J. M. & Cubby, P. R. (1994a). Status of Rare Fish, Project Record Volume 1. *Commissioned report from Institute of Freshwater Ecology to National Rivers Authority*. WI/T11050m1/9. 244 pp.

Winfield, I. J., Fletcher, J. M. & Cubby, P. R. (1994b). Ecology of the vendace, *Coregonus albula*, in Bassenthwaite Lake. *Commissioned report from Institute of Freshwater Ecology to North West Water Limited*. WI/T11050s1/6. 62 pp.

Winfield, I. J., Cragg-Hine, D., Fletcher, J. M. & Cubby, P. R. (1996). The conservation ecology of *Coregonus albula* and *C. lavaretus* in England and Wales, U.K. In *Conservation of Endangered Freshwater Fish in Europe* (Kirchhofer, A. & Hefti, D. eds), pp. 213-223. Basel: Birkhauser Verlag.

Winfield, I. J., Fletcher, J. M. & Cubby, P. R. (1998a). Fish introductions in Bassenthwaite Lake and Derwentwater. Final Report. *Report to Environment Agency, North West Region*. WI/T11063h5/6. 104 pp.

Winfield, I. J., Fletcher, J. M. & Cubby, P. R. (1998b). Spawning beds of vendace in Bassenthwaite Lake and Derwentwater. Final Report. *Report to English Nature.*

WI/T11063f1/2. 22 pp.

Winfield, I. J., Fletcher, J. M. & Cubby, P. R. (1998c). The threat to vendace (*Coregonus albula*) eggs from introduced ruffe (*Gymnocephalus cernuus*) in Bassenthwaite Lake, U.K. *Advances in Limnology* 50, 171-177.

Winfield, I. J. (1999). A preliminary investigation of the feasibility of improving the spawning grounds of vendace in Bassenthwaite Lake. Final Report. *Report to English Nature, Environment Agency, Lake District National Park Authority and North West Water Ltd*. WI/T11050d2/5. 21 pp.

Winfield, I. J. & Fletcher, J. M. (2002). Captive rearing of the vendace of Bassenthwaite Lake, with an analysis of the winter diet of ruffe. *Report to Environment Agency, North West Region*. WI/C01644/1. 30 pp.

Winfield, I. J., Fletcher, J. M. & James, B. J. (2002). Species introductions to two English lake fish communities of high conservation value: a 10-year study. In: Collares-Pereira, M. J., Coelho, M. M. & Cowx, I. G. (editors) *Conservation of Freshwater Fishes: Options for the Future*. Fishing News Books, Blackwell Scientific Publications, Oxford, 271-281.

Winfield, I. J., Fletcher, J. M. & James, J. B. (2004a). Conservation ecology of the vendace (*Coregonus albula*) in Bassenthwaite Lake and Derwent Water, U.K. *Annales Zoologici Fennici* 41, 155-164.

Winfield, I. J., Fletcher, J. M. & James, J, B. (2004b). The Urban Waste Water Treatment Directive: Monitoring the vendace populations of Bassenthwaite Lake and Derwentwater, 2003. *Report to Environment Agency, North West Region*. WI/C01752/10. 26 pp.

Winfield, I. J., Fletcher, J. M. & James, J. B. (2004c). Coexistence of the Eurasian perch (*Perca fluviatilis*) and an introduced population of ruffe (*Gymnocephalus cernuus*): an 11 year study. In: Barry, T. P. & Malison, J. A. (editors) *Proceedings of Percis III: The Third International Percid Fish Symposium*. University of Wisconsin Sea Grant Institute, Madison, WI, pp. 97-98.

Winfield, I. J., Fletcher, J. M. & James, J, B. (2005). The Urban Waste Water Treatment Directive: Monitoring the vendace populations of Bassenthwaite Lake and Derwent Water, 2004. *Report to Environment Agency, North West Region*. LA/C01752/13. 44 pp.

Winfield, I. J., Fletcher, J. M. & James, J. B. (2006). Ecology and management of vendace spawning grounds. Final Report. *Report to Environment Agency, North West Region*. LA/C02998/3. 62 pp.

Winfield, I. J., Fletcher, J. M. & James, J. B. (2007). Further development of an artificial spawning substrate system for vendace. Final Report. *Report to Environment Agency, North West Region*. LA/C03215/3. 72 pp.

Winfield, I. J., Fletcher, J. M. & James, J. B. (2008a). Assessment of the vendace population of Bassenthwaite Lake including observations on vendace spawning grounds. Final Report.

Report to Environment Agency, North West Region, and Scottish Natural Heritage. LA/C03462/3. 36 pp.

Winfield, I. J., Fletcher, J. M., & Lyle, A. A. (2008b). Assessment of the vendace refuge population of Loch Skeen. Final Report. *Report to Scottish Natural Heritage*. LA/C02539/3. 20 pp.

Winfield, I. J., Fletcher, J. M. & James, J. B. (2008c). Monitoring the fish populations of Bassenthwaite Lake and Derwent Water, 2007. *Report to Environment Agency, North West Region*. LA/C03461/1. 52 pp.

Winfield, I. J., Fletcher, J. M. & James, J. B. (2009a). Monitoring the fish populations of Bassenthwaite Lake and Derwent Water, 2008. *Report to Environment Agency, North West Region*. LA/C03461/3. 52 pp.

Winfield, I. J., Fletcher, J. M. & James, J. B. (2009b). Investigation of vendace spawning grounds in Derwent Water. Final Report. *Report to Environment Agency, North West Region*. LA/C03635/3. 42 pp.

Winfield, I. J., Fletcher, J. M. & James, J. B. (2010a). Monitoring the fish populations of Bassenthwaite Lake and Derwent Water, 2009. *Report to Environment Agency, North West Region*. LA/C03461/5. 54 pp.

Winfield, I. J., Fletcher, J. M. & James, J. B. (2010b). Further investigation of vendace spawning grounds in Derwent Water. Final Report. *Report to Environment Agency, North West Region*. LA/C03784/3. 56 pp.

Winfield, I. J., Adams, C. E., Bean, C. W., Durie, N. C. Fletcher, J. M., Gowans, A. R., Harrod, C., James, J. B., Lyle, A. A., Maitland, P. S., Thompson, C. & Verspoor, E. (in press). Conservation of the vendace (*Coregonus albula*), the U.K.'s rarest freshwater fish. *Advances in Limnology*.

Table 1. GPS locations for 10 hydroacoustic transects and 5 gill-netting sites used at Bassenthwaite Lake in 2010. Locations are given in degrees and decimal minutes.

Event	Latitude (North)	Longitude (West)
Transect 1 start	54, 38.639	3, 12.997
Transect 1 end	54, 38.877	3, 12.344
Transect 2 start	54, 38.877	3, 12.344
Transect 2 end	54, 38.838	3, 13.096
Transect 3 start	54, 38.838	3, 13.096
Transect 3 end	54, 38.994	3, 12.552
Transect 4 start	54, 38.994	3, 12.552
Transect 4 end	54, 39.052	3, 13.251
Transect 5 start	54, 39.052	3, 13.251
Transect 5 end	54, 39.230	3, 12.670
Transect 6 start	54, 39.230	3, 12.670
Transect 6 end	54, 39.202	3, 13.358
Transect 7 start	54, 39.202	3, 13.358
Transect 7 end	54, 39.347	3, 12.869
Transect 8 start	54, 39.347	3, 12.869
Transect 8 end	54, 39.362	3, 13.530
Transect 9 start	54, 39.362	3, 13.530
Transect 9 end	54, 39.497	3, 12.957
Transect 10 start	54, 39.497	3, 12.957
Transect 10 end	54, 39.662	3, 13.641
Site 1	54, 40.278	3, 13.951
Site 2	54, 38.838	3, 13.096
Site 3	54, 38.890	3, 12.909
Site 4	54, 38.542	3, 12.581
Site 5	54, 38.327	3, 12.233

Table 2. GPS locations for 5 hydroacoustic transects and 5 gill-netting sites used at Derwent Water in 2010. Locations are given in degrees and decimal minutes.

Event	Latitude (North)	Longitude (West)
Transect 1 start	54, 34.575	3, 09.469
Transect 1 end	54, 34.302	3, 08.162
Transect 2 start	54, 34.302	3, 08.162
Transect 2 end	54, 34.749	3, 09.372
Transect 3 start	54, 34.749	3, 09.372
Transect 3 end	54, 34.330	3, 08.033
Transect 4 start	54, 34.330	3, 08.033
Transect 4 end	54, 34.797	3, 08.881
Transect 5 start	54, 34.797	3, 08.881
Transect 5 end	54, 34.438	3, 07.999
Site 1	54, 35.571	3, 09.150
Site 2	54, 35.101	3, 08.585
Site 3	54, 34.738	3, 08.715
Site 4	54, 34.547	3, 08.433
Site 5	54, 34.363	3, 08.024

Table 3. Summary data (given as geometric means with lower and upper 95% confidence limits in parentheses) for densities of small, medium, large and all fish recorded during the two hydroacoustic surveys undertaken on Bassenthwaite Lake in 2010.

Date	Small fish (fish ha^{-1})	Medium fish (fish ha^{-1})	Large fish (fish ha^{-1})	All fish (fish ha^{-1})
6 May 2010	5.3 (1.8, 16.1)	1.7 (0.8, 4.0)	1.0 (1.0, 1.0)	6.1 (1.9, 20.0)
1 July 2010	865.9 (606.1, 1237.0)	30.0 (21.9, 41.1)	1.3 (0.7, 2.4)	899.0 (634.6, 1273.6)
2 September 2010	286.1 (175.4, 466.9)	52.3 (18.5, 148.3)	1.3 (0.7, 2.4)	352.9 (211.1, 589.8)

Table 4. Numbers of fish individuals recorded in the gill-net survey of Bassenthwaite Lake on 2 September 2010. The basic (bottom set) version of the Norden survey gill net was used at all sites, together with its pelagic (surface set) version at Site 3 only. The catch of the latter is shown as Site 3 (P).

Site	Dace	Eel	Minnow	Perch	Pike	Roach	Ruffe	Salmon	Trout	Vendace	Total
1	0	0	0	28	0	6	7	0	1	0	42
2	0	0	0	28	1	16	17	0	0	0	62
3	0	0	0	20	1	0	13	0	0	0	34
4	0	0	0	44	1	7	7	0	0	0	59
5	0	0	0	73	1	5	12	0	0	0	91
3 (P)	0	0	0	191	3	9	0	0	0	0	203
Total	0	0	0	384	7	43	56	0	1	0	491

Table 5. Summary data (given as geometric means with lower and upper 95% confidence limits in parentheses) for densities of small, medium, large and all fish recorded during the three hydroacoustic surveys undertaken on Derwent Water in 2010.

Date	Small fish (fish ha^{-1})	Medium fish (fish ha^{-1})	Large fish (fish ha^{-1})	All fish (fish ha^{-1})
18 May 2010	4.6 (0.8, 25.9)	30.4 (8.2, 112.5)	1.4 (0.6, 3.2)	34.8 (8.7, 138.8)
27 July 2010	93.5 (65.3, 133.9)	83.9 (36.2, 194.7)	7.0 (1.6, 29.9)	191.5 (116.8, 313.9)
20 September 2010	290.2 (122.8, 685.7)	38.9 (2.5, 600.8)	2.2 (0.6, 8.0)	364.9 (135.5, 982.9)

Table 6. Numbers of fish individuals recorded in the gill-net survey of Derwent Water on 20 September 2010. The basic (bottom set) version of the Norden survey gill net was used at all sites, together with its pelagic (surface set) version at Site 4 only. The catch of the latter is shown as Site 4 (P).

Site	Dace	Eel	Minnow	Perch	Pike	Roach	Ruffe	Salmon	Trout	Vendace	Total
1	0	0	0	7	1	17	0	0	0	0	25
2	0	0	0	22	1	3	2	0	0	0	28
3	0	0	0	13	1	3	8	0	0	0	25
4	0	0	0	2	0	0	0	0	0	3	5
5	0	0	0	14	2	5	8	0	1	0	30
4 (P)	0	0	0	0	0	2	0	0	0	5	7
Total	0	0	0	58	5	30	18	0	1	8	120

Fig. 1. Bassenthwaite Lake showing depth contours (in metres) and the locations of 10 hydroacoustic transects (continuous lines) and 5 gill-netting sites (closed circles). GPS locations are given in Table 1. Redrawn with permission from Ramsbottom (1976).

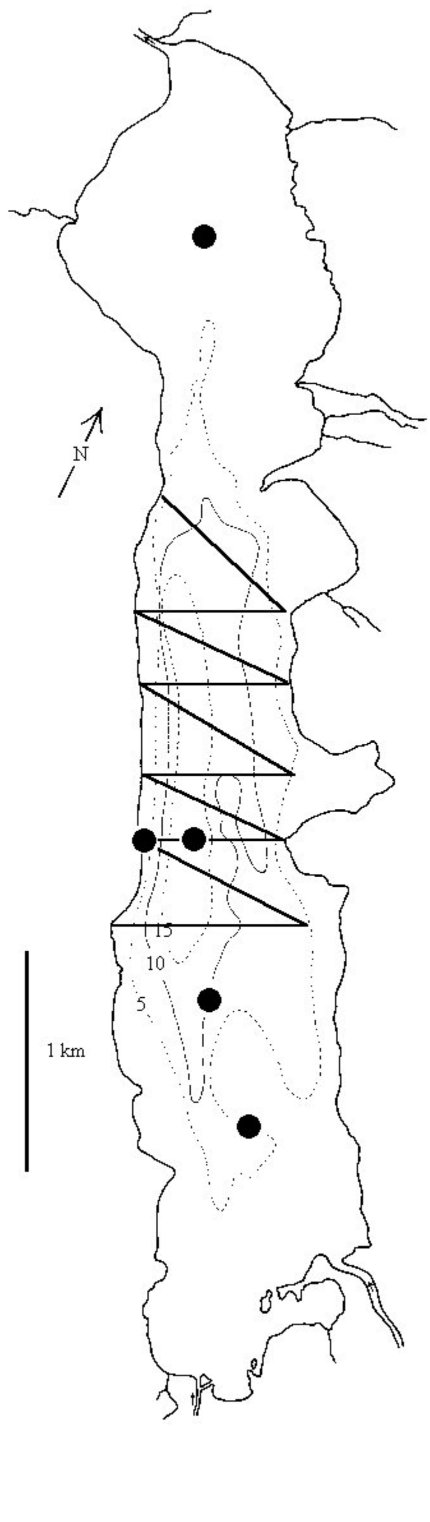


Fig. 2. Derwent Water showing depth contours (in metres) and the locations of 5 hydroacoustic transects (continuous lines) and 5 gill-netting sites (closed circles). GPS locations are given in Table 2. Redrawn with permission from Ramsbottom (1976).

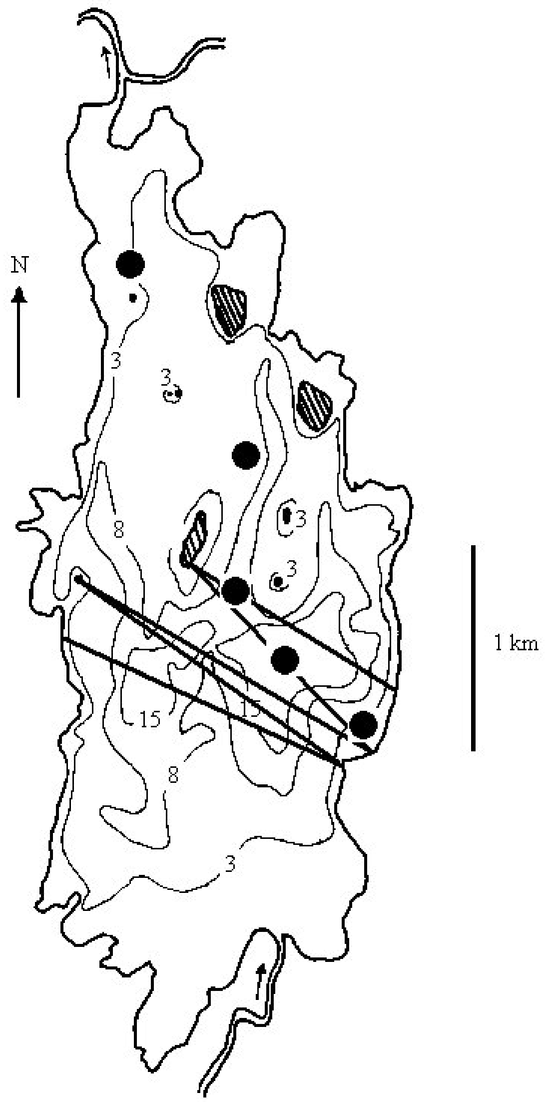
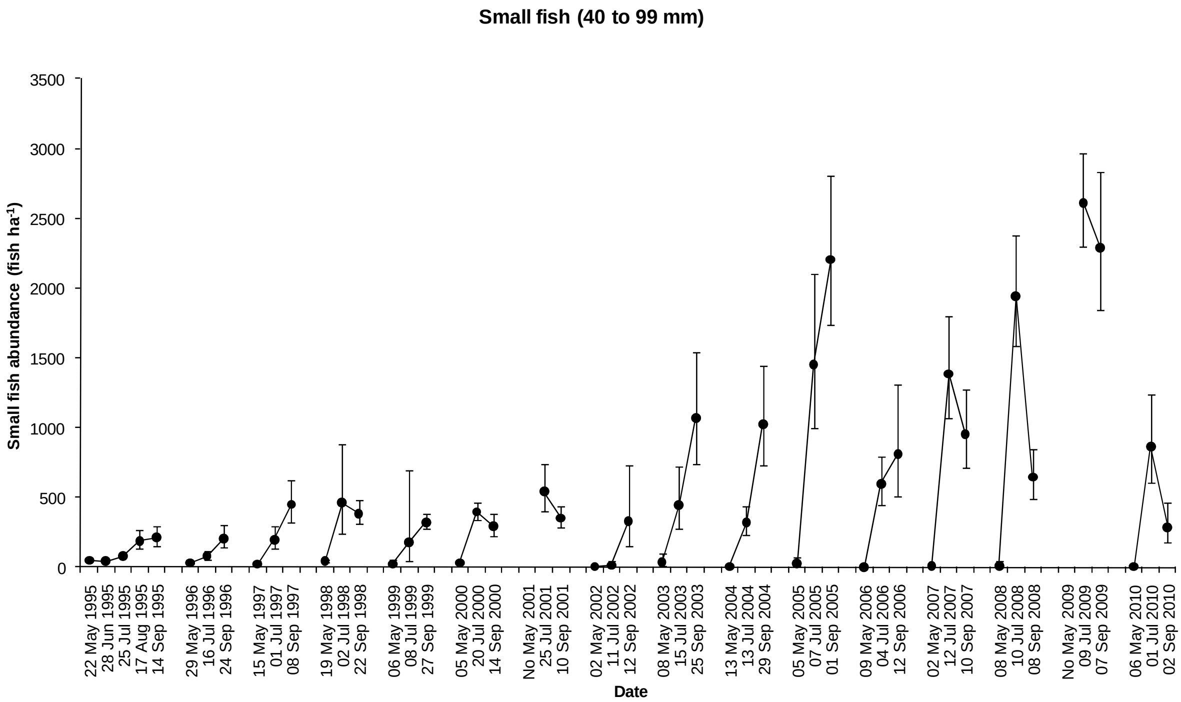


Fig. 3. Abundance estimates expressed as population density (fish ha^{-1}, geometric means with 95% confidence limits) for small and medium fish in Bassenthwaite Lake from 1995 to 2010. Note that only a single transect was carried out in July 1995 and no survey was possible in May 2001 due to access restrictions because of foot-and-mouth disease.



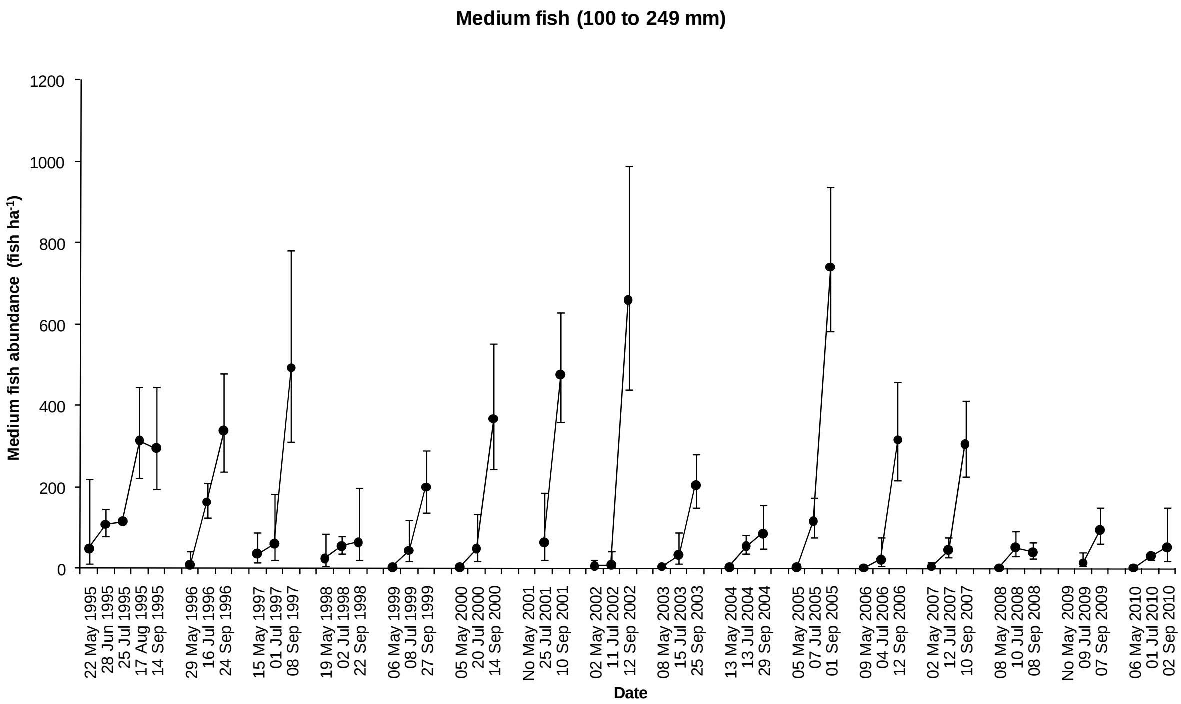
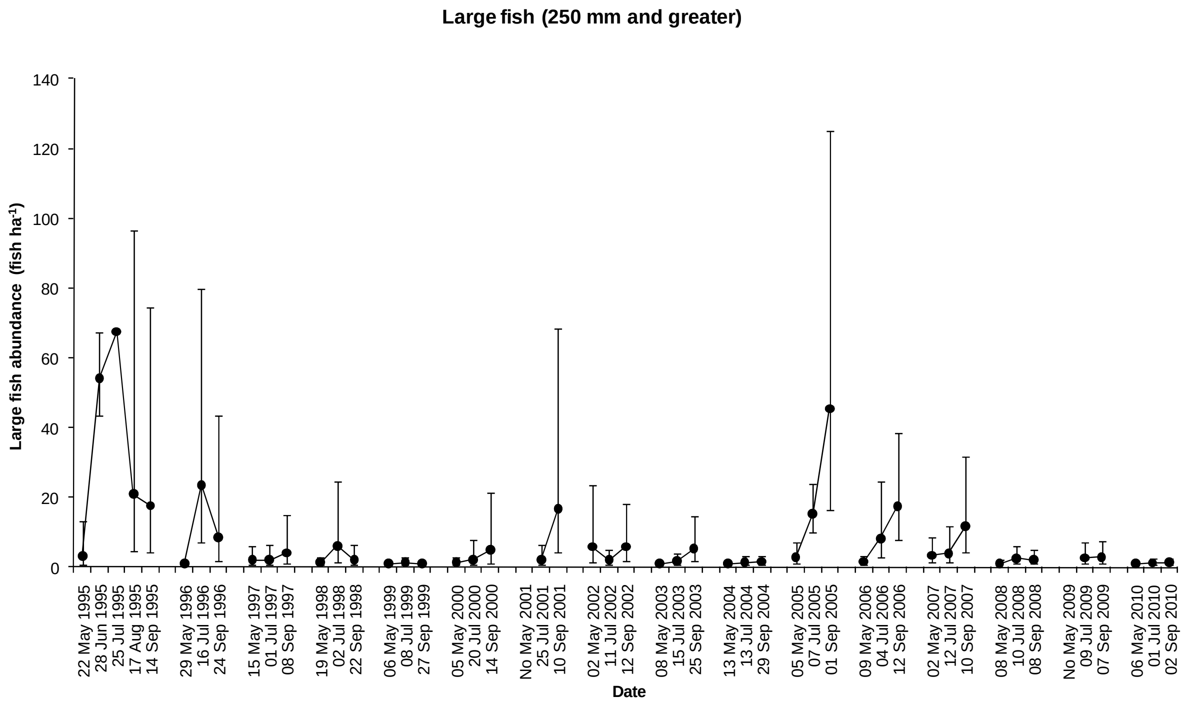


Fig. 4. Abundance estimates expressed as population density (fish ha^{-1}, geometric means with 95% confidence limits) for large and all fish in Bassenthwaite Lake from 1995 to 2010. Note that only a single transect was carried out in July 1995 and no survey was possible in May 2001 due to access restrictions because of foot-and-mouth disease.



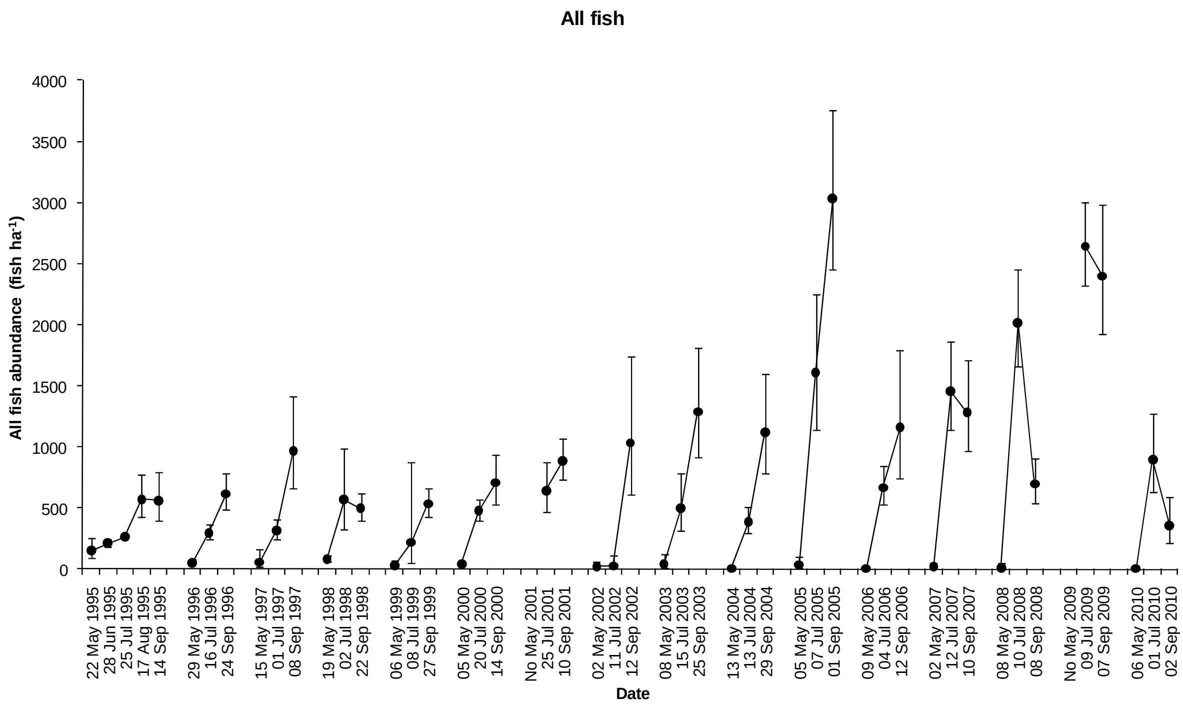
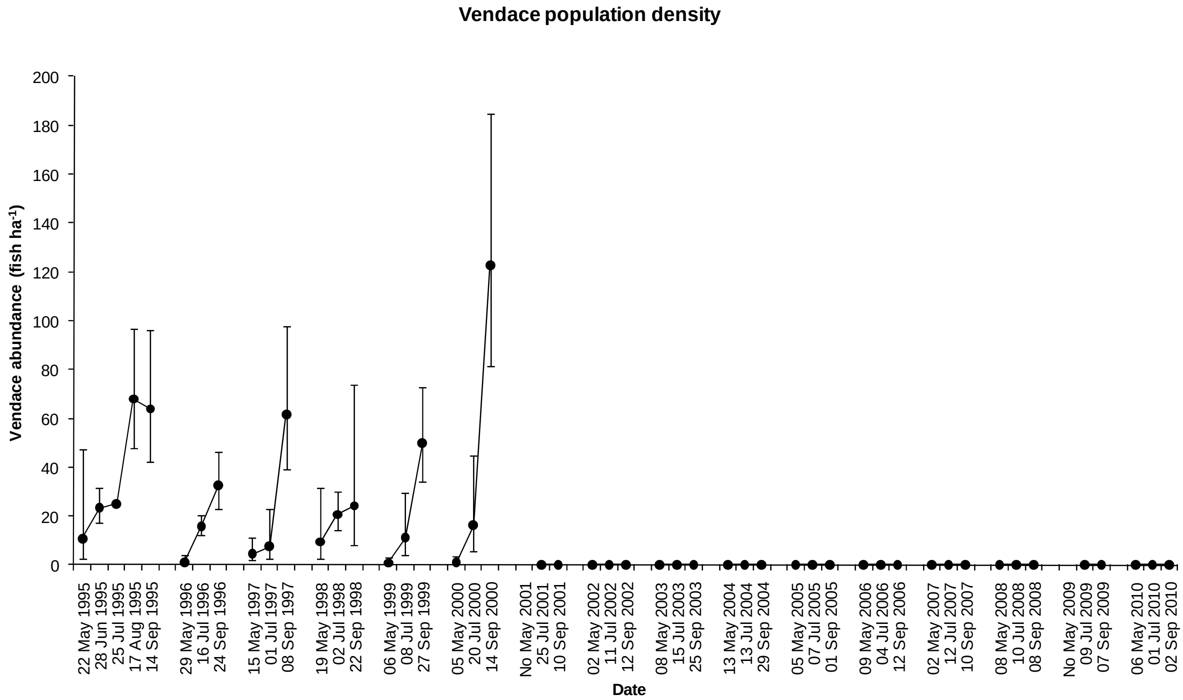


Fig. 5. Abundance estimates expressed as population density (fish ha^{-1}, geometric means with 95% confidence limits) and population size (fish, geometric means with 95% confidence limits) for vendace in Bassenthwaite Lake from 1995 to 2010.



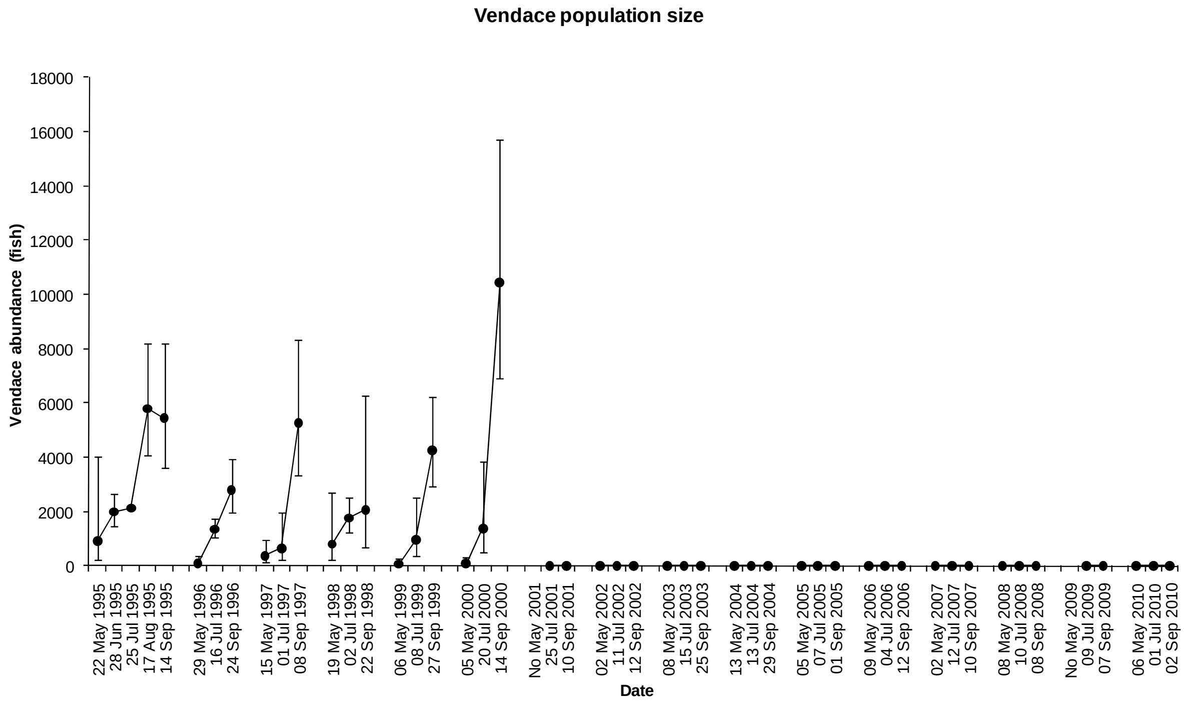


Fig. 6. Medium (100 to 249 mm in length) fish community composition (by numbers) for Site 3 of Bassenthwaite Lake from 1995 to 2010 on which vendace population estimates are partly based.

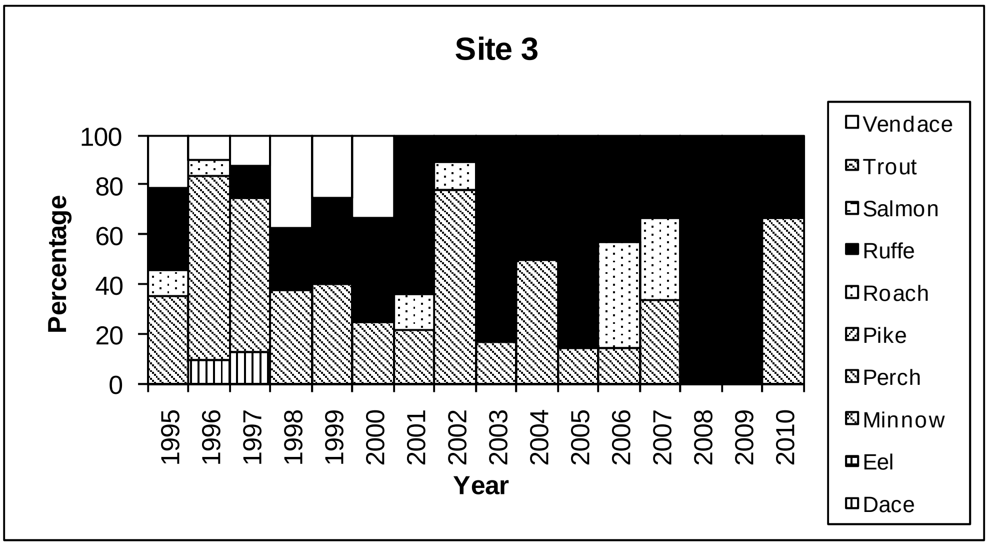
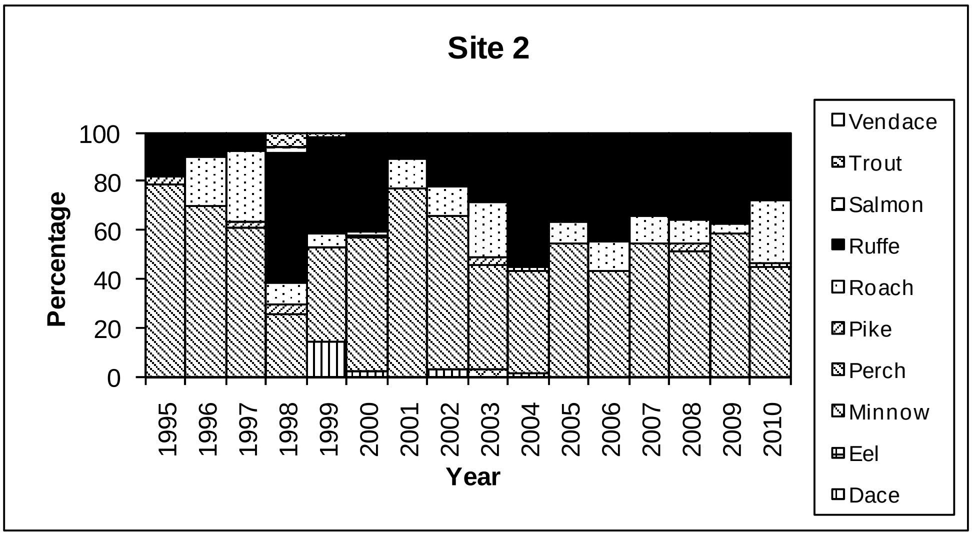
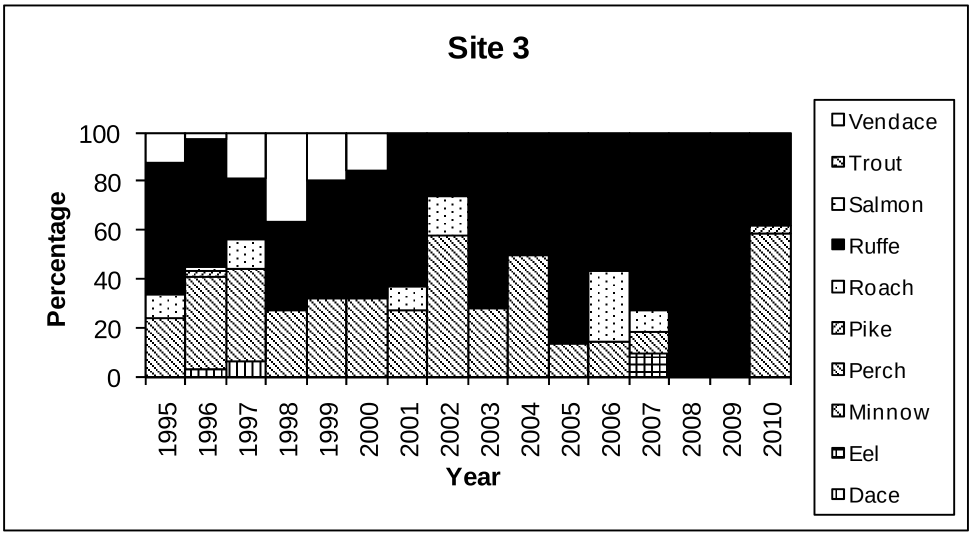


Fig. 7. Fish community compositions (by numbers) for Site 2 (a shallow site), Site 3 (a deep site) and the entire lake of Bassenthwaite Lake from 1995 to 2010.





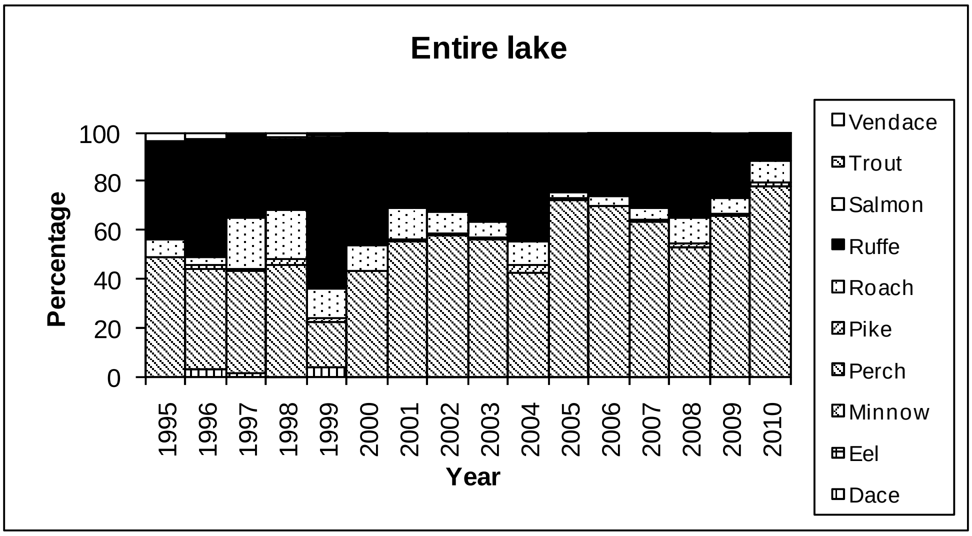
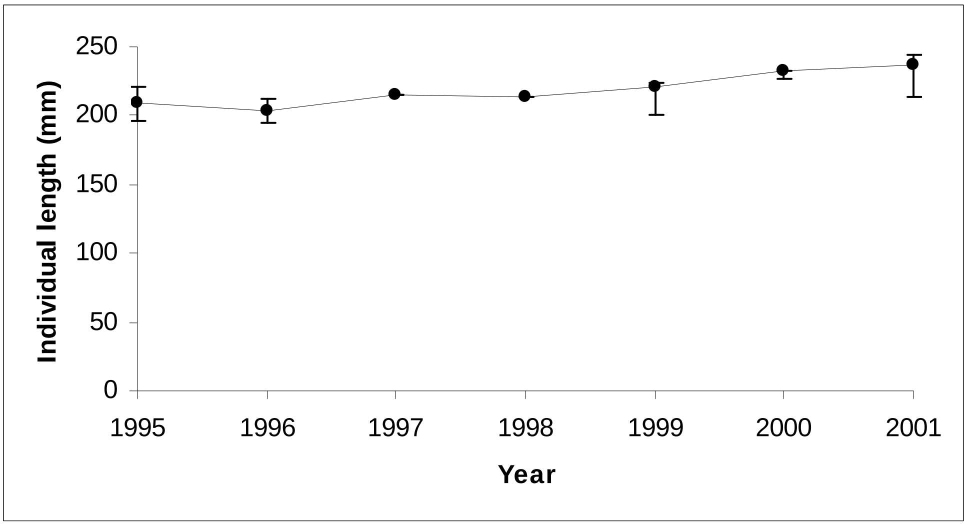


Fig. 8. Individual length and age (medians with first and third quartiles) of vendace from Bassenthwaite Lake between 1995 and 2001. Note that no vendace have been recorded by the monitoring programme since 2000, with the data from 2001 taken from Winfield & Fletcher (2002).



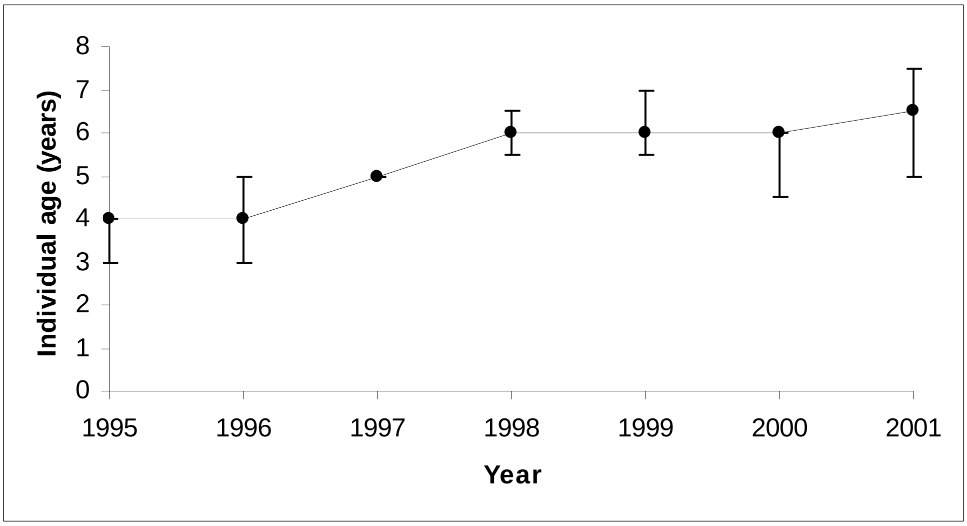
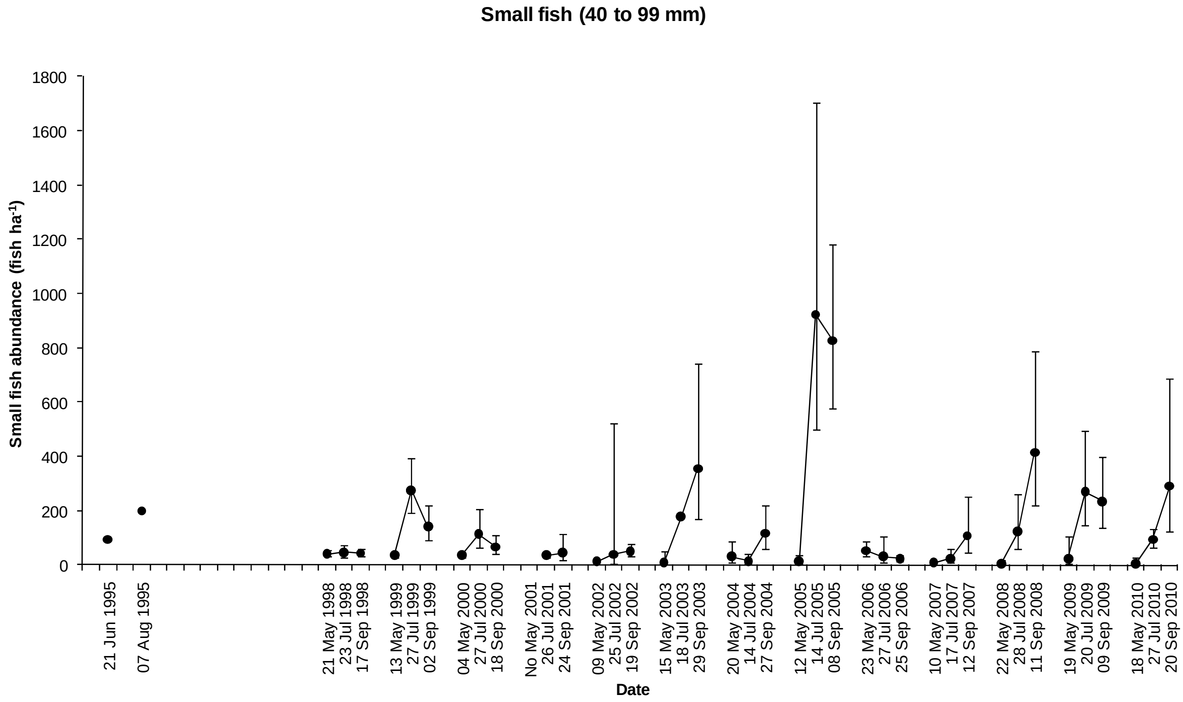


Fig. 9. Abundance estimates expressed as population density (fish ha^{-1}, geometric means with 95% confidence limits) for small and medium fish in Derwent Water from 1995 to 2010. Note that only single transects were carried out in June and August 1995 and July 2003 and no survey was possible in May 2001 due to access restrictions because of foot-and-mouth disease.



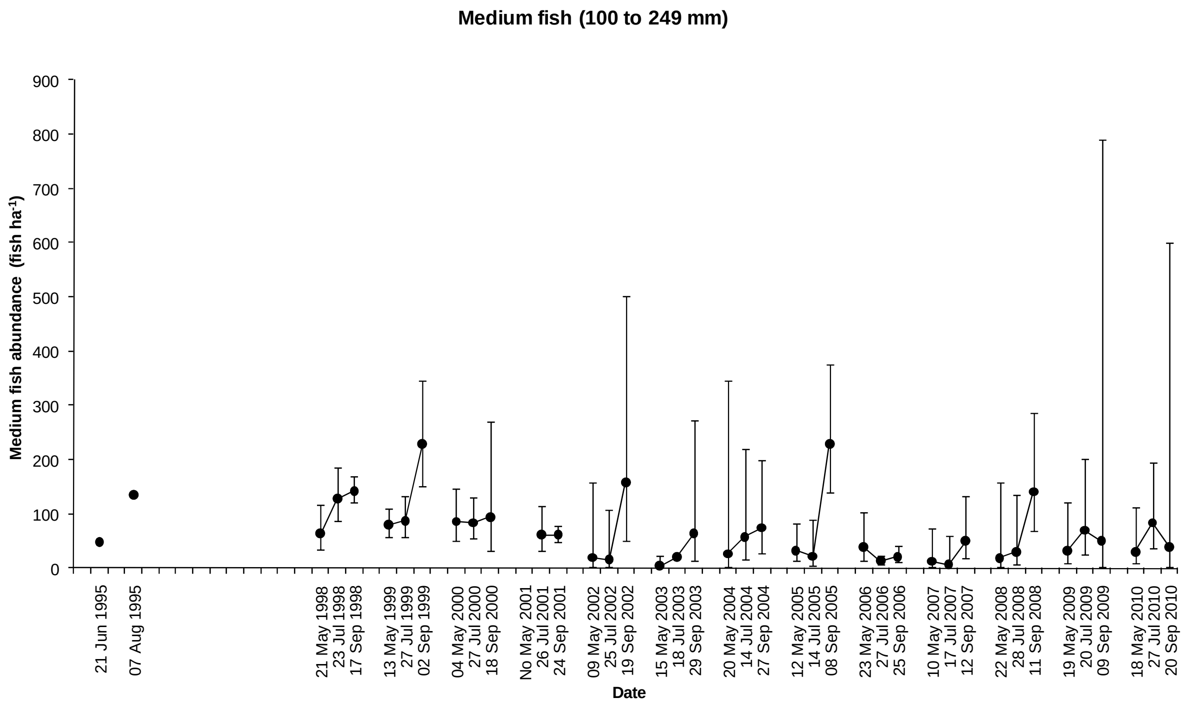
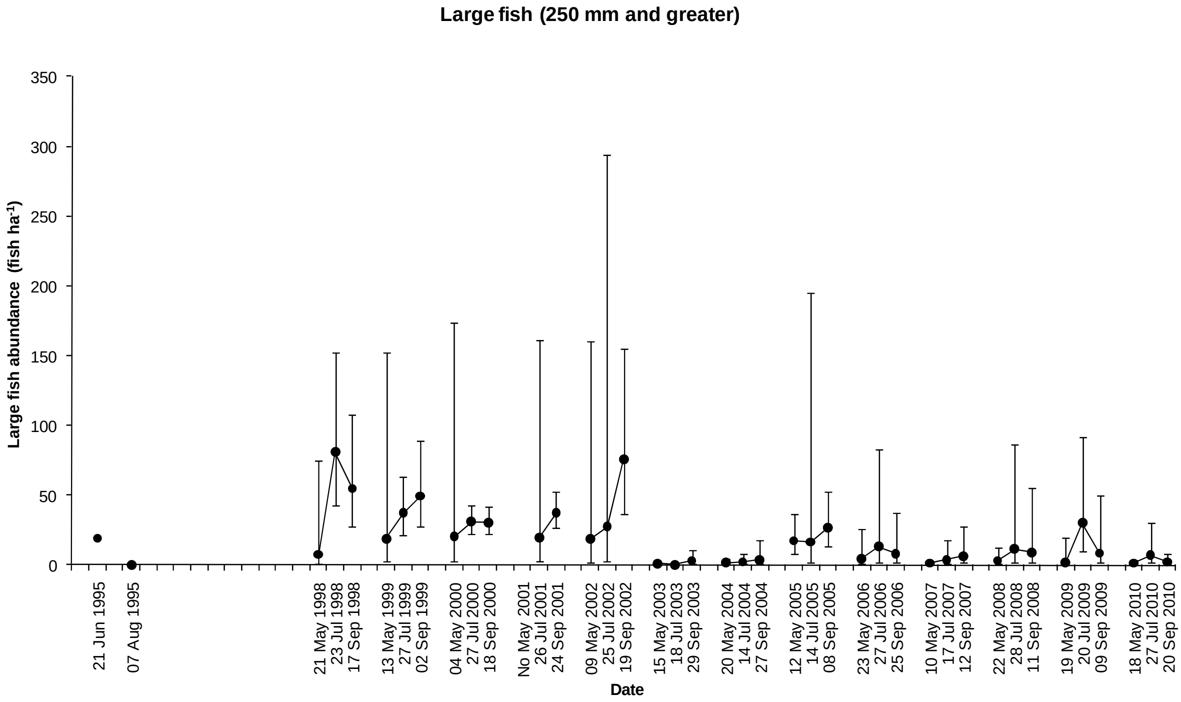


Fig. 10. Abundance estimates expressed as population density (fish ha^{-1}, geometric means with 95% confidence limits) for large and all fish in Derwent Water from 1995 to 2010. Note that only single transects were carried out in June and August 1995 and July 2003 and no survey was possible in May 2001 due to access restrictions because of foot-and-mouth disease.



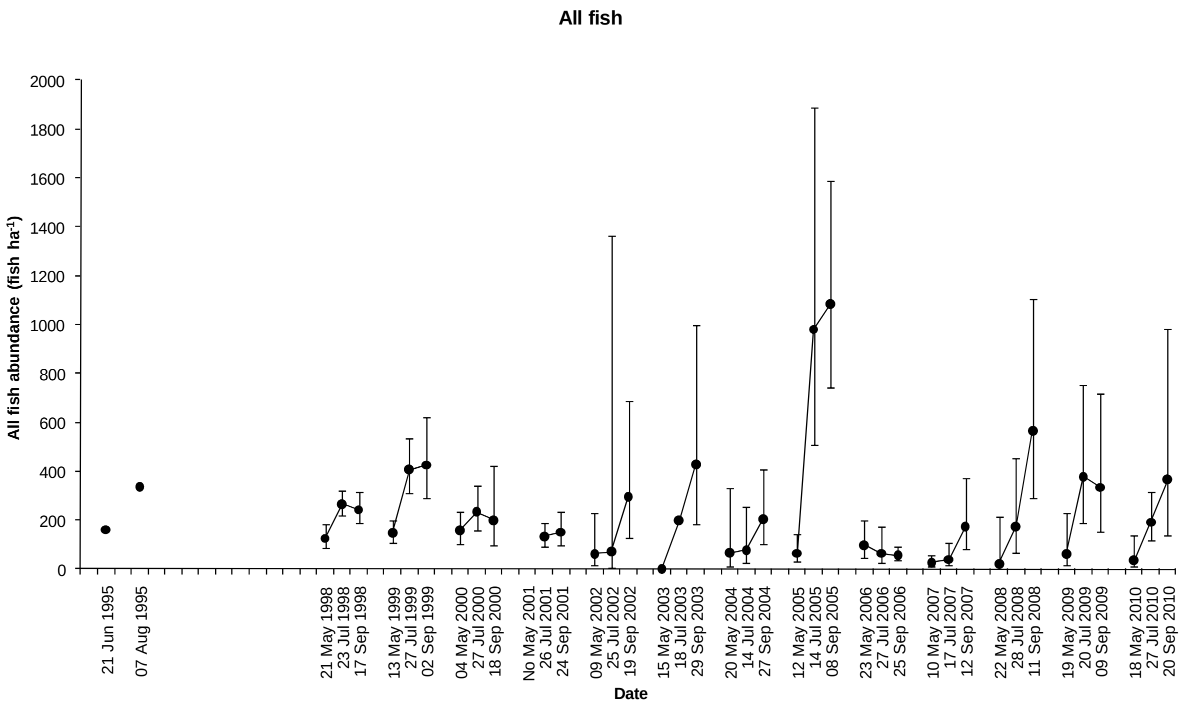
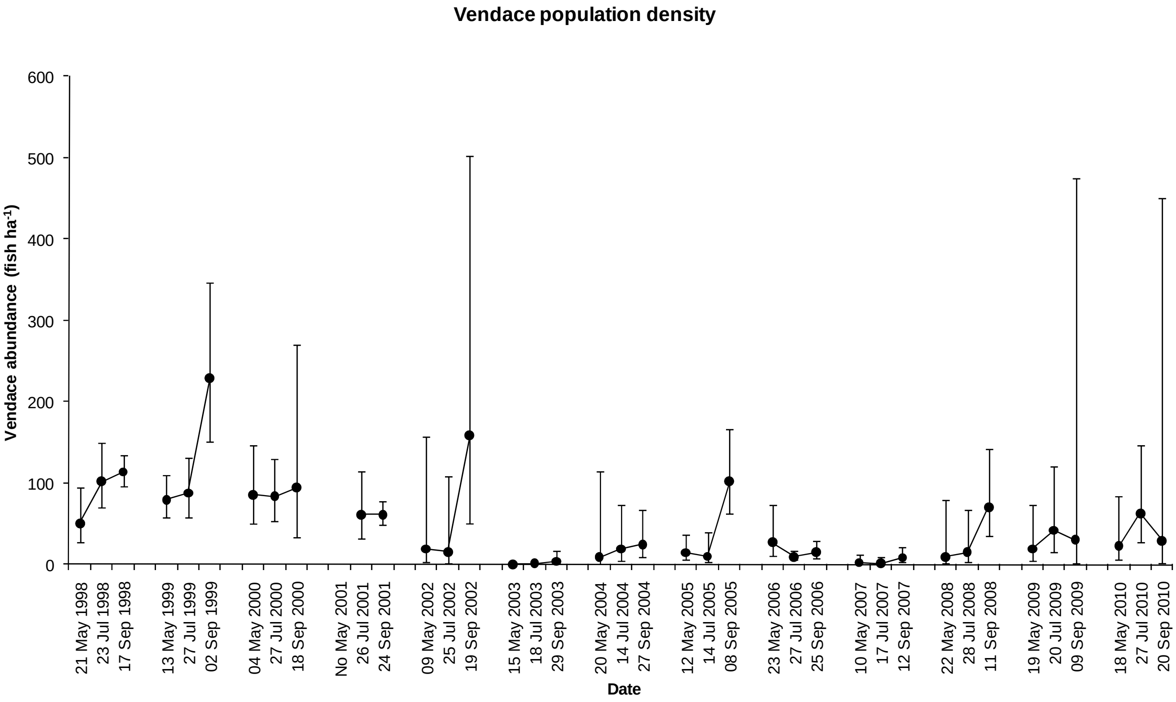


Fig. 11. Abundance estimates expressed as population density (fish ha^{-1}, geometric means with 95% confidence limits) and population size (fish, geometric means with 95% confidence limits) for vendace in Derwent Water from 1998 to 2010.



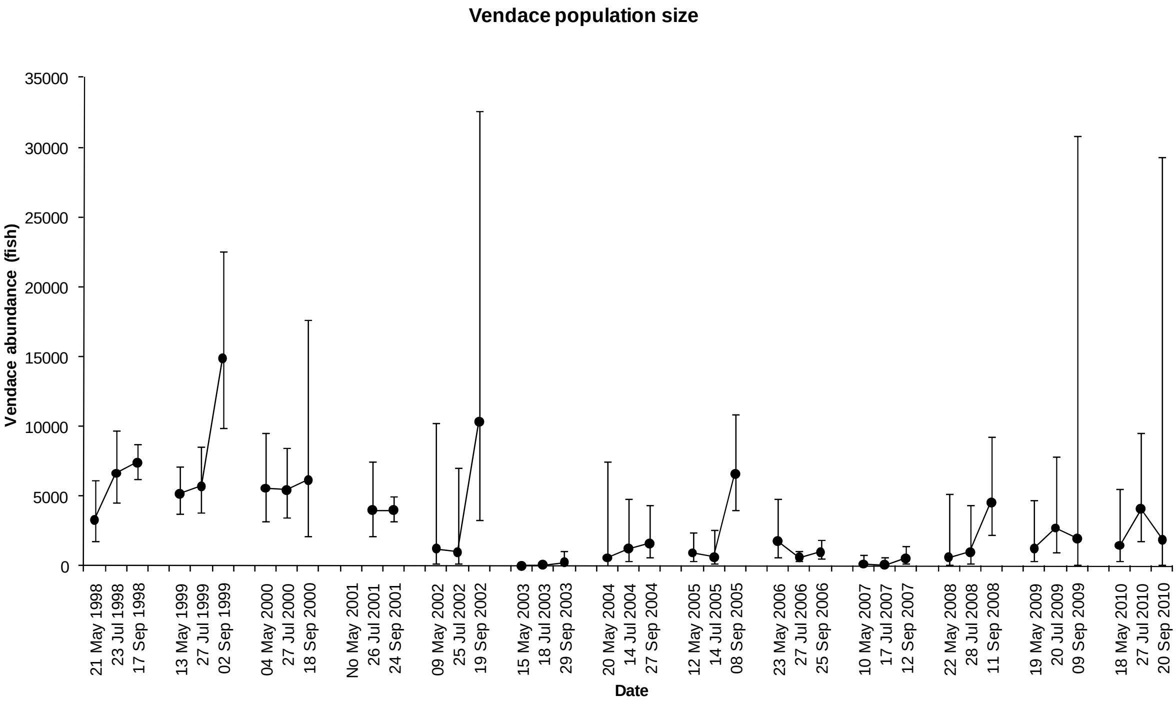


Fig. 12. Medium (100 to 249 mm in length) fish community composition (by numbers) for Site 4 of Derwent Water from 1995 to 2010 on which vendace population estimates are partly based.

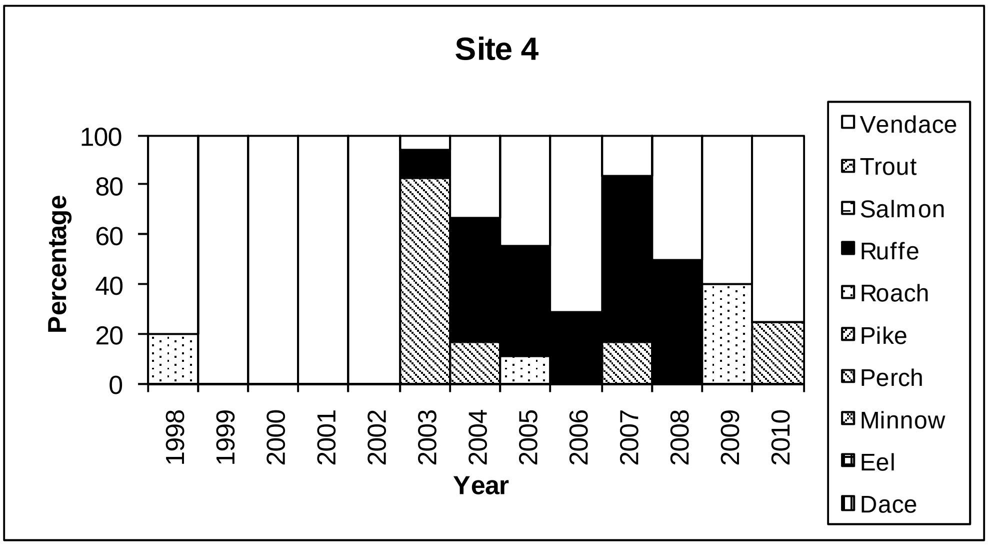
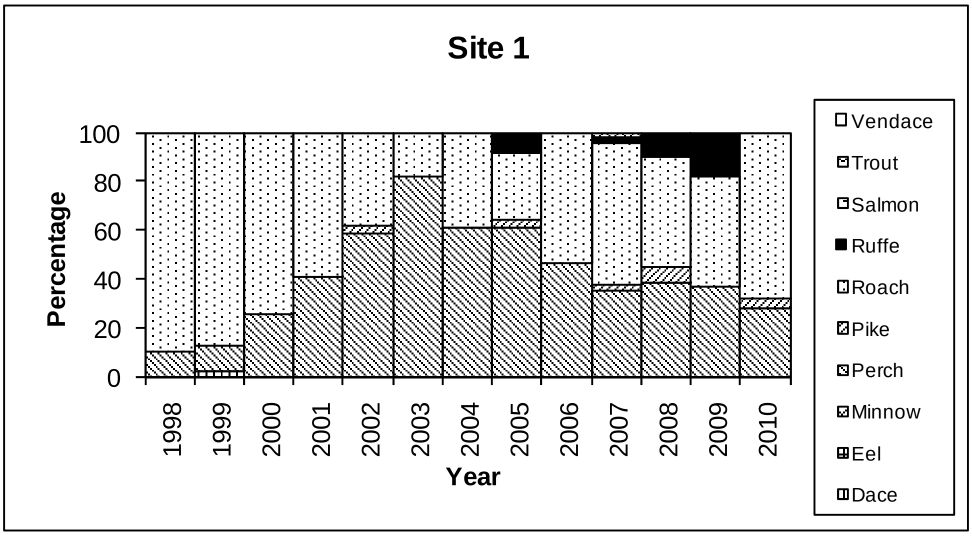
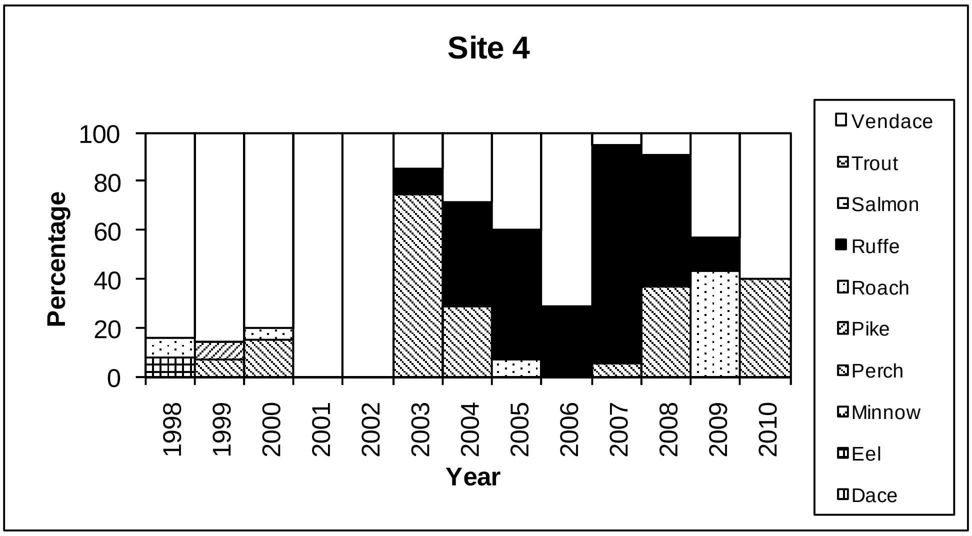


Fig. 13. Fish community compositions (by numbers) for Site 1 (a shallow site), Site 4 (a deep site) and the entire lake of Derwent Water from 1998 to 2010.





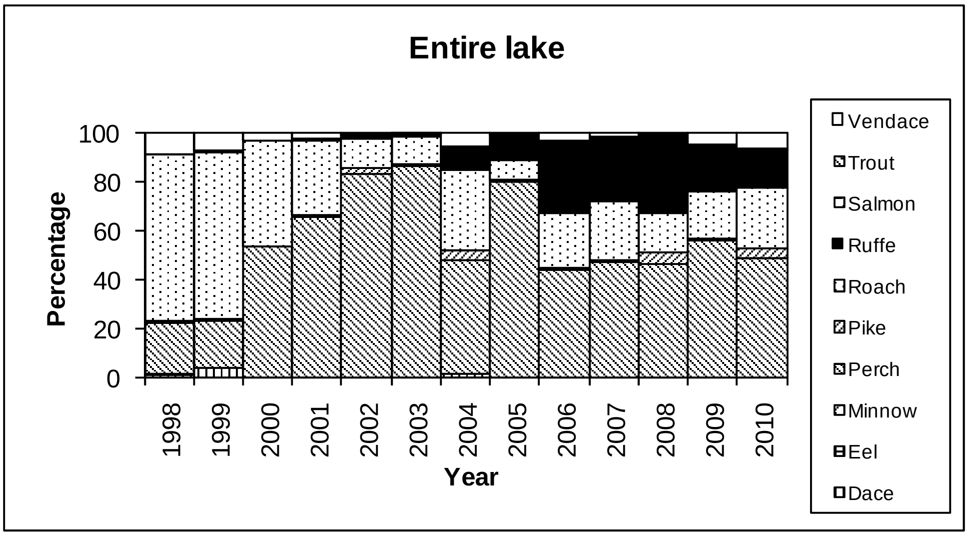


Fig. 14. Individual length and age (medians with first and third quartiles) of vendace from Derwent Water between 1998 and 2010. Note that no length measurements were possible in 2009 due to all vendace having sustained extensive damage while in the gill net prior to lifting.