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FURTHER INVESTIGATION OF VENDACE SPAWNING GROUNDS IN DERWENT WATER

FINAL REPORT

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CONTENTS **PAGE**

EXECUTIVE SUMMARY

1. Previous studies and a current monitoring programme have shown that the status of vendace (*Coregonus albula*) in Derwent Water in north-west England has remained acceptable, even though it faces a number of environmental threats including species introductions and climate change. However, a precautionary attempt to establish a refuge population for the vendace of this lake has been hampered by a lack of detailed knowledge concerning the locations of its spawning grounds.

2. The objectives of the present project were to locate and describe current vendace spawning grounds in Derwent Water in late 2009 and early 2010 to support conservation initiatives and, if judged appropriate on the basis of initial experiences, to make limited observations at appropriate whitefish (i.e. schelly (*Coregonus lavaretus*) and/or gwyniad (*Coregonus lavaretus*)) spawning grounds in other lakes in early 2010.

3. Prolonged adverse weather conditions greatly compromised the planned programme of field work at Derwent Water using a Remotely Operated Vehicle (ROV) equipped with video, imaging sonar and a still camera, together with a monopod-mounted still camera and a static-mounted still camera capable of making interval exposures. However, three boat-based and four shore-based visits were made to this lake between 1 and 18 December 2009, during which time a total of 15 sites was examined. All boat-based visits were made after dark and used the ROV, while shore-based visits were made after dark and during the day and used still cameras. One shore-based visit also used the ROV. Finally, the ROV was also deployed together with independent still cameras from the shore at a site in the schelly lake of

Ullswater on three evening visits between 26 January and 11 February 2010.

4. In Derwent Water, habitat conditions for spawning vendace showed a considerable deterioration since the previous winter due to expansion of New Zealand pygmy weed (*Crassula helmsii*) and particularly because of a marked increase in the amounts of fine sediments present, the latter of which were presumably deposited by an extreme flood event in November 2009. During the after-dark ROV and still camera observations, no vendace were seen at any site although brown trout (*Salmo trutta*), minnow (*Phoxinus phoxinus*), perch (*Perca fluviatilis*), pike (*Esox lucius*) and ruffe (*Gymnocephalus cernuus*) were encountered.

5. In Ullswater, habitat conditions for spawning schelly were excellent and allowed exhaustive testing of the ROV and independent still camera systems. A single adult schelly was recorded, together with numerous brown trout. The ROV's imaging sonar proved to be particularly effective at detecting fish up to a range of 10 m and navigating closer to allow visual contact, while the independent still camera deployed on a static lake bottom mount recorded a number of small fish which were probably brown trout.

6. Although greatly impacted by prolonged adverse weather during the winter of 2009/2010, in addition to the above site-specific findings the present project demonstrated that underwater video deployed on an ROV equipped with imaging sonar can be used to provide an effective and non-destructive survey technique for spawning coregonids. In addition, the stand-alone still camera deployed on the lake bottom to take photographs at intervals produced some encouraging results. Further research activities were recommended.

CHAPTER 1 INTRODUCTION

1.1 Background

The vendace (*Coregonus albula*) is the U.K.'s rarest freshwater fish species and is accordingly protected by its inclusion on Schedule 5 of the Wildlife and Countryside Act of 1981. It is also included on the List of Priority Species of the U.K. Biodiversity Action Plan (www.ukbap.org.uk). Following the loss of two populations from south-west Scotland during the previous century (Winfield *et al.*, 2004) and the more recent apparent loss of a population from Bassenthwaite Lake in north-west England (Winfield *et al.*, 2008), the only remaining native population now occurs near to the latter site in Derwent Water.

Previous studies (Mubamba, 1989; Winfield *et al.*, 1994) and a current monitoring programme (Winfield *et al.*, 2009a) have shown that the status of vendace in Derwent Water in north-west England has remained acceptable, even though that of the nearby population in Bassenthwaite Lake had been poor for at least approximately two decades prior to the recent declaration of its extinction (Winfield *et al.*, 2008). Nevertheless, the vendace population of Derwent Water faces a number of environmental threats including species introductions, particularly of ruffe (*Gymnocephalus cernuus*) which is currently increasing in abundance, and climate change (Winfield *et al.*, 2004; Winfield *et al.*, submitted).

In anticipation of the potential consequences of deteriorating environmental conditions observed in Bassenthwaite Lake during the 1990s, a refuge population of vendace originating from this water body was established in Loch Skeen (or Skene) in south-west Scotland (Lyle *et al.*, 1999; Maitland *et al.*, 2003). This new population now forms a potential source of vendace for restocking into Bassenthwaite Lake when environmental conditions have been improved. The value of a corresponding prudent action at Derwent Water has been appreciated for several years and attempts have been made to establish appropriate refuge populations in Daer Reservoir in Scotland and Sprinkling Tarn in Cumbria (Lyle *et al.*, 1999; Lyle *et al.*, 2005; Lyle *et al.*, 2006), although not yet with any demonstrable success (Maitland *et al.*, 2003; Winfield *et al.*, submitted). One notable feature of the recent attempts by Lyle *et al.* (2005) and Lyle *et al.* (2006) to obtain eggs from Derwent Water vendace was the difficulty of capturing spawning adults in significant numbers. Extremely high levels of sampling effort were used, with extremely variable results and this stage of the process has formed a significant bottleneck in the overall refuge programme. This difficulty is despite, or perhaps because of, the fact that earlier (Winfield *et al.*, 1998) and more recent (Coyle & Adams, 2008; Winfield *et al.*, 2008) underwater video observations have consistently shown that suitable vendace spawning habitat is extensive in Derwent Water.

Given the above situation, it is now highly desirable to acquire a more robust assessment of the locations of current vendace spawning grounds in Derwent Water in order to inform and thus increase the efficiency of any future attempts at egg collection for refuge population purposes. In addition, limited observations at appropriate whitefish (i.e. schelly and/or gwyniad, *Coregonus lavaretus*) spawning grounds would also be worthwhile both in terms of developing observation techniques and providing some information on these other rare fish populations. Some aspects of such work were undertaken by Winfield *et al.* (2009b), although prolonged adverse weather at Derwent Water throughout much of late November and December 2008 limited the progress made with respect to this last surviving native vendace population in the U.K.

1.2 Objectives

To locate and describe the condition of current vendace spawning grounds in Derwent Water in late 2009 and early 2010 to support conservation initiatives and, if judged appropriate on the basis of initial experiences, to make limited observations at appropriate whitefish (i.e. schelly and/or gwyniad) spawning grounds at other lakes in early 2010.

CHAPTER 2 VENDACE SPAWNING GROUNDS IN DERWENT WATER

2.1 Introduction

Although recent attempts by Lyle *et al.* (2005) and Lyle *et al.* (2006) to obtain eggs from Derwent Water vendace encountered great difficulty in capturing spawning adults in significant numbers, earlier (Winfield *et al.*, 1998) and more recent (Coyle & Adams, 2008; Winfield *et al.*, 2008; Winfield *et al.*, 2009b) underwater video observations have consistently shown that suitable vendace spawning habitat is extensive in Derwent Water.

In particular, underwater video observations and air-lift sampling for eggs carried out in 1997 and 1998 by Winfield *et al.* (1998), together with a consideration of the results of earlier gill-netting for spawning vendace undertaken by Lyle *et al.* (1999), allowed Winfield *et al.* (*op. cit.*) to locate and describe six actual (i.e. spawning vendace captured by gill nets) spawning grounds in good condition (south of Victoria Bay, south of St Herbert’s Island, north of St Herbert’s island, north of Rampsholme Island, south of Scarf Stones, and south of Calfclose Bay), 14 potential (i.e. underwater video observations indicated appropriate habitat) spawning grounds, and six unsuitable spawning grounds.

The objective of this part of the present project was to locate and describe vendace spawning grounds in Derwent Water used during the spawning season of late 2009.

2.2 Methods

2.2.1 Approach

On the basis of earlier underwater video and other observations including those of Winfield *et al.* (1998), Coyle & Adams (2008), Winfield *et al.* (2008) and particularly Winfield *et al.* (2009b), plans were made for extensive underwater video observations on potential vendace spawning grounds in Derwent Water during late November and December 2009. These areas included all of the vendace spawning grounds previously shown by Winfield *et al.* (1998) to have been used in the 1990s, i.e. south of Victoria Bay, south of St Herbert's Island, north of St Herbert's island, north of Rampsholme Island, south of Scarf Stones, and south of Calfclose Bay. The underwater video observations were performed exclusively using cameras deployed on a Remotely Operated Vehicle (ROV), supplemented by a stand-alone still camera occasionally mounted on the ROV and complemented by this and another stand-alone still camera deployed in a static mode on the lake bottom.

2.2.2 ROV observations

The particular ROV used was a VideoRay Pro 3 XEGTO (VideoRay LLC, Phoenixville, U.S.A., www.videoray.com)) employed previously at Derwent Water by Winfield *et al.* (2009b) and similar to that used at this lake during the summer of 2007 by Coyle & Adams (2008). The ROV was equipped with a depth meter and onboard lights (two forward facing 20 watts high efficiency halogen lights, one rear facing high intensity LED light array) and an integral underwater video system with colour (forward facing, resolution 570 lines, sensitivity 0.3 lux) and monochrome (rear facing, resolution 430 lines, sensitivity 0.1 lux) video cameras. In addition to real-time video observations in the field, this system also allowed video recordings to be made to a Sony Digital HD Videocassette Recorder GV-HD700E (www.sony.co.uk) for subsequent detailed examination in the laboratory, including the production of selected still images.

Since its use by Winfield *et al.* (2009b), the ROV had also been fitted with the real-time video enhancement system LYYN Hawk Card (LYYN, Lund, Sweden, www.lyyn.com) and a ProViewer P-900E-20 Imaging Sonar (www.videoray.com/accessories/6-sonar) which has a field of view of 45 º and a theoretical maximum range of approximately 50 m for large targets in unobstructed water. Within this theoretical maximum range, the effective range for a particular application depends in part on image resolution which itself decreases with increasing range at a rate dependent on the sizes of the targets of interest. The imaging sonar also recorded moving image files to a laptop computer for subsequent detailed examination in the laboratory, again including the production of selected still images. With the fish sizes and environmental conditions (i.e. primarily bottom topography and at times degree of ROV involuntary movement due to wave action, but independent of water clarity) of the present investigation, maximum effective range was found to be between approximately 5 and 10 m. In addition, a Pentax Optio W80 (www.pentax.com) digital still camera with an inboard flash unit able to take photographs remotely at time intervals was prepared for deployment on the ROV. Finally, an infra-red underwater video camera with integral lights (SeaViewer Underwater Video System, SeaViewer Cameras, Inc., Tampa, U.S.A., www.seaviewer.com)) and its own recording system (ARCHOS 604 Portable Multimedia Player, ARCHOS, Igny, France, www.archos.com) was also prepared for deployment on the ROV, although it was never actually used because of the poor environmental conditions subsequently encountered in the field (see below). The overall dimensions of the ROV including the imaging sonar but excluding the detachably-mounted Pentax Optio W80 and infra-red underwater video camera were 361 mm, 279 mm and 275 mm (length x width x height) (Fig. 1). The entire ROV system was deployed exclusively under battery power in order to minimise disturbance to fish. As extensive field work with the ROV was planned to comprise almost exclusively observations after dark during the evening, arrangements were made for some field support from the Environment Agency in the form of a powered cabin boat and crew.

Unfortunately, as in late 2008 (Winfield *et al.*, 2009b), prolonged adverse weather conditions again significantly compromised the planned programme of field work at Derwent Water. Unprecedented rainfall with consequent extremely high lake levels in late November made field work impossible towards the end of that month, while high winds restricted opportunities during early December. Extreme snowfall in mid December then stopped field activities towards the end of that month.

As a result of the above adverse weather conditions, three planned boat-based ROV visits (16 and 24 November 2009 and 7 December 2009) had to be abandoned. In addition, extensive driftwood accumulations precluded vehicular access and thus shore-based ROV deployment at the site previously used by Winfield *et al.* (2009b) just south of Calfclose Bay on the east shore of the lake (54°, 34.778’ North, 3°, 07.968’ West). Nevertheless, within the period from 1 to 18 December 2009, three boat-based evening visits and one shore-based evening visit were made with the ROV as described below and covered eight sites.

On 1 December 2009, ROV observations were made by boat north of St Herbert’s Island (54°, 34.941’ North, 3°, 08.883’ West) from 16.00 to 17.00 hours, at which time deteriorating weather conditions forced the abandonment of field work.

On 14 December 2009, ROV observations were made by boat north of Rampsholme Island (54°, 34.973’ North, 3°, 08.424’ West) from 16.00 to 16.45 hours, south of Rampsholme Island (54°, 34.873’ North, 3°, 08.407’ West) from 16.50 to 17.20, and south of Calfclose Bay (54°, 34.776’ North, 3°, 08.019’ West) from 17.30 to 18.15 hours.

On 15 December 2009, ROV observations were made from shore at the National Trust car park on the east shore of the lake (54°, 33.930’ North, 3°, 08.119’ West) from 16.00 to 17.00 hours, at which time deteriorating weather conditions together with the presence of large amounts of New Zealand pygmy weed (*Crassula helmsii*) forced the abandonment of field work.

On 17 December 2009, ROV observations were made by boat in Abbot’s Bay (54°, 33.838’ North, 3°, 09.348’ West) from 16.00 to 16.45 hours, south of Victoria Bay (54°, 34.416’ North, 3°, 09.323’ West) from 17.00 to 18.00, and south of St Herbert’s Island (54°, 34.767’ North, 3°, 08.910’ West) from 18.10 to 18.55 hours.

On all occasions, surface water temperature was recorded from the anchored boat just before the ROV was deployed with approximately 55 m of umbilical cable in the water such that a semi-circle of radius approximately 50 m could be searched. Maximum water depth encountered was approximately 4.0 m. Real-time video and imaging sonar outputs were monitored continuously throughout this period, although only periodic video and imaging sonar recordings were made. The onboard lights were used at variable intensities during the search when the ROV was being moved, although they were turned off for long periods when the ROV was allowed to rest immobile on the bottom and fish movements monitored using only the imaging sonar. The lights were also kept turned off when the ROV was being manoeuvred closer to a fish target detected by the imaging sonar. The Pentax Option W80 was occasionally used mounted on the ROV to take photographs at intervals of 1 minute to supplement the underwater video and imaging sonar recordings.

Because no current vendace spawning grounds were positively identified by any observations in late 2009, weather disruptions in late 2009 reduced the amount of time available for further surveys and periods of extensive ice cover were experienced in early 2010, no additional habitat-typing work was performed at Derwent Water in 2010.

2.2.3 Stand-alone still camera observations

Two digital still cameras were prepared for use as stand-alone items. Firstly, the Pentax Optio W80 described above was also deployed by foot during daylight on a monopod using its internal timer to record habitat images at depths of up to approximately 1.0 m. All images were recorded in jpeg file format at a resolution of 12.1 megapixels. Secondly, a Nikon D300 (www.nikon.com) fitted with a 10.5mm f/2.8G ED DX Fisheye-Nikkor fish-eye lens (www.nikon.com) and installed in an Ikelite 6812.3 underwater housing with an Ikelite DS160 Substrobe on a static lake bottom mount (Fig. 2) was deployed using its interval exposure capability to record images at 1 minute intervals before and after dark at a depth of approximately 1.0 m. All images were recorded in raw file format at a resolution of 12.3 megapixels. Following initial field trials (see below), manual focussing set at infinity was used on all subsequent deployments of this camera.

All images were subsequently examined in the laboratory using Lightroom 2.7 (Adobe Systems Incorporated, www.adobe.com).

As a result of the adverse weather conditions described above, two planned shore-based visits using the still cameras (2 and 22 December 2009) had to be abandoned. Nevertheless, within the period from 7 to 18 December 2009, three shore-based daytime visits were made as described below to cover seven sites. Only two of these sites (Abbot's Bay and south of Victoria Bay) were adjacent to the slightly deeper (up to approximately 4.0 m) areas examined using the ROV.

On 7 December 2009, visits were made by foot to south of Calfclose Bay (54°, 34.778' North, 3°, 07.968' West), inner Calfclose Bay (54°, 34.849' North, 3°, 07.889' West) and the National Trust car park on the east shore of the lake (54°, 33.930' North, 3°, 08.119' West). At the latter site, the Nikon D300 system was deployed from 15.00 to 15.15 hours and from 16.00 to 16.15 hours in order to explore appropriate camera settings.

On 15 December 2009, a visit was made by foot to the National Trust car park on the east shore of the lake (54°, 33.930' North, 3°, 08.119' West) where the Nikon D300 system was deployed from 16.00 to 18.00 hours.

On 18 December 2009, visits were made by foot to south of Calfclose Bay, the National Trust car park on the east shore of the lake, Myrtle Bay (54°, 33.765' North, 3°, 09.250' West), Abbot's Bay (54°, 33.807' North, 3°, 09.387' West), Brandelhow Bay (54°, 33.948' North, 3°, 09.549' West) and south of Victoria Bay (54°, 34.426' North, 3°, 09.376' West).

On all occasions, surface water temperature was recorded at the first site visited on the day and three underwater photographs were then taken in daylight using the monopod-mounted Pentax Optio W80 at each site to record the prevalent underwater habitat features.

2.3 Results

2.3.1 Habitat observations

Surface water temperatures on 1, 7, 14, 15, 17 and 18 December 2009 were 5.7, 6.1, 3.9, 4.9, 4.0 and 3.6 ºC, respectively.

The areas of Derwent Water examined using the ROV showed considerable variation in the context of their suitability for spawning vendace. The bottom substrate north of St Herbert's Island (Fig. 3) was covered by large amounts of deposited terrestrial leaves and fine sediments and showed no clean areas of gravel. In contrast, north of Rampsholme Island (Fig. 4) there were extensive areas of suitable spawning substrate although extensive growths of New Zealand pygmy weed and possible *Callitriche* sp. were also present. South of Rampsholme Island (Fig. 5) also showed suitable spawning habitat, including the presence of extensive low-growing macrophytes including isoetids and elodeids. South of Calfclose Bay

(Fig. 6) the bottom substrate was composed mainly of cobbles with a noticeable covering of fine sediment, interspersed with occasional growths of low-growing macrophytes including isoetids. Conditions at the National Trust car park on the east shore of the lake (Fig. 7) were completely unsuitable for spawning vendace, with large amounts of fine sediment and growths of New Zealand pygmy weed and elodeids so extensive that manoeuvring the ROV was very difficult. At Abbot's Bay (Fig. 8), the bottom substrate was completely hidden underneath a carpet of New Zealand pygmy weed. The more exposed conditions of the area south of Victoria Bay (Fig. 9) showed substantial areas of low-growing macrophytes including isoetids and possible Callitriche sp., although considerable amounts of fine sediment were also apparent. Finally, south of St Herbert's Island (Fig. 10) the bottom substrate was composed mainly of cobbles with a noticeable covering of fine sediment, interspersed with occasional growths of low-growing macrophytes again including isoetids.

The areas of Derwent Water examined using the stand-alone still cameras also showed considerable variation in the context of their suitability for spawning vendace, even though observations were made at shallow depths and in more restricted areas than those made using the ROV. South of Calfclose Bay (Fig. 11) the bottom substrate was composed mainly of cobbles with a noticeable covering of fine sediment, with similar conditions prevailing in inner Calfclose Bay (Fig. 12). Conditions at the National Trust car park on the east shore of the lake (Fig. 13) were dominated by large amounts of deposited terrestrial leaves and showed no clean areas of gravel. In Myrtle Bay (Fig. 14), the bottom substrate was composed mainly of cobbles with a noticeable covering of fine sediment, while in Abbot's Bay (Fig. 15) the bottom substrate was completely hidden underneath a carpet of New Zealand pygmy weed and elodeids. In Brandelhow Bay (Fig. 16), the bottom substrate was composed mainly of cobbles with a noticeable covering of fine sediment. Finally, south of Victoria Bay (Fig. 17) cobbles covered with fine sediment again dominated the substrate. This covering of fine sediment south of Victoria Bay extended into extremely shallow water with an almost universal coverage (Fig. 18).

2.3.2 Fish observations

No identifiable fish targets were detected using the imaging sonar of the ROV, although several fish species were observed by its video camera. No vendace were observed on any occasion and no fish at all were seen north of St Herbert's Island. However, ruffe and perch (*Perca fluviatilis*) were observed north of Rampsholme Island, while these two species and brown trout (*Salmo trutta*) were seen south of Rampsholme Island. South of Calfclose Bay, numerous ruffe, some perch and a single minnow (*Phoxinus phoxinus*) were observed. A single pike (*Esox lucius*) was seen at the National Trust car park on the east shore. No fish were observed in Abbot's Bay or Victoria Bay, but several ruffe were seen south of St Herbert's Island.

No immediate rapid reactions were shown by any of the fish to the lights or movement of the ROV and several individuals were approached to within less than 0.25 m.

No fish were observed using either of the stand-alone still cameras, even though the Nikon D300 system recorded 120 images.

2.4 Discussion

Unfortunately, prolonged adverse weather conditions in late 2009 greatly interfered with the planned programme of field work at Derwent Water. The unprecedented rainfall with consequent extremely high lake levels in late November made field work impossible towards the end of that month, while high winds restricted opportunities during early December. Extreme snowfall in mid December then curtailed any further field activities during the vendace spawning season, with continuing low temperatures and extensive inshore ice cover then impacting on plans for further habitat observations in early 2010. However, by adopting a very flexible approach, observations were successfully made at a number of known and potential vendace spawning grounds on the east and west shores and on the islands of the lake first identified by Winfield *et al.* (1998). This greatly increased the extent of ROV observations over that previously achieved in late 2008 by Winfield *et al.* (2009b).

In terms of habitat conditions in the context of vendace spawning requirements, three observations were particularly notable. Firstly, the surface water temperature range of 3.6 to 6.1 ºC recorded during the field work was well within the range of 0.4 to 8.0 ºC required for spawning (Zuromska, 1982). Thus, any failure to observe spawning vendace could not be attributed to unsuitable temperature conditions, as may have been the case for the relatively warmer conditions experienced in December 2008 by Winfield *et al.* (2009b). Secondly, a number of sites on the lake's east shore (National Trust car park), islands (north of Rampsholme Island) and west shore (Abbot's Bay) had developed very extensive growths of the invasive macrophyte New Zealand pygmy weed which appeared to be more extensive than observed at sites in 2007 by Winfield *et al.* (2008) and in 2008 by Winfield *et al.* (2009b). Thirdly, both the lake bottom and the water column itself contained substantial amounts of fine sediments in almost all areas of the lake that were surveyed. Such sediments were visible at the east shore (inner Calfclose Bay, south of Calfclose Bay, National Trust car park), islands (north of St Herbert's Island, south of St Herbert's Island) and west shore (Brandelhow Bay, Myrtle Bay, south of Victoria Bay). Large areas of sites inspected by foot and photographed on the west shore of the lake exhibited a fine layer of sediments which persisted to at least mid December. Such large amounts of fine sediments at sites on the east shore, islands and west shore were certainly not seen during the observations made during earlier winters by Winfield *et al.* (2008) and Winfield *et al.* (2009b), with the latter specifically commenting on the good vendace spawning conditions evident south of Calfclose Bay. Furthermore, following the application to parts of the east shore of Derwent Water of an ROV and direct observation protocol for the assessment of vendace spawning habitat in July 2007, Coyle & Adams (2008) categorised the present sites of inner Calfclose Bay (their site 12) and south of Calfclose Bay (their site 10) as 'optimal' and 'sub-optimal', respectively, indicating that extensive fine sediments were not present at that time. Unfortunately, Coyle & Adams (2008) did not assess any of the other sites of the present investigation. The observations of late 2009 thus revealed a notable deterioration in the quality of spawning habitat available for vendace in Derwent Water, with the only areas of the lake offering clean spawning conditions being parts of the areas north and south of Rampsholme Island. The most likely explanation for this sudden deterioration in conditions is that the fine sediments were deposited by the extreme flood event of November. Unfortunately, it is not possible to quantify this impact nor to judge its permanence.

In terms of actual fish observations, the present after-dark ROV observations failed to record any vendace, although brown trout, minnow, perch, pike and ruffe were all encountered. The fine sediments in the lake's water column mentioned above greatly reduced the efficiency of the visual searches made using the video camera of the ROV, but they did not appear to impact adversely on the performance of the imaging sonar. The apparent scarcity of fish in the lake's inshore areas thus appears to have been real and not simply an artefact of reduced sampling ability. Although purely speculative, it is possible that the failure to record any spawning vendace was because they did not spawn in the study areas in 2009. This may itself have been due to the unsuitable conditions for egg laying, or because of a simple avoidance reaction to the relatively high levels of fine sediments suspended in the water column in these areas.

CHAPTER 3 SCHELLY SPAWNING GROUNDS IN ULLSWATER

3.1 Introduction

The extremely severe weather-induced disruptions to the planned November and December 2009 field work on vendace at Derwent Water described in Chapter 2 failed to identify positively, i.e. by direct observations of spawning individuals, any vendace spawning grounds currently being used in the lake. In addition, the abandonments of several field visits had consumed significantly greater than anticipated contingency resources in terms of staff time. Consequently, further extensive habitat-typing activities planned for such locations in Derwent Water in early 2010 could not be undertaken. Instead, the limited further field activity that could be undertaken was directed at schelly spawning as it had also been by Winfield *et al.* (2009b). Such observations, which can be carried out weeks after observations of spawning vendace because spawning schelly lay their eggs considerably later in January and February, can be justified both in terms of developing observation techniques and providing some information on this ecologically-similar rare fish population.

Native schelly populations occur in four water bodies in the English Lake District, i.e. Brotherswater, Haweswater, Red Tarn (Hellvelyn) and Ullswater. Although all of these populations have been subjected to scientific study, spawning grounds have been described only for those of Haweswater and Ullswater (Winfield *et al.*, 1994) and only ROV observations at the latter lake by Winfield *et al.* (2009b) produced positive results. Available resources did not permit further work on the gwyniad population of Llyn Tegid (or Bala Lake) of North Wales, although ROV observations by Winfield *et al.* (2009b) at this site in early 2009 had produced positive results. On the basis of this background information, attention in the present project was focussed exclusively on the known schelly spawning ground at Skelly Nab of Ullswater (Winfield *et al.*, 1994; Winfield *et al.*, 2009b) using a shore-based ROV and stand-alone still camera approach similar to these components of the work undertaken at Derwent Water in late 2009.

The objective of this part of the present project was thus to make limited observations at the schelly spawning ground at Skelly Nab of Ullswater in early 2010.

3.2 Methods

3.2.1 Approach

The ROV, supplemented by a stand-alone still camera occasionally mounted on the ROV and complemented by this and another stand-alone still camera deployed in a static mode on the lake bottom, as previously used at Derwent Water as described in Chapter 2, was deployed with an identical shore-based protocol at Ullswater in early 2010.

3.2.2 ROV observations

Within the period from 26 January to 11 February 2010, three shore-based evening visits to just west of Skelly Nab (54°, 34.895’ North, 2°, 52.557’ West) were made with the ROV as described below.

On 26 January 2010, ROV observations were made from 17.00 to 18.55 hours.

On 4 February 2010, ROV observations were made from 17.15 to 19.05 hours.

On 11 February 2010, ROV observations were made from 18.00 to 20.00 hours.

Maximum water depth encountered was approximately 5.0 m.

3.2.3 Stand-alone still camera observations

Within the period from 26 January to 11 February 2010, three shore-based evening visits to just west of Skelly Nab (54°, 34.895’ North, 2°, 52.557’ West) were made with the Nikon D300 system with the interval between successive photographs reduced to 30 s as described below.

On 26 January 2010, stand-alone still camera observations were made from 17.00 to 19.00 hours.

On 4 February 2010, stand-alone still camera observations were made from 17.00 to 19.00 hours.

On 11 February 2010, stand-alone still camera observations were made from 18.00 to 20.00 hours.

On all occasions, surface water temperature was recorded on arrival at the site and three underwater photographs were then taken in daylight using the monopod-mounted Pentax Optio W80 at each site to record the prevalent underwater habitat features.

3.3 Results

3.3.1 Habitat observations

Surface water temperatures on 26 January, 4 February and 11 February 2010 were 3.7, 4.2 and 4.3 ºC, respectively.

The area west of Skelly Nab examined using the ROV showed very suitable conditions for spawning schelly with clean substrate of a variety of sizes from extensive sand to substantial rocks, together with some areas of low-growing macrophytes including isoetids (Fig. 19, Fig. 20).

3.3.2 Fish observations

Numerous identifiable fish targets were detected using the imaging sonar of the ROV, with numerous brown trout and a single schelly observed by its video camera.

Although the imaging sonar was used primarily to guide the unlit ROV near to fish targets before its lights were turned on and observations continued by video, an example of its output is given in Fig. 21. Under the environmental conditions of Ullswater, the system-inherent trade-off between increasing range and decreasing image resolution resulted in almost all observations being made with a range set between 5 and 10 m. In the example of Fig. 21, the immobile ROV resting on the lake bottom detected a fish moving from left to right at a range of 4.5 m. In real-time and when subsequently viewing the recorded moving image file, such presence and movement of fish were extremely clear. In the field they were successfully used a number of times to allow the unlit ROV to be moved within 1 m of the target fish before its lights were turned on for observation and identification by video.

During the ROV observations, small and medium brown trout were observed frequently on all three evenings and a single medium to large adult schelly at a depth of 4.6 m was recorded during the evening of 26 January 2010 (Fig. 22).

No immediate rapid reactions were shown by any of the fish to the lights or movement of the ROV and several individuals were approached to within less than 0.25 m.

No fish were observed using the Pentax Optio W80, although single individuals were recorded in at least 17 (6 on 16 January, 10 on 4 February and 1 on 11 February 2010) of 720 images recorded by the Nikon D300 system. However, due to their distance from the camera coupled with the use of a wide-angle lens their identification to species could not be made with certainty although they appeared to be small brown trout.

3.4 Discussion

Although weather conditions in early 2010 were difficult at times in terms of access to Ullswater, this part of the project successfully achieved its objective to make limited observations at the schelly spawning ground at Skelly Nab. As was the case for the vendace in Derwent Water, the surface water temperature range of 3.7 to 4.3 ºC recorded during the field work at Ullswater was well within the range of 0.4 to 8.0 ºC required for spawning (Zuromska, 1982). Furthermore, underwater conditions in terms of water clarity and calmer conditions were much better than experienced in Derwent Water and so exhaustive testing of the ROV and Nikon D300 systems was possible.

In terms of habitat suitability for spawning schelly, conditions at Skelly Nab remained excellent. As in early 2009 (Winfield *et al.*, 2009b), a single adult schelly was recorded by the ROV's underwater video camera, together with numerous brown trout. The ROV's imaging sonar proved to be particularly effective at detecting fish up to a range of 10 m, with limitations beyond this distance being imposed primarily by a loss of resolution on the screen of the viewing laptop, although bottom topography also played a role due to the casting of acoustic shadows by boulders and taller macrophytes. The Nikon D300 system also produced some encouraging results, even though it did not record any schelly. It did, however, record a number of small fish which were probably brown trout and their appearance on successive exposures suggested that they were not disturbed by the system's flashlight. Furthermore, because of the system being fixed and thus the background effectively unchanging, the appearance of a fish in successive exposures was remarkably easy to detect and follow manually when the exposures were reviewed in rapid sequence.

The major limitation to the effectiveness of the ROV and Nikon D300 systems is undoubtedly the amount of time for which they can be deployed in the lake. For the ROV system, this limitation results from a combination of battery performance and the need for continuous operator presence. The former issue could be addressed by the use of a generator power source rather than a battery or batteries, although this could introduce an element of disturbance and so is not recommended. The latter issue is intractable. For the Nikon D300 system, there is no technical reason why the system cannot be left running by itself overnight and retrieved the next day. Of course, this would introduce an element of possible accidental or intentional physical interference while the system was unattended which must be balanced against a high unit cost. However, with current rapid developments in camera technology and associated reductions in costs, a functionally similar but less expensive system is probably feasible. The issue of further technical development is considered again in Chapter 4.

CHAPTER 4 GENERAL DISCUSSION AND RECOMMENDATIONS

4.1 General discussion

Although the vendace field work of the present project was greatly impacted by prolonged adverse weather conditions at Derwent Water throughout most of November and December 2009, it and subsequent observations in January and February 2010 at the schelly spawning ground of Skelly Nab in Ullswater demonstrated that underwater video deployed on an ROV equipped with imaging sonar can be used to provide an effective and non-destructive survey technique for spawning coregonids. In addition, the stand-alone still camera deployed on the lake bottom to take photographs at intervals produced some encouraging results.

The work at the vendace lake of Derwent Water and the schelly lake of Ullswater generated valuable information on these specific localities which has already been discussed in Chapter 2 and 4, but it also contributed to generic experience with these indirect visual survey techniques. In addition to their non-destructive nature readily apparent before work began, experiences at the lakes indicated that the technique also has a negligible disturbance effect. A variety of fish species displayed no apparent reaction to the movement or lights of the ROV, further justifying the use of ROVs in rare fish research and conservation. Furthermore, the addition of an imaging sonar to the ROV allowed the detection of fish targets at much greater distances and enabled them to be approached more closely for visual inspection.

A particularly notable finding of generic interest was the performance of the bottom-mounted Nikon D300 system operated in its time lapse mode. This meant that the system simply needed to be deployed in the field and then recovered some hours later, after which recorded images could be reviewed in the laboratory. The latter procedure proved to be extremely rapid and easy to accomplish, with the appearance and subsequent movement of a fish in successive exposures being easy to detect and follow manually when the exposures were reviewed in rapid sequence. In this way, large numbers of images could be searched in a very short time. This was somewhat unexpected and may remove the need for the development of a motion-triggered underwater still camera system designed to take more selective photographs in the field as discussed by Winfield & Fletcher (2009).

Finally, during the course of the present project several discussions and a field meeting were held with Stephen Hewitt of Tullie House Museum, Carlisle, who has been investigating the feasibility of recovering identifiable coregonid remains from otter (*Lutra lutra*) spraints as a means of locating spawning grounds. This work has involved collecting spraints from a number of locations around Ullswater, including Skelly Nab, and has produced some positive and promising preliminary results (Hewitt, 2010). It appears that schelly congregating to spawn in the shallow waters off Skelly Nab in January have provided otters with an opportunity to exploit a temporarily abundant food supply and further work to test and develop this technique is being continued at Ullswater and Haweswater (S. Hewitt, *pers. comm.*).

4.2 Recommendations

This further use of an ROV in an attempt to produce underwater video recordings of spawning vendace, schelly, gwyniad and their habitats, and the first use of stand-alone still camera deployed on the lake bottom to take photographs at intervals, has produced both positive and negative results. It has also suggested five further research activities, some of which were initially considered by Winfield *et al.* (2009b). These suggested actions are presented below in no particular order.

Firstly, the ROV survey of potential spawning habitat for vendace in the substantial areas of Derwent Water not covered by Coyle & Adams (2008) and for other coregonids in other lakes continues to have some merit. Furthermore, with specific reference to Derwent Water it would be highly informative to repeat and extend the surveys by Coyle & Adams (2008) in order to assess the extent and persistence of the fine sediments observed in the present study which apparently arose from the flooding of November 2009. This kind of work has the substantial advantage of being possible at any time of year and it is anticipated that attempts will be made to undertake it within an independent project currently under discussion between the authors and Natural England, developments with which the Environment Agency will be kept fully informed.

Secondly, instead of attempting to locate vendace spawning grounds by the use of an ROV to observe spawning adults, it is recommended that such location could be made by searching for incubating eggs using an ROV with a fine-mesh net attachment. With the exception of using a simple fine-mesh net attachment to collect broadcast-spawned vendace eggs, such work would be similar very recent work by Marsden *et al.* (2009) who used an ROV to collect redd-spawned eggs of lake trout (*Salvelinus namaycush*) in North America. As part of restoration efforts for spawning in the deep water of Lake Michigan, U.S.A., a suction sampler was mounted on an ROV and used successfully to find spawning habitat and collect eggs from sites as deep as 60 m. Using this equipment, Marsden *et al.* (*op. cit.*) have begun to characterise spawning habitat in deep water, and compare spawning activity between shallow and deep sites. A similar approach to vendace, schelly and gwyniad populations is likely to be equally productive.

Thirdly, as discussed in some detail above further development of a bottom-mounted still camera system operated in its time lapse mode has great potential. It appears that a sophisticated motion-triggered is not actually needed and large numbers of recorded images can be searched manually with great efficiency. This means that instead of incurring substantial development costs, further work in this area can focus on minimising unit cost and thus greatly increasing sampling effort in the field through the simultaneous deployment of a number of systems.

Fourthly, the success of locating fish at distance brought about by the addition of an imaging sonar to the ROV suggests that it may be possible to use this technology to guide the ROV in Derwent Water to make a video recording of adult vendace in the deepwater of the lake during daytime. Previously, it had been thought that without such a system this would probably be impossible due to the relatively low density of vendace in the lake and the limited distance at which they can be detected by purely visual means. Although even if successful this activity would produce no information relevant to vendace spawning grounds, it would require little effort and any successful video recordings would be unique for the species in the U.K., if not in its entire geographical distribution, and would be invaluable for public awareness purposes.

Fifthly, as discussed above the work of Stephen Hewitt of Tullie House Museum, Carlisle, to investigate the feasibility of recovering identifiable coregonid remains from otter (*Lutra lutra*) spraints as a means of locating spawning grounds is extremely promising and worthy of continuation.

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Fig. 1. VideoRay Pro 3 XEGTO Remotely Operated Vehicle (ROV) fitted with a ProViewer P-900E-20 Imaging Sonar (visible below the main body of the ROV and bearing the manufacturer's name BlueView Technologies) and a Pentax Optio W80 digital still camera (visible above the main body of the ROV). Dimensions and further details are given in the text.

Fig. 2. Nikon D300 digital still camera fitted with a 10.5mm f/2.8G ED DX Fisheye-Nikkor fish-eye lens (www.nikon.com) and installed in an Ikelite 6812.3 underwater housing with an Ikelite DS160 Substrobe on a static lake bottom mount.

Fig. 3. Representative still video image of habitat features recorded in Derwent Water north of St Herbert's Island during the evening of 1 December 2009. Despite the use of a real-time video enhancement system, image quality was very poor due to the environmental conditions including large amounts of suspended solids.

Fig. 4. Representative still video image of habitat features recorded in Derwent Water north of Rampsholme Island during the evening of 14 December 2009.

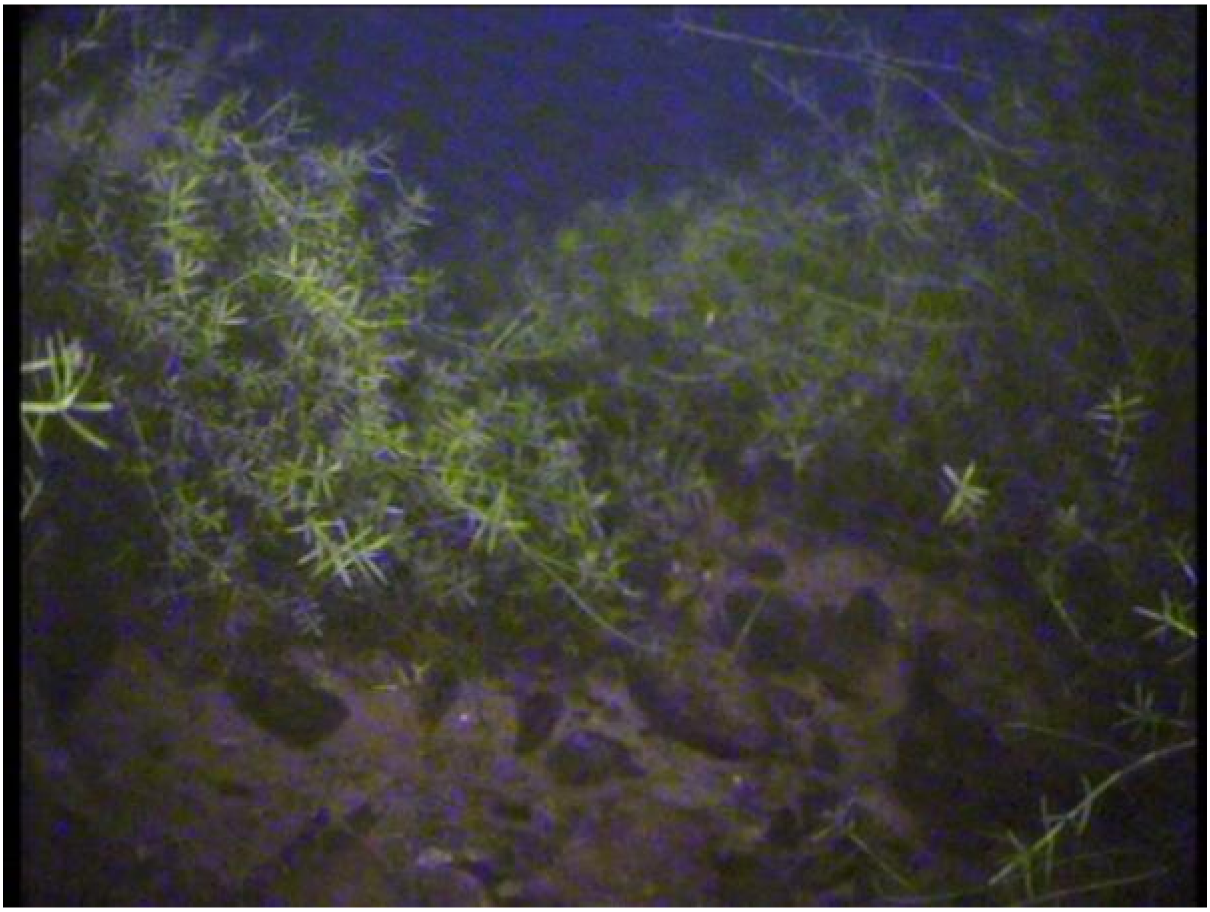

Fig. 5. Representative still video image of habitat features recorded in Derwent Water south of Rampsholme Island during the evening of 14 December 2009.

Fig. 6. Representative still video image of habitat features recorded in Derwent Water south of Calfclose Bay during the evening of 14 December 2009.

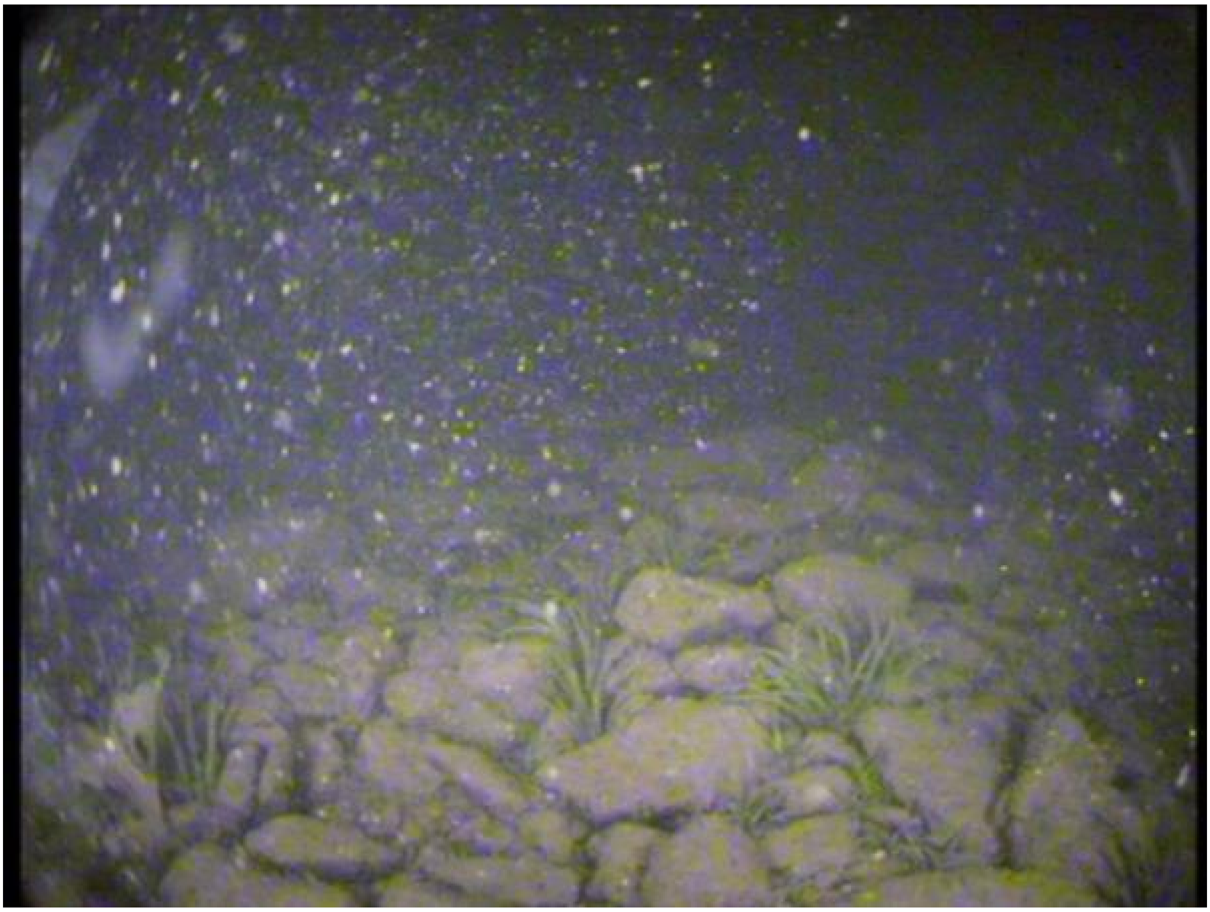

Fig. 7. Representative still video image of habitat features recorded in Derwent Water at the National Trust car park on the east shore during the evening of 15 December 2009.

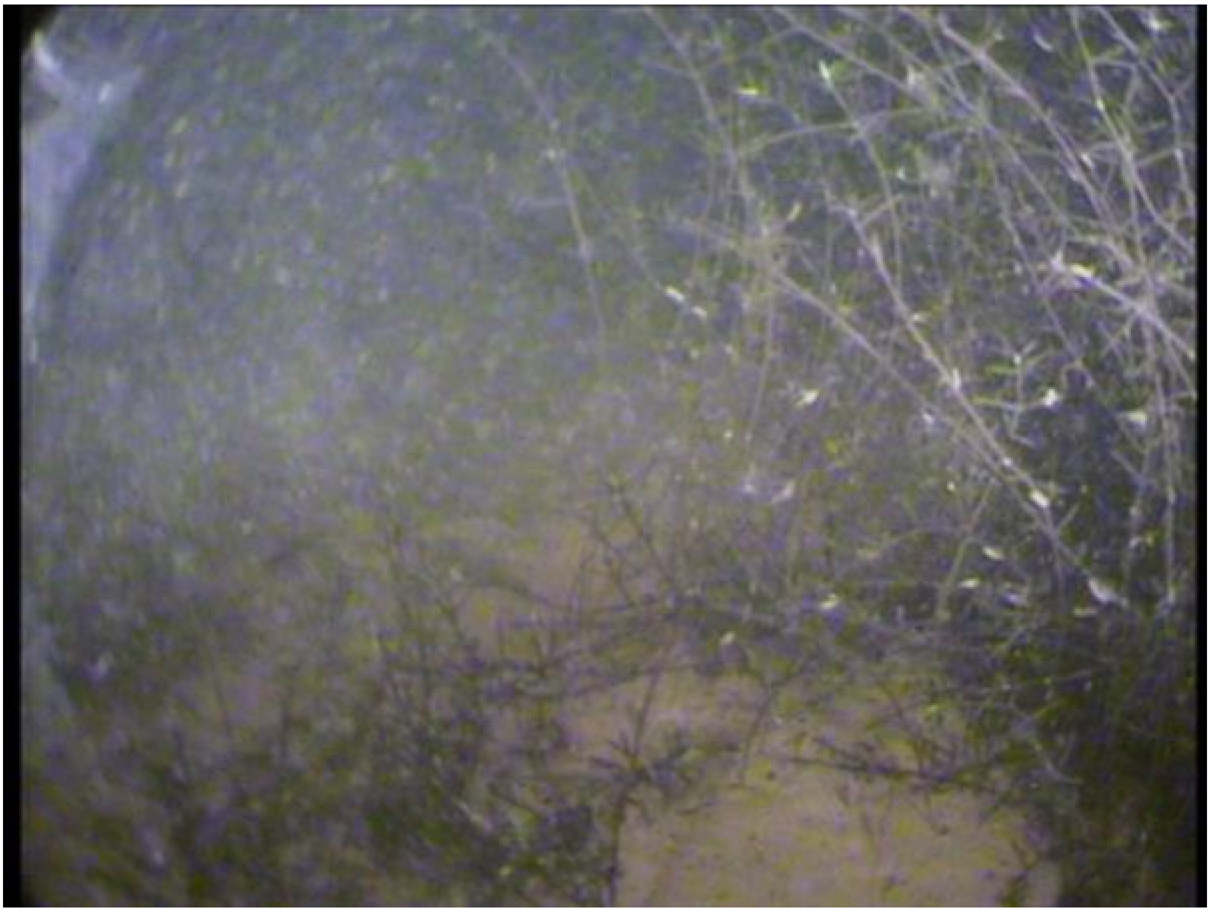

Fig. 8. Representative still video image of habitat features recorded in Derwent Water in Abbot's Bay during the evening of 17 December 2009.

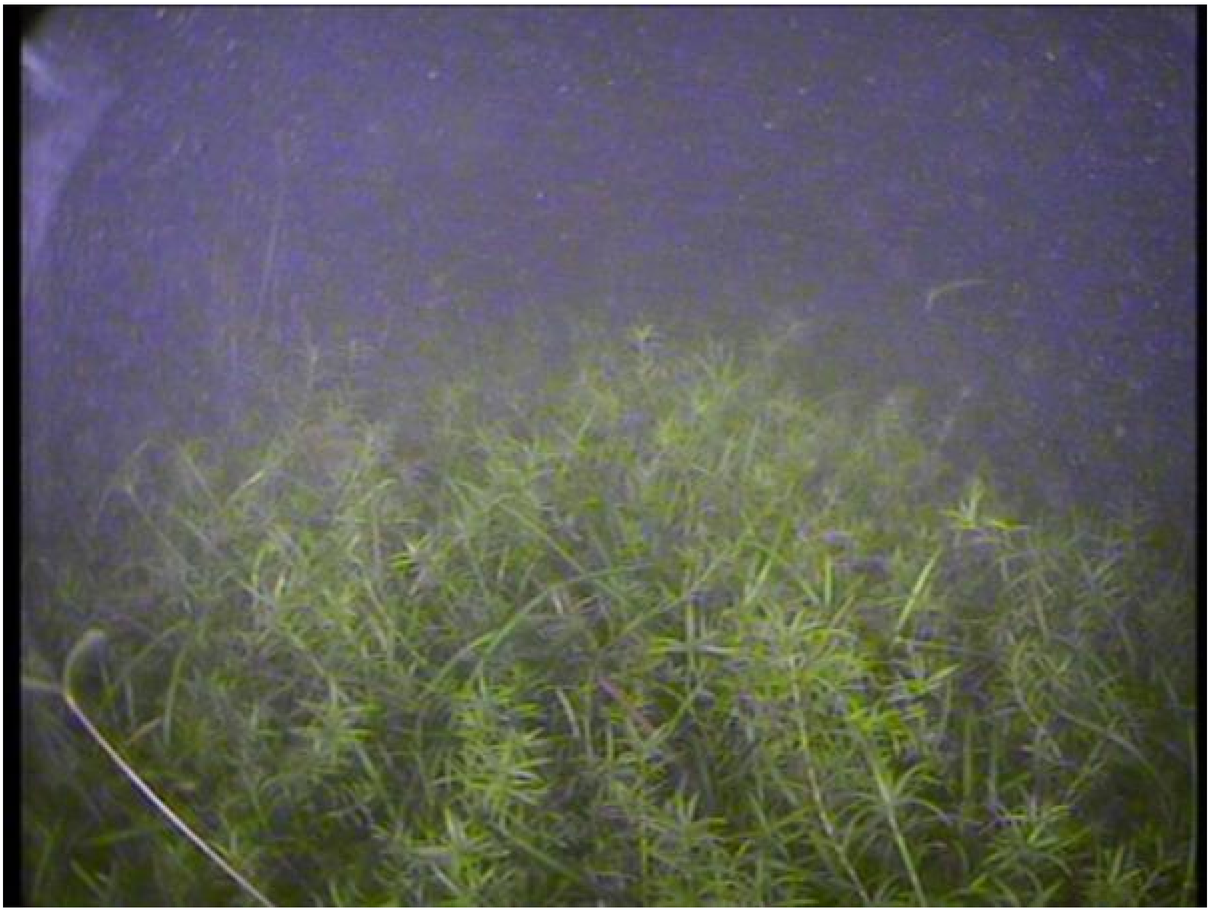

Fig. 9. Representative still video image of habitat features recorded in Derwent Water south of Victoria Bay during the evening of 17 December 2009.

Fig. 10. Representative still video image of habitat features recorded in Derwent Water south of St Herbert's Island during the evening of 17 December 2009.

Fig. 11. Representative photographic image of habitat features recorded in Derwent Water south of Calfclose Bay on 18 December 2009.

Fig. 12. Representative photographic image of habitat features recorded in Derwent Water in inner Calfclose Bay on 7 December 2009.

Fig. 13. Representative photographic image of habitat features recorded in Derwent Water at the National Trust car park on the east shore on 7 December 2009.

Fig. 14. Representative photographic image of habitat features recorded in Derwent Water in Myrtle Bay on 18 December 2009.

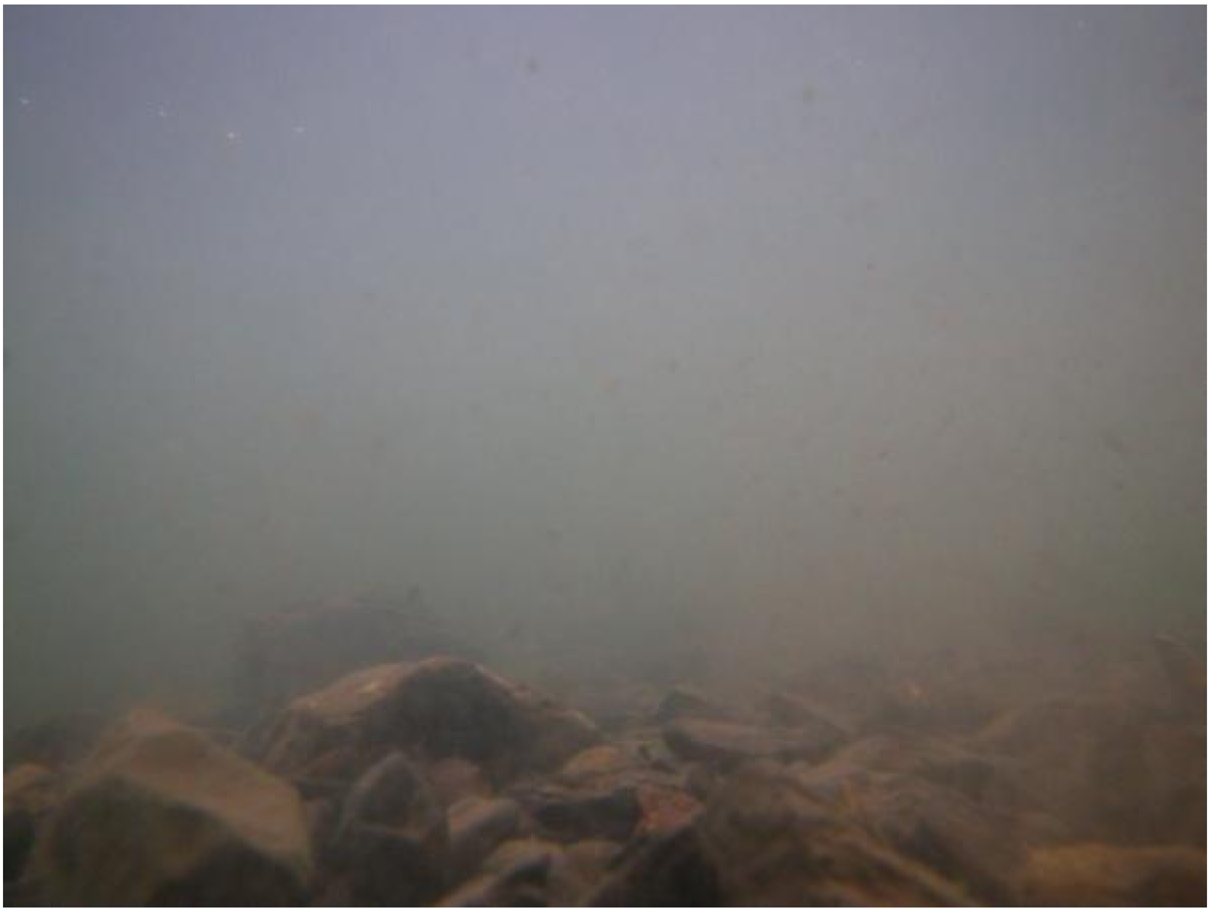

Fig. 15. Representative photographic image of habitat features recorded in Derwent Water in Abbot’s Bay on 18 December 2009.

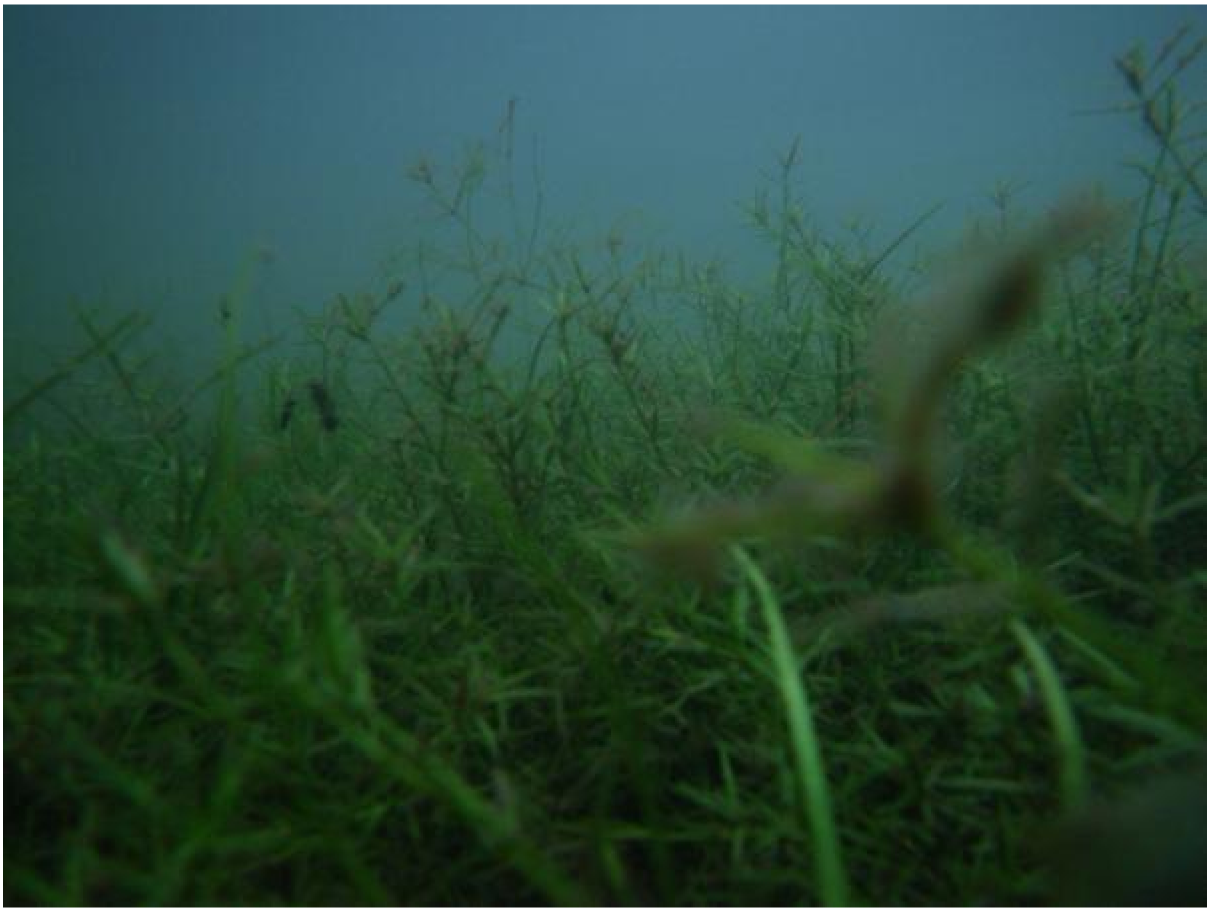

Fig. 16. Representative photographic image of habitat features recorded in Derwent Water in Brandelhow Bay on 18 December 2009.

Fig. 17. Representative photographic image of habitat features recorded in Derwent Water south of Victoria Bay on 18 December 2009.

Fig. 18. Representative photographic images of extreme inshore habitat features recorded in Derwent Water south of Victoria Bay on 18 December 2009. In the lower image, the central approximately 20 mm by 10 mm area of fine sediment has been scraped away by the observer.

Fig. 19. Representative still video image of habitat features recorded in Ullswater west of Skelly Nab during the evening of 26 January 2010.

Fig. 20. Representative photographic image of habitat features recorded in Ullswater west of Skelly Nab on 26 January 2010.

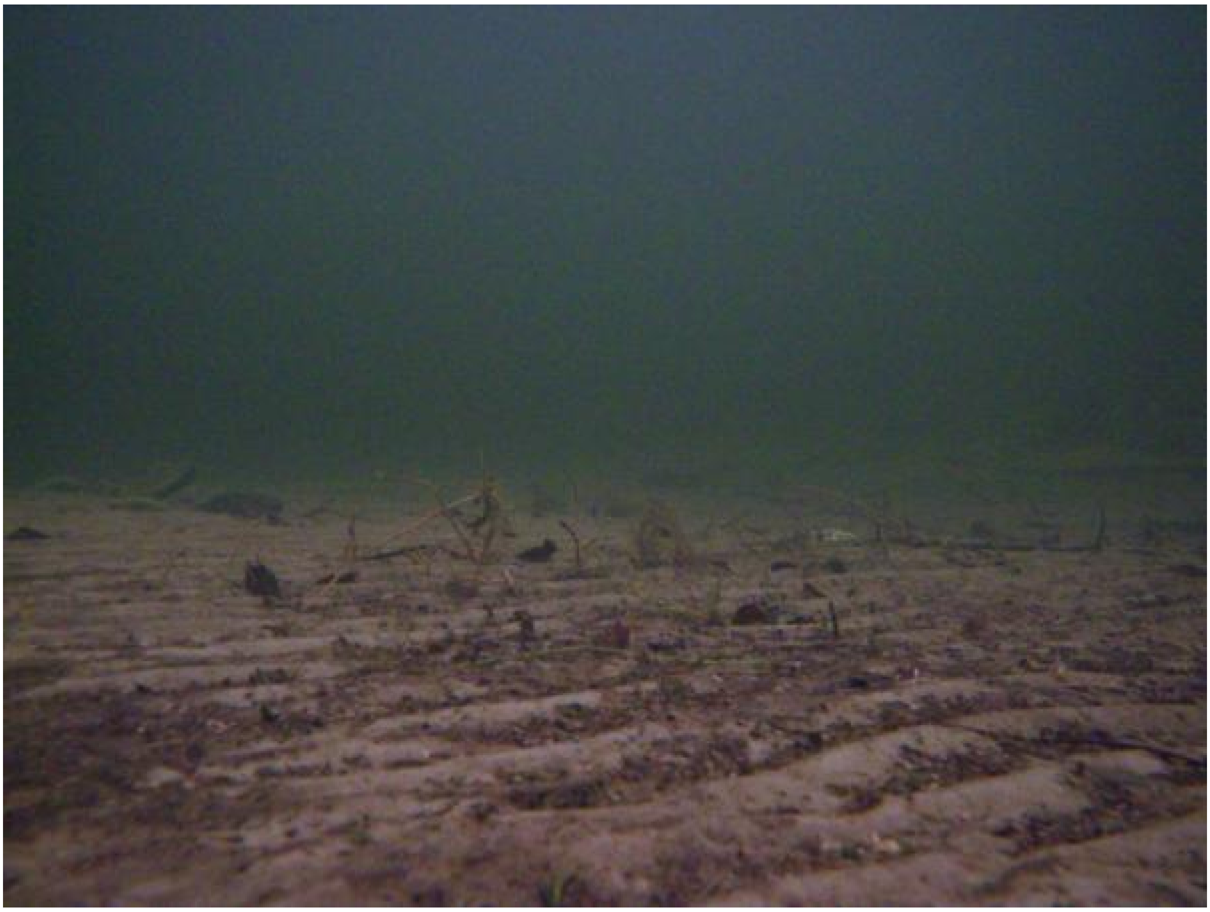

Fig. 21. Series of four still images taken from an imaging sonar file recorded in Ullswater west of Skelly Nab during the evening of 26 January 2010. A fish (circled in red) can be seen appearing at a range of approximately 4.5 m near the top of image (b) and then moving from left to right in images (c) and (d). See text for further details.

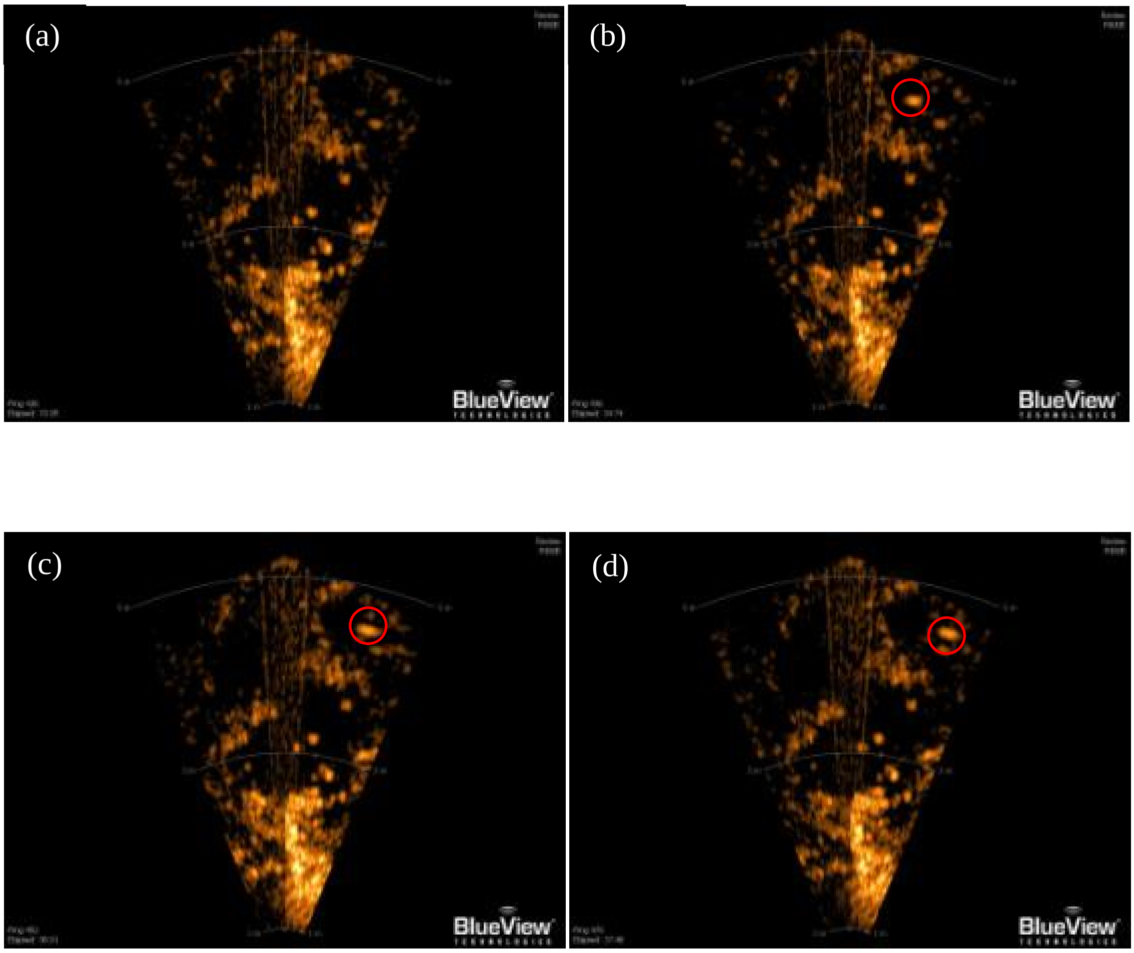

Fig. 22. Representative still video image of a medium to large adult schelly recorded in Ullswater west of Skelly Nab during the evening of 26 January 2010.