LLYN ARENIG FAWR GWYNIAD SURVEY 2012

Ian J Winfield, Janice M Fletcher & J Ben James

CCW Contract Science Report No 1013

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LLYN ARENIG FAWR GWYNIAD SURVEY 2012

CCW CONTRACT SCIENCE REPORT NO. 1013

FINAL REPORT

A collaborative project between the Countryside Council for Wales, Environment Agency Wales and the Snowdonia National Park Authority

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2. Amcanion y prosiect presennol oedd defnyddio hydroacwsteg ac arolwg rhwyd ddrysu ynghyd â chasglu proffiliau ocsigen a thymheredd a dyfnder Secchi fel yr ail gam ym monitro tymor hir Llyn Arenig Fawr fel safle ar gyfer derbyn gwyniaid.

3. Fe wnaeth arolwg hydroacowsteg ar 7 Awst 2012 gofnodi amlder cymedr geometric o bob maint o bob pysgodyn 1.8 ha^{-1}, gyda chyfyngiadau hyder 95% is ac uwch o 0.7 a 4.7 o bysgod ha^{-1}, yn y drefn yna. Roedd y ffigurau yma yn trawsnewid i amcangyfrif poblogaeth absoliwt o 65 o unigolion, gyda chyfyngiadau hyder 95% is ac uwch o 26 a 164 unigolyn, yn y drefn yna.

4. Fe wnaeth arolwg rhwyd ddrysu ar 7 Awst 2012 gofnodi cyfanswm o 23 pysgodyn o dair rhywogaeth, h.y. pum brithyll (yn amrywio o ran hyd o 149 i 258 mm, yn amrywio o ran pwysau o 43 i 229 g), dau wyniad (yn amrywio o ran hyd o 122 i 124 mm, yn amrywio o ran pwysau o 17 i 21 g) ac 16 draenog (yn amrywio o ran hyd o 70 i 183 mm, yn amrywio o ran pwysau o 4 i 80 g). O archwilio'r ddau wyniad yn fanylach gwelwyd fod un o bosib yn wryw a'r llall o bosib yn fenyw, yr un o'r ddau wedi cyrraedd eu llawn dwf, y ddau yn flwydd oed ac felly y ddau'n aelodau o ddosbarth blwyddyn 2011. Roedd eu cyflwr mynegrifo yn 0.94 a 1.10.

5. Roedd y proffiliau ocsigen a thymheredd a gofnodwyd ar 7 Awst 2012 yn amrywio o

9.9 mg L^{-1} a 15.3 °C ar yr wyneb i 9.0 mg L^{-1} a 7.3 °C ar waelod y golofn ddŵr (amcangyfrif dyfnder 33 m), yn y drefn yna. Dim ond gostyngiad cyffredinol bychan iawn mewn crynodiad yr oedd y proffil ocsigen yn ei ddangos gyda dyfnder gan gynnwys cynnydd bychan iawn yn yr hypolimnion uchaf, tra oedd y proffil tymheredd yn dangos thermoclein cryf ar oddeutu 12 m. Roedd dyfnder Secchi yn 5.1 m. Mae'r holl baramedrau yma o fewn neu'n agos iawn at ystod goddefiant amgylcheddol y gwyniaid.

6. Deuir i'r casgliad fod rhai o wyau'r gwyniad gafodd eu trawsleoli o Lyn Tegid i Lyn Arenig Fawr rhwng 2005 a 2007 nid yn unig wedi deor yn llwyddiannus ac wedi cyrraedd eu llawn dwf ond hefyd bellach wedi silio'n llwyddiannus ac wedi cenhedlu o leiaf un genhedlaeth arall o wyniaid. Arweiniodd arsylwadau ffisigocemegol o amgylchedd Llyn Arenig Fawr hefyd i'r casgliad ei fod yn annhebygol o osod unrhyw gyfyngiadau ar wasgariad gofodol poblogaeth y gwyniaid sy'n datblygu yn y lloches.

7. Yn unol â'r rhaglen fonitro tymor hir ar gyfer Llyn Arenig Fawr, lluniwyd argymhellion yn nhrefn blaenoriaeth ar gyfer gwneud gwaith pellach. Mae'r argymhellion hyn yn cynnwys:

- trydydd asesiad hydroacowsteg a rhwyd ddrysu o'r poblogaethau pysgod yn 2015 (blaenoriaeth uchel)
- archwilio rhwydo fyke a/neu rwydo sân sydd ddim yn ddinistriol i ganfod gwyniaid llawn dwf pan maent yn symud i'r lan i silio (blaenoriaeth ganolig),
- archwilio'r defnydd o weithgareddau bwydo cregyn y dyfrgi (*Lutra lutra*) i ddangos gweithgaredd silio'r gwyniad ac i ddatgelu lleoliadau meysydd silio (blaenoriaeth ganolig)
- mesuriadau pellach o baramedrau ansawdd dŵr gan gynnwys tymheredd, ocsigen, pH, alcalinedd, crynodiadau maetholion a chloroffylf *a* (blaenoriaeth ganolig).

EXECUTIVE SUMMARY

1. The conservation importance of the gwyniad (*Coregonus lavaretus*, conspecific with schelly in England and powan in Scotland) population of Llyn Tegid in Wales is recognised on a national level. Nevertheless, it is considered to face a range of environmental threats of varying magnitude and so has been subjected to a translocation programme. Between 2005 and 2007, a total of approximately 81,300 gwyniad eggs was introduced to Llyn Arenig Fawr. As part of a long-term monitoring programme, in 2009 a hydroacoustics and gill-netting survey recorded the presence of brown trout (*Salmo trutta*), perch (*Perca fluviatilis*) and an adult female gwyniad likely to belong to the first generation to reproduce in this refuge site.

2. The objectives of the present project were to employ hydroacoustics and survey gill netting, together with the collection of oxygen and temperature profiles and Secchi depth, as a second step in the long-term monitoring of Llyn Arenig Fawr as a recipient site for gwyniad.

3. A hydroacoustic survey on 7 August 2012 recorded a geometric mean abundance of all sizes of all fish of 1.8 fish ha^{-1}, with lower and upper 95% confidence limits of 0.7 and 4.7 fish ha^{-1}, respectively. These figures converted to an absolute population estimate of 65 individuals, with lower and upper 95% confidence limits of 26 and 164 individuals, respectively.

4. A gill-netting survey on 7 August 2012 recorded a total of 23 fish of three species, i.e. five brown trout (length range 149 to 258 mm, weight range 43 to 229 g), two gwyniad (length range 122 to 124 mm, weight range 17 to 21 g) and 16 perch (length range 70 to 183 mm, weight range 4 to 80 g). Further examination of the two gwyniad revealed one a probable male and one a probable female, both immature, both of age 1 year and thus both members of the 2011 year class. Their condition indices were 0.94 and 1.10.

5. Oxygen and temperature profiles recorded on 7 August 2012 ranged from 9.9 mg L^{-1} and 15.3 °C at the surface to 9.0 mg L^{-1} and 7.3 °C at the bottom of the water column

(approximate depth 33 m), respectively. The oxygen profile showed only a slight overall fall in concentration with depth, including a slight increase in the upper hypolimnion, while the temperature profile showed a strong thermocline at approximately 12 m. Secchi depth was 5.1 m. All of these parameters are within or extremely close to the environmental tolerance range of gwyniad.

6. It is concluded that some of the gwyniad eggs translocated from Llyn Tegid to Llyn Arenig Fawr between 2005 and 2007 have not only successfully hatched and reached maturity, they have also now successfully spawned and produced at least one subsequent generation of gwyniad. In addition, physico-chemical observations of the environment of Llyn Arenig Fawr lead to the conclusion that it is unlikely to impose any restrictions on the spatial distribution on the developing gwyniad refuge population.

7. In accordance with the long-term monitoring programme for Llyn Arenig Fawr, prioritised recommendations were made for further work including;

- a third hydroacoustics and gill-netting assessment of the fish populations in 2015 (high priority),
- exploration of non-destructive fyke netting and/or seine netting to detect adult gwyniad when they move inshore to spawn (medium priority),
- exploration of the use of otter (*Lutra lutra*) feeding activities to demonstrate gwyniad spawning activity and to reveal the locations of spawning grounds (medium priority),
- further measurement of water quality parameters including temperature, oxygen, pH, alkalinity, nutrient concentrations and chlorophyll *a* (medium priority).

CHAPTER 1 INTRODUCTION

1.1 Background

The conservation importance of the gwyniad (*Coregonus lavaretus*, conspecific with schelly in England and powan in Scotland) population of Llyn Tegid in Wales is recognised on a national level by its protection under Schedule 5 of the Wildlife and Countryside Act, 1981, and by its inclusion in a list of globally threatened/declining species in the U.K. Biodiversity Action Plan (Winfield *et al.*, in press). Nevertheless, this population, which is the only representation of the species in Wales, is considered to face a range of environmental threats of varying magnitude, including eutrophication, sedimentation on spawning grounds, lake-level fluctuations, species introductions and potentially climate change (Winfield, 2001; Thomas *et al.*, in press). A short review of the ecology and biology of the gwyniad, including the mechanisms by which such threats may impact on its population status, may be found in Winfield & Fletcher (2001). Fuller accounts are given in Winfield *et al.* (1994a), Winfield *et al.* (1994b) and Thomas *et al.* (in press).

Assessments of environmental data by Winfield (2001) and Winfield & Fletcher (2001) led to the conclusion that several of the above environmental problems had become considerable at Llyn Tegid, a view which has been supported more recently by Burgess *et al.* (2006) who concluded that the lake is now in overall unfavourable condition as a result of a loss of extent of standing water, poor water quality in terms of nutrients and oxygen levels and excessive growth of cyanobacteria or green algae, an unnatural hydrological regime and significant environmental change in the form of eutrophication. Although management procedures could in theory be developed to combat these problems, there are at present no fully effective mechanisms to deal with diffuse pollution and sediment transport into the lake. Current schemes to reduce diffuse pollution in the Afon Twrch and Afon Llafar tributaries in the form of a Catchment Sensitive Farming demonstration project administered by the Welsh Assembly are a valuable contribution to solving these problems, but they are limited to a small catchment and so are unlikely to result in a full recovery of the lake. In addition, management of the environmental threat posed by the introduction of new species to a water body is even more difficult. In the context of the gwyniad the most important species

introduction issue is that of the ruffe (*Gymnocephalus cernuus*), which Winfield *et al.* (1994a) and Winfield *et al.* (1996a) demonstrated had become extremely abundant in Llyn Tegid by the early 1990s and which Winfield *et al.* (2003a) found to have persisted to more recent times. This development gives cause for concern because elsewhere in the U.K this species is known to consume large numbers of *Coregonus* eggs during the winter months. (Maitland *et al.*, 1983; Winfield *et al.*, 1996b; Winfield *et al.*, 1998; Winfield *et al.*, 2004). This fear has been substantiated by local observations of gwyniad egg consumption by ruffe reported by staff of Environment Agency Wales (EAW), as documented in Winfield (2001). All of these environmental threats to the gwyniad in Llyn Tegid were recently reviewed by Thomas *et al.* (in press).

Given the above concerns, a detailed translocation project plan covering theoretical considerations, an assessment of Llyn Arenig Fawr (National Grid Reference SH 847 380, altitude 405 m, surface area 35.1 ha, data sourced from www.UKLakes.net) as the proposed receiver site, a translocation strategy and a post-release monitoring strategy was subsequently commissioned by the Countryside Council for Wales (CCW), EAW and the Snowdonia National Park Authority (SNPA) and delivered by Winfield & Fletcher (2001). An unsuccessful attempt to carry out an initial translocation of gwyniad eggs from Llyn Tegid to the nearby Llyn Arenig Fawr was made in early 2003, the full details of which may be found in Winfield *et al.* (2003b). Second, third and fourth more successful translocation attempts were undertaken in early 2005, 2006 and 2007 by EAW assisted by SNPA wardens with greater field effort and with technical assistance from the present authors. The 2005 attempt resulted in the introduction of approximately 48,500 eggs (Winfield *et al.*, 2005), followed in 2006 by a further approximately 24,000 eggs (Winfield *et al.*, 2006a) and finally in 2007 by another approximately 8,800 eggs (Winfield *et al.*, 2007) making a total of approximately 81,300 eggs. An unsuccessful attempt to detect any resulting underyearling gwyniad using a restricted range of fine-mesh gill nets, as recommended by Winfield & Fletcher (2001), was made by EAW in the autumn of 2006.

In 2006, the partner organisations (CCW, EAW and SNPA) of the above projects concerning the gwyniad population of Llyn Tegid identified a number of appropriate conservation actions and research areas, including the production of a long-term monitoring plan for Llyn

Arenig Fawr. The latter was subsequently reported by Winfield *et al.* (2008) and updated the initial plan formulated by Winfield & Fletcher (2001) by reviewing recent fish translocation assessments in the U.K. and taking into account a standardised survey and monitoring protocol for the assessment of native whitefish (i.e. *Coregonus lavaretus* and vendace (*Coregonus albula)*) populations which had subsequently been developed by Bean (2003). This plan precipitated the first fish survey of Llyn Arenig Fawr to use hydroacoustics and survey gill netting. This was undertaken in July 2009 and resulted in the capture of a total of 19 fish of three species, i.e. 2 brown trout (*Salmo trutta*), 1 gwyniad (length 170 mm, single weight 58 g) and 16 perch (*Perca fluviatilis*). Further examination of the single gwyniad revealed it to be 170 mm in length, 58 g in weight, female, with maturing ovaries, and 4 years in age (Winfield *et al.*, 2010a). Its age of 4 years means that it originated from the first year of translocations in 2005 and, assuming that it was not alone, is likely to belong to the first generation of gwyniad to attempt to reproduce in the refuge site.

1.2 Objectives

Following the long-term monitoring plan for Llyn Arenig Fawr and its potential gwyniad refuge population formulated by Winfield *et al.* (2008) and its first component survey in 2009 reported by Winfield *et al.* (2010a), the objectives of the present project were to employ hydroacoustics and survey gill netting, together with the collection of oxygen and temperature profiles and Secchi depth, as a second step in the long-term monitoring of Llyn Arenig Fawr as a recipient site for gwyniad. Field and initial laboratory work was compliant with the protocol of Bean (2003), which has subsequently been adopted for U.K. whitefish (i.e. *Coregonus albula* and *C. lavaretus*) Common Standards Monitoring (CSM) assessments by the Joint Nature Conservation Committee in the form of JNCC (2005a). However, the conservation assessment aspects of this protocol currently remain inappropriate because any gwyniad present in this site cannot have yet formed a fully functional population of the nature rightly envisaged by Bean (2003). Consequently, these aspects of the protocol were not undertaken.

CHAPTER 2 METHODS

2.1 Approach

Winfield *et al.* (2008) and the reference therein to Bean (2003) clearly indicated the required methodology for the hydroacoustic and gill-netting surveys of the present work, although two proposed minor deviations from the protocol of Bean (2003) were previously presented to and accepted by CCW. These deviations are documented towards the end of this section.

The precise approach taken was influenced by our extensive experience in surveying and monitoring populations of gwyniad (e.g. Winfield *et al.* (1994a); Winfield *et al.* (1996a)), powan (e.g. Winfield *et al.* (2006b)), schelly (e.g. Winfield *et al.*, 2003c), vendace (e.g. Winfield *et al.* (2003d)) and Arctic charr (*Salvelinus alpinus*) (e.g. Winfield *et al.* (2003e); Winfield *et al.* (2006b)) in England, Scotland and Wales.

The basic approach taken for the hydroacoustic survey was as follows. Oxygen and temperature profiles and a Secchi depth reading were recorded during day-time, immediately followed by a hydroacoustic survey. A night-time hydroacoustic survey was then begun after sunset. Raw data files were then copied from the hard drive of the hydroacoustics system to a second laptop computer as a data security precaution and post-processed at a later date.

This approach incorporated two minor deviations from the protocol of Bean (2003).

Firstly, rather than using the target strength to fish length relationship of Foote (1987), as indeed we have done in some of our early studies (e.g. Winfield *et al.* (1994a)), we used the relationship given by Love (1971) which allows wider comparisons because it includes an allowance for different sound frequencies. In practice, the fish lengths predicted by these two relationships for targets of a given strength differ only by very small amounts of no biological consequence.

Secondly, rather than regard a vessel speed of 2.0 m s^{-1} as an absolute upper limit, we prefer to adopt this as a general target mean speed but vary actual speed depending on weather conditions.

The basic approach taken for the gill-netting survey was a number of gill nets set overnight in inshore, offshore bottom and offshore surface habitats on the same day that the hydroacoustic survey was undertaken.

2.2 Hydroacoustic survey

2.2.1 Field work

Day and night hydroacoustic surveys were undertaken on 7 August 2012.

Surveys were carried out using a BioSonics DT-X echo sounder with a 200 kHz split-beam vertical transducer of circular beam angle 6.5° operating under the controlling software Visual Acquisition Version 6.0.1.4318 (BioSonics Inc, Seattle, U.S.A., www.biosonicsinc.com). Throughout the surveys, data threshold was set at -130 dB, pulse rate at 5 pings s^{-1}, pulse width at 0.4 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 disk. The system was deployed from a 4.8 m inflatable dinghy powered by a 25 horse power petrol outboard engine moving at a speed of approximately 2.0 to 2.5 m s^{-1} (approximately 7.2 to 9.0 km h^{-1}), depending on wind conditions. Navigation was accomplished using a Garmin GPSMAP 60CSx GPS (Global Positioning System) (www.garmin.com) with accuracy to less than 10 m, while a JRC Model DGPS212 GPS (www.jrc.co.jp) with accuracy to less than 5 m inputted location data directly to the hydroacoustic system where they were incorporated into the recorded hydroacoustic data files. Prior to the surveys, the hydroacoustic system had been calibrated using a tungsten carbide sphere of target strength (TS) -39.5 dB at a sound velocity of 1470 m s^{-1}.

Surface water temperature was recorded before the day-time hydroacoustic survey was undertaken following the route shown in Fig. 1. 10 transects were surveyed in full daylight

between approximately 15.56 and 16.34 hours and repeated between approximately 21.58 and 22.36 hours after dark during the night-time survey. Corresponding waypoints are given in Table 1 and shown in Fig. 1. Following Jurvelius (1991), coverage ratios (length of survey : square root of the research area) were calculated with respect to the lake's nominal total surface area (35.1 ha) and with respect to the area actually surveyed, where water depth exceeded approximately 5 m (30.0 ha) which is taken as the effective minimum water depth required for vertical hydroacoustics.

As earlier examinations of hydroacoustic data concerning gwyniad collected at Llyn Tegid during day-time surveys by Winfield *et al.* (2010b) and previous studies had showed them to have little obvious value for the present gwyniad survey at Llyn Arenig Fawr, such data were not analysed further here although they were collected and archived with little extra effort in case an appropriate use becomes apparent in the future.

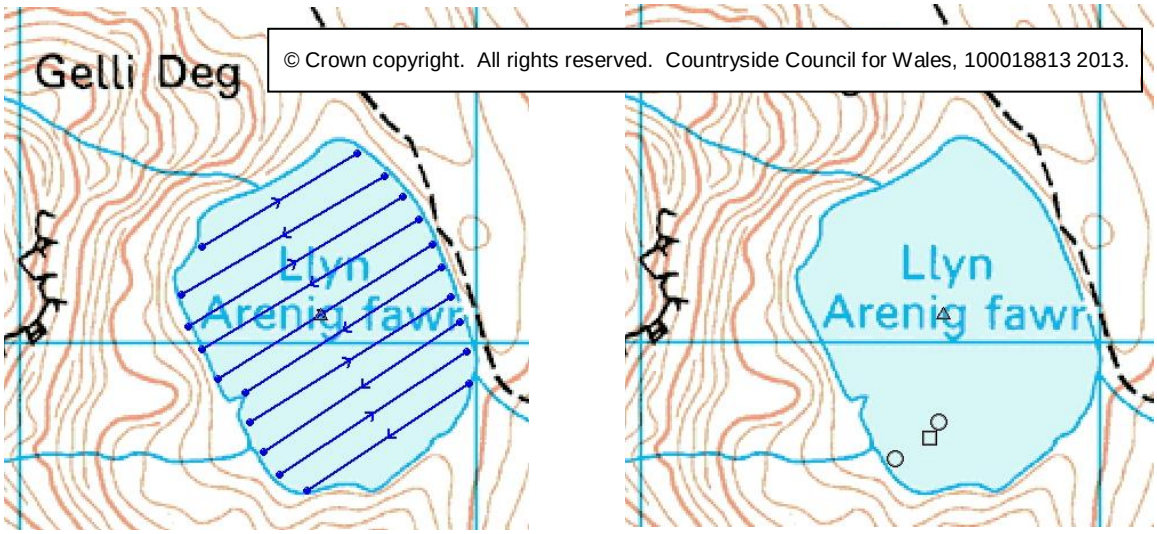

Fig. 1. Locations of 10 hydroacoustic transects (left map, with the direction of travel indicated by an arrowhead), three gill-netting sites and one oxygen and temperature profiles and Secchi depth site used at Llyn Arenig Fawr in 2012 (right map, with bottom and surface nets and profiles and Secchi depth indicated by circles, a square and a triangle, respectively). Detailed location data are presented in Table 1. Scale is indicated by the 1 km grid. Based upon Ordnance Survey 1:25000 data.

Event	Latitude (North)	Longitude (West)
Transect 1 start	52, 55.725	3, 43.270
Transect 1 end	52, 55.841	3, 42.968
Transect 2 start	52, 55.814	3, 42.916
Transect 2 end	52, 55.669	3, 43.307
Transect 3 start	52, 55.633	3, 43.290
Transect 3 end	52, 55.792	3, 42.877
Transect 4 start	52, 55.764	3, 42.844
Transect 4 end	52, 55.604	3, 43.265
Transect 5 start	52, 55.570	3, 43.229
Transect 5 end	52, 55.737	3, 42.819
Transect 6 start	52, 55.708	3, 42.800
Transect 6 end	52, 55.555	3, 43.177
Transect 7 start	52, 55.514	3, 43.166
Transect 7 end	52, 55.674	3, 42.778
Transect 8 start	52, 55.644	3, 42.760
Transect 8 end	52, 55.486	3, 43.139
Transect 9 start	52, 55.458	3, 43.107
Transect 9 end	52, 55.610	3, 42.748
Transect 10 start	52, 55.573	3, 42.741
Transect 10 end	52, 55.442	3, 43.050
Inshore	52, 55.478	3, 43.121
Offshore bottom	52, 55.522	3, 43.036
Offshore surface	52, 55.503	3, 43.053
Profiles and Secchi depth	52, 55.650	3, 43.034

Table 1. GPS locations for 10 hydroacoustic transects, three gill-netting sites (inshore, offshore bottom and offshore surface) and one oxygen and temperature profiles and Secchi depth site used at Llyn Arenig Fawr in 2012. Locations are given in degrees and decimal minutes.

2.2.2 Laboratory examination and analysis

Subsequent data analysis was performed by trace formation, which is also known as fish tracking. In this context, the term 'trace' is synonymous with 'fish', each being composed of a number of echoes. All results presented here refer to the night-time survey.

Trace formation was carried out using SonarData Echoview Version 3.40.47.1551 (Myriax, Hobart, Australia, www.echoview.com) with a target threshold of -70 dB. This process was applied individually to each transect of the night-time surveys.

Mean target strength of each trace produced by Echoview was converted to fish length using the relationship described by Love (1971),

$$TS = (19.1 \log L) - (0.9 \log F) - 62.0$$

where TS is target strength in dB, L is fish length in cm, and F is frequency in kHz.

Mean target strength of each trace was then categorised into 'small' (i.e. -52 to -45 dB, length 40 to 99 mm), 'medium' (-44 to -37 dB, length 100 to 249 mm) or 'large' (greater than -37 dB, length equal to or greater than 250 mm) length classes, with the addition of a length class of 'very small' (i.e. less than -52 dB, length less than 40 mm) to contain the remaining traces. The latter may be significantly contaminated by non-fish echoes and are not considered further here. Traces of each transect were also categorised into 1 m deep strata from a depth of 2 m below the water surface down to the lake bottom. Such counts were then converted to fish densities expressed as individuals per hectare of lake surface area by the use of a spreadsheet incorporating the insonification volume for each depth stratum.

The average population density of fish during the night-time survey was calculated as the geometric mean with 95% confidence limits of the component transects. This population density estimate was then converted to an absolute population estimate by scaling it up to the total surface area of the lake (35.1 ha). Although this estimate of the abundance of all species could in theory be converted to a specific estimate for gwyniad using offshore (i.e. simple unweighted pooling of offshore bottom and offshore surface) community composition data from the gill-netting survey, the small numbers of nets used and fish caught render such calculations very unreliable and so they were not made.

2.3 Gill-netting survey

2.3.1 Field work

Gill netting was undertaken using basic and pelagic versions of the Norden survey gill net, which was formerly known as the Nordic survey gill net (Appelberg, 2000). The basic version of this net, which is set on the lake bottom, is approximately 1.5 m deep and 30 m long, with 12 panels of equal length of bar mesh sizes 5, 6.25, 8, 10, 12.5, 15.5, 19.5, 24, 29,

35, 43 and 55 mm, while the pelagic version, which is set floating on the lake surface, is approximately 6.0 m deep and 27.5 m long, with 11 panels of equal length of bar mesh sizes 6.25, 8, 10, 12.5, 15.5, 19.5, 24, 29, 35, 43 and 55 mm. Locations of gill-net sets were recorded using a Garmin GPSMAP 60CSx GPS (Global Positioning System) (www.garmin.com) with accuracy to less than 10 m.

On 7 August 2012, one basic net was set at a site in the inshore habitat of the lake at a depth of approximately 3 to 4 m during the late afternoon (16.54 to 17.00 hours), together with a basic and a pelagic net in the offshore habitat in areas of water depth of approximately 22 m (Fig. 1, Table 1). Hereafter, these nets are referred to as inshore, offshore bottom and offshore surface, respectively. Nets were then lifted during the subsequent morning (09.32 to 09.51 hours) and all fish were removed from the nets and killed before being identified and enumerated. In addition, gwyniad were photographed. All fish were then frozen at -20 °C to await future processing in the laboratory.

2.3.2 Laboratory examination and analysis

After being partially thawed, all fish were enumerated, measured (fork length, mm), weighed (total wet, g), sexed (male, female or indeterminate) and assessed with respect to maturity (immature, mature) by internal examination. For gwyniad, opercular bones were removed for subsequent age determination by examination under a binocular microscope. The condition of individual gwyniad was assessed using the condition index (CI),

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

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

2.4 Oxygen and temperature profiles and Secchi depth

Oxygen and temperature profiles, to a maximum depth of approximately 33 m, and Secchi depth were taken at the location specified in Fig. 1 and Table 1 at 15.22 hours on 7 August

2012 using an Oxi 340i Handheld Oxygen Meter (Wissenschaftlich-Technische Werkstätten GmbH & Co KG, Weilheim, Germany) and a standard Secchi disc.

CHAPTER 3 RESULTS

3.1 Hydroacoustic survey

Surface water temperature was 15.3 ° C. The survey achieved a coverage ratio of 8.5:1 with respect to total surface, while for the area actually surveyed this figure was 9.2:1.

Fig. 2 presents abundance estimates for small, medium and large fish recorded during the survey, with data also given in numerical form in Table 2. Note that no small or large fish were actually recorded during the survey and the apparent geometric mean abundances for such fish of 1.0 fish ha^{-1} were the result of the (x + 1) logarithmic transformations performed during the calculation of geometric means.

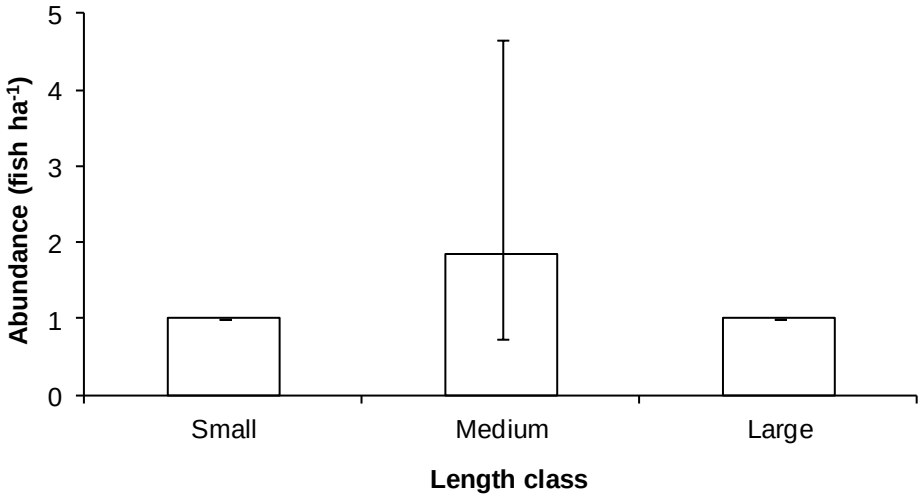

Fig. 2. Abundance estimates (geometric means with 95% confidence limits) by length class for small (length 40 to 99 mm), medium (length 100 to 249 mm) and large (length equal to or greater than 250 mm) fish recorded on 7 August 2012.

Survey date	Species	Abundance (fish ha^{-1})			
		Small	Medium	Large	All
27 August 2012	All	1.0 (1.0, 1.0)	1.8 (0.7, 4.7)	1.0 (1.0, 1.0)	1.8 (0.7, 4.7)

Table 2. Abundance estimates (geometric means with 95% confidence limits) by length class for small (length 40 to 99 mm), medium (length 100 to 249 mm) and large (length equal to or greater than 250 mm) fish recorded on 7 August 2012.

The geometric mean abundance of all sizes of all fish was 1.8 fish ha^{-1}, with lower and upper 95% confidence limits of 0.7 and 4.7 fish ha^{-1}, respectively. These figures converted to an absolute population estimate of 65 individuals, with lower and upper 95% confidence limits of 26 and 164 individuals, respectively.

3.2 Gill-netting survey

A total of 23 fish of three species, i.e. five brown trout (*Salmo trutta*) (length range 149 to 258 mm, weight range 43 to 229 g), two gwyniad (length range 122 to 124 mm, weight range 17 to 21 g) and 16 perch (*Perca fluviatilis*) (length range 70 to 183 mm, weight range 4 to 80 g) was recorded from the inshore, offshore bottom and offshore surface habitats. Brown trout occurred in the inshore (four individuals) and offshore surface (one individual) habitats, gwyniad occurred in the offshore bottom (one individual) and offshore surface (one individual) habitats, and all of the perch were restricted to the inshore habitat.

Further examination of the two gwyniad (Fig. 3) revealed one a probable male and one a probable female, both immature, both of age 1 year and thus both members of the 2011 year class. Their condition indices were 0.94 and 1.10. Full individual details are given in Table 3.

Fig. 3. Two gwyniad (References ARGW2 and ARGW3 as indicated) sampled on 7 August 2012. Full individual details are given in Table 3.

Reference	Site	Length (mm)	Weight (g)	Sex	Maturity	Age (years)	Year class	Condition index
ARGW2	Offshore surface	124	21	Female	Immature	1	2011	Fail
ARGW3	Offshore bottom	122	17	Male	Immature	1	2011	Pass

Table 3. Individual details of two gwyniad sampled on 7 August 2012. Note that due to their immaturity, both sex determinations are only probable.

3.3 Oxygen and temperature profiles and Secchi depth

Oxygen and temperature profiles are given in Fig. 4. Values observed for oxygen levels and temperatures ranged from 9.9 mg L^{-1} and 15.3 °C at the surface to 9.0 mg L^{-1} and 7.3 °C at the bottom of the water column (approximate depth 33 m), respectively. The oxygen profile showed only a slight overall fall in concentration with depth, including a slight increase in the upper hypolimnion, while the temperature profile showed a strong thermocline at approximately 12 m. Secchi depth was 5.1 m.

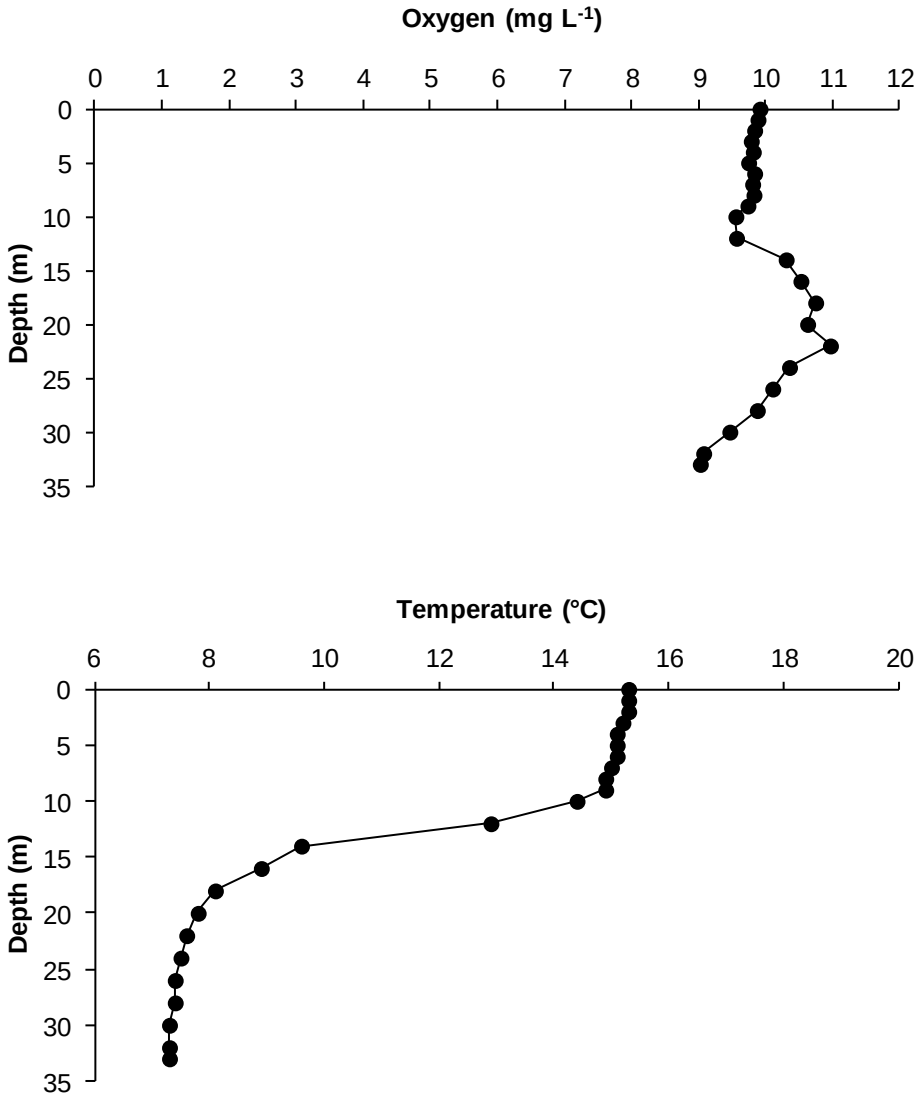

Fig. 4. Oxygen (upper graph) and temperature (lower graph) profiles recorded on 7 August 2012.

CHAPTER 4 DISCUSSION

4.1 Introduction

The first post-translocation attempt to detect underyearling gwyniad in Llyn Arenig Fawr was made in September 2006 by EAW using only a restricted range of fine-mesh gill nets as recommended by Winfield & Fletcher (2001), but this sampling recorded only one brown trout and five perch. The first survey to use hydroacoustics and survey gill netting compliant with the assessment protocol of Bean (2003) was undertaken in July 2009 by Winfield *et al.* (2010a). This survey recorded a geometric mean abundance of all sizes of all fish of 1.7 fish ha^{-1}, with lower and upper 95% confidence limits of 0.8 and 3.8 fish ha^{-1}, respectively. It also sampled 19 fish of three species, i.e. two brown trout, one gwyniad and 16 perch. The single gwyniad was 4 years in age and thus originated from the first year of translocations in 2005. The present survey thus consitutes the second assessment of the fish populations of Llyn Arenig Fawr to be carried out using hydroacoustics and survey gill netting. In accordance with the reporting requirements, this discussion will be short and will first consider findings from the hydroacoustic and gill-netting surveys, before a brief consideration is made of the apparent suitability of Llyn Arenig Fawr for a gwyniad refuge population in terms of oxygen, temperature and water clarity.

4.2 Hydroacoustic survey

The geometric mean abundance of all sizes of all fish observed in 2012 of 1.8 fish ha^{-1} was very low, although it was only just below the range previously recorded from other upland, oligotrophic U.K. standing water bodies (e.g. Winfield *et al.* (2006b)). It was also extremely similar to the corresponding figure of 1.7 fish ha^{-1} recorded at Llyn Arenig Fawr in 2009 by Winfield *et al.* (2010a). As discussed by Winfield *et al.* (2008), the abundance of any fish population introduced exclusively by eggs will inevitably decrease to potentially very low levels during its first few years as many introduced young fish die through natural mortality but its members remain too young to reproduce. Only once recruitment begins, and assuming that survival rates are adequate, will population abundance pass through this trough and begin to increase. The precise timing of these dynamics depends on a number of population and

other parameters and requires specific population modelling in order to be elucidated, but a significant timescale somewhere upwards of 5 years can be anticipated before a significant population increase is detected. From the present hydroacoustic findings, it may be concluded that indicate that the introduced gwyniad population of Llyn Arenig Fawr continues to remain in this population trough.

4.3 Gill-netting survey

As in the previous gill-netting survey of Llyn Arenig Fawr in 2009 reported by Winfield *et al.* (2010a), the survey of 2012 recorded the three fish species of brown trout, gwyniad and perch. On both occasions, brown trout and perch were not recorded outside the inshore and offshore surface habitats and were recorded in very similar or identical numbers (two brown trout in 2009, five brown trout in 2012; 16 perch in 2009, 16 perch in 2012. Consequently, gwyniad was again the only species recorded in the offshore bottom habitat, which is also the only habitat adequately surveyed by the hydroacoustic system used in the present study. This persistent species-specific pattern of spatial distribution means that hydroacoustic surveys provide a robust measure of the future dynamics of the introduced gwyniad population.

The most important finding of the gill-netting survey was without doubt the capture of two gwyniad. While the 2009 survey recorded a single adult female in good individual condition apparently preparing to spawn in early 2010 and originating from the first year of translocations, the present 2012 survey recorded two immature gwyniad in good individual condition and of age 1 year which must have originated from natural spawning in Llyn Arenig Fawr. Clearly, some of the gwyniad eggs translocated from Llyn Tegid to Llyn Arenig Fawr between 2005 and 2007 have not only successfully hatched and reached maturity, they have also successfully spawned and produced at least one subsequent generation of gwyniad.

4.4 Oxygen and temperature profiles and Secchi depth

As expected on the basis of earlier evaluations of Llyn Arenig Fawr as a suitable refuge site for gwyniad (Gray, 1998; Winfield & Fletcher, 2001) and corresponding observations in

2009 (Winfield *et al.*, 2010a), the oxygen (9.9 to 9.0 mg L^{-1}) and temperature (15.3 to 7.3 °C) profiles observed in August 2012 were both within or extremely close to the environmental tolerance range of gwyniad summarised by Winfield (2001) to include a minimum oxygen concentration of 2 mg L^{-1} and a maximum temperature of 15 ºC. In addition, the observed Secchi depth of 5.1 m is typical of an upland, oligotrophic standing water body.

Although measurements of the pH characteristics of Llyn Arenig Fawr were not within the scope of the present study, relevant data collected during 2012 by EAW were obtained and are presented here as Table 4.

Date	pH	Pass or fail JNCC pH criterion
13 January 2012	4.67	Fail
7 February 2012	5.70	Pass
21 March 2012	6.58	Pass
26 April 2012	5.93	Pass
22 May 2012	5.78	Pass
18 June 2012	5.69	Pass
6 July 2012	6.06	Pass
14 August 2012	7.19	Pass
5 September 2012	5.51	Pass
4 October 2012	5.77	Pass
6 November 2012	8.86	Pass
7 December 2012	6.91	Pass

Table 4. pH values for Llyn Arenig Fawr recorded during 2012 outside the present project by EAW, together with their pass or failure with respect to the criterion of greater than pH 5.5 required for favourable condition specified by JNCC (2005a) after JNCC (2005b). The annual average pH 5.54 also passed the criterion.

The criterion of greater than pH 5.5 required for whitefish CSM favourable condition specified by JNCC (2005a) was passed on 11 of the 12 monthly sampling occasions, with a pass also being achieved when these data were expressed as an annual average (pH 5.54). The sole date-specific failure was recorded in January and may have resulted from a short pulse of acid water arising from snow melt, as discussed in general terms for CSM standing water assessments by JNCC (2005b). In general terms the pH conditions of Llyn Arenig Fawr appear to continue to be suitable for gwyniad, although this aspect of local water chemistry is worthy of continued monitoring and assessment as discussed below.

Consequently, it is concluded that the physico-chemical environment of Llyn Arenig Fawr is unlikely to impose any restrictions on the spatial distribution on the developing gwyniad refuge population.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objectives of the present project were to employ hydroacoustics and survey gill netting, together with the collection of oxygen and temperature profiles and Secchi depth, as a second step in the long-term monitoring of Llyn Arenig Fawr as a recipient site for gwyniad. These were achieved in full and led to the conclusions that some of the gwyniad eggs translocated from Llyn Tegid to Llyn Arenig Fawr between 2005 and 2007 have not only successfully hatched and reached maturity, they have now also successfully spawned and produced at least one subsequent generation of gwyniad. In addition, physico-chemical observations of the environment of Llyn Arenig Fawr lead to the conclusion that it is unlikely to impose any restrictions on the spatial distribution on the developing gwyniad refuge population.

5.2 Recommendations

In their long-term monitoring plan for Llyn Arenig Fawr, Winfield *et al.* (2008) recommended adoption of the hydroacoustics and survey gill-netting approach of Bean (2003). The present survey continues the implementation of this recommendation and its timing conforms with the recommendation that it be carried out 3 years after the first such assessment made in 2009 by Winfield *et al.* (2010a). Thereafter, Winfield *et al.* (2008) recommended that post-initial assessments should be made at 3 year intervals for the subsequent two assessments, with a window of ± 1 year being acceptable, which would schedule the next survey in 2015. Such further work, accompanied by oxygen and temperature profiles and Secchi depth, is strongly recommended here with a high priority.

Winfield *et al.* (2008) also made further recommendations concerning potential additional ways in which the gwyniad population of Llyn Arenig Fawr and its habitat could be assessed. It is possible that non-destructive fyke netting and/or seine netting (if suitable snag-free areas can be identified) could be used to detect adult gwyniad when they move inshore to spawn. The seasonality of such spawning during the winter may present some logistical difficulties

to sampling at Llyn Arenig Fawr, particularly for seine netting, but it would have the benefit of being non-destructive. If successful, such sampling could only demonstrate the presence of adult gwyniad and could not address the population parameters required by Bean (2003). It would, however, constitute a simple form of monitoring and is recommended here with low priority. As a newly developed and highly cost-effective alternative approach, recent work on two Cumbrian whitefish populations has demonstrated that the spraints and prey remains of otters (*Lutra lutra*) can be used to demonstrate whitefish spawning activity and to reveal the locations of spawning grounds (Hewitt & Winfield, in press). This technique may have applicability to Llyn Arenig Fawr if the site is frequented by otters and is recommended here with medium priority. Winfield *et al.* (2010a) also recommended that water quality parameters including temperature, oxygen, pH, alkalinity, nutrient concentrations and chlorophyll *a* are measured at least annually and preferably on a quarterly basis. This recommendation is repeated here with medium priority, with the further recommendation that the frequency of pH measurements is increased to a monthly basis.

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APPENDIX 1: DATA ARCHIVE

Data outputs associated with this project are archived as Project No. 389 and Media No. 1405 on server–based storage at the Countryside Council for Wales

The data archive contains:

A. The final report in Microsoft Word and Adobe PDF formats.

B. Echoview Data from the laboratory examination and analysis of output from the echo sounder and GPS used in the field (*.csv format).

C. Oxygen and temperature profiles in .xls spreadsheet format

D. Visual acquisition raw data derived from the echo sounder (*.dt4 format).

E. Species data in .xls format

F. Images in .jpg format

Metadata for this project is publicly accessible through Countryside Council for Wales' Library Catalogue http://www-library.ccw.gov.uk/olibcgi/w24.cgi by searching 'Dataset Titles'. The metadata is held as record no 115217.

Date: 14th February, 2013