DOLMANT

Development of targeted ecological modelling tools for lake management

2014

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Summary findings and recommendations 2014

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Report context

This summary report outlines the findings and recommendations which are the culmination of the research conducted through the EU INTERREG IVA funded DOLMANT project. This report was presented at the DOLMANT Closure Event on the 17th September 2014. The more detailed Volume 1: DOLMANT Technical Report, contains further background, results and discussion.

Introduction

The aim of the DOLMANT project (2011 – 2014) was to produce practical management tools to help managers achieve ecological targets for lakes and it is these tools, constructed from lake models, which can assist in the development of a programme of catchment management. The project focused specifically on developing tools in: Lough Neagh, Lough Erne and a set of synoptic lakes which represented lakes in the cross border INTERREG region.

During the previous two decades there has been a monumental shift in the way freshwater resources have been managed on the island of Ireland. Previously, lake management focused almost exclusively on chemical water quality. There is now recognition that sustainable use of freshwater is possible only through the protection of biological integrity. The biological integrity of a lake is related to its ecological quality.

The European Water Framework Directive (WFD) was adopted in 2000, requiring member states to "protect, enhance and restore all surface waters ... with the aim of achieving good surface water status (by 2015)" (European Commission, 2000). The WFD established a new, integrated approach to the protection, improvement and sustainable use of European waters. It outlined how European waters were to be managed on the basis of natural geographical areas, River Basin Districts (RBDs), with a management plan for each district. According to the WFD, Ireland is divided into eight districts and those which cross the border between Northern Ireland and the Republic of Ireland are referred to as International River Basin Districts (IRBDs). The DOLMANT study lakes were located across many of the RBDs shown in Figure 1. The lakes included Lough Neagh and Lower Lough Erne, located in the Neagh-Bann IRBD and North-Western IRBD respectively. A series of smaller lakes, representative of the region, distributed throughout the Western RBD, North-Western RBD, Neagh-Bann IRBD and North-Eastern RBD were also included.

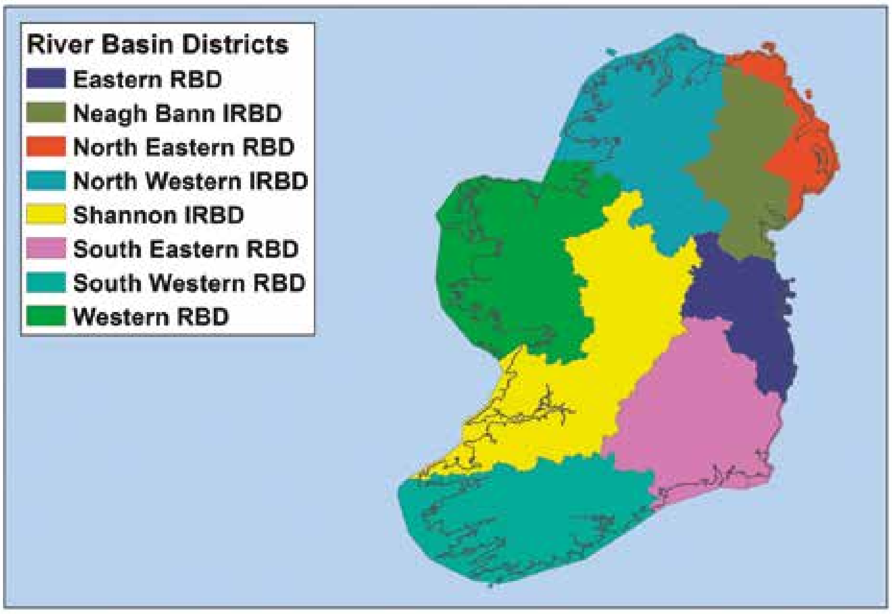


Figure 1 River Basin Districts on the island of Ireland (EPA, 2005)

Previously, there has been no attempt to integrate all the major biological elements of lakes with water chemistry, hydromorphology and catchment properties in the cross border region. Only a limited number of similar studies have been conducted further afield. This integration; especially of biological elements such as zooplankton - central to biotic processes in lakes, is essential to allow the development of tools that can be used for lake management purposes. To date, each biological element has been considered separately, particularly when developing lake management metrics. The DOLMANT project investigated interactions between biological groups, lake water chemistry and catchment characteristics and described these relationships using statistical models that in future can be used as predictive tools. These tools can be used to help manage lake ecosystems. Although zooplankton monitoring and status is not a reporting requirement of the WFD, they are an important part of the food web as they link the trophic levels of phytoplankton, macro-invertebrates and fish.

Lough Eske

Model Development

The DOLMANT lake catchments were analysed in order to characterise landuse and quantify the loading of nutrients to the lakes and apportion their sources. This nutrient (nitrogen and phosphorus) data together with information relating to other catchment characteristics were used to inform the lake ecology models that were subsequently developed. In the catchment characterisation study, information was used from sources such as high resolution agricultural censuses, population censuses, building directories, landcover maps and soil maps to derive a series of metrics. The information was used in two ways:

1. To derive metrics that helped calculate the loading of nutrients to each lake;
2. To apportion the sources of the nutrients.

The influence of these nutrient data on lake ecology was investigated. In the case of the relatively large Lough Neagh and Erne catchments, values for the metrics were also calculated for the main subcatchments. New data were collected for hydromorphological, topographical and climatic variables where necessary. For the first time a cross-border digital elevation model was created for Northern Ireland and the Republic of Ireland allowing detailed catchment characterisation to occur across the INTERREG region.

Nitrogen and phosphorus loading from the catchments

Due to the availability of agricultural census data and human population data the following years were selected for detailed study regarding landuse and nutrient source apportionment.

- Lough Neagh and Erne: 2003, 2005, 2008, 2010
- Lakes of the synoptic survey: 2010

A geographic information system (GIS) was used to join data from Northern Ireland and the Republic of Ireland and calculate data on landuse. Subsequently, several approaches were used to calculate nutrient loadings to the study lakes depending on information availability. At least two methods were used in each catchment for quality control purposes. Use of mass balance models allowed detailed apportionment of nutrient sources for all of the study lake catchments. Export coefficients were used (2010 data) as a quality control measure. Weekly river water chemistry monitoring allowed the use of an interpolation method for calculation of Lough Neagh nutrient loading. This means that both mean nutrient concentration and river flow data were integrated to produce a loading estimate. The major sources of nutrients in the catchments are shown in Tables 1 to 5.

Table 1 Sources of phosphorus and nitrogen in the synoptic lake catchments

Lake	Area (ha)	Sewer (kg N ha^{-1} yr^{-1})	Septic Tank (kg N ha^{-1} yr^{-1})	Excreta (kg N ha^{-1} yr^{-1})	Fertiliser (kg N ha^{-1} yr^{-1})	Sewer (kg P ha^{-1} yr^{-1})	Septic Tank (kg P ha^{-1} yr^{-1})	Excreta (kg P ha^{-1} yr^{-1})	Fertiliser (kg P ha^{-1} yr^{-1})
Akibbon	755	0.00	0.46	76.86	65.32	0.00	0.08	11.83	6.08
an tSeisigh	100	0.00	0.33	1.19	1.01	0.00	0.06	0.19	0.09
Anure	3683	0.00	0.33	7.90	6.71	0.00	0.06	1.12	0.62
Auva	193	0.00	0.00	0.56	0.48	0.00	0.00	0.07	0.04
Ballydugan	886	0.00	0.68	107.24	91.14	0.00	0.12	19.56	8.48
Ballysaggart	66	7.40	1.83	59.86	50.87	2.32	0.33	10.92	4.73
Barra	1940	0.00	0.01	17.86	15.18	0.00	0.00	2.53	1.41
Bawn	665	1.23	0.90	16.67	14.17	0.39	0.16	3.01	1.32
Begny	195	0.00	1.21	100.17	85.13	0.00	0.22	18.27	7.92
Bunerky	572	0.00	0.37	4.63	3.94	0.00	0.07	0.84	0.37
Cashel Upper	105	0.00	1.00	40.81	34.69	0.00	0.18	7.45	3.23
Castlewellan	238	0.00	0.02	47.12	40.05	0.00	0.00	8.60	3.73
Corglass	1594	0.00	0.42	34.83	29.60	0.00	0.08	6.21	2.75
Cowey	388	0.00	0.54	68.67	58.36	0.00	0.10	12.53	5.43
Derg	3493	0.00	0.01	3.46	2.94	0.00	0.00	0.50	0.27
Drumgay	77	2.13	0.64	80.69	68.58	0.67	0.11	14.72	6.38
Dunglow	3776	0.71	0.22	7.24	6.15	0.22	0.04	1.03	0.57
Easky	1068	0.00	0.01	4.22	3.59	0.00	0.00	0.62	0.33
Egish	716	0.00	0.61	71.50	60.76	0.00	0.11	13.28	5.65
Eske	8011	0.00	0.26	10.82	9.20	0.00	0.05	1.60	0.86
Fad	62	0.00	0.00	0.48	0.40	0.00	0.00	0.07	0.04
Finnebrogue	673	0.06	1.05	42.97	36.52	0.02	0.19	7.84	3.40
Formal	139	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gartan	7738	0.00	0.15	11.58	9.84	0.00	0.03	1.74	0.92
Gill	36306	0.10	0.42	28.49	24.22	0.03	0.07	4.43	2.25
Glen	12430	0.00	0.12	10.95	9.31	0.00	0.02	1.65	0.87
Glencar	3847	0.00	0.16	48.70	41.39	0.00	0.03	6.76	3.85
Golagh	466	0.00	0.08	7.22	6.14	0.00	0.01	1.25	0.57
Jenkin	27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Keel	256	0.00	0.30	6.91	5.88	0.00	0.05	1.15	0.55
Kiltooris	546	0.00	0.26	2.25	1.91	0.00	0.05	0.40	0.18
Kilturk	1116	0.02	0.64	47.81	40.63	0.01	0.11	8.72	3.78
Kindrum	428	0.00	0.66	3.04	2.58	0.00	0.12	0.51	0.24

Table 1 Sources of phosphorus and nitrogen in the synoptic lake catchments (cont'd)

Lake	Area (ha)	Sewer (kg N ha^{-1} yr^{-1})	Septic Tank (kg N ha^{-1} yr^{-1})	Excreta (kg N ha^{-1} yr^{-1})	Fertiliser (kg N ha^{-1} yr^{-1})	Sewer (kg P ha^{-1} yr^{-1})	Septic Tank (kg P ha^{-1} yr^{-1})	Excreta (kg P ha^{-1} yr^{-1})	Fertiliser (kg P ha^{-1} yr^{-1})
Lattone	688	0.00	0.36	18.33	15.58	0.00	0.06	3.19	1.45
Lee	80	0.00	0.00	41.94	35.63	0.00	0.00	7.28	3.31
Legane	54	0.00	0.00	179.67	152.70	0.00	0.00	32.78	14.20
MacNean Lower	18631	0.07	0.32	18.30	15.55	0.02	0.06	2.91	1.45
Madral	46	0.00	0.12	6.19	5.25	0.00	0.02	1.07	0.49
Martray	56	0.00	0.49	56.33	47.87	0.00	0.09	10.28	4.45
Mourne	498	0.00	0.67	69.08	58.71	0.00	0.12	12.60	5.46
Muckno	16131	0.41	0.76	109.04	92.67	0.13	0.14	20.06	8.62
Nadarra	13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nalughoge	24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nasnahida	204	0.00	0.00	0.30	0.25	0.00	0.00	0.03	0.02
Scolban	1356	0.11	0.36	9.50	8.07	0.04	0.06	1.73	0.75
Screeby	36	0.00	1.21	63.42	53.89	0.00	0.22	11.57	5.01
Templehouse	27467	0.09	0.43	38.71	32.90	0.03	0.08	7.07	3.06
Vearty	212	0.00	0.05	3.40	2.89	0.00	0.01	0.59	0.27
White	12315	0.06	0.79	123.97	105.36	0.02	0.14	22.85	9.80

Mass balance models were used to determine the major sources of phosphorus and nitrogen to the lakes. Models were produced for the overall catchment of Loughs Neagh and Erne as well as the main subcatchments. Nutrient loading and source apportionment for the subcatchments are detailed in Volume 1: DOLMANT Technical Report.

Nutrient loading as a result of fertiliser use in the Lough Neagh and Erne catchment has decreased between 2003 and 2010. Excreta sourced loading has shown a similar trend. Loadings from domestic sources have shown a larger increase in the Lough Neagh catchment compared to that of Lough Erne. Tables 2 to 5 show major catchment sources used in the mass balance model.

Table 2 Nitrogen loading and sources in the Lough Neagh catchment (t N yr^{-1}) 2003-2010.

Year	Total N loading (t N yr^{-1})	Sewer (t N yr^{-1})	Septic Tank (t N yr^{-1})	Excreta (t N yr^{-1})	Fertiliser (t N yr^{-1})
2003	7,581	302	277	42,950	38,558
2005	6,905	721	306	41,922	32,330
2008	6,156	752	330	41,560	24,803
2010	6,646	763	394	35,839	30,459

Table 3 Phosphorus loading and sources in the Lough Neagh catchment (t P yr $^{-1}$) 2003-2010.

Year	Total P loading (t P yr $^{-1}$)	Sewer (t P yr $^{-1}$)	Septic Tank (t P yr $^{-1}$)	Excreta (t P yr $^{-1}$)	Fertiliser (t P yr $^{-1}$)
2003	485	223	54	7,835	3,377
2005	481	226	55	7,647	2,460
2008	483	236	59	7,581	880
2010	485	239	58	6,408	1,237

Table 4 Nitrogen loading and sources in the Lough Erne catchment (t N yr $^{-1}$) 2003-2010.

Year	Total N loading (t N yr $^{-1}$)	Sewer (t N yr $^{-1}$)	Septic Tank (t N yr $^{-1}$)	Excreta (t Nyr $^{-1}$)	Fertiliser (t N yr $^{-1}$)
2003	4,836	114	210	26,220	27,290
2005	4,512	117	217	28,230	23,510
2008	3,980	121	224	27,347	18,619
2010	4,282	122	235	26,297	21,682

Table 5 Phosphorus loading and sources in the Lough Erne catchment (t N yr $^{-1}$) 2003-2010

Year	Total P loading (t P yr $^{-1}$)	Sewer (t P yr $^{-1}$)	Septic Tank (t P yr $^{-1}$)	Excreta (t P yr $^{-1}$)	Fertiliser (t P yr $^{-1}$)
2003	245	36	38	4,788	2,390
2005	245	37	39	5,154	1,881
2008	238	38	40	4,995	659
2010	240	38	40	4,659	880

Figure 2 shows the loading of nitrogen and phosphorus from the entire Neagh catchment to the lake from 1984 to 2009 as calculated by an interpolation method. Figure 3 shows loadings for the Lough Erne catchment 1972 to 2012. In recent years nutrient loading to the Loughs have decreased.

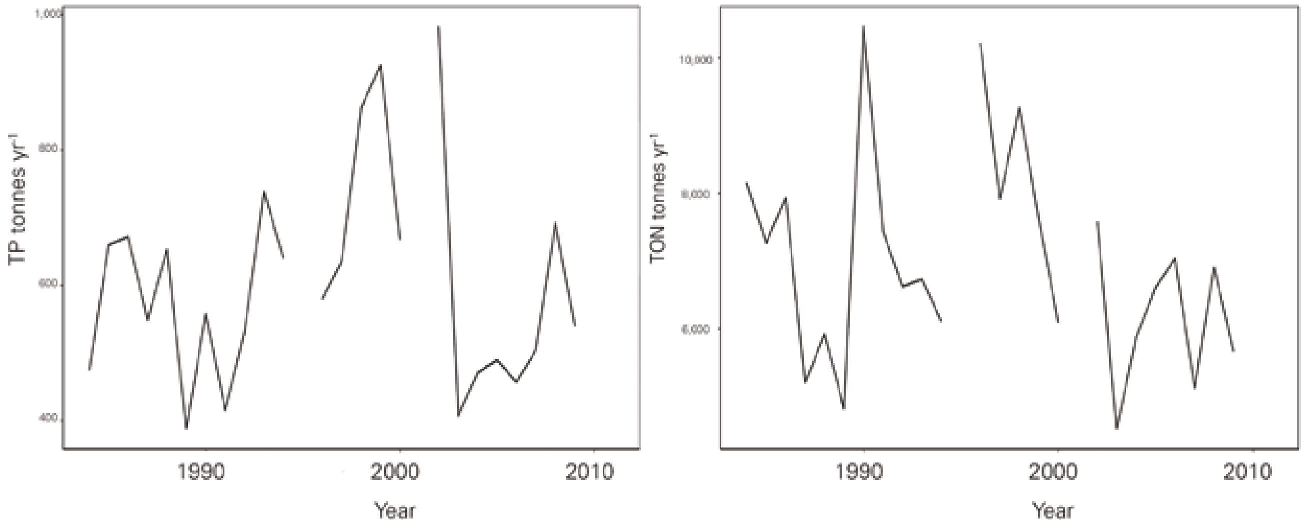


Figure 2 Total oxidised nitrogen and total phosphorus loading to Lough Neagh 1984 - 2009

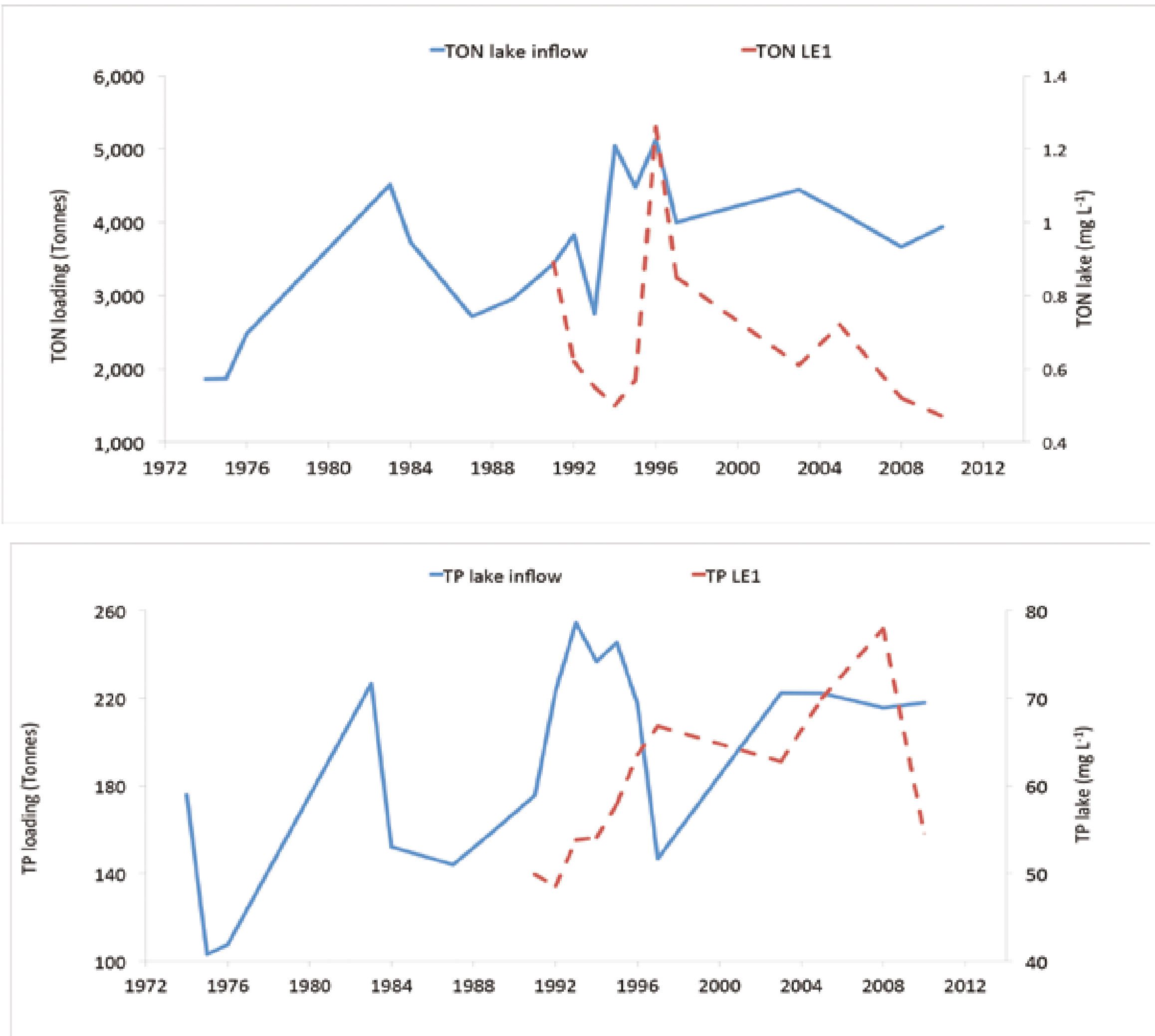


Figure 3 Total oxidised nitrogen (top) and total phosphorus (bottom) loading to Lough Erne 1972 to 2012 (with information from Zhou, et al. 2000). Dashed line is lake nutrient concentration.

Development of management tools for the synoptic lakes

The DOLMANT project included the investigation of lakes located across the northern part of the island (INTERREG region). The lakes were selected to best represent the range of lake characteristics found in the region with a range of nutrient status and catchment landuse. Detailed information on lake catchment landuse, lake biology and lake water chemistry was collected for lakes (Figure 4). Information for additional lakes was incorporated where possible. The biological elements were fish, macrophytes, phytoplankton and zooplankton. The lake water characteristics included nutrient concentrations, chlorophyll, colour and alkalinity. The aim of the work was to produce management tools for lakes in the region. These tools incorporate information on catchment pressures. The catchment characterisation study identified the specific characteristics of the surrounding land using data from 2010.

Fish stock survey for DOLMANT

Fifty lakes that covered the range of key lake characteristics such as size, water depth, alkalinity and nutrient concentration were included in this work. They were visited in spring, summer and autumn and samples taken and surveys completed during 2012 and 2013. In comparison to what is usually included in this type of investigation, a particularly wide range of properties were measured, in particular, the species and abundance of phytoplankton, macrophytes, zooplankton and fish, as well as the more usual lake water properties.

Figure 4 The location of the DOLMANT synoptic lakes.

An extensive analysis of the results was completed and a very wide range of statistical methods used. As well as the usual relationships between chlorophyll *a* and nutrient concentration, including the effect of water colour, food web effects were assessed, in particular, grazing of phytoplankton by zooplankton and predation of zooplankton by fish.

The key finding of the synoptic lake study was that lakes in the landscape fall into four groups which are determined by their biological and chemical characteristics and this provides a framework for managing them.

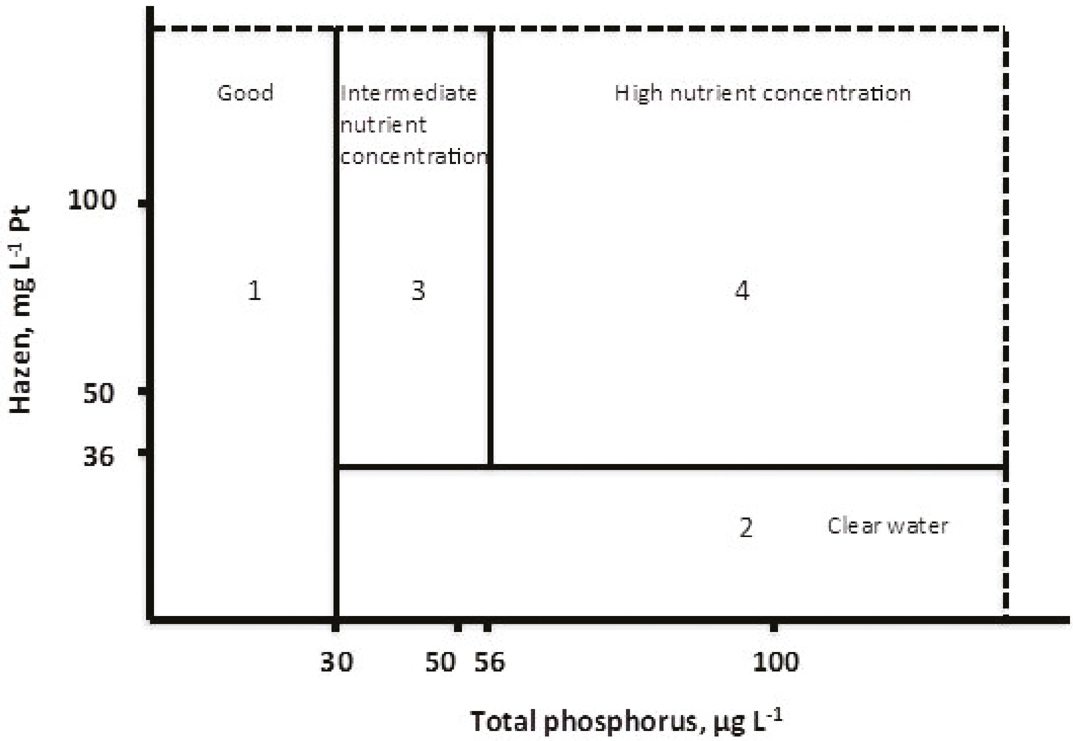


Figure 5 Framework for synoptic lakes

The framework for the synoptic lakes is outlined in Figure 5 and shows how the biological and chemical characteristics of the lakes fall into four groups: Group 1 contains good quality lakes with a total phosphorus concentration less than 30 µg L^{-1}; Group 2 contains higher phosphorus concentration, clear water lakes, with a Hazen less than 36 mg L^{-1} Pt; Group 3 contains coloured water lakes with a phosphorus concentration between 30 and 56 µg L^{-1}; Group 4 are coloured water lakes with a phosphorus concentration greater than 56 µg L^{-1}.

Group 1 lakes are of high quality and could be taken to represent Good Ecological Status; if so, then their characteristics are shown in the Table 6.

Table 6 The key characteristics of Group 1 lakes. These lakes have an annual mean total phosphorus concentration of less than 30 µg L^{-1}. IE lake phytoplankton index and IE lake phytoplankton Cryptomonas submetric are the most important metrics for lake phytoplankton and the Free Macrophyte Index and Plant Trophic Score are the most important for lake macrophytes.

	Mean	Standard error	10 %-ile	90 %-ile	n
Total phosphorus, µg L^{-1}	17	6.5	7.0	27	52
Hazen, mg L^{-1} Pt	90	12	31	180	52
Chlorophyll *a*, µg L^{-1}	4.2	0.26	2.1	6.6	52
IE lake phytoplankton index	0.817	0.027	0.612	0.980	29
IE lake phytoplankton Cryptomonas submetric	0.973	0.012	0.900	1.000	26
Free Macrophyte Index	0.603	0.018	0.476	0.722	28
Plant Trophic Score	0.929	0.027	0.770	1.000	28

The characteristics of Group 1 lakes could be taken as the target for all lakes in the region.
Group 3 and 4 lakes represent the progressive deterioration of lake quality as a result of increasing nutrient concentration, especially from phosphorus, and so they represent the change to Moderate and then Good and Poor Ecological Status. While Group 3 and 4 lakes have different total phosphorus and chlorophyll *a* concentrations, there are no differences in their biological characteristics, except for the fish community. The deterioration in quality is general and gradual.

The identification of Group 2 lakes, clear water with total phosphorus concentrations 30 µg L^{-1} or greater, is new and the implications of this need further consideration. While their phosphorus concentrations are similar to Group 3 and 4 lakes, their biological communities are not different to the lower nutrient concentration, Group 3 lakes; the only exception is the summer-autumn phytoplankton community. Overall, these nutrient-enriched clear water lakes are the most biologically productive and the implications of this for remediation needs further consideration.

Recommendations for synoptic lake management

- It is recommended that the biological and chemical characteristics of the Group 1 lakes are taken to represent Good Ecological Status for the many lakes in the Irish landscape and that impacted lakes are assigned to Group 2, 3 or 4 in order to establish the starting point of a trajectory of management to achieve Good Status.
- It is also recommended that biological and chemical information from other lakes is collated and included in an expanded analysis so that the precision of the characterization of the four lake groups is improved.
- The final recommendation is that the distinction between clear and coloured water nutrient-enriched lakes, between Group 2 and Group 3 and 4 lakes, be considered further, as there may be implications for remediation or timescales for improvement.

Final check equipment for DOLMANT synoptic lake surveys

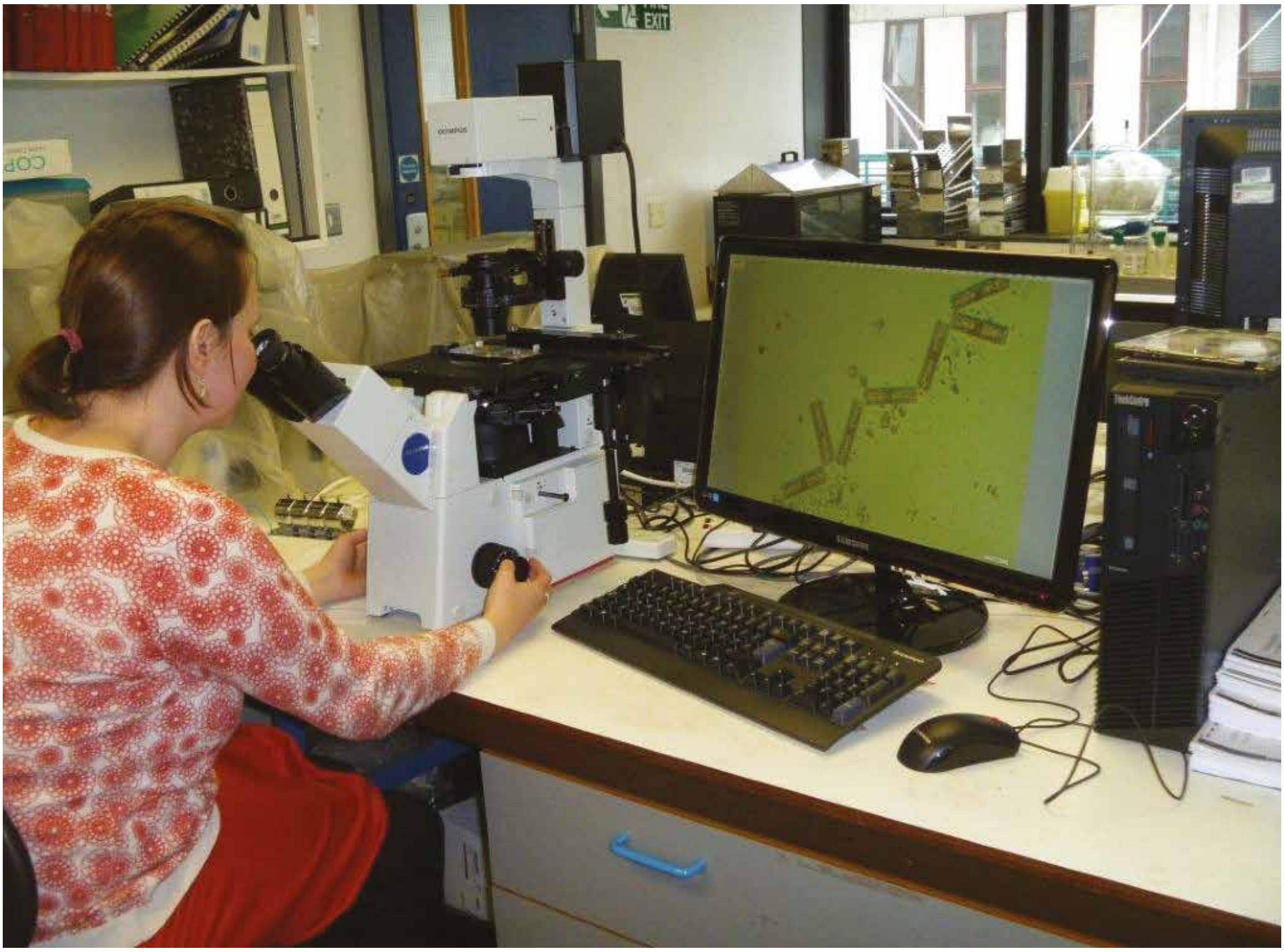
Development of management tools for Lough Neagh

Lough Neagh is the largest freshwater lake in Ireland with a total surface area of 383km^2. The lough was designated as a Ramsar site in 1976, an area of scientific interest (ASSI) in 1993 and a Special Protection Area (SPA) in 1996. The Lough is currently classified as a heavily modified water body for WFD purposes due to water level regulation within the Lough.

In order to produce management tools for Lough Neagh the project collated existing biological and water chemistry data as well as collecting new data on phytoplankton, zooplankton and fish. This information was related to catchment characteristics that were defined using GIS in order to describe the ecology of the Lough and predict future changes based on biology and nutrient data.

Both the phytoplankton and zooplankton communities have shown marked changes over the study period. There has been a decline in three of the main phytoplankton species particularly in the biomass of blue-green algae during the summer bloom. The main findings were:

- Chlorophyll *a*, a metric of phytoplankton biomass, has decreased in the Lough
- In the last decade zooplankton numbers have increased significantly in spring and summer
- Water temperature in the spring and summer months had a positive relationship with zooplankton numbers



Laboratory analysis of lake samples

Figure 6 describes chlorophyll *a* in the lake in June; the model explained a large amount (63%) of the variance. Although summer phosphorus levels in Lough Neagh have remained high there has been a significant decline in chlorophyll *a*. This means that phytoplankton are not using all of the available phosphorus. Total oxidised nitrogen levels are decreasing in the lough contributing to longer periods of potential nitrogen limitation. The model also showed that zooplankton grazing had a negative relationship with the phytoplankton biomass within the lough. According to the model, water temperature had an influence on zooplankton numbers, this, combined with nitrogen limitation, may be contributing to the observed decline in summer phytoplankton biomass. Details of model development are available in Volume1: DOLMANT Technical Report.

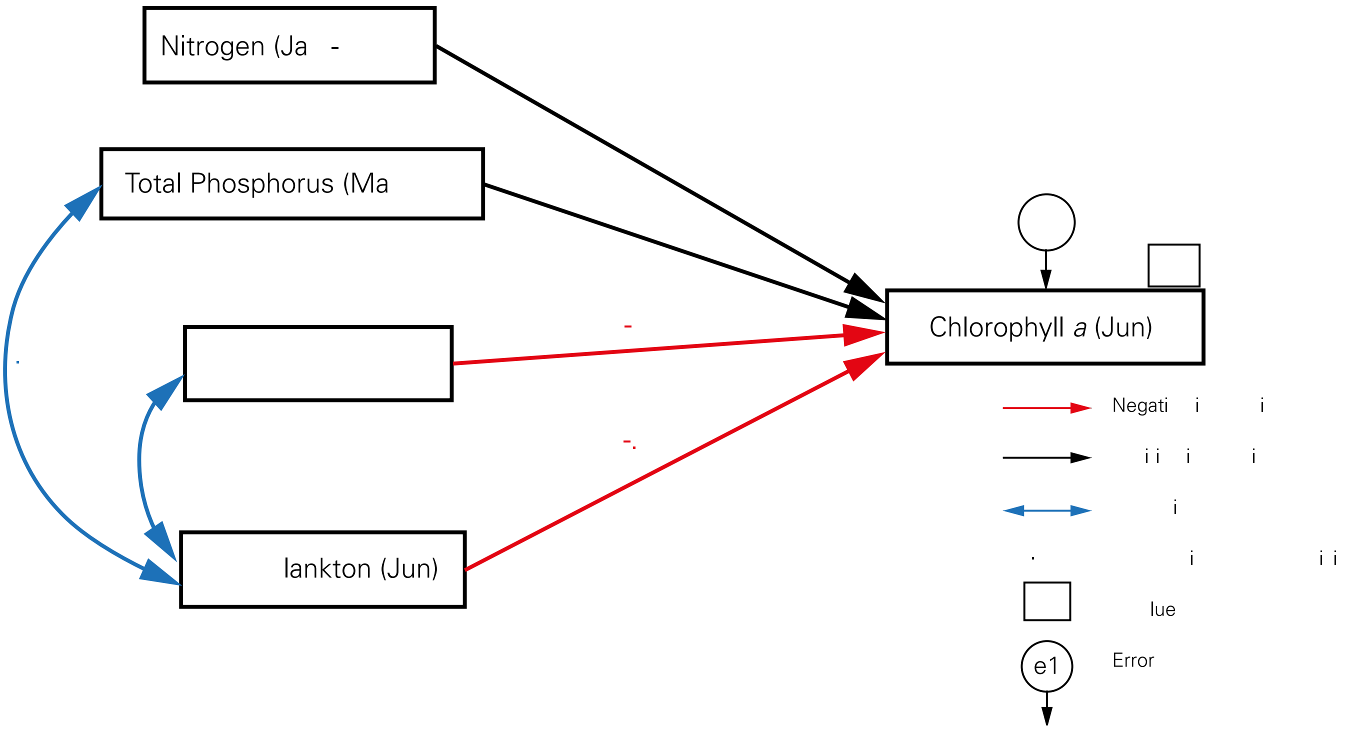
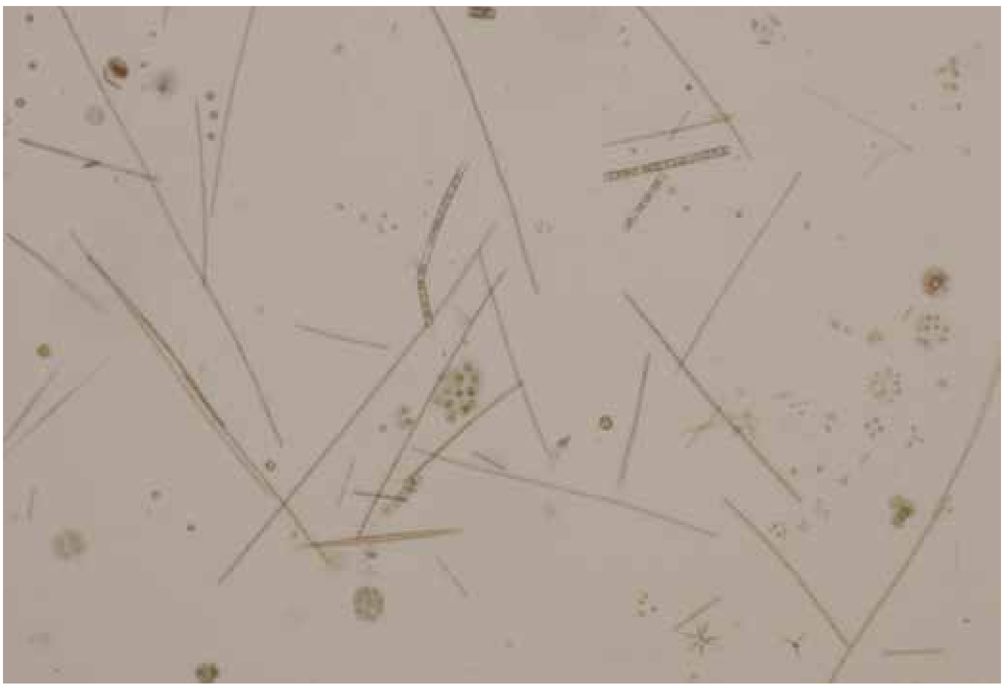


Figure 6 Structural equation model of Lough Neagh chlorophyll *a* for June (1975 to 2012). Numbers shown are the standardised regression coefficients, showing the strength and direction of the relationships between model elements



Left: Typical phytoplankton sample from Lough Neagh (100x magnification)

The Lough Neagh fish community sampled during the DOLMANT project was atypical for a lowland Irish lake. A total of seven species were encountered during the study: bream, eel, pollan, three-spined stickleback, river lamprey, perch and roach and the main findings were:

- Pollan, perch and roach dominated survey catches
- Draft (seine) netting, a novel sampling method, provided reliable results. Draft netting also provided a more accurate reflection of the fish community structure in this waterbody
- Growth analyses of perch showed slower growth when compared to the majority of other lakes in Northern Ireland/Republic of Ireland
- Pollan growth rates in Lough Neagh have decreased over the last 40 years
- Growth rates for roach were comparable to other lakes in Northern Ireland/Republic of Ireland.

Lough Neagh pollan (*Coregonus autumnalis)*

As a conservation species, pollan recruitment is a major factor in determining abundance. As such, the DOLMANT study of pollan larval abundance during the years 2011-2014, is an important tool for predicting future population size. The WFD ecological assessments were completed for each of the draft and gill net surveys and ecological quality ratios for fish were found to be good/high throughout the study period.

Recommendations for Lough Neagh management

- The structural equation model developed can be used to predict ecological changes in the Lough
- Bi-monthly zooplankton monitoring should continue and be examined in greater detail
- Due to the unique nature of Lough Neagh draft net sampling provides a better description of fish population characteristics and should be used in future assessments
- Triennial autumn multi-method fish stock assessment is advised
- Annual monitoring of recruitment of a pollan, a conservationally important species, is advised.

Lough Neagh

Development of management tools for Lough Erne

Lower Lough Erne is the fourth largest Irish lake, with a surface area of 110 km^2, and it is part of a system that comprises of 361 additional satellite lakes. This lake is designated as a heavily modified waterbody for WFD purposes due to the presence of flow regulation and hydropower on its outflowing river.

The objective of this part of the study was to create a management tool for Lough Erne by bringing together existing water chemistry and biological data, including zooplankton and fish.

Above: Lough Erne

Left: Biological sampling

Zooplankton data were used to describe the likely effects of roach (*Rutilus rutilus*) and zebra mussel (*Dreissena polymorpha*) on the zooplankton and chlorophyll *a* of the open water of Lower Lough Erne. The main findings were:

- Roach initially reduced the abundance of zooplankton up to 1996, by an average of 85%, and the zebra mussel further reduced it between 1997 and 2003, by an average of 76%
- All zooplankton taxa were affected by the zebra mussel (a reduction of 50 to 90%; mainly effected rotifera, cycloid copepods and *Eudiaptomus*); it was also responsible for the reduction in the chlorophyll *a* concentration by 25%
- There was a selective recovery in the zooplankton composition: the abundance of *Eudiaptomus*, nauplii and *Bosmina* species increased between 2003 and 2013. Based on observations from the Hudson River study (2010), this could be due to a decrease in the filtering capacity of the mussel population as a result of a natural reduction in the proportion or large mussels in the population

Three types of model were developed to integrate the results and findings in order to predict the chlorophyll *a* concentration in Lower Lough Erne, with an emphasis on the impact caused by the zebra mussel. Multiple regression, structural equation modelling (Figure 7) and regression tree analyses found that zebra mussel has been the dominant influence on phytoplankton biomass in Lower Lough Erne since 1996. The annual mean concentration is now approximately 10 μg L^{-1} lower in the Lough as a result of this invasive species.

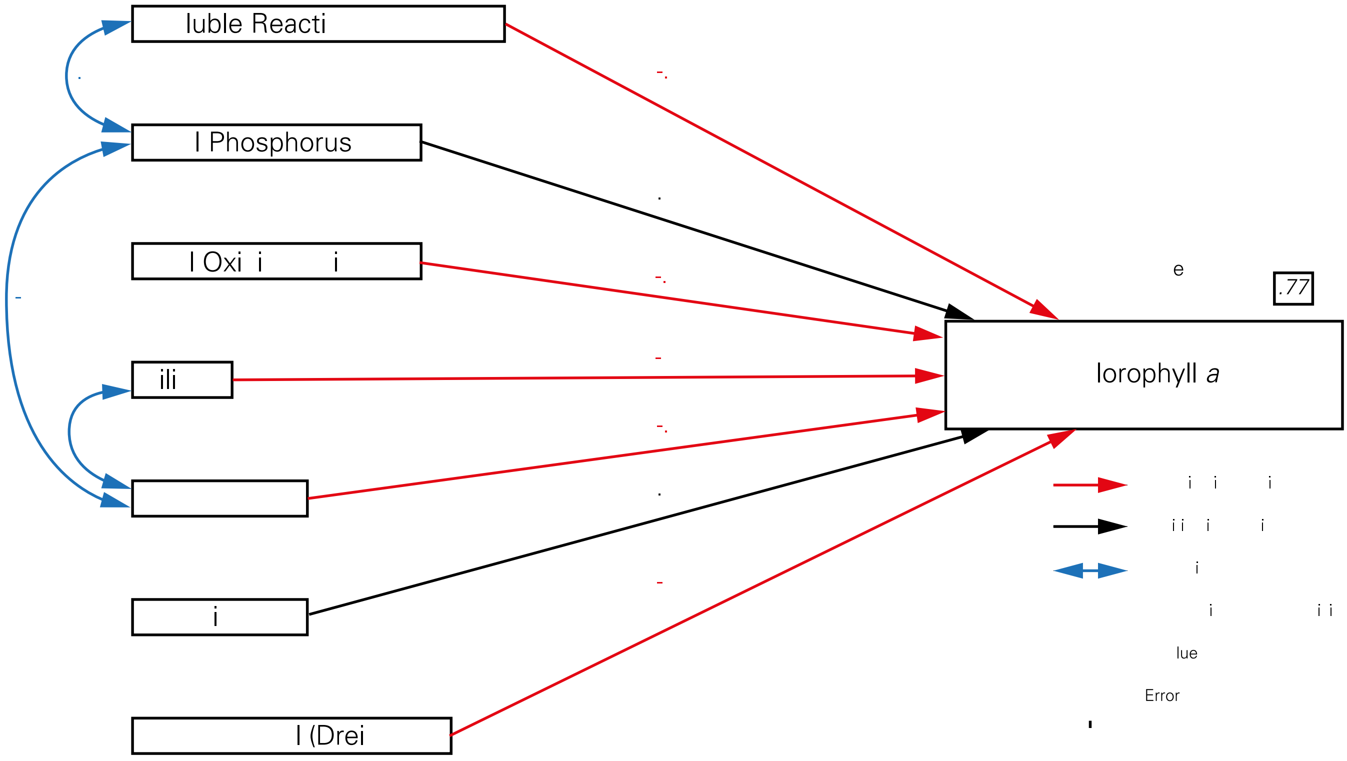


Figure 7 Structural equation model for the monthly mean chlorophyll *a* concentration in Lower Lough Erne over the 1986 to 2010 period. Numbers shown are the standardised regression coefficients, showing the strength and direction of the relationships between model elements.

Bloody Red Shrimp (*Hemimysis anomala)*

Recommendations for Lough Erne management

- Use of the multiple regression model produced to inform likely changes in lake ecology.
- Monitor the effect of key invasive species, roach and zebra mussel, on the zooplankton and chlorophyll *a* of Lower Lough Erne
- Evaluate (and monitor) the density of zebra mussels to assess the likelihood of further adverse impacts at all trophic levels of the ecosystem
- Assess presence or absence of the invasive alien species Bloody Red Shrimp (*Hemimysis anomala*) in the Lower Lough Erne basin. Through the DOLMANT project the presence of the shrimp was established in Upper Lough Erne
- Continue bi-monthly assessment of water chemistry and zooplankton communities

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Notes