

**LLYN ARENIG FAWR GWYNIAD SURVEY
2009**

Ian J Winfield, Janice M Fletcher & J Ben James

CCW Contract Science Report No 904

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LLYN ARENIG FAWR GWYNIAD SURVEY 2009
CCW CONTRACT SCIENCE REPORT NO. 904
FINAL REPORT

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

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EXECUTIVE SUMMARY

English

1. The gwyniad (*Coregonus lavaretus*, conspecific with schelly in England and powan in Scotland) population of Llyn Tegid, north Wales has been considered for a number of years to be threatened by deteriorating environmental conditions, especially those associated with eutrophication. Following a first and unsuccessful attempt to establish a refuge population in the nearby water body of Llyn Arenig Fawr in early 2003, successful second, third and fourth translocation attempts were carried out in early 2005, 2006 and 2007 during which a total of approximately 81,300 gwyniad eggs was introduced to Llyn Arenig Fawr.
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 an initial step in the long-term monitoring of Llyn Arenig Fawr and its potential gwyniad refuge population.
3. A hydroacoustic survey in July 2009 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. These figures converted to an absolute population estimate of 60 individuals, with lower and upper 95% confidence limits of 27 and 132 individuals, respectively.
4. A gill-netting survey in July 2009 recorded a total of 19 fish of three species, i.e. 2 brown trout (*Salmo trutta*) (length range 200 to 288 mm, weight range 106 to 291 g), 1 gwyniad (length 170 mm, single weight 58 g) and 16 perch (*Perca fluviatilis*) (length range 116 to 183 mm, weight range 21 to 90 g). Further examination of the gwyniad revealed it to be a female, with maturing ovaries, of age 4 years and thus a member of the 2005 year class. Its condition index was 1.18.
5. Oxygen levels and temperatures recorded in July 2009 ranged from 9.5 mg L⁻¹ and 14.4 °C at the surface to 7.8 mg L⁻¹ and 7.8 °C at the bottom of the water column (approximate depth 34 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 13 m. Secchi depth was 5.5 m. All of these parameters are within the environmental tolerance range of gwyniad.

6. Although the observed fish abundance was very low, it was only just below the range recorded from other upland, oligotrophic U.K. standing water bodies. Furthermore, the abundance of a gwyniad population introduced exclusively by eggs will inevitably decrease to potentially very low levels during its first few years as young fish die through natural mortality but its members remain too young to reproduce. The sampling of only gwyniad in the offshore bottom habitat suggests that subsequent hydroacoustic surveys will provide a robust measure of the future dynamics of the introduced gwyniad population. Although the growth of the single gwyniad was lower than that of similarly-aged individuals in Llyn Arenig Fawr, its condition index was comparable and its maturing ovaries suggest that it was preparing to spawn in early 2010. Its age of 4 years shows that it originated from the first year of translocations and it is likely to belong to the first generation to reproduce in the refuge site.

7. Prioritised recommendations were made for further work at Llyn Arenig Fawr including;

- a second hydroacoustics and gill-netting assessment of the fish populations in 2012 (high priority),
- exploration of non-destructive fyke netting and/or seine netting to prove the existence of adult gwyniad when they move inshore to spawn (medium priority),
- further measurement of water quality parameters including temperature, oxygen, pH, alkalinity, nutrient concentrations and chlorophyll *a* (medium priority).

Welsh

1. Ers nifer o flynyddoedd, ystyrir bod poblogaeth y gwyniad (*Coregonus lavaretus*, o'r un rhywogaeth â'r 'schelly' yn Lloegr a'r 'powan' yn yr Alban) yn Llyn Tegid, Gogledd Cymru dan fygythiad o ganlyniad i ddirywiad yn yr amodau amgylcheddol, yn enwedig y rheini sy'n gysylltiedig ag ewtroffigedd. Yn dilyn cynnig cyntaf ac aflwyddiannus i sefydlu poblogaeth

mewn hafan yn Llyn Arennig Fawr, corff dŵr cyfagos, yn gynnar yn 2003, cafwyd ail, trydydd a phedwerydd cynnig llwyddiannus i drawsleoli'r pysgod yn gynnar yn 2005, 2006 a 2007, pan gyflwynwyd cyfanswm o oddeutu 81,300 o wyau gwyniaid i Llyn Arennig Fawr.

2. Amcanion y prosiect presennol oedd defnyddio hydroacwsteg ac arolygu rhwydi drysu, a chasglu proffiliau ocsigen a thymheredd a dyfnder Secchi, fel cam cyntaf gwaith monitro hirdymor mewn perthynas â Llyn Arennig Fawr a'i boblogaeth bosibl o wyniaid mewn hafan.

3. Cynhaliwyd arolwg hydroacwstig ym mis Gorffennaf 2009, a'r ffigwr a gofnodwyd ar gyfer cyfanswm cymedrig geometrig yr holl bysgod o bob maint oedd 1.7 o bysgod fesul ha⁻¹, gyda ffiniau hyder 95% isaf ac uchaf o 0.8 a 3.8 o bysgod fesul ha⁻¹. O'u trosi'n amcangyfrif o boblogaeth absoliwt y gwyniad, roedd y ffigyrau hyn yn cyfateb i 60 o unigolion, gyda ffiniau hyder 95% isaf ac uchaf o 27 a 132 o unigolion.

4. Wrth arolygu rhwydi drysu ym mis Gorffennaf 2009, cofnodwyd cyfanswm o 19 o bysgod o dair rhywogaeth, h.y. 2 frithyll (*Salmo trutta*) (ystod hyd rhwng 200 a 288 mm, ystod pwysau rhwng 106 a 291 g), 1 gwyniad (hyd 170 mm, pwysau unigol 58 g) a 16 draenogyn dŵr croyw (*Perca fluviatilis*) (ystod hyd rhwng 116 a 183 mm, ystod pwysau rhwng 21 a 90 g). Datgelodd archwiliad pellach o'r gwyniad mai benyw 4 oed ag ofariau'n aeddfedu ydoedd, a oedd felly'n aelod o griw pysgod 2005. Mynegrif cyflwr y pysgodyn oedd 1.18.

5. Roedd y lefelau ocsigen a thymheredd a gofnodwyd ym mis Gorffennaf 2009 yn amrywio o 9.5 mg L⁻¹ a 14.4 °C ar yr wyneb i 7.8 mg L⁻¹ a 7.8 °C ar waelod y golofn ddŵr (dyfnder o oddeutu 34 m). Dangosodd y proffil ocsigen mai ychydig o gwmp cyffredinol yn unig oedd yng nghrynodiad yr ocsigen wrth fynd yn ddyfnach, gan gynnwys cynnydd bach yn yr hypolimnion uchaf, a dangosodd y proffil tymheredd bod thermoclein cryf ar ddyfnder o oddeutu 13 m. Roedd y dyfnder Secchi yn 5.5 m. Mae pob un o'r paramedrau hyn o fewn terfynau ystod cynefinder amgylcheddol y gwyniad.

6. Er bod nifer y pysgod a welwyd yn isel iawn, nid oedd ond ychydig yn is na'r ystod a gofnodwyd o gyrff dŵr llonydd oligotroffig eraill yr ucheldir yn y DU. At hynny, mae'n anochel y bydd maint poblogaeth o wyniaid a gyflwynir drwy wyau'n unig yn lleihau i

lefelau a allai fod yn isel iawn yn ystod ychydig flynyddoedd cyntaf oes y boblogaeth wrth i bysgod ifanc farw am resymau naturiol ond bod aelodau'r boblogaeth yn parhau'n rhy ifanc i atgynhyrchu. Mae gwaith samplu'r unig wyniad yn y cynefin gwaelod sydd i ffwrdd o'r lan yn awgrymu y bydd arolygon hydroacwstig dilynol yn darparu mesur cadarn yn y dyfodol o ddynameg y boblogaeth o wyniaid a gyflwynir. Er bod twf yr unig wyniad yn llai na thwf unigolion o oed tebyg yn Llyn Arennig Fawr, roedd ei fynegrif cyflwr yn debyg ac mae'r ofariau sy'n aeddfedu'n awgrymu bod y pysgodyn yn paratoi i silio'n gynnar yn 2010. Mae'r ffaith ei fod yn 4 oed yn dangos ei fod yn hanu o griw'r flwyddyn gyntaf o bysgod a drawsleolwyd, ac mae'n debyg y bydd yn perthyn i'r genhedlaeth gyntaf i atgynhyrchu yn safle'r hafan.

7. Cyflwynwyd argymhellion wedi'u blaenoriaethu mewn perthynas â gwaith pellach yn Llyn Arennig Fawr, a oedd yn cynnwys:

- asesu hydroacwsteg a rhwydi drysu am yr eilwaith mewn perthynas â'r poblogaethau pysgod yn 2012 (blaenoriaeth uchel),
- archwilio rhwydi sân a/neu rwydi 'fyke' anninistriol i brofi bodolaeth gwyniaid yn eu llawn dwf pan fyddant yn symud tua'r lan i silio (blaenoriaeth ganolig),
- mesur paramedrau ansawdd dŵr ymhellach, gan gynnwys tymheredd, ocsigen, pH, alcalinedd, crynodiadau maetholion a chloroffyl *a* (blaenoriaeth ganolig).

CHAPTER 1 INTRODUCTION

1.1 Background

The conservation importance of the population of gwyniad (*Coregonus lavaretus*, conspecific with schelly in England and powan in Scotland) in Llyn Tegid 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. 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). 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) and Winfield *et al.* (1994b).

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).

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.*, 2006) 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 2007.

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 albula* and *C. lavaretus*) populations which had subsequently been developed by Bean (2003).

1.2 Objectives

Following Winfield *et al.* (2008), 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 an initial step in the long-term monitoring of Llyn Arenig Fawr and its potential gwyniad refuge population. Although field and initial laboratory work was compliant with the protocol of Bean (2003), the conservation assessment aspects of the protocol were inappropriate because any gwyniad present in this site cannot have yet formed a functional population. 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), 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) in England and Wales.

The basic approach taken for the hydroacoustic survey was as follows. Oxygen and temperature profiles and Secchi depth 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 29 July 2009.

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 5.0.4 (BioSonics Inc, Seattle, U.S.A., www.biosonicsinc.com). Throughout the surveys, data threshold was set at -70 dB, pulse rate at 5 pings s^{-1} , pulse width at 0.4 ms, and data recorded from a range of 2 m from the transducer. In addition to the real-time production of an echogram through a colour display on a laptop computer, data were also recorded to hard disk. The system was deployed from a 4.8 m inflatable dinghy powered by a 15 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. The transducer was positioned approximately 0.5 m below the surface of the water. During all surveys, a JRC Model DGPS212 DGPS (Differential Global Positioning System) (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 *c.* 14.22 and 15.05 hours and repeated between *c.* 22.11 and 22.50 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.* (2010) 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.

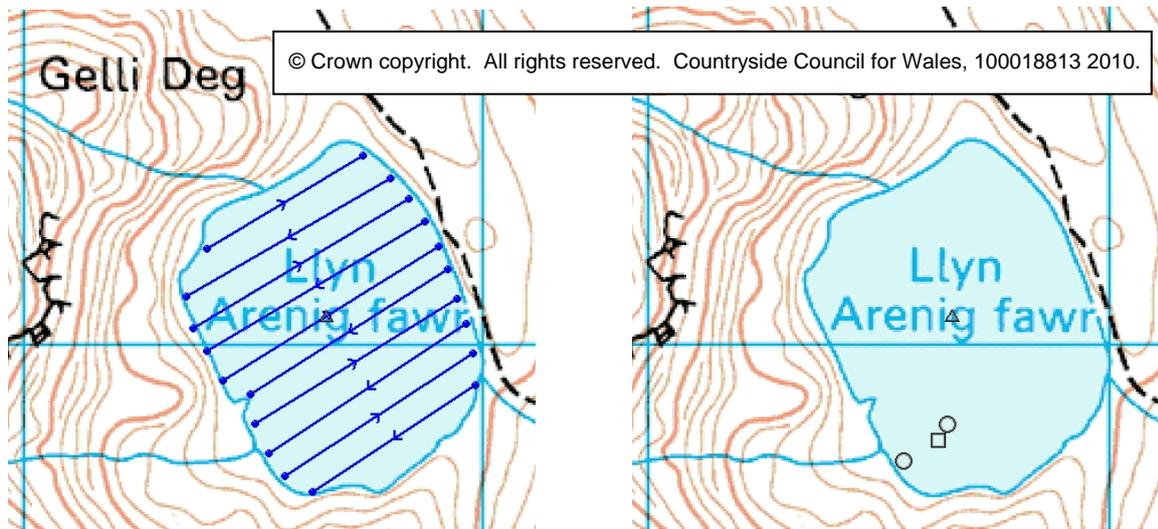


Fig. 1. Locations of 10 hydroacoustic transects (left map, with the direction of travel indicated by an arrowhead), three gill-netting sites and one oxygen and temperature profiles and Secchi depth site used in 2009 (right map, with bottom and surface nets and profiles and Secchi depth indicated by circles, 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 and one oxygen and temperature profiles and Secchi depth site. 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 Echoview Version 3.25.55.00 (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 29 July 2009, 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 (16.25 to 16.40 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 (10.15 to 10.25 hours) and all fish were removed from the nets and killed before being identified and enumerated. 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 34 m, and Secchi depth were taken at the location specified in Fig. 1 and Table 1 at 15.15 hours on 29 July 2009 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 14.4 ° 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 medium 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.

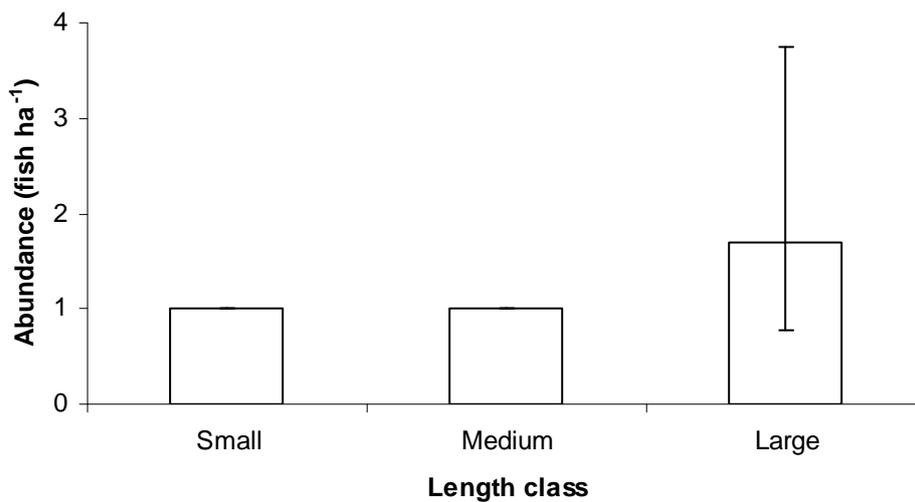


Fig. 2. Abundance estimates (geometric means with 95% confidence limits) by length class for small (length 40 to 99 mm), medium (length 100 to 249 mm) and large (length equal to or greater than 250 mm) fish recorded on 29 July 2009.

Survey date	Species	Abundance (fish ha ⁻¹)			
		Small	Medium	Large	All
29 July 2009	All	1.0 (1.0, 1.0)	1.0 (1.0, 1.0)	1.7 (0.8, 3.8)	1.7 (0.8, 3.8)

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 29 July 2009.

The geometric mean abundance of all sizes of all fish was 1.7 fish ha⁻¹, with lower and upper 95% confidence limits of 0.8 and 3.8 fish ha⁻¹, respectively. These figures converted to an absolute population estimate of 60 individuals, with lower and upper 95% confidence limits of 27 and 132 individuals, respectively.

3.2 Gill-netting survey

A total of 19 fish of three species, i.e. 2 brown trout (*Salmo trutta*) (length range 200 to 288 mm, weight range 106 to 291 g), 1 gwyniad (length 170 mm, weight 58 g) and 16 perch (*Perca fluviatilis*) (length range 116 to 183 mm, weight range 21 to 90 g) was recorded from the inshore, offshore bottom and offshore surface habitats. Brown trout occurred in the inshore and offshore surface habitats, the gwyniad was found in the offshore bottom habitat and all of the perch were restricted to the inshore habitat.

Further examination of the gwyniad (Fig. 3) revealed it to be a female, with maturing ovaries, of age 4 years and thus a member of the 2005 year class. Its condition index was 1.18.

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 9.5 mg L⁻¹ and 14.4 °C at the surface to 7.8 mg L⁻¹ and 7.8 °C at the bottom of the water column (approximate depth 34 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 13 m. Secchi depth was 5.5 m.



Fig. 3. Female gwyniad of length 170 mm, weight 58 g and age 4 years sampled at Llyn Arenig Fawr.

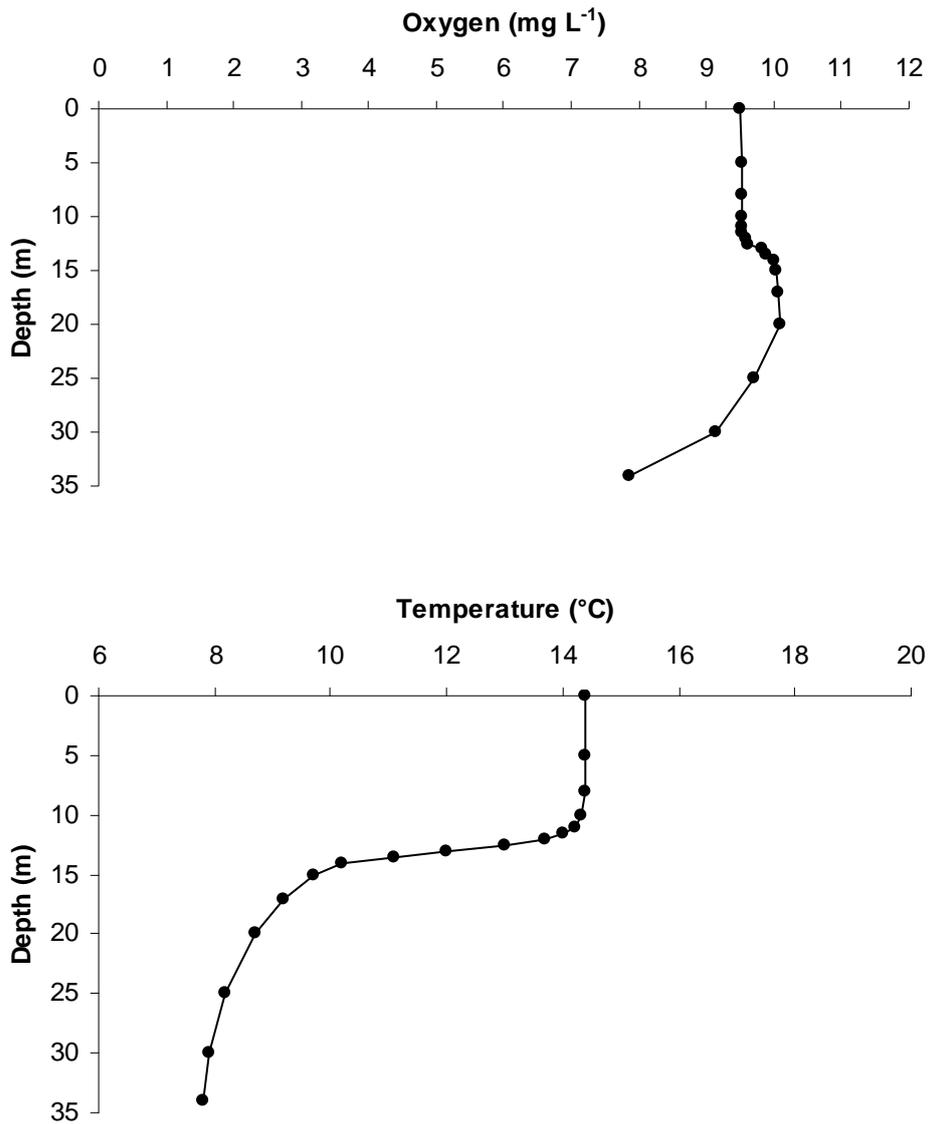


Fig. 4. Oxygen (upper graph) and temperature (lower graph) profiles taken on 29 July 2010.

CHAPTER 4 DISCUSSION

4.1 Introduction

The present survey is the first assessment of the fish populations of Llyn Arenig Fawr to be carried out using quantitative hydroacoustics and survey gill nets. Although an attempt to detect underyearling gwyniad was made in September 2006 by EAW using a restricted range of fine-mesh gill nets as recommended by Winfield & Fletcher (2001), only one brown trout and five perch were captured and this did not constitute a full population assessment. In contrast, the present work was compliant with the field and initial laboratory components of the assessment protocol for native whitefish populations specified by Bean (2003). The findings from the hydroacoustic and gill-netting surveys will be discussed in turn, 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. Finally, recommendations are made for further work.

4.2 Hydroacoustic survey

The observed geometric mean abundance of all sizes of all fish was very low, although it was only just below the range recorded from other upland, oligotrophic U.K. standing water bodies summarised by Winfield *et al.* (in press). Furthermore, as noted 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 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 will 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. 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 anglers' observations and limited gill netting by EAW had previously revealed that brown trout and perch were present in Llyn Arenig Fawr (Gethin Morris, EAW, *pers. comm.*), the present gill-netting observations of these species were not surprising. However, they were notable in that they did not record either species outside the inshore and offshore surface habitats. Consequently, only gwyniad was recorded in the offshore bottom habitat, which is also the only habitat adequately surveyed by the hydroacoustic system used in the present study. If this species-specific pattern of spatial distribution persists, then subsequent hydroacoustic surveys will 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 a gwyniad. Although only a single female was recorded, it was an adult in good condition with a condition index of 1.18 which falls close to and is not statistically significantly different from (t test, $t = 1.28$, $df = 41$, $p > 0.10$) a mean of 1.21 observed for the Llyn Tegid gwyniad population by Winfield *et al.* (2003a). Although its growth manifested as a fork length of 170 mm at age 4 years was statistically significantly lower than the mean fork length of similarly-aged individuals examined by Winfield *et al.* (*op. cit.*) (mean fork length of 217 mm; t test, $t = 11.57$, $df = 4$, $p < 0.001$), this is to be expected given the higher altitude and associated lower temperature and nutrient levels of Llyn Arenig Fawr. The individual's maturing ovaries suggest that it was preparing to spawn in early 2010 and, as its age of 4 years shows that it originated from the first year of translocations, it is likely to belong to the first generation to reproduce in the refuge site.

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), the oxygen (9.5 to 7.8 mg L⁻¹) and temperature (14.4 to 7.8 °C) profiles observed in July 2009 were both within 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 °C. In

addition, the observed Secchi depth of 5.5 m is typical of an upland, oligotrophic standing water body.

Although the pH characteristics of Llyn Arenig Fawr were not within the scope of the present study, relevant data collected since the start of the gwyniad translocation programme in early 2005 have subsequently been obtained from EAW and are presented here as Table 3.

Date	pH	Pass or fail JNCC pH criterion
27 January 2005	4.82	Fail
14 February 2005	5.29	Fail
18 March 2005	5.74	Pass
15 April 2005	5.44	Fail
27 May 2005	6.69	Pass
15 November 2005	5.16	Fail
16 November 2006	6.60	Pass
20 April 2007	5.51	Pass
30 September 2008	5.63	Pass

Table 3. pH values for Llyn Arenig Fawr recorded since the start of the gwyniad translocation programme, together with their pass or failure with respect to the criterion of greater than pH 5.5 required for favourable condition specified by JNCC (2005). Note that measurements were discontinued after 2008.

Some caution must be taken with the interpretation of such a limited and inconsistent time series because pH is likely to show significant seasonal variations, but pH conditions appear to be improving and for the last 3 years they have consistently passed the appropriate criterion for favourable condition specified by JNCC (2005) as also shown in Table 3.

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.

4.5 Recommendations for further work

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 represents the implementation of this recommendation and its timing conforms with the recommendation that it be carried out 4 years after the initial

translocation, i.e. in 2009. Thereafter, Winfield *et al.* (*op. cit.*) recommended that subsequent assessments should be made at 3 year intervals for the first three assessments, with a window of ± 1 year being acceptable, which would schedule the next survey in 2012. 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. Firstly, it is possible that non-destructive fyke netting and/or seine netting (if suitable snag-free areas can be identified) could be used to prove the existence of 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, demonstrate that translocated eggs had survived and matured into reproducing adults, and thus constitute a simple form of monitoring. Secondly, Winfield *et al.* (*op. cit.*) 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. Both of these recommendations are again made here with medium priority.

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APPENDIX 1: DATA ARCHIVE

Data outputs associated with this project are archived as Project No. 258 and Media No. 952. These data outputs include:

- A. The final report in Microsoft Word format.
- B. Echoview data from the laboratory examination and analysis of output from the echo sounder and GPS used in the field. These are in Comma-separated Values (.csv) format with metadata in Microsoft Word format.
- C. Nets data in Microsoft Excel format.
- D. Oxygen and temperature data in Microsoft Excel format.
- E. Recorder data (gill netting and hydroacoustic data) in Excel format with metadata in Microsoft Word format.
- F. Visual acquisition raw data derived from the echo sounder (in .dt4 format).
- G. Metadata for this project is available at: <http://www-library.ccw.gov.uk/olibcgi?session=20937484&infile=details.glu&loid=101834&rs=101055&hitno=3>.

Date: 15th January 2010