Cyfoeth Naturiol Cymru
Natural Resources Wales

Lake Ecological Surveys (Wales) 2013

Goldsmith B, Salgado, J, Bennion, H & Goodrich, S.
ENSIS Ltd, London

NRW Evidence Report No. 28

About Natural Resources Wales

Natural Resources Wales is the organisation responsible for the work carried out by the three former organisations, the Countryside Council for Wales, Environment Agency Wales and Forestry Commission Wales. It is also responsible for some functions previously undertaken by Welsh Government.

Our purpose is to ensure that the natural resources of Wales are sustainably maintained, used and enhanced, now and in the future.

We work for the communities of Wales to protect people and their homes as much as possible from environmental incidents like flooding and pollution. We provide opportunities for people to learn, use and benefit from Wales' natural resources.

We work to support Wales' economy by enabling the sustainable use of natural resources to support jobs and enterprise. We help businesses and developers to understand and consider environmental limits when they make important decisions.

We work to maintain and improve the quality of the environment for everyone and we work towards making the environment and our natural resources more resilient to climate change and other pressures.

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We will realise this vision by:

- Maintaining and developing the technical specialist skills of our staff;
- Securing our data and information;
- Having a well resourced proactive programme of evidence work;
- Continuing to review and add to our evidence to ensure it is fit for the challenges facing us; and
- Communicating our evidence in an open and transparent way.

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- Mae'r rhywogaethau planhigion dyfrol wedi eu rhestr yn yr adroddiad a chyflenwyd canlyniadau cyflawn yr arolwg i Cyfoeth Naturiol Cymru ar ffurf cronfa ddata MS Access.
- Caiff cyfrifiadau eu cyflwyno i'w defnyddio o hyn ymlaen i bennu statws ecolegol y llynnoedd mewn perthynas â'r Gyfarwyddeb Fframwaith Dŵr.
- Mae dadansoddiad diatom o graidd Llyn Goddionduon yn dangos bod y safle wedi asidio dros amser. Mae'r rhesymau dros hyn yn debygol o fod yn ymwneud â choedwigo'r dalgylch a dyddodiad atmosfferig sylffwr a nitrogen.
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Mae canlyniadau'r arolygon planhigion dŵr yn addas at ddibenion asesu cyflwr safle ar gyfer nodweddion merddwr y Gyfarwyddeb Cynefinoedd a statws SoDdGA. Mae mesuriadau metrig y llynnoedd yn berthnasol ar gyfer cynhyrchu cymarebau ansawdd ecolegol y gellir eu defnyddio i ddosbarthu'r llynnoedd, yn unol â gofynion y Gyfarwyddeb Fframwaith Dŵr (2000/60/EC).

Executive Summary

This project set out to collect, process and supply to NRW ecological and environmental data from a network of 16 lake sites across Wales, in support of NRW's integrated monitoring programme for protected sites (SACs and SSSIs), the Water Framework Directive, and other legislative and policy drivers. Using standard methods, lakes were surveyed to assess the species and abundance of aquatic plants growing within and directly around the lake and to measure water clarity, dissolved oxygen and temperature within the lakes. At Llyn Goddionduon a sediment core was collected from deep water and analysed for the fossil remains of diatoms which can be used to infer past environmental conditions and water quality.

- The aquatic plant species are listed within the report and the complete survey results supplied to NRW as an MS Access database.
- Calculations are presented for the onward use of determining the ecological status of the lakes with respect to the Water Framework Directive.
- Diatom analysis from the Llyn Goddionduon core show the site to have become acidified over time. The reasons for this are likely to relate to afforestation of the catchment and atmospheric deposition of sulphur and nitrogen.
- Further work is recommended to enhance the interpretation of the Llyn Goddionduon sediment core.

The results of the aquatic plant surveys are suitable for the purposes of assessing site condition for Habitats Directive standing water features and SSSI status. The lake metrics are applicable for the production of ecological quality ratios from which the lakes may be classified in accordance with the requirements of Water Framework Directive (2000/60/EC).

2. Introduction

2.1. Background

Natural Resources Wales (NRW) is the new organisation that will take on the functions of the Countryside Council for Wales, Forestry Commission Wales and the devolved functions of Environment Agency Wales. These functions include the management and monitoring of the freshwater environment including protected sites designated under UK and European legislation (SSSIs and SACs) and environmental monitoring for the Water Framework and Nitrates Directives.

NRW will bring the management of our natural resources and environment together; it will enable a more integrated approach to achieving Welsh Government's objectives and will have sustainable development at the heart of its operations, delivering results for the people, environment and economy in Wales.

NRW has an agreement with the Environment Agency to use the National Ecosystem Services Framework Contract. This specification has been prepared under the general terms and conditions of this framework.

2.2. Aim of the Report

The aim of the project is to collect, process and supply to NRW ecological and limnological data from a network of 16 lake sites across Wales, in support of NRW's integrated monitoring programme for protected sites (SACs and SSSIs), the Water Framework Directive, and other legislative and policy drivers.

3. Methods

3.1. Sites

The data presented in Table 1 provides details of the 16 lakes included in this report, detailing habitat feature types, WFD typologies and CSM aquatic macrophyte survey dates. All sites were subject to aquatic macrophyte surveys using standard methods (JNCC 2005) and at the same time dissolved oxygen and temperature profiles were undertaken from the deepest point.

Table 1 Details of the lakes included in this report

Lake Name	WBID	LA Area	Protected site	Habitat Type*	WFD Type**
Llyn Cadarn	32792	Anglesey	SAC	HC	HA, S
Llyn yr Wyth-Eidion	32761	Anglesey	SAC	HC	HA, S
Llyn Coron	33337	Anglesey	SAC	NE	HA, V
Llyn Goddionduon	33889	Conwy	SSSI	OML	LA, S
Llyn Anafon	33374	Gwynedd	SAC	OML	LA, S
Gloyw Lyn	35233	Gwynedd	SAC	OML	LA, S
Llyn Cwm Bychan	35180	Gwynedd	SAC	OML	LA, S
Llyn Eiddew-mawr	35056	Gwynedd	SAC	OML	LA, S
Llangorse Lake	40067	Powys	SAC	NE	HA, V
Llyn Mawr	37168	Powys	SSSI	OML (M)	MA, V
Cosmeston Lake	38321	Cardiff	SSSI	HC	HA, V
Llyn Eiddwen	38422	Ceredigion	SSSI	OML (M)	LA, V
Llyn Fanod	38544	Ceredigion	SSSI	OML	LA, S
Upper Talley Lake	39813	Carmarthenshire	SSSI	OML (M)	MA, V
Lower Talley Lake	39796	Carmarthenshire	SSSI	OML (M)	MA, V
Llyn Penrhyn	32968	Anglesey	SSSI	NE	HA, V

* HC = Hard oligo-mesotrophic waters, NE = Naturally eutrophic Waters, OML = Oligo-mesotrophic waters, (M) = Mesotrophic

** HA = High alkalinity, MA = Medium alkalinity, LA = Low alkalinity, S = Shallow (mean depth 3-15 m), V = Very shallow (mean depth < 3 m).

3.2. Aquatic Macrophyte Surveys - JNCC

The full description of the survey methods used to collect macrophyte data are detailed in the Joint Nature Conservation Committee publication for the CSM guidance for standing waters (see JNCC, 2005). In brief, the plant surveys consisted of four components; a strandline survey, emergent and marginal survey, shoreline wader survey and boat survey. These were carried out at each site on four discrete 100m sections of shoreline which were considered representative of the lake and gave good geographical coverage. In order to reduce disturbance, a maximum of 25% of the shoreline was surveyed, resulting in less than four sections being selected at smaller lakes. Where possible, surveying was performed using a bathyscope, but a double-headed rake was used in deeper water or where poor

water clarity restricted visibility. The locations of all survey sections and boat transects were recorded using a Global Positioning System (GPS), backed up with digital photographs where necessary.

These methods were devised to provide quantitative species-abundance data that can be obtained in a pragmatic and repeatable manner. The technique optimises the chance of recording those species most typical of a lake site and detecting marked changes in their frequency. However, they do not aim to produce a complete species list for a lake. Additional efforts such as sampling drift line flora were made to record other species which did not occur in any of the survey sections, but the absence of species expected or known to occur from a particular lake does not necessarily denote absence from the site.

The CSM aquatic macrophyte surveys, upon which the data assessments in this report are based, were carried out between July and September 2013. *In-situ* macrophyte identifications were made by Ben Goldsmith (JNCC accredited and Protected Species Licence holder 33567:OTH:SP:2011) or Jorge Salgado. Voucher specimens were collected for all taxonomically ambiguous species, unless very rare, and identifications confirmed either from fresh materials (usually in the evening of the survey) or at a later date from pressed specimens by Ben Goldsmith. Vouchers of charophytes and *Utricularia* were preserved in alcohol and sent to Nick Stewart for confirmation. Quality control was performed in-house with reference to previously collected herbaria specimens. Botanical nomenclature follows Stace (1997).

All field data were recorded onto standard forms printed onto waterproof paper and transferred onto a Microsoft Access database specifically designed to hold CSM records (Mike Hughes, UCL). Macrophyte data from each site were then transcribed into standard MS Excel spreadsheets designed to calculate values for the following metrics (see Willby *et al*. 2010 and WFD-UKTAG 2009):

- Lake Macrophyte Nutrient Index (LMNI)
- Number of typical taxa for habitat type (NTYP) based on draft CSM guidance (June 2014)
- Number of Functional Groups (NFG)
- Number of Macrophyte Taxa (NTAXA)
- Mean % cover of hydrophytes (COV)
- Relative per cent cover of filamentous algae (ALG)
- Maximum depth of macrophyte colonisation (MAXD)

An additional calculation was made for the relative % cover of non-native species (NNS) recorded; expressed relative to the overall COV score.

3.3. Physico-Chemical Survey

Dissolved oxygen concentration and temperature profiles were taken at the deepest recorded point of each site on the same dates as the macrophyte surveys, using a YSI 550 meter. These data were used to assess oxygen availability within the water. Secchi disc depths were recorded at the time of the macrophyte surveys from the deepest point of all lakes and further measurements were taken at each survey section at sites where variability in water clarity was observed. A standard 20 cm

diameter Secchi plate was used and the Secchi depth (Z_s) expressed in metres. These data are integral with the MS Access database .

3.4. Palaeolimnological data

At one site, Llyn Goddionduon, palaeolimnological were collected to assist with the assessment of current condition. Sedimentary diatom remains are used to reconstruct past and present environmental conditions, providing evidence for change or stability of the lake ecosystems over time. Diatoms are used to estimate changes in total phosphorus (DI-TP) and acidity (DI-pH), and hence to compare the current water quality of the lake with conditions in the past (Battarbee *et al*., 2012; Bennion, H. *et al*. 2004).

A single sediment core was collected using a Renberg gravity corer (Renberg & Hanson 2008). The core was sliced at 1cm intervals and the top, middle and bottom samples retained for the preparation of diatom samples. Samples were prepared in dedicated laboratories at University College London and diatoms identified and enumerated using standard methods (Battarbee 1986). The diatom data were used to infer changes to pH and nutrient status using the Di-pH and Di-TP transfer function models (Bennion *et al*. 2004) and interpreted in the context of the ecological condition of the lake.

4. Survey Results and Metrics.

4.1. Lake metrics

The following table summarises the results of the aquatic macrophyte-derived metrics. A full list of species for each site is given in the tables below

Table 2 Summary of the LEAFPACS lake metrics, typical taxa, non-native species and maximum depth of macrophyte colonisation for the 16 lakes

Site	LMNI	NTAXA	NFG	COV	ALG	NNS	MAXD	NTYP
Llyn Cadarn	6.04	7	5	8.89	0.04	0.00	4.70	1
Llyn yr Wyth-Eidion	5.74	8	6	8.16	0.06	0.00	5.50	0
Cosmeston Lakes	6.93	13	9	8.76	0.59	0.08	4.60	1
Upper Talley Lake	5.90	10	7	7.31	0.12	4.30	2.50	0
Lower Talley Lake	6.81	9	6	6.87	0.26	1.36	1.70	0
Llyn Coron	7.11	17	12	4.11	0.29	0.10	2.30	4
Llyn Goddionduon	3.68	14	9	5.98	0.42	0.00	2.40	5
Llyn Anafon	3.71	17	10	5.03	0.15	0.00	3.60	6
Llyn Penrhyn	6.92	18	10	3.89	0.23	0.24	2.60	4
Llyn Eiddwen	3.55	15	8	4.24	0.15	0.00	2.50	8
Llangorse Lake	6.71	20	10	4.60	0.21	0.98*	3.00	3
Llyn Fanod	4.35	16	10	4.57	0.16	0.00	3.80	6
Llyn Cwm Bychan	3.51	14	8	4.11	0.16	0.00	4.90	8
Llyn Eiddew-mawr	2.97	12	7	5.25	0.20	0.00	4.20	6
Llyn Mawr	4.48	12	8	4.16	0.34	0.00	1.30	2
Gloyw Lyn	3.79	6	3	7.20	0.27	0.00	2.20	3

* This value increases to 1.11 if including *Nympoides peltata* which is not native to Wales

Table 3 Summary of all aquatic and emergent macrophyte species for the 16 lakes. Figures represent per cent frequency at a site; typical species are shaded green and NNS / locally absent species in orange

	Llyn Cadarn	Llyn yr Wyth-Eidion	Cosmeston Lakes	Upper Talley Lake	Lower Talley Lake	Llyn Coron	Llyn Goddionduon	Llyn Anafon	Llyn Penrhyn	Llyn Eiddwen	Llangorse Lake	Llyn Fanod	Llyn Cwm Bychan	Llyn Eiddew-mawr	Llyn Mawr	Gloyw Lyn
Alisma plantago-aquatica			2	2							2					
Bolboschoenus maritimus			7													
Butomus umbellatus											3					
Callitriche brutia				4	29											
Callitriche hamulata								49						4	6	
Callitriche sp.									3							
Callitriche truncata						2										

	Llyn Cadarn	Llyn yr Wyth-Eidion	Cosmeston Lakes	Upper Talley Lake	Lower Talley Lake	Llyn Coron	Llyn Goddionduon	Llyn Anafon	Llyn Penrhyn	Llyn Eiddwen	Llangorse Lake	Llyn Fanod	Llyn Cwm Bychan	Llyn Eiddew-mawr	Llyn Mawr	Gloyw Lyn
Carex rostrata	1			32	29		16		2	6		8	7		22	15
Ceratophyllum demersum			24						39		13					
Chara contraria			46													
Chara globularis						61			28		5					
Chara rudis	2															
Chara virgata								10	4							
Cladium mariscus	10	5														
Elatine hexandra						2				2		17				
Elatine hydropiper						14			10							
Eleocharis acicularis						7										
Eleocharis palustris			4	4			10		3	1		14			1	
Eleocharis palustris				4												
Eleogiton fluitans							8						19			
Elodea canadensis			1	93	64	7			23		16					
Elodea nuttallii			11								77					
Equisetum fluviatile				31	40		3			3		8	33		1	29
Fontinalis antipyretica	90	99													29	
Glyceria fluitans												1				
Hippuris vulgaris		31														
Iris pseudacorus			1			4			5							
Isoetes echinospora													27			
Isoetes lacustris							20	18		25		46	26	54	4	44
Juncus bulbosus							14	73					54	23		
Lemna minor			3	8	56	1			9							
Lemna trisulca	37					3			38		68					
Littorella uniflora							39	47		46		42	41	48	42	63
Liverworts aquatic														21		
Lobelia dortmanna							64	10		66		47	53	55		48
Luronium natans										14			18			
Menyanthes trifoliata	5			9			15		2	7	1	2	1		4	2
Myriophyllum alterniflorum							28	8					33	30	22	
Myriophyllum spicatum			5			13					30					
Nitella flexilis s.s.												22				
Nitella translucens										43		30				
Nitellopsis obtusa			7													
Nuphar lutea	52	78		13	14				4		60	20			32	
Nymphaea alba	7	31		11	27		11		5		13	13				
Nymphoides peltata											23					
Persicaria amphibia			29			1			10		1					
Phragmites australis	44	5	9				12		39		47		6			
Potamogeton alpinus								2								
Potamogeton alpinus × *praelongus* = *P.* × *grithiffii*								13								
Potamogeton berchtoldii								2		21			8			

	Llyn Cadarn	Llyn yr Wyth-Eidion	Cosmeston Lakes	Upper Talley Lake	Lower Talley Lake	Llyn Coron	Llyn Goddionduon	Llyn Anafon	Llyn Penrhyn	Llyn Eiddwen	Llangorse Lake	Llyn Fanod	Llyn Cwm Bychan	Llyn Eiddew-mawr	Llyn Mawr	Gloyw Lyn
Potamogeton crispus			2		7											
Potamogeton lucens											20					
Potamogeton natans				7			18			3		8			7	
Potamogeton natans × *polygonifolius*								6								
Potamogeton obtusifolius				11	31										21	
Potamogeton pectinatus			55			21			18		10					
Potamogeton perfoliatus						3			7		5					
Potamogeton polygonifolius							3							1		
Potamogeton pusillus		18	16		11	15			50		2					
Ranunculus aquatilis agg.			2			2		5								
Ranunculus circinatus						42										
Ranunculus lingua											1					
Schoenoplectus lacustris	30	4	7			4	29		29		8		7			
Schoenoplectus tabernaemontani						3										
Sparganium angustifolium							4	18		15			14	5		
Sparganium erectum				14					4		15					
Sparganium natans		9														
Sphagnums aquatic							6	2					35	26		
Spirodela polyrhiza											55					
Subularia aquatica								17		24		63				
Typha angustifolia	42		4								38					
Typha latifolia			15	7	36				8		1			3		
Utricularia intermedia agg.														3		
Utricularia minor								7				2		21		
Utricularia vulgaris agg.													27			
Zannichellia palustris						12			2							

4.2. Llyn Goddionduon - Palaeolimnological evidence

A 26 cm sediment core (COCH2) was taken from the deep point (3.5 m) at SH7534558662 using a Renberg gravity corer. The core was sliced at 1 cm intervals in the field and levels 0-1 cm, 13-14 cm and 25-26 cm retained for diatom analysis, the common species are presented in Table 4.

Table 4 Summary diatom results from Core GODD1 show all species > 2% abundance

TaxonName	0-1 cm	13-14 cm	25-26 cm
Fragilaria exigua	20.7	11.1	0.8
Cyclotella distinguenda var. *unipunctata*	4.0	6.5	18.9
Cyclotella aff. *comensis*	8.7	14.7	14.3
Aulacoseira ambigua	2.7	2.8	10.9
Brachysira vitrea	7.4	8.8	4.6
Cyclotella radiosa	0.7	5.5	7.6
Cymbella cesatii	0.7	6.9	0.8
Achnanthes minutissima	6.7	5.5	3.4
Aulacoseira subarctica	0.3	4.1	6.3
Fragilaria elliptica	3.0	5.5	0.4
Navicula difficillima	0.3	5.5	4.6
Fragilaria construens var. *venter*	4.3	0.5	0
Denticula tenuis	4.0	0.9	0
Fragilaria pinnata	4.0	0.9	2.5
Cymbella microcephala	3.0	1.4	0.8
Cymbella gracilis	2.7	0.9	2.1
Brachysira brebissonii	2.3	0	0
Frustulia rhomboides var. *saxonica*	2.3	0.5	0
Nitzschia perminuta	2.3	0.5	0
Tabellaria [*flocculosa* (short)]	1.3	2.3	0.4
Sellaphora pupula	0	0.9	2.1

The diatom flora of the surface sediment was dominated by benthic taxa, consistent with the lake being shallow and having clear water. *Fragilara exigua* (20.7%) is typical of slightly acid lakes with extensive benthic habitats. The middle and lower samples had higher abundance of planktonic *Cyclotella* species and *Aulacoseira distans* was recorded at 10.9 % in the basal sample. Analysis of the data using squared chord distance (SCD) show a similar change in the species composition between the bottom sample and the middle sample and the middle sample and top sample. The SCD between bottom and upper sample of 0.95 is relatively high and demonstrates a considerable shift in the species assemblage over the full length of the core (Table 5).

Table 5 Results of Llyn Goddionduon overview sediment core analysis

Sample Code	Depth (cm)	Sum of species in modern data (pH)	DI-pH	Sum of species in modern data (TP)	DI-TP	SCD dissimilarity score between the 3 core samples
GODD1-00	0-1	97	**6.5**	90	**8.0**	0.95
GODD1-13	13-14	95	**6.7**	78	**8.1**	0.53
GODD1-25	25-26	93	**7.0**	82	**10.6**	0.00

Reconstructions of diatom-inferred pH (DI-pH) were produced using the SWAP training set (RMSEP = 0.32 pH units). A high percentage of the taxa in the fossil samples were present in the SWAP training set and there were no major analogue problems. The DI-pH results suggest the site has become slightly more acid over the time period covered by the core. There are no current pH data available for comparison, but two separate samples taken by ENSIS in 1996 (February and July) measured the pH as 6.33 and 6.62 which is in good accordance with the surface and mid sample sediment DI-pH. The impact of the surrounding conifer forestry plantation is a potential driver of acidification alongside longer term acid deposition from atmospheric sulphur and nitrogen. Sediment dating and higher resolution diatom work would be required to determine the cause of acidification at Llyn Goddionduon.

Reconstructions of diatom-inferred TP (DI-TP) are inconclusive and show very little change between the three samples (Table 5). The percentage of fossil diatoms from the middle and bottom samples was slightly low and thus a number of analogues were missing from the NW European training reducing confidence in the model results.

In summary, there appears to have been a gradual but significant floristic change in the fossil diatoms from the Llyn Goddionduon sediment core. While the fossil diatoms infer there to have been a slight acidification at the site it remains unclear if this is related to atmospheric deposition or catchment processes associated with afforestation, or both. High resolution diatom analysis of a dated sediment core would be beneficial to understanding the impact of atmospheric deposition over the past 150 years and of the forestry on the lake water quality in the last few decades. The modeling of DI-TP at the site is not a suitable method to assess nutrient changes within the site.

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6. Appendices

6.1. Data Archive Appendix

Data outputs associated with this project are archived as project 451, media 1493, metadata number 115704 on server–based storage at Natural Resources Wales. A working copy is held at H:\Science\MFSG\Fresh Water Science\ENSIS Lake Survey Data\

The data archive contains:

[A] The final report in Microsoft Word and Adobe PDF formats, named Lake Ecological Surveys 2013.doc and Lake Ecological Surveys 2013.pdf respectively.

[B] A database named sca_database_v2.1_NRW2013 in Microsoft Access 2000 format with metadata described in a Microsoft Word document “NRW Macrophyte DB 2013 ReadMe.doc”

[C] A full set of images produced in [jpg] format

[D] Leafpacs data spreadsheets in xls format (derived data using environment Agency methods to calculate metrics for water quality)

[E] Water Chemistry data in xls fomat - BAP Lakes Chemistry 2013.xls

Metadata for this project is publicly accessible through Natural Resources Wales’ Library Catalogue http://194.83.155.90/olibcgi by searching ‘Dataset Titles’. The metadata is held as record no 115704

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