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ECOLOGY AND MANAGEMENT OF VENDACE SPAWNING GROUNDS

FINAL REPORT

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EXECUTIVE SUMMARY

1. Previous studies and a current monitoring programme have shown that the status of vendace (*Coregonus albula*) in Bassenthwaite Lake, Cumbria, is very poor. Furthermore, sedimentation on the spawning grounds of this species appears to be the most severe environmental threat to its continued local survival. A potential short-term solution for this problem is the use of an artificial spawning substrate system.

2. The objectives of the present project were to survey ecological conditions on the vendace spawning grounds of Bassenthwaite Lake and nearby Derwent Water using underwater video recording and hydroacoustic techniques, to undertake a desk study of the feasibility of developing an appropriate artificial spawning substrate system, and to field trial such a system and produce plans for an operational system.

3. In Bassenthwaite Lake, extensive inshore deposits of fine sediments were recorded at all three sites, while macrophytes which may otherwise offer an alternative incubation substrate were extremely scarce. Macrophytes were not detected at one site and were present at the other two only with a maximum percentage area inhabited of 0.35 ± 0.52% (mean ± 95% confidence limits). In contrast, in Derwent Water the levels of fine sediments were much lower while growths of macrophytes were generally much higher such that they were detected at all six sites with a maximum percentage area inhabited of 21.90 ± 7.47%. Despite the recent arrival and spread of New Zealand pygmy weed (*Crassula helmsii*) to four of the six sites, all sites remained suitable for spawning and incubation..

4. Extensive searches of the scientific literature and the internet together with numerous personal enquiries failed to produce any information directly relevant to the use of artificial spawning substrates for vendace, although four potentially suitable artificial spawning substrates were identified.

5. The potential vendace artificial spawning substrates Spawntex Spawning Material, Floating Spawning Bed, Erosamat Type 3 and Artificial Grass Model RA1 were deployed in a field trial at Bassenthwaite Lake on 5 December 2005. Visits up to 23 May 2006 using underwater video recording and/or still photography revealed that only the substrate Floating Spawning Bed remained effectively clean throughout this period. It was concluded that an operational system would be most effective based on this substrate, but with individual strips arranged at a density twice that recommended by the manufacturer for other fish species.

6. The substrate Floating Spawning Bed was also subjected to trials at Derwent Water from 28 November 2005 to 4 February 2006 to observe its actual performance as an incubation substrate for vendace eggs. Unfortunately, vendace eggs were never recorded on the substrate.

7. Implications for the conservation of vendace in Bassenthwaite Lake and Derwent Water were discussed and a series of recommendations made for future activities, including investigating the actual presence of vendace in Bassenthwaite Lake, further hydroacoustic macrophyte surveys, further testing of the substrate Floating Spawning Bed, modelling explorations of the amount of substrate required, and continued development of contacts with the international research community in relation to artificial spawning substrates.

CHAPTER 1 INTRODUCTION

1.1 Background

Previous studies (Winfield *et al.*, 1994a) and a current monitoring programme (Winfield *et al.*, 2006) have shown that the status of vendace (*Coregonus albula*) in Bassenthwaite Lake is very poor. Furthermore, although this population faces a number of environmental threats including species introductions, eutrophication, climate change and sedimentation on its spawning grounds (Winfield *et al.*, 2004a), the latter problem appears to be the most severe and seriously threatens the continued survival of the population. In particular, during extensive surveys of known and potential vendace spawning grounds in Bassenthwaite Lake and nearby Derwent Water using primarily underwater video recording as a sampling technique in 1997 and 1998, Winfield *et al.* (1998) recorded widespread deposits of fine sediments in the former but not latter lake. A subsequent preliminary assessment of the feasibility of providing appropriate spawning habitat by the introduction of a bottom-set artificial spawning substrate into Bassenthwaite Lake revealed this technique to be ineffective due to the smothering effects of sediment resuspension (Winfield, 1999).

The above feasibility study used a very simple artificial spawning substratum of a type which has been used with success for the related coregonid species schelly (*Coregonus lavaretus*), albeit in environments with no sedimentation problems (Winfield *et al.*, 1997). The degree of sedimentation problems at Bassenthwaite Lake is clearly too great for such a simple system to be successful in the foreseeable future. However, the technology of artificial spawning substrate systems for other fish species is developing rapidly (Winfield, in press) and may include systems appropriate to the present problem.

Given the uncertainties involved in such a pioneering project, a three-part approach was considered to be appropriate. This involved the repeating of surveys of ecological conditions on the vendace spawning grounds of Bassenthwaite Lake and Derwent Water, the undertaking of a desk study of the feasibility of developing an appropriate artificial spawning substrate system, and the field trialling of such a system.

1.2 Objectives

The objectives of the present project were to survey ecological conditions on the vendace spawning grounds of Bassenthwaite Lake and Derwent Water, to undertake a desk study of the feasibility of developing an appropriate artificial spawning substrate system, and to field trial such a system and produce plans for an operational system.

CHAPTER 2 ECOLOGICAL CONDITIONS OF VENDACE SPAWNING GROUNDS

2.1 Introduction

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

Using the above background information as a guide, Winfield *et al.* (1998) used air-lift sampling and kick sampling to search for incubating vendace eggs and thus identify spawning sites, together with underwater video camera recording to describe site conditions, at Bassenthwaite Lake and Derwent Water during 1997 and 1998. In addition, information on the locations of spawning vendace in Bassenthwaite Lake in 1996 and in both lakes in 1997 subsequently reported by Lyle *et al.* (1998) was also taken into consideration. This allowed the categorisation of sites as actual spawning grounds (spawning adults or incubating eggs located), potential spawning grounds (no spawning adults or incubating eggs located, but site conditions apparently suitable for spawning and incubation) or unsuitable spawning grounds (no spawning adults or incubating eggs located, and site conditions apparently unsuitable for spawning and incubation).

At Bassenthwaite Lake, three actual spawning grounds in very poor condition (Beck Wythop (Site 2 of Winfield *et al.* (1998)), Hursthole Point (Site 8) and Blackstock Point (Site 11)), no potential spawning grounds, and 17 unsuitable spawning grounds were located and described. All sites examined were heavily laden with fine sediments. Moreover, in addition to being sediment-laden, all three spawning grounds supported no macrophytes or only sparse growths in the form of isoetids.

At Derwent Water, Winfield *et al.* (1998) located and described six actual spawning grounds in good condition (south of Victoria Bay (Site 21 of Winfield *et al.* (1998)), south of St Herbert's Island (Site 22), north of St Herbert's Island (Site 23), north of Rampsholme Island (Site 24), south of Scarf Stones (Site 25) and south of Calfclose Bay (Site 26)), 14 potential spawning grounds, and six unsuitable spawning grounds. Conditions for spawning vendace were much more appropriate, with far less or no fine sediments at many sites and frequently extensive macrophyte growths in the form of isoetids or elodeids. Five of the spawning grounds contained extensive growths of isoetids, while the remaining site contained extensive elodeids. In terms of the composition of the lake bottom, four of these sites had a substratum dominated by stone, one was dominated by fine sediments, and the substratum of one was not visible due to the extensive growth of elodeids.

While it was initially envisaged that a repeated Derwent Water survey would simply serve as a reference condition for the Bassenthwaite Lake situation, recent sampling at the former lake during a vendace translocation effort in late 2004 revealed the presence of large amounts of the invasive macrophyte New Zealand pygmy weed (*Crassula helmsii*) on inshore areas previously used by spawning vendace, apparently to the detriment of the latter (Lyle *et al.*, 2005). Assessment of any increase in macrophyte abundance on vendace spawning grounds in Derwent Water since the surveys of 1997 and 1998 by Winfield *et al.* (1998) thus became an area of interest.

The objective of this part of the present project was to resurvey all of the above actual vendace spawning grounds during the spawning season of late 2005 using the more powerful of the two underwater video systems used in 1997 and 1998 by Winfield *et al.* (1998). In addition, the abundance and distribution of macrophytes in these locations were also investigated using recently developed, and still developing, hydroacoustic techniques.

2.2 Methods

2.2.1 Underwater video surveys

Underwater video surveys of vendace spawning grounds were undertaken using a Simrad OE 1372 Miniature High Definition Colour Underwater Camera recording to a Sony Video Walkman GV-S50E. At each site, the camera was deployed in 2 to 3 m of water *c.* 0.2 m above the bottom on a tripod for a period of *c.* 3 minutes, during which time its location was moved *c.* 20 times. The video recordings were subsequently digitised in the laboratory using the hardware and software system WinTV-USB (Hauppauge Computer, Inc., www.hauppauge.com) which was also used to review the recording and produce representative still images.

At Bassenthwaite Lake, the survey was undertaken on 5 December 2005 and covered sites named here as BA1 to BA3 (Table 1, Fig. 1), which correspond to sites 2, 8 and 11, respectively, of Winfield *et al.* (1998).

At Derwent Water, the survey was undertaken on 22 November 2005 and covered sites named here as DA1 to DA6 (Table 2, Fig. 2), which correspond to sites 21, 25, 26, 24, 23 and 22, respectively, of Winfield *et al.* (1998).

2.2.2 Hydroacoustic surveys

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 5.0.4 (BioSonics Inc, Seattle, U.S.A.). Throughout the surveys, data threshold was set at -130 dB, pulse rate at 5 pings s^{-1}, pulse width at 0.1 ms, and data recorded from a range of 0 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 *c.* 1.1 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 Magellan SporTrak Pro (EU basemap) Global Positioning System (GPS) (www.magellangps.com) with accuracy to less than 7 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 during daylight using five approximately parallel inshore-offshore transects to a maximum depth of no more than *c.* 5 m at sites BA1 to BA3 of Bassenthwaite Lake on 5 December 2005 (Transect lengths 16 to 211 m depending on local bathymetry, Table 3, Fig. 1) and sites DA1 to DA6 of Derwent Water on 22 November 2005 (Transect lengths 44 to 202 m depending on local bathymetry, Table 4, Fig. 2).

Although it was initially planned to analyse resulting data using the macrophyte analysis software EcoSAV (BioSonics Inc, Seattle, U.S.A.) developed in an estuarine environment by Sabol *et al.* (2002) and validated for a lake environment by Winfield *et al.* (submitted), the very soft bottom of Bassenthwaite Lake and contrasting bottom types of Derwent Water made such analysis difficult and unreliable without additional and extensive verification in the field. Consequently, analysis was instead carried out using a very recently developed macrophyte analysis option within the hydroacoustic software Sonar5-Pro Version 5.9.6 (Lindem Data Acquisition, Oslo, Norway, www.fys.uio.no/~hbalk/sonar4_5). During these analyses, macrophyte 'roots' were detected using the option of 'image analysis' with default settings with the exceptions of a threshold of -50 dB and a minimum range of 0.3 m. Macrophyte 'tops' were detected using the option of 'image analysis' with default settings with the exceptions of a threshold of -70 dB and a minimum range of 0.3 m. A macrophyte height threshold of 0.1 m was used and some manual editing of 'roots' and 'tops' was undertaken where this was judged appropriate. In this way, estimates were produced of mean macrophyte height, percentage area inhabited by macrophytes (PAI) and percentage volume inhabited by macrophytes (PVI) for each transect. For comparison, a similar analysis but based on the entire survey (i.e. not broken into individual transects) with an option of 'bottom up' with a margin of 0.30 m was performed for data collected previously over extensive growths of New Zealand pygmy weed in the Derwent Bay area (54° 34.725' N, 3° 9.594' W) of Derwent Water on 24 January 2003 (CEH, unpublished data).

Finally, a further hydroacoustic survey was undertaken at Derwent Water on 23 November 2005 in collaboration with Jon Hateley of Environment Agency using a DIDSON hydroacoustic system (Ocean Marine Industries, Inc., U.S.A., www.didson.com) with the objective of providing additional information on the distribution of macrophytes, particularly New Zealand pygmy weed, at sites DA1 and DA5. However, it subsequently proved impossible to interpret with any confidence the resulting recordings produced by this novel and previously untried approach. Consequently, this survey is not considered further in this report.

2.3 Results

2.3.1 Underwater video surveys

At Bassenthwaite Lake, all three spawning grounds showed very high levels of fine sediments. Sites BA1 and BA2 were completely devoid of any macrophytes, while Site BA3 supported only very sparse isoetids. A representative image taken from the recording of Site BA1 is shown in Fig. 3.

The situation was more diverse at Derwent Water where levels of fine sediments were clearly much lower on all six spawning grounds, while growths of macrophytes were generally much higher. Site DA1 displayed extensive growths of isoetids, together with a very few elodeids but more substantial amounts of New Zealand pygmy weed. The only macropytes at Site DA2 were extensive growths of isoetids, which were also abundant at Site DA3 which in addition supported some New Zealand pygmy weed. Sites DA4 and DA5 were both devoid of isoetids, but both contained extensive elodeid growths and some New Zealand pygmy weed. Finally, Site DA6 contained only extensive growths of isoetids.

Representative images of isoetids (from Site DA6), elodeids (from Site DA5) and New Zealand pygmy weed (from Site DA3) are shown in Figs 4 to 6, respectively.

2.3.2 Hydroacoustic surveys

At Bassenthwaite Lake (Table 5), macrophytes were not detected at Site BA1 and were present at sites BA2 and BA3 only with small mean heights (0.03 ± 0.01 m (mean ± 95% confidence limits)) and maximum percentage area inhabited and percentage volume inhabited of 0.35 ± 0.52% and 0.01 ± 0.02%, respectively.

The situation was again more diverse at Derwent Water (Table 6). Mean height ranged from 0.04 ± 0.01 m at Site DA6 to 0.09 ± 0.09 m at Site DA1, while percentage area inhabited ranged from 0.75 ± 1.16% at Site DA3 to 21.90 ± 7.47% at Site DA5 and percentage volume inhabited ranged from 0.02 ± 0.03% at Site DA3 to 0.85 ± 0.32% at Site DA5.

For comparison, over the extensive growths of New Zealand pygmy weed in the Derwent Bay area of Derwent Water on 24 January 2003, values for mean macrophyte height, PAI and PVI were 0.24 m, 73.77% and 6.80%, respectively.

2.4 Discussion

The underwater video observations of the present study can be directly compared with similar observations made at the same nine sites in 1998 by Winfield *et al.* (1998). Note that although this earlier survey was performed in August rather than in November or December as in the present survey, it is still possible to make valid comparisons of macrophyte distribution and abundance at a gross scale.

At Bassenthwaite Lake in 1998, Site BA1 supported sparse growths of isoetids but these were not recorded in 2005. Site BA2 was devoid of macrophytes on both occasions, while Site BA3 had very sparse growths of isoetids on both occasions. Fine sediments were abundant at all sites during both the surveys. It thus appears that if there has been any change in the conditions of the vendace spawning grounds between 1998 and 2005, it has been negative with the now apparent complete loss of macrophytes at Site BA1 and what appeared to be a general increase in fine sediments as judged by the amounts disturbed by the camera tripod (first author, personal observation). Suitable vendace spawning substrate at Bassenthwaite Lake is clearly extremely limited and remains extremely unlikely to be able to facilitate significant recruitment.

With the exception of the arrival of New Zealand pygmy weed which will be discussed below, the situation is more encouraging at Derwent Water. Site DA1 showed extensive isoetids and sparse elodeids in both 1998 and 2005, while sites DA2 and DA3 were also unchanged showing extensive isoetids in both years. Site DA4 had showed a change in its native flora between the surveys, supporting only extensive isoetids in 1998 but only extensive elodeids in 2005. Site DA5 was unchanged, displaying no isoetids but extensive elodeids in both years. Finally, Site DA6 was also unchanged, consistently displaying extensive isoetids. With five out of six sites unchanged in terms of their native flora and with what appeared to be no increase in fine sediments as judged by the amounts disturbed by the camera tripod (first author, personal observation), suitable vendace spawning substrate at Derwent Water remains extensive and is thus likely to be able to facilitate significant recruitment.

Derwent Water has, however, shown a major change between 1998 and 2005 in terms of the greatly increased distribution of New Zealand pygmy weed. This invasive species was not recorded at any site in 1998, but in 2005 it was observed at four of the six sites where it was present on both the west and east shores of the lake and on the north shores of both St Herbert's Island and Rampsholme Island. However, even though gill-net sampling on vendace spawning grounds at Derwent Water during a vendace translocation effort in late 2004 suggested the presence of large amounts of New Zealand pygmy weed (Lyle *et al.,* 2005), the areal coverage by this invasive macrophyte observed by underwater video in the present survey was relatively limited. New Zealand pygmy weed thus poses no immediate significant threat to the spawning of vendace in Derwent Water.

Although the application of hydroacoustics to the survey of macrophytes is still in a relatively early stage of development and is likely to improve in effectiveness in the near future, which will allow additional retrospective data analyses, the hydroacoustics surveys provided a useful quantification of the aubundance of macrophytes at the nine vendace spawning grounds of Bassenthwaite Lake and Derwent Water. Not surprisingly, at Bassenthwaite Lake the technique simply confirmed the near complete absence of any form of macrophytes. At Derwent Water, more interestingly, it provided an objective measure of current macrophyte distribution and abundance. The greatest value of these measurements will probably be to serve as a datum against which to judge any further expansion of New Zealand pygmy weed in the lake. The present maximum percentage area inhabited by macrophytes on any spawning ground of 21.90% is clearly far below that of 73.77% observed in 2003 over the very abundant growths of New Zealand pygmy weed in Derwent Bay. If such a level of occupation by New Zealand pygmy weed ever spreads to the vendace spawning grounds, it is possible that associated effects of fine sediment accumulation below such masses would have adverse implications for the survival of any eggs deposited below it, although it may itself form an acceptable incubation substrate.

Current ecological conditions on the vendace spawning grounds of Bassenthwaite Lake and Derwent Water thus show extremely contrasting characteristics. In Bassenthwaite Lake, extensive inshore deposits of fine sediments are likely to prevent successful egg incubation directly on the lake bottom, while macrophytes which may otherwise offer an alternative incubation substrate are extremely scarce. As a result, significant successful vendace recruitment is increasingly unlikely in Bassenthwaite Lake, a conclusion which is supported by the recent results of the vendace monitoring programme described by Winfield *et al.*

(2006). In contrast, conditions in Derwent Water are much better for vendace spawning and, despite the arrival and spread of New Zealand pygmy weed, all sites remained suitable for spawning and incubation. Again, this conclusion is supported by the recent results of the vendace monitoring programme described by Winfield *et al.* (2006).

CHAPTER 3 DESK STUDY OF AN ARTIFICIAL SPAWNING SUBSTRATE SYSTEM

3.1 Introduction

Given the continued poor vendace spawning and egg incubation conditions in Bassenthwaite Lake, which were confirmed in Chapter 2, the extremely poor current status of the population and the fact that recovery of the lake is proceeding only very slowly (Winfield *et al.*, 2006), it is appropriate to consider other options to improve such conditions in the shorter term.

Although salmonid spawning grounds in small, shallow streams have been successfully cleaned by mechanical means for many years (reviewed by Mih (1978)), such procedures would be technically very difficult on the vendace spawning grounds of Bassenthwaite Lake. As an alternative approach, Winfield *et al.* (1998) suggested that the temporary introduction of a clean artificial spawning and incubation substrate would be the most practical way of providing appropriate spawning conditions for this species. Such substrates in the form of artificial bottom-set grass mats have been used successfully for the spawning and incubation of eggs of the closely related schelly in Haweswater, Blea Water and Small Water in north-east Cumbria (Winfield *et al.*, 1997; Winfield *et al.*, 1999). However, given the high susceptibility of Bassenthwaite Lake to sediment resuspension and movement by high winds (Parker *et al.*, 1999), there was a concern that any such introduced substrate would itself become sediment-laden before egg incubation is completed. Such fears were subsequently borne out by a field trial undertaken in 1998 by Winfield (1999), during which bottom-set artificial grass mats installed on a vendace spawning ground became covered with very heavy deposits of fine sediments after only 15 days. In contrast, the duration of vendace egg incubation from late November through to the following May is such that a clean spawning substrate is required for *c.* 150 days (Winfield *et al.*, 1994a).

The degree of sedimentation problems at Bassenthwaite Lake is clearly too great for a substrate system as simple as that explored by Winfield (1999) to be successful in the foreseeable future. However, the technology of artificial spawning substrate systems for other fish species is developing rapidly (Winfield, in press) and may include systems appropriate to the present problem. In particular, a potential solution for Bassenthwaite Lake may be the use of a more elaborate artificial spawning substrate designed to be less susceptible to sedimentation by being slightly raised off the lake bottom, or by being moved to a less depositional habitat within the lake, if such areas exist, after spawning.

The objective of this part of the present project was to undertake a desk study of the feasibility of developing an appropriate artificial spawning substrate system, including searches of the published and unpublished literature and potentially making visits to selected individuals or laboratories. If considered feasible, this part of the project would also produce detailed plans for a field trial at Bassenthwaite Lake including provision for a comparative deployment of a system in Derwent Water.

3.2 Methods

Three approaches were used to seek relevant primary information for the desk study.

Firstly, several searches of the scientific literature and the internet were made between November 2005 and February 2006. The scientific literature was searched using the online *ISI Web of Knowledge Service for UK Education*, which covers publications from 1970 to the present, using permutations of various search terms including ‘coregon*’, ‘vendace’, ‘spawn*’, ‘artificial’ and ‘substrate’. The internet was searched using the search engine *Google* with the same permutations and search terms.

Secondly, specific requests for personal experience with or knowledge of the use of artificial spawning substrate for vendace or other fish species were made to personal contacts of the first author in Austria, Canada, Denmark, Finland, France, Germany, Poland, Sweden, U.K. and the U.S.A.

Thirdly, following similar enquiries made in anticipation of the present project in person to participants of the *IX International Symposium on the Biology and Management of Coregonid Fishes* held at Olsztyn, Poland, from 21 to 27 August 2005, similar enquiries were made at the *Institute of Fisheries Management Annual Conference* held at Salford, U.K., from 15 to 17 November 2005 and at the workshop *Evaluation of the ecological quality of lakes by their fish fauna* held at Berlin, Germany, from 2 to 3 March 2006.

As a result of the paucity of relevant information produced by the above approaches (see below), no personal visits were made to selected individuals or laboratories.

3.3 Results

No information directly relevant to the use of artificial spawning substrates for vendace or any other coregonids was found by the searches of the scientific literature or the internet, nor was any found in response to the personal enquiries including those made at the *IX International Symposium on the Biology and Management of Coregonid Fishes*, the *Institute of Fisheries Management Annual Conference* or the workshop *Evaluation of the ecological quality of lakes by their fish fauna*.

However, searches of the internet identified two new potentially suitable artificial spawning substrates which had been used with success with other fish species. These were Spawntex Spawning Material (Aquatic Eco-Systems, Inc., www.aquaticeco.com) and Floating Spawning Bed (Aquatic Services, www.aquatic-services.co.uk), both of which are described further in Chapter 4.

In addition, personal enquiry to John Martin of the Environment Agency identified Erosamat Type 3 (ABG Ltd, www.abg-geosynthetics.com), which is also described further in Chapter 4, as a potentially spawning substrate even though he only had personal experience of it as a climbing substrate in elver (*Anguilla anguilla*) passes.

3.4 Discussion

The extensive published and unpublished literature searches and personal enquiries of this desk study failed to produce any information directly relevant to the development of an artificial spawning substrate system appropriate to vendace. Although spawning habitats in many parts of this species' range have been adversely impacted by poor environmental conditions and so poor natural recruitment is an extensive problem for commercial fisheries for this species in many parts of Europe (Winfield *et al.*, 1994b), this apparent absence of any research into artificial spawning substrates was not surprising because many such impacted vendace populations are maintained by extensive stocking operations (Bninska, 2000). Thus, it is clear that no artificial spawning substrate systems for vendace have been developed anywhere in Europe, nor has anything similar been developed for related species with similar requirements.

However, the desk study made sufficient progress to inform the planned field trial with respect to potentially suitable artificial spawning substrates. Three such materials were identified, i.e. Spawntex Spawning Material, Floating Spawning Bed and Erosamat Type 3, to which can be added for comparative purposes the Artificial Grass Model RA1 investigated earlier by Winfield (1999). These will be considered further in Chapter 4.

As a result of the above limited progress of the desk study and in contrast to original plans, no visits were made to selected individuals or laboratories. However, discussions with a number of international contacts continue at the time of writing and the first author plans to attend the *American Fisheries Society Annual Meeting* to be held at Lake Placid, U.S.A., from 10 to 14 September 2006, where many companies exhibit their latest developments in spawning and other technologies. If either of these avenues produce relevant information after the completion of the current project, this will be summarised and conveyed to Environment Agency in a special report.

CHAPTER 4 FIELD TRIAL OF AN ARTIFICIAL SPAWNING SUBSTRATE SYSTEM

4.1 Introduction

The preliminary assessment of simple bottom-set artificial grass mats installed on a vendace spawning ground of Bassenthwaite Lake in 1998 by Winfield (1999) illustrated the problem of sediment resuspension, resulting as it did in very heavy deposits of fine sediments covering the mats after only 15 days. In contrast, the duration of vendace egg incubation from late November through to the following May is such that a clean spawning substrate is required for *c.* 150 days (Winfield *et al.*, 1994a). While such a simple system facilitated the successful spawning and incubation of eggs of the closely related schelly in Haweswater, Blea Water and Small Water in north-east Cumbria (Winfield *et al.*, 1997; Winfield *et al.*, 1999), a more sophisticated substrate and possibly a more sophisticated deployment are clearly required for success in such a sediment-laden environment as that of Bassenthwaite Lake. The desk study of Chapter 3 identified three such potential artificial spawning substrates, i.e. Spawntex Spawning Material, Floating Spawning Bed and Erosamat Type 3, to which can be added for comparative purposes the Artificial Grass Model RA1 originally investigated by Winfield (1999).

The objectives of this part of the present project were to field trial the potential artificial spawning substrates to assess their resistance to sedimentation and to produce, as far as possible, recommendations for an operational system. Given the failure of the desk study to find any directly relevant information on appropriate systems, these objectives were slightly less ambitious than those originally planned, i.e. including a field test of a full system rather than simply the substrates. Following the arising of an appropriate opportunity, an additional objective was subsequently added to assess directly the capacity of one of the potential artificial spawning substrates (Spawntex Spawning Material) to hold coregonid eggs.

4.2 Methods

4.2.1 Potential artificial spawning substrates

Four potential artificial spawning substrates were investigated.

Spawntex Spawning Material (Aquatic Eco-Systems, Inc., www.aquaticeco.com) is a black matrix constructed of a *c.* 25 to 37 mm thick layer of coconut fibres with a latex binder on a polyester net backing. According to the supplier's website (see above), its usual application is as an artificial spawning substrate for shiners (mainly *Notropis* spp.), goldfish (*Carassius auratus*) and 'similar shore-spawning fish'.

Floating Spawning Bed (Aquatic Services, www.aquatic-services.co.uk) is composed of 150 mm long green polypropylene fibres set in 20 bunches of 1,000 in a 1 m long, 30 mm wide and 25 mm thick black plastic base, resulting in 20,000 fibres to each 1 m strip. The recommended deployment for these strips is on a structural frame at a density of 15 strips per square metre, resulting in a density of 150,000 fibres m^{-2} (Cazin, 1994). According to the supplier's website (see above), its usual application is in lakes, large streams, rivers, canals and gravel pits as an artificial spawning substrate for various species of fish including pike

(*Esox lucius*), perch (*Perca fluviatilis)*, roach (*Rutilus rutilus*) and carp (*Cyprinus carpio*). Use of the term 'Floating' in the name of this substrate is somewhat misleading because in addition to being deployed as a floating structure, it can also be deployed on the bottom or even sides of a water body.

Erosamat Type 3 (ABG Ltd, www.abg-geosynthetics.com) is a black matrix of HDPE polyethylene fibres, thermally bonded together to create a tough and flexible, long-lasting mat which is non-corrodible and chemically and microbiologically inert. According to the supplier's website (see above), its usual application is in water channels where an element of erosion control is permanently required in conjunction with natural vegetation. The system provides the root reinforcement necessary for natural vegetation to resist the extreme effects of wind, rain and water erosion. This material has apparently never been used as a spawning substrate, but as noted in Chapter 3, John Martin of the Environment Agency suggested it to be a potentially suitable spawning substrate even though he only had personal experience of it as a climbing substrate in elver passes

Artificial Grass Model RA1 (Nordon Enterprises Ltd, www.gt-group.co.uk) is composed of green plastic blades of length *c.* 13 mm, width *c.* 1.5 mm and thickness *c.* 0.2 mm arranged on a black plastic backing in tufts of *c.* 14 blades at a density of *c.* 840,000 blades m^{-2}. This material had been investigated earlier by Winfield (1999) and so was included here for comparative purposes.

4.2.2 Field trial at Bassenthwaite Lake

The four substrates were deployed in a field trial at Bassenthwaite Lake as follows.

Three metal frames each measuring 1 m by 1 m were each fitted with 0.25 m^2 of each of the four substrates as shown in Fig. 7, which raised the substrates *c.* 30 mm above the surface on which the frame was set. The three frames were then deployed singly in Bassenthwaite Lake on the lake bottom in depths of *c.* 1 m tethered at a distance of *c.* 10 m from the shore at vendace spawning grounds BA1 to BA3 (Table 1, Fig. 1) on 5 December 2005.

Subsequently, visits were made to the frames to assess the extent of fine sediment deposition on each of the substrates using underwater video recording (Simrad OE 1372 Miniature High Definition Colour Underwater Camera recording to a Sony Video Walkman GV-S50E). The video recordings were subsequently digitised in the laboratory using the hardware and software system WinTV-USB (Hauppauge Computer, Inc., www.hauppauge.com) which was also used to review the recordings and produce representative still images. Depending on environmental conditions, underwater still photography (Nikon COOLPIX S3 digital compact camera in a Nikon WPCP5 waterproof housing set at an image resolution of 6 megapixels) was also used at each site and the resulting digital photographs reviewed at a later date in the laboratory.

Such visits were made on 15 and 22 December 2005, and 3 and 25 January, 4 February, 11 March, 20 April and 23 May (when Site BA2 could not be inspected due to an unusually high water level) 2006. Note that on 25 January 2006, the frame at Site BA3 could not be found despite intensive searching under difficult conditions of significant wave action. This frame remained missing during searches under much better and perfect conditions on 4 February and 11 March 2006, respectively, and so was presumed lost. Some movements of the frames at sites BA1 (moved inshore to a depth of *c.* 0.5 m where it was left) and BA2 (moved inshore to a depth of *c.* 0.2 m, from which it was returned to its original position) was also recorded on 20 April 2006.

4.2.3 Field trial at Derwent Water

As the chances of finding vendace eggs on the substrates introduced to Bassenthwaite Lake were judged to be improbably small given the present scarcity of the species in this location, the substrate Floating Spawning Bed was also subjected to a field trial at Derwent Water in the hope of observing its performance as an incubation substrate for the eggs of this more abundant vendace population.

Five metal frames each measuring 1 m by 1 m were each fitted with 1 m^2 of Floating Spawning Bed as shown in Fig. 8. The five frames were then deployed singly in Derwent Water on the lake bottom in depths of *c.* 1 m tethered at a distance of *c.* 10 m from the shore at vendace spawning grounds DA1, DA3, DA4, DA5 and DA6 (Table 2, Fig. 2) on 28 November 2005.

Subsequently, visits were made to the frames to check for the presence of vendace eggs using underwater video recording (Simrad OE 1372 Miniature High Definition Colour Underwater Camera recording to a Sony Video Walkman GV-S50E). The video recordings were subsequently digitised in the laboratory using the hardware and software system WinTV-USB (Hauppauge Computer, Inc., www.hauppauge.com) which was also used to review the recordings. Depending on environmental conditions, underwater still photography (Nikon COOLPIX S3 digital compact camera in a Nikon WPCP5 waterproof housing set at an image resolution of 6 megapixels) was also used at each site and the resulting digital photographs reviewed at a later date in the laboratory. On the same visits, three sweeps of each frame were made using a Freshwater Biological Association hand net of mesh size sufficiently small to retain vendace eggs.

Such visits were made to all frames on 15 December 2005, and then again to frames on sites DA1 and DA3 only on 22 December 2005 and 3 January (when Site DA3 could not be inspected due to an unusually high water level) and 4 February 2006.

4.2.4 Hatchery observations of Spawntex Spawning Material

In addition to the above field trials, an opportunity to assess directly the capacity of one of the potential artificial spawning substrates to hold coregonid eggs arose through the assistance of Hubert Gassner of the Institute of Freshwater Ecology, Scharfling, Austria and Vesa Määttä of the Finnish Game and Fisheries Research Institute, Taivalkoski, Finland. In December 2005, both individuals were supplied with small (*c.* 150 mm by 100 mm) samples of Spawntex Spawning Material in order to test its capacity to hold and retain incubating eggs (eyed stage) of vendace (Määttä, Finland), and small (*Coregonus lavaretus* eggs of age 2 days from the lake of Mondsee, Austria) and large (*Coregonus maraena* eggs of age 21 days from ponds) eggs from different races of whitefish (Gassner, Austria) which were available as part of normal aquaculture activities at these two institutes.

4.3 Results

4.3.1 Field trial at Bassenthwaite Lake

Almost constantly high levels of suspended fine particles made both underwater video recording and still photography extremely difficult at Bassenthwaite Lake. However, both methods successfully provided information on the development of sedimentation on the artificial spawning substrates.

As an example from the early incubation period, still images taken from the underwater video recordings of the substrates at Site BA2 taken on 15 December 2005 are shown in Fig. 9. All four substrates remained clean at this time.

As an example from the mid incubation period, still photographs of the substrates at Site BA2 taken on 25 January 2006 are shown in Fig. 10. While the substrates Artificial Grass Model RA1, Spawntex Spawning Material, and Erosamat Type 3 showed significant accumulations of fine sediments, the substrate Floating Spawning Bed remained clean at this time.

As an example from the late incubation period, still photographs of the substrates at Site BA2 taken on 11 March 2006 are shown in Fig. 11. The substrates Artificial Grass Model RA1, Spawntex Spawning Material, and Erosamat Type 3 showed even greater accumulations of fine sediments, but the substrate Floating Spawning Bed still remained clean with the exception of its extreme outside fibres.

Overall, all four substrates remained clean from installation on 5 December to 3 January 2006, but after that the substrates Artificial Grass Model RA1, Spawntex Spawning Material, and Erosamat Type 3 rapidly accumulated fine sediments such that they were extensively covered by 25 January 2006. Some cleaning of the substrates was evident on 20 April 2006, presumably by a particular combination of wind-induced water movements, although they were still unsuitable for vendace eggs. In contrast, the substrate Floating Spawning Bed remained largely clean from installation through to the last inspection on 23 May 2006.

4.3.2 Field trial at Derwent Water

Although visibility conditions were much better than in Bassenthwaite Lake, both underwater video recording and still photography were still relatively difficult at Derwent Water. However, both methods successfully allowed detailed inspections of the artificial spawning substrate.

As an example, a still photograph of the substrate at Site DA1 on 3 January 2006 is shown in Fig. 12. Fine sediments were never observed to accumulate on the substrates, but neither were vendace eggs ever recorded visually.

Vendace eggs were also never recorded by the hand-net sampling.

4.3.3 Hatchery observations of Spawntex Spawning Material

For the vendace eggs, most of the eggs remained on the upper surface of the spawning substrate, with the rest falling within the upper third and none passing right through the substrate.

For both sizes of whitefish eggs, all eggs stayed within the spawning substrate (Fig. 13) and were resistant to deliberate attempts to dislodge them.

4.4 Discussion

The field trial in Bassenthwaite Lake clearly demonstrated that the artificial substrate Floating Spawning Bed was much more resistant to sedimentation than Spawntex Spawning Material, Erosamat Type 3 or Artificial Grass Model RA1. Furthermore, it was the only substrate which remained effectively clean throughout the likely incubation period of vendace eggs from its installation in early December to the following May, despite the almost constantly high levels of suspended fine particles in the inshore water column of Bassenthwaite Lake.

It was notable that in 1998 the substrate Artificial Grass Model RA1 was covered in heavy deposits of fine sediments after only 15 days immersion from 5 to 20 December 1998 (Winfield, 1999), but in the present study it remained clean from 5 December 2005 to 3 January 2006, i.e. for 29 days. Although this difference in performance may have been attributable in part to the substrate being raised *c.* 30 mm off the lake bottom in the present study but only *c.* 5 mm in 1998 (first author, unpublished data), it is also possible that differences in water movements and thus sediment resuspension between the two studies was a more important factor. Even with this minor improvement in performance, this substrate was still clearly incapable of supporting successful vendace egg incubation under the conditions of Bassenthwaite Lake in early 2006.

The performances of the two substrates Spawntex Spawning Material and Erosamat Type 3 were very similar and they could play a role in a system which worked on the principle of allowing natural spawning to take place over them, before they and the resulting eggs were moved to a less depositional habitat. In such circumstances, Spawntex Spawning Material would be the preferred substrate because the present observations showed that it retained coregonid eggs within its matrix extremely well while the coarser matrix of Erosamat Type 3 is likely to be less effective in this context.

The present deployment of the substrate Floating Spawning Bed was very encouraging in terms of its resistance to sedimentation. However, its capacity to retain vendace eggs was not directly tested given the disappointing results at Derwent Water as discussed below. Consequently, it would be useful to conduct a hatchery test of this capacity in the future if such further cooperation would be acceptable to Vesa Määttä of the Finnish Game and Fisheries Research Institute, Taivalkoski, Finland. In addition, it was clear from the deployments of the substrate Floating Spawning Bed in both Bassenthwaite Lake and Derwent Water that arrangement of the strips at the horizontal intervals on the frame recommended by the manufacturer resulted in substantial gaps between the rows of fibres which amounted to *c.* 50% of the frame's surface area (see for example Fig. 10). While this may not be an issue for species such as pike, perch, roach and carp which actively seek macrophytes or macrophyte substitutes when spawning, for species such as vendace and other broadcast spawners it is likely to result in a loss of *c.* 50% of eggs immediately on their release. An obvious solution would be to reduce the interval length by *c.* 50%, with no adverse implications other than increased cost.

It was disappointing that the installation of the substrate Floating Spawning Bed on five known vendace spawning grounds in Derwent Water did not result in observations of any vendace eggs despite the increasing abundance of the population in this lake (Winfield *et al.*, 2006), and so could not assess the capacity of this substrate to retain vendace eggs. It is relevant that simultaneous gill netting for spawning vendace in a stripping programme reported by Lyle *et al.* (2006) captured relatively few individuals on these known spawning grounds, but had more successful catches slighty further offshore in deeper water. The reason for this apparent change in behaviour is unknown, but the observations of Chapter 2 indicate that it is not the local spread of New Zealand pygmy weed.

In conclusion, an operational artificial spawning substrate system would be most effective based on the substrate Floating Spawning Bed with individual strips arranged with a density twice that recommended by the manufacturer. The present relatively simple deployment with substrate raised off the lake bottom by only *c.* 30 mm worked well and was robust to winter storms. Larger frame sizes would also be more effective, which as a result would also require more robust anchoring. The desk study of Chapter 3 failed to find any information which could inform the decision on how much such artificial substrate should be introduced to Bassenthwaite Lake, but this is an area which could be taken up in the future by direct communications with researchers engaged in the use of artificial spawning substrates for non-coregonid lake fish species including lake trout (*Salvelinus namaycush*) in North America (e.g. Marsden & Chotkowski, 2001), even though such species have significantly different spawning habitat requirements to vendace. Such enquires may be possible at the *5th International Charr Symposium* held at Reykjavik, Iceland, from 2 to 5 August 2006, which the first author will be attending, and at the *American Fisheries Society Annual Meeting* to be held at Lake Placid, U.S.A., from 10 to 14 September 2006, which the first author plans to attend.

CHAPTER 5 GENERAL DISCUSSION AND RECOMMENDATIONS

5.1 General discussion

The findings of the various components of this project have already been discussed within their specific chapters. However, a brief and more general discussion is warranted here with respect to the present situations at Bassenthwaite Lake and Derwent Water and the spawning ecology and conservation of their vendace populations.

Ecological conditions on the vendace spawning grounds of Bassenthwaite Lake and Derwent Water clearly differ significantly. The poor conditions in Bassenthwaite Lake which have existed since at least the early 1990s have at best persisted and at worst declined even further since the late 1990s. Suitable vendace spawning substrate at Bassenthwaite Lake is thus clearly extremely limited and remains extremely unlikely to be able to facilitate significant recruitment. Successful *in situ* spawning, even if adults were returned to the lake from the refuge population now established at Loch Skene (Maitland *et al.*, 2003), is unlikely for many years without the introduction of an artificial spawning substrate system.

In contrast, with five out of six sites unchanged in terms of their native flora and with what appeared to be no increase in fine sediments, suitable vendace spawning substrate at Derwent Water remains extensive and is thus likely to be able to facilitate significant recruitment. This lake has has, however, shown a major change between 1998 and 2005 in terms of the greatly increased distribution of New Zealand pygmy weed such that in the latter year it was observed at four of six vendace spawning sites. However, the areal coverage by this invasive macrophyte was relatively limited and appears to pose no immediate significant threat to local vendace spawning. Nevertheless, if it develops at these sites to the degree already shown in the Derwent Bay area there may be significant adverse effects.

Disappointingly but not completely unexpectedly, extensive published and unpublished literature searches and personal enquiries failed to produce any information directly relevant to the development of an artificial spawning substrate system appropriate to vendace. Thus, it is clear that no artificial spawning substrate systems for this species have been developed anywhere in Europe, nor has anything similar been developed for related species with similar requirements. However, work on artificial spawning substrates has been undertaken for non-coregonid lake fish species in North America and, even though such species have significantly different spawning habitat requirements to vendace, its findings may have some relevance.

The field trial at Bassenthwaite Lake clearly showed that an operational artificial spawning substrate system would be most effective based on the substrate Floating Spawning Bed, with individual strips arranged with a density twice that recommended by the manufacturer. Furthermore, the relatively simple deployment with the substrate raised off the lake bottom by only *c.* 30 mm worked well and was robust to winter storms. An operational system would benefit from larger frame sizes, which as a result would require more robust anchoring. However, before taking development of this system any further it would be prudent to assess directly that the substrate Floating Spawning Bed will actually retain vendace eggs. This issue is discussed further below.

5.2 Recommendations

Three general areas for further work were noted in the earlier chapters of the present report and are collated here for clarity, to which are added a further two concerning the actual presence of vendace in Bassenthwaite Lake and the issue of the amount of artificial spawning substrate needed to have an effect significant at the population level. These will be presented with the first two relating to conditions in Bassenthwaite Lake and Derwent Water, while the third to fifth relate to further development of the artificial spawning substrate system.

Firstly, although to some degree outside the specific topic of the present study it is now appropriate to consider a gill-net sampling effort outside the monitoring programme of Winfield *et al.* (2006) with the specific and simple objective of determining if the vendace is still extant in Bassenthwaite Lake. Although the failure of the monitoring programme to record any vendace since 2000 may suggest a local extinction, the capture of a few individuals in 2001 during other sampling on a spawning ground (Winfield & Fletcher, 2002) suggests that the population may persist, even if only at a very low population density. Clearly, whether or not the vendace is still extant in Bassenthwaite Lake is of great strategic importance to its conservation management and so such efforts to try to demonstrate a continued presence, even if a negative result would not be conclusive, are extremely worthwhile.

Secondly, given the apparent recent deterioration in the already scarce macrophytes of the spawning grounds of vendace in Bassenthwaite Lake, which are likely to offer the only viable egg incubation substrate in this sediment-rich environment, it is recommended that further hydroacoustic macrophyte surveys are performed on the three sites of the present study during the next vendace spawning or incubation seasons. It would also be useful to determine by the same means the distributions of macrophytes on the other then unsuitable sites investigated in 1997 by Winfield *et al.* (1998). Similarly, further hydroacoustic surveys at Derwent Water would be extremely useful to investigate the present abundance of macrophytes at then apparently suitable sites in this lake also surveyed in 1997 by Winfield *et al.* (1998). A return to the Derwent Bay area of this lake to repeat the 2003 hydroacoustic survey of New Zealand pygmy weed in this location would also be informative in the context of this potential threat to vendace spawning success.

Thirdly, given the failure at Derwent Water to test directly the capacity of the substrate Floating Spawning Bed to retain vendace eggs it is recommended that further testing of this capacity is conducted prior to any further development of the artificial spawning substrate system on a larger scale. Given the difficulty experienced in locating spawning vendace in Derwent Water in 2005, such assessment would be best carried out in cooperation with Vesa Määttä of the Finnish Game and Fisheries Research Institute, Taivalkoski, Finland, where vendace eggs are in plentiful supply and their use in experiments does not have any conservation implications. At this stage, the authors have not proposed this course of action to Vesa Määttä, but given the limited scale of such an experiment it is likely that cooperation would be forthcoming. Such a hatchery-based test would address the retention of vendace eggs by the substrate Floating Spawning Bed under benign physical conditions, although a full test incorporating the effects of wave action would still require field observations either in Derwent Water or possibly at a lake in Finland or elsewhere with an abundant spawning vendace population.

Fourthly, the amount of artificial spawning substrate needed to have an effect significant at the population level could be explored using a population modelling approach similar to that recently employed at Haweswater in a study of schelly recruitment by Winfield *et al.* (2004b). Although necessarily requiring a number of assumptions to be made and the use of published life table and associated data derived from other vendace populations, such work would at least begin to underpin and inform what is at present a completely unaddressed aspect of the use of artificial spawning substrate for vendace conservation.

Fifthly, it is recommended that the current discussions concerning artificial spawning substrates with a number of international contacts are continued and that this issue is also raised with participants at the *5th International Charr Symposium* to be held at Reykjavik, Iceland, from 2 to 5 August 2006 and at the *American Fisheries Society Annual Meeting* to be held at Lake Placid, U.S.A., from 10 to 14 September 2006.

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Table 1. Locations of three vendace spawning grounds in Bassenthwaite Lake surveyed by underwater video survey and by hydroacoustic survey on 5 December 2005. Locations are given in degrees and decimal minutes.

Site	Latitude (North)	Longitude (West)
BA1	54, 38.822	3, 13.053
BA2	54, 38.297	3, 12.629
BA3	54, 38.158	3, 12.340

Table 2. Locations of six vendace spawning grounds in Derwent Water surveyed by underwater video survey and by hydroacoustic survey on 22 November 2005. Locations are given in degrees and decimal minutes.

Site	Latitude (North)	Longitude (West)
DA1	54, 34.487	3, 9.364
DA2	54, 34.743	3, 8.468
DA3	54, 34.834	3, 7.970
DA4	54, 34.962	3, 8.448
DA5	54, 34.962	3, 8.806
DA6	54, 34.782	3, 8.914

Table 3. Locations of a total of 15 hydroacoustic transects at three sites used at Bassenthwaite Lake on 5 December 2005. Locations are given in degrees and decimal minutes.

Site	Event	Latitude (North)	Longitude (West)
BA1	Transect 1 start	54, 38.802	3, 13.051
	Transect 1 end	54, 38.806	3, 13.041
	Transect 2 start	54, 38.819	3, 13.045
	Transect 2 end	54, 38.816	3, 13.064
	Transect 3 start	54, 38.833	3, 13.082
	Transect 3 end	54, 38.840	3, 13.067
	Transect 4 start	54, 38.852	3, 13.070
	Transect 4 end	54, 38.845	3, 13.096
	Transect 5 start	54, 38.868	3, 13.117
	Transect 5 end	54, 38.883	3, 13.075
BA2	Transect 1 start	54, 38.289	3, 12.634
	Transect 1 end	54, 38.341	3, 12.598
	Transect 2 start	54, 38.340	3, 12.617
	Transect 2 end	54, 38.290	3, 12.655
	Transect 3 start	54, 38.290	3, 12.671
	Transect 3 end	54, 38.350	3, 12.650
	Transect 4 start	54, 38.350	3, 12.669
	Transect 4 end	54, 38.296	3, 12.688
	Transect 5 start	54, 38.296	3, 12.700
	Transect 5 end	54, 38.374	3, 12.686
BA3	Transect 1 start	54, 38.154	3, 12.352
	Transect 1 end	54, 38.210	3, 12.332
	Transect 2 start	54, 38.214	3, 12.353
	Transect 2 end	54, 38.151	3, 12.380
	Transect 3 start	54, 38.148	3, 12.417
	Transect 3 end	54, 38.215	3, 12.424
	Transect 4 start	54, 38.221	3, 12.451
	Transect 4 end	54, 38.145	3, 12.477
	Transect 5 start	54, 38.148	3, 12.499
	Transect 5 end	54, 38.248	3, 12.532

Table 4. Locations of a total of 30 hydroacoustic transects at six sites used at Derwent Water on 22 November 2005. Locations are given in degrees and decimal minutes.

Site	Event	Latitude (North)	Longitude (West)
DA1	Transect 1 start	54, 34.448	3, 9.354
	Transect 1 end	54, 34.441	3, 9.217
	Transect 2 start	54, 34.445	3, 9.202
	Transect 2 end	54, 34.452	3, 9.354
	Transect 3 start	54, 34.457	3, 9.358
	Transect 3 end	54, 34.467	3, 9.201
	Transect 4 start	54, 34.470	3, 9.193
	Transect 4 end	54, 34.473	3, 9.371
	Transect 5 start	54, 34.476	3, 9.378
	Transect 5 end	54, 34.493	3, 9.208
DA2	Transect 1 start	54, 34.731	3, 8.565
	Transect 1 end	54, 34.676	3, 8.578
	Transect 2 start	54, 34.676	3, 8.559
	Transect 2 end	54, 34.728	3, 8.536
	Transect 3 start	54, 34.736	3, 8.516
	Transect 3 end	54, 34.693	3, 8.520
	Transect 4 start	54, 34.699	3, 8.493
	Transect 4 end	54, 34.738	3, 8.478
	Transect 5 start	54, 34.742	3, 8.464
	Transect 5 end	54, 34.722	3, 8.452
DA3	Transect 1 start	54, 34.856	3, 7.986
	Transect 1 end	54, 34.856	3, 8.074
	Transect 2 start	54, 34.840	3, 8.062
	Transect 2 end	54, 34.835	3, 7.998
	Transect 3 start	54, 34.822	3, 7.997
	Transect 3 end	54, 34.820	3, 8.065
	Transect 4 start	54, 34.805	3, 8.065
	Transect 4 end	54, 34.801	3, 8.003
	Transect 5 start	54, 34.790	3, 8.000
	Transect 5 end	54, 34.782	3, 8.044
DA4	Transect 1 start	54, 34.974	3, 8.399
	Transect 1 end	54, 35.014	3, 8.456
	Transect 2 start	54, 35.009	3, 8.463
	Transect 2 end	54, 34.967	3, 8.412
	Transect 3 start	54, 34.966	3, 8.422
	Transect 3 end	54, 34.996	3, 8.485
	Transect 4 start	54, 34.999	3, 8.511
	Transect 4 end	54, 34.964	3, 8.453
	Transect 5 start	54, 34.956	3, 8.466
	Transect 5 end	54, 34.991	3, 8.532
DA5	Transect 1 start	54, 34.975	3, 8.805
	Transect 1 end	54, 35.015	3, 8.932
	Transect 2 start	54, 35.013	3, 8.939
	Transect 2 end	54, 34.972	3, 8.821
	Transect 3 start	54, 34.964	3, 8.826
	Transect 3 end	54, 34.997	3, 8.961
	Transect 4 start	54, 34.996	3, 8.969
	Transect 4 end	54, 34.943	3, 8.848
	Transect 5 start	54, 34.934	3, 8.864
	Transect 5 end	54, 34.969	3, 8.983
DA6	Transect 1 start	54, 34.790	3, 8.935
	Transect 1 end	54, 34.698	3, 8.872
	Transect 2 start	54, 34.694	3, 8.868
	Transect 2 end	54, 34.780	3, 8.921
	Transect 3 start	54, 34.783	3, 8.910
	Transect 3 end	54, 34.741	3, 8.858
	Transect 4 start	54, 34.757	3, 8.861
	Transect 4 end	54, 34.786	3, 8.877
	Transect 5 start	54, 34.794	3, 8.863
	Transect 5 end	54, 34.778	3, 8.843

Table 5. Macrophyte mean height, percentage area inhabited (PAI) and percentage volume inhabited (PVI) of three vendace spawning grounds in Bassenthwaite Lake surveyed by hydroacoustic survey on 5 December 2005. Values are given as means with 95% confidence limits in parentheses. Note that no macrophytes were detected at Site BA1.

Site	Mean height (m)	PAI (%)	PVI (%)
BA1	-	0	0
BA2	0.03 (0.01)	0.35 (0.52)	0.01 (0.02)
BA3	0.03 (0.01)	0.31 (0.38)	0.01 (0.02)

Table 6. Macrophyte mean height, percentage area inhabited (PAI) and percentage volume inhabited (PVI) of six vendace spawning grounds in Derwent Water surveyed by hydroacoustic survey on 22 November 2005. Values are given as means with 95% confidence limits in parentheses.

Site	Mean height (m)	PAI (%)	PVI (%)
DA1	0.09 (0.09)	7.56 (4.39)	0.61 (1.06)
DA2	0.05 (0.01)	11.64 (4.96)	0.67 (0.29)
DA3	0.04 (0.04)	0.75 (1.16)	0.02 (0.03)
DA4	0.08 (0.10)	9.32 (3.73)	0.31 (0.12)
DA5	0.07 (0.01)	21.90 (7.47)	0.85 (0.32)
DA6	0.04 (0.01)	5.52 (3.36)	0.22 (0.19)

Fig. 1. Locations of three vendace spawning grounds (closed circles labelled BA1 to BA3) in Bassenthwaite Lake surveyed by underwater video survey and by hydroacoustic survey on 5 December 2005. Latitudes and longitudes of sites are given in Table 1.

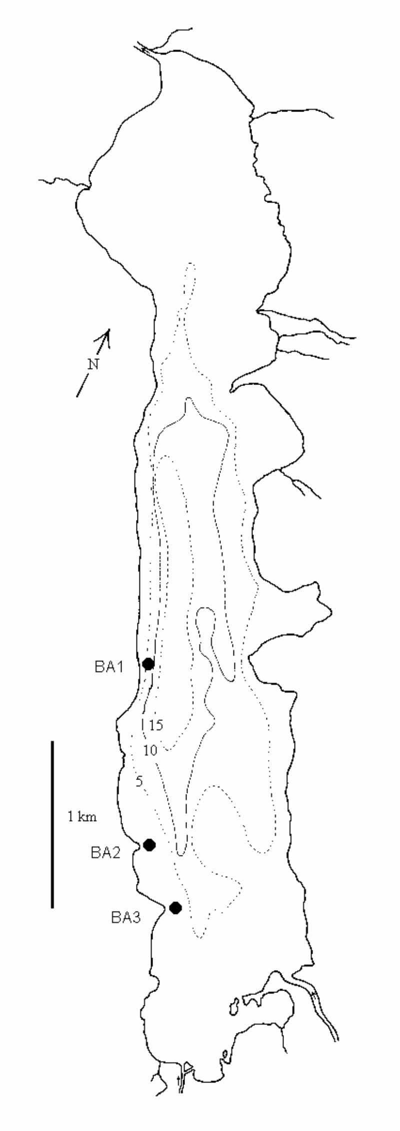

Fig. 2. Locations of six vendace spawning grounds (closed circles labelled DA1 to DA6) in Derwent Water surveyed by underwater video survey and by hydroacoustic survey on 22 November 2005. Latitudes and longitudes of sites are given in Table 2.

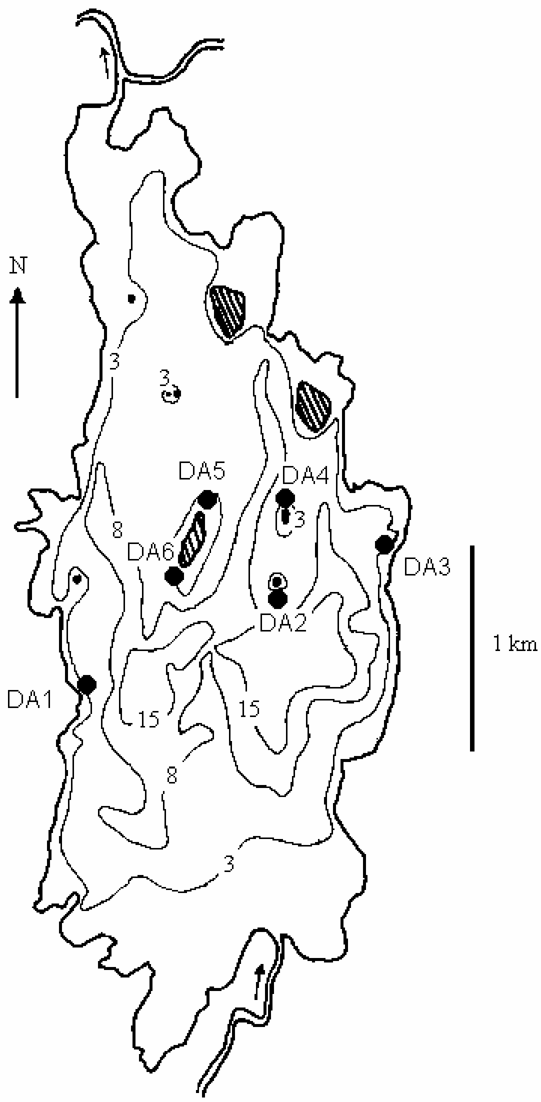

Fig. 3. A representative image taken from the underwater video recording of Site BA1 of Bassenthwaite Lake on 5 December 2005 showing the complete absence of macrophytes.

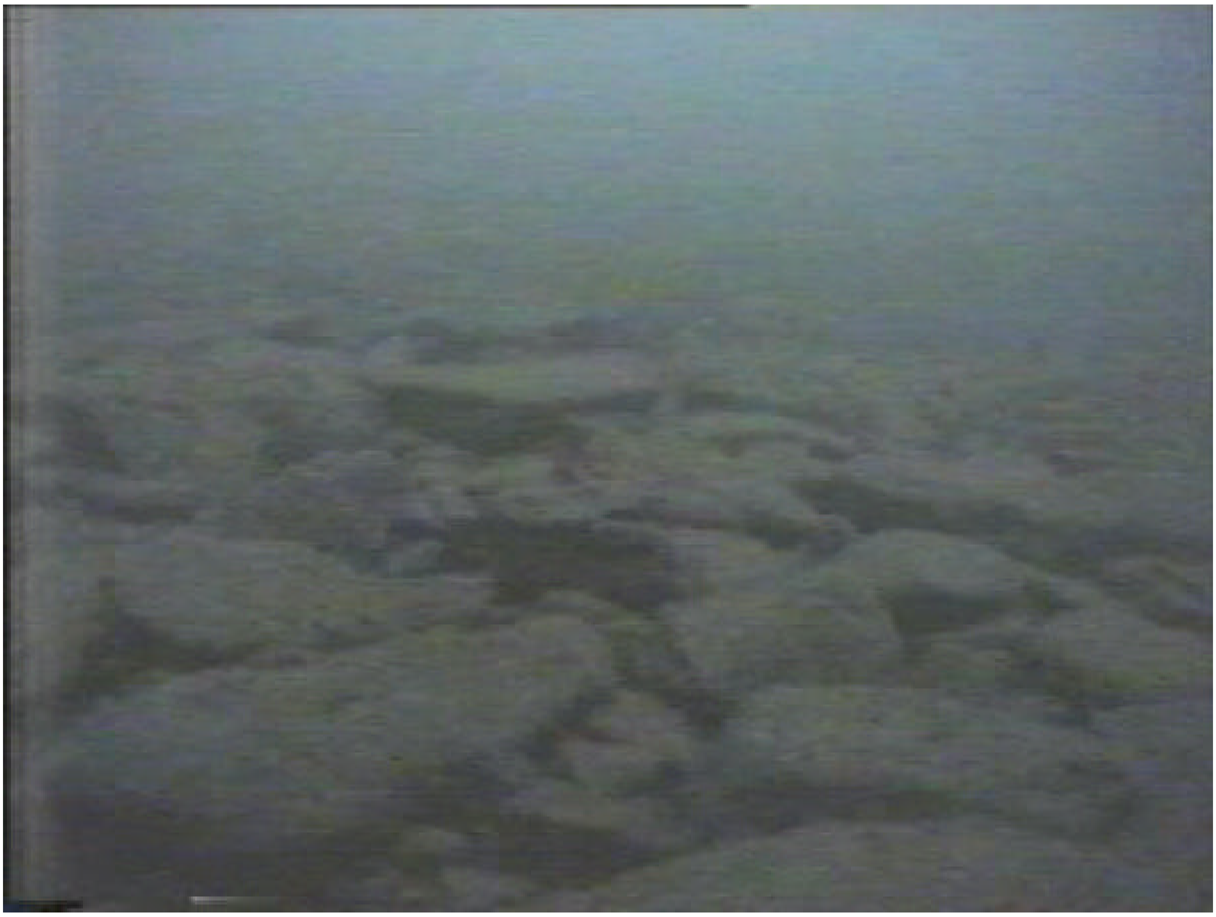

Fig. 4. A representative image taken from the underwater video recording of Site DA6 of Derwent Water on 22 November 2005 showing extensive growths of isoetids.

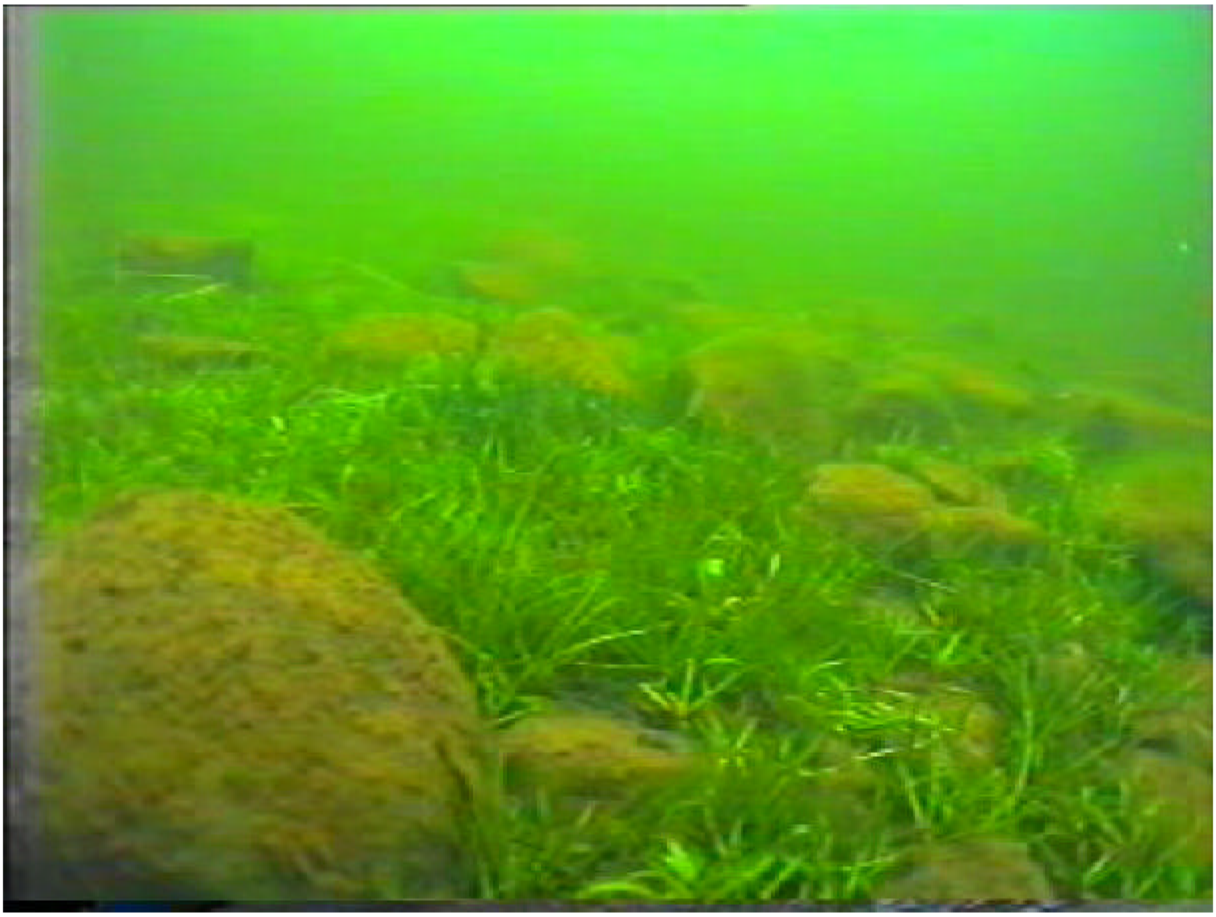

Fig. 5. A representative image taken from the underwater video recording of Site DA5 of Derwent Water on 22 November 2005 showing extensive growths of elodeids.

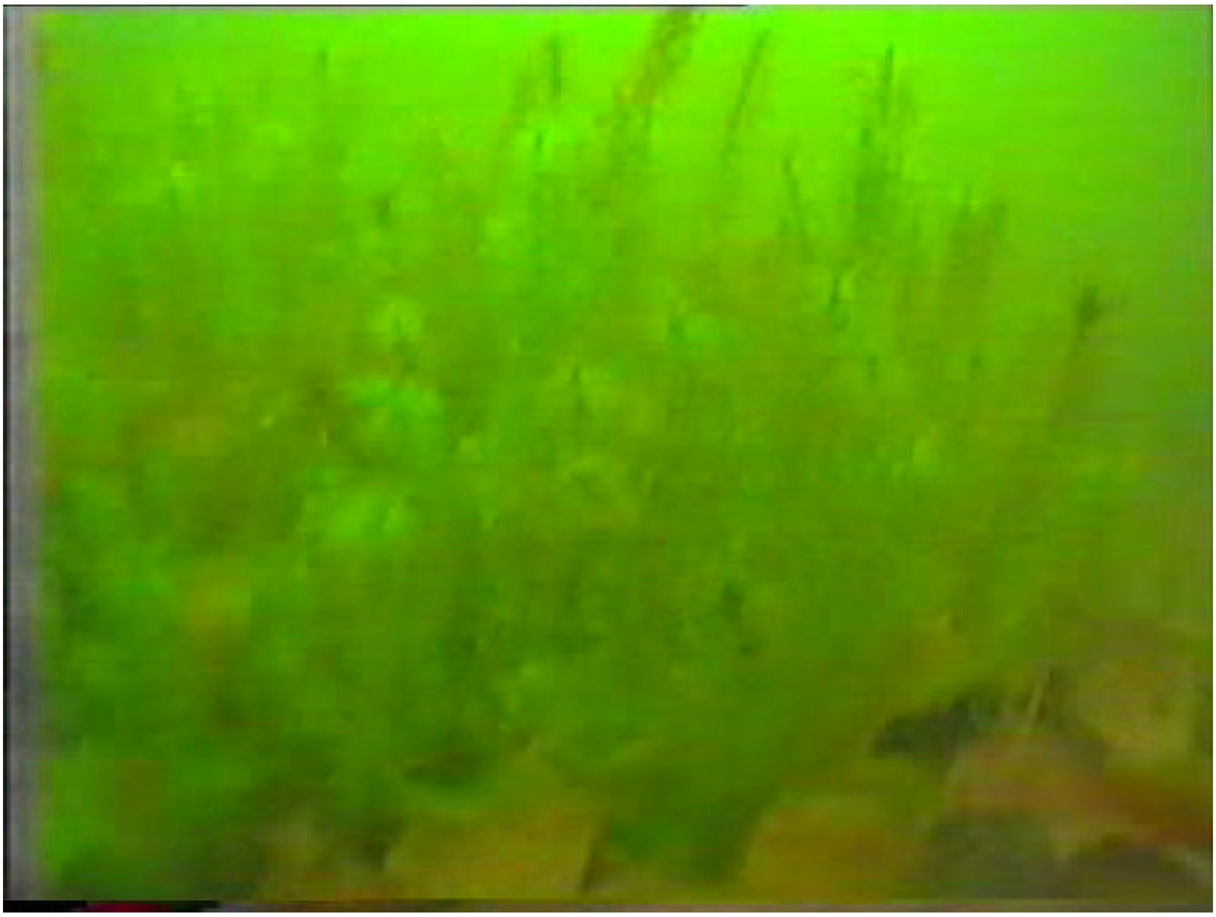

Fig. 6. A representative image taken from the underwater video recording of Site DA3 of Derwent Water on 22 November 2005 showing extensive growths of New Zealand pygmy weed.

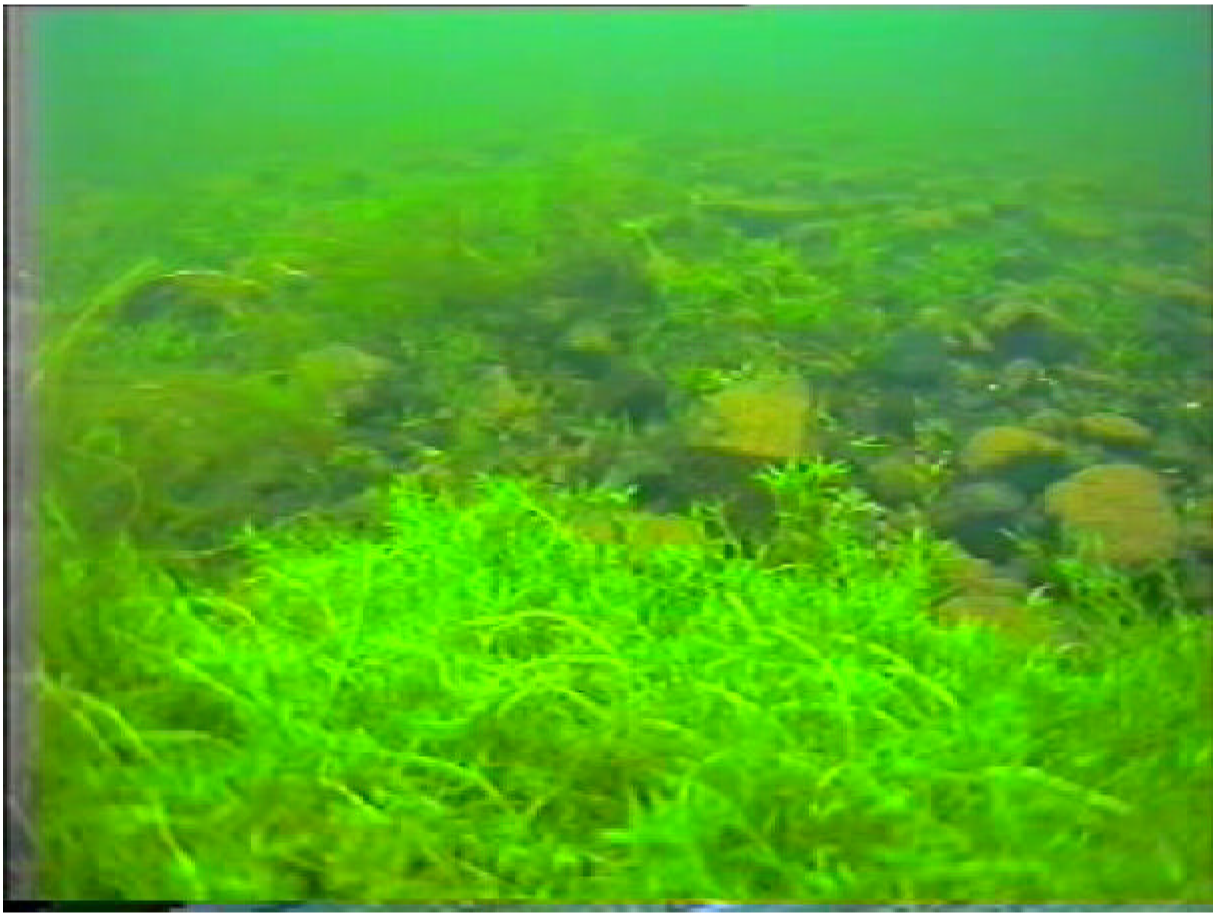

Fig. 7. One of the three frames used in the field trial of artificial spawning substrates in Bassenthwaite Lake. The frame is 1 m by 1 m and contains 0.25 m^2 of each of (clockwise from top left) Artificial Grass Model RA1, Spawntex Spawning Material, Floating Spawning Bed and Erosamat Type 3.

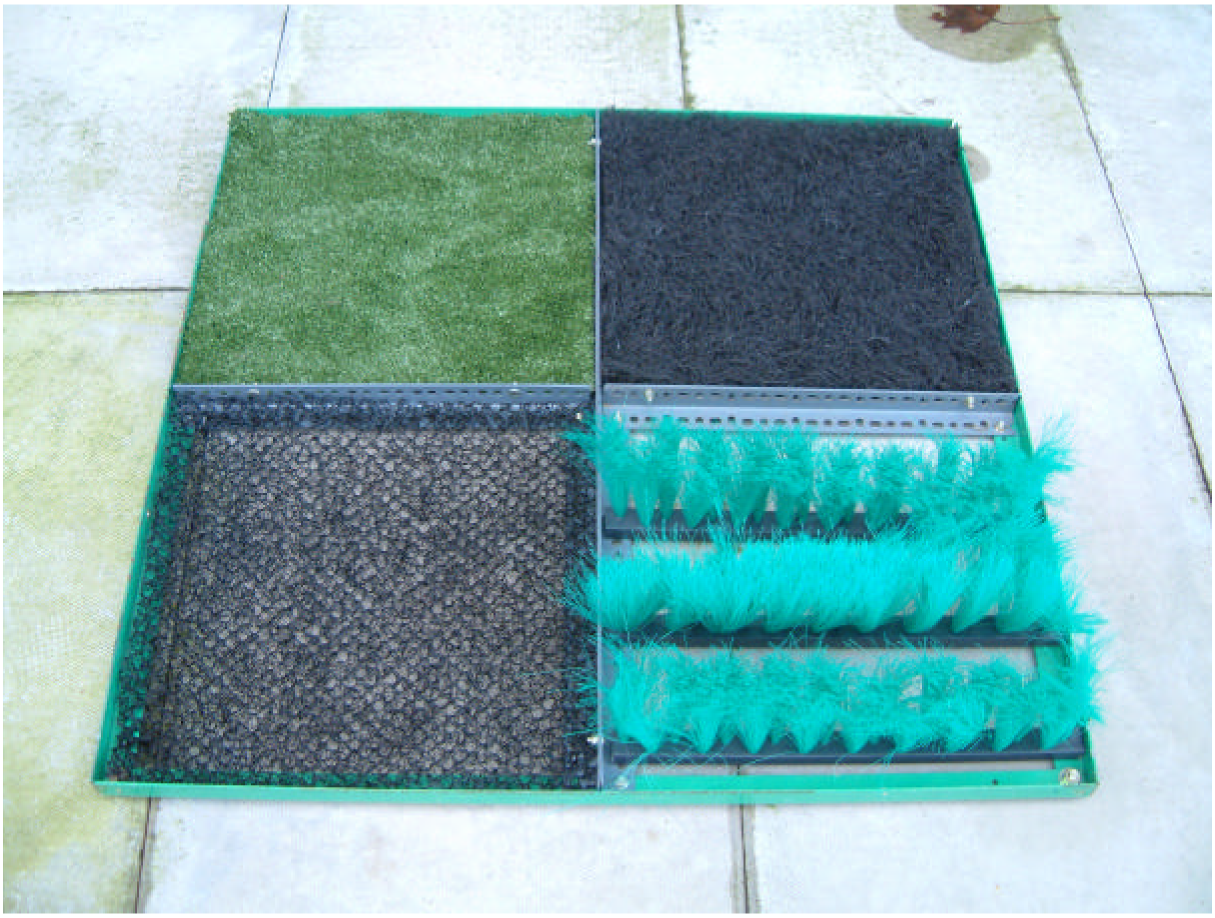

Fig. 8. One of the five frames used in the field trial of artificial spawning substrate Floating Spawning Bed in Derwent Water. The frame is 1 m by 1 m and contains 1 m^2 of substrate.

Fig. 9. Still images taken from the underwater video recordings of the substrates (clockwise from top left) Artificial Grass Model RA1, Spawntex Spawning Material, Floating Spawning Bed and Erosamat Type 3 at site BA2 in Bassenthwaite Lake during the early vendace incubation period on 15 December 2005.

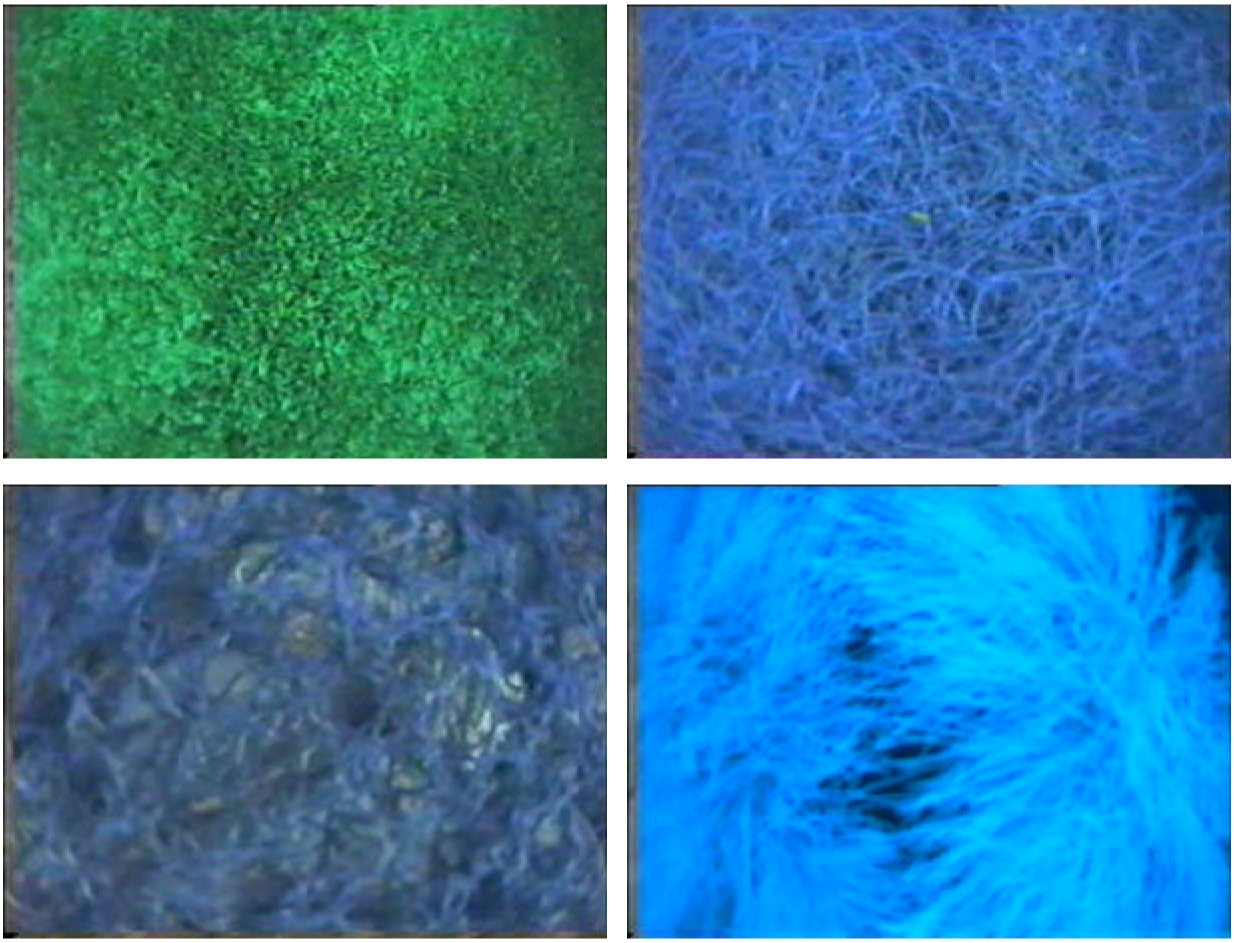

Fig. 10. Underwater still photography of the substrates (clockwise from top left) Artificial Grass Model RA1, Spawntex Spawning Material, Floating Spawning Bed and Erosamat Type 3 at site BA2 in Bassenthwaite Lake during the mid vendace incubation period on 25 January 2006.

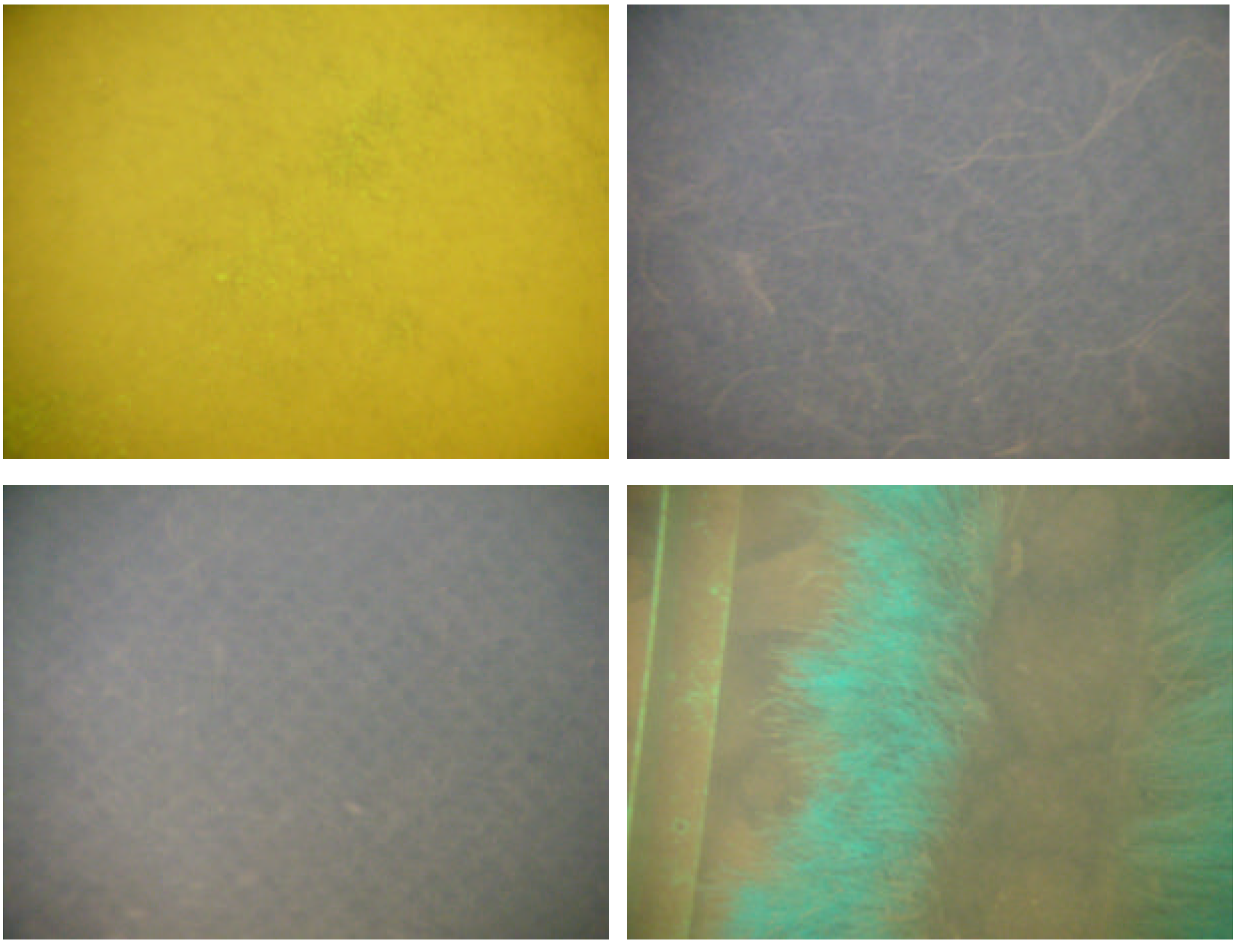

Fig. 11. Underwater still photography of the substrates (clockwise from top left) Artificial Grass Model RA1, Spawntex Spawning Material, Floating Spawning Bed and Erosamat Type 3 at site BA2 in Bassenthwaite Lake during the late vendace incubation period on 11 March 2006.

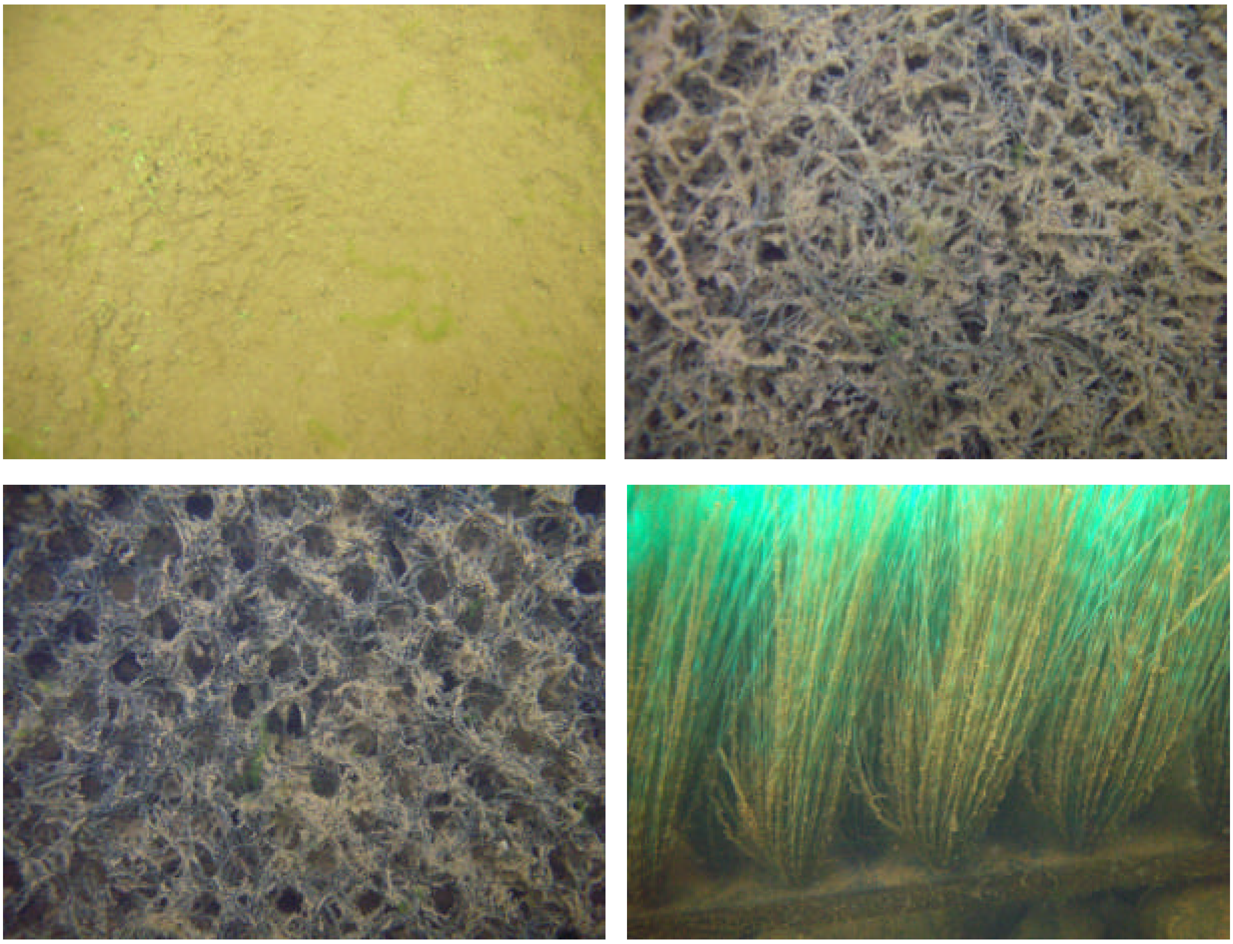

Fig. 12. Underwater still photography of the substrate Floating Spawning Bed at site DA1 in Derwent Water on 3 January 2006.

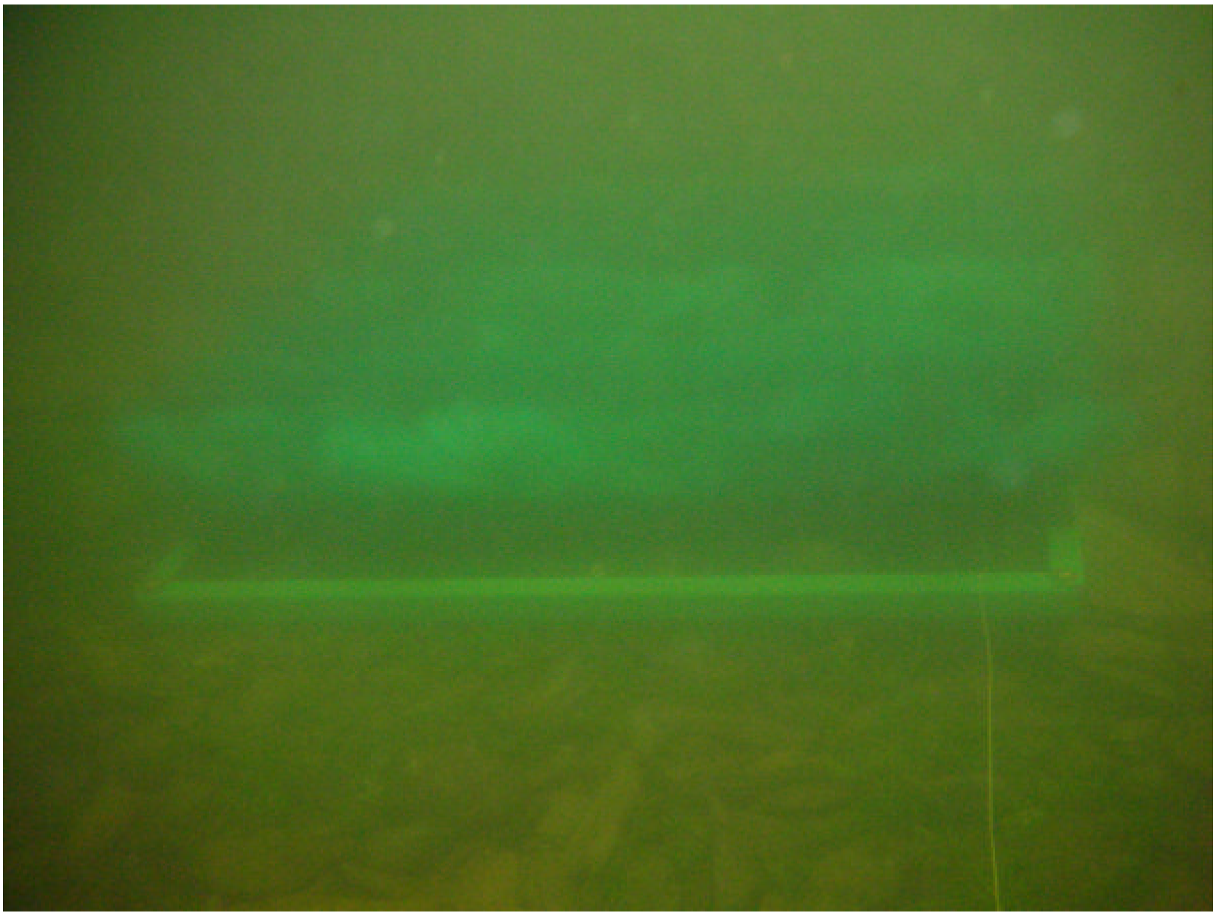

Fig. 13. Eggs of *Coregonus lavaretus* on the artificial spawning substrate Spawntex Spawning Material. Photograph courtesy of Hubert Gassner of the Institute of Freshwater Ecology, Scharfling, Austria.