A PRELIMINARY CLASSIFICATION OF LAKE TYPES IN NORTHERN IRELAND

BRIAN RIPPEY, SHELLEY DOE, JOANNA GIRVIN, PETER HALE, YVONNE MCELARNEY, MARTIN NEALE AND JANE PRESTON

(Dr B. Rippey, S. Doe, Y. McElarney and M. Neale, School of Environmental Studies, The University of Ulster, Coleraine BT52 ISA; Dr V. Crone, Environment and Heritage Service, Clavert House, 23 Castle Place, Belfast BT1 1FY; P. Hale, Industrial Research and Technology Unit, 17 Antrim Road, Lisburn BT28 3AL; Drs J. Preston and J. Girvin, School of Biology and Biochemistry, The Queen's University of Belfast, 97 Lisburn Road, Belfast BT9 7BL.) [Email: BHRT. Rippey@ulst.ac.uk]

Introduction

The EC Water Framework Directive (WFD) introduces the concept of the ecological status of surface waters. In order to compare the ecological status of, for example, lakes across Europe, methods based on either the idea of the continuum or of discrete biological communities need to be developed. The best example of the use of the continuum approach is that of RIVPACS for macroinvertebrates in rivers (Wright et al. 1998, 2000), and for discrete communities that of Johnson & Goedkoop (2000) for lake macroinvertebrates.

As the first stage in establishing the ecological status of surface waters, the WFD requires that a waterbody is placed into one of the regional "types" described by lilies (1966). These biogeographical regions or ecoregions are areas of relatively homogeneous ecological systems. Biological communities are correlated with these ecoregions; e.g. fishes, macroinvertebrates and periphyton communities in streams (Whittier et al. 1988) and macroinvertebrates in streams and the littoral parts of lakes (Johnson & Goedkoop 2000).

As ecoregions are quite large - for example Ireland is one (region 17, Irland) of lilies' (1966) biogeographical regions - there may be variations in the natural biological communities within an ecoregion. The WFD requires that this variation is described by dividing (for example) lakes into waterbody "types" or "ecotypes". This approach is based on the idea of discrete communities. The waterbody type is determined by physico-chemical *descriptors.* For lakes the descriptors are some or all of altitude, latitude, longitude, depth, geology, size, shape, hydraulic residence time, air temperature, mixing characteristics, acid neutralising capacity, background nutrient status, mean substratum composition and water-level fluctuation.

A group of representatives from two government environmental agencies (Environment and Heritage Service and the Industrial Research and Technology Unit) and the two universities (Queen's University Belfast and the University of Ulster) in Northern Ireland, has been established to develop methods for measuring the ecological status of lakes, for the purposes of the WFD. The current objectives of the work are (1) to classify Northern Ireland's lakes into waterbody types and investigate if they are related to the phytoplankton, macrophyte, macroinvertebrate and fish communities, (2) to investigate sampling methodologies for phytoplankton, macrophytes, macro-invertebrates and fish in lakes, and (3) to investigate data analysis techniques to measure departures from high ecological status in lakes. The work reported here is that contributing to the first objective: classification into waterbody types.

The Northern Ireland lake survey (1989-1991)

There are 1668 lakes in Northern Ireland. Most of them are small; only Lough Neagh (380.0 km^2), Upper (109.5) and Lower (34.5) Lough Erne, Lough Melvin (18.6), Upper Lough Macnean (10.1), Lough Beg (7.0), Lower Lough Macnean (5.2) and Portmore Lough (1.8) are larger than 1 km^2. A sample of 614 lakes with surface areas greater than 0.2 ha was surveyed during 1989 to 1991, in the Northern Ireland Lake Survey (Smith et al. 1991; Gibson et al. 1995). This survey provided most of the data used here to classify lakes in Northern Ireland. Lakes that are or were recently used as reservoirs were omitted, leaving a sample of 566 lakes.

To classify the lakes into "types", we used System B summarised in Annex II of the WFD, which specifies six obligatory physical and chemical descriptors: altitude, latitude, longitude, depth, geology and size.

For our sample, variation in lake altitude (Fig. 1) suggested that three categories of low (<175 m), medium (176-375 m) and high (>375 m) altitude could be used. In Sweden, Johnson & Goedkoop (2000) used similar categories of <200, 200-800 and >800 m altitude. The categories describing catchment geology in our sample were siliceous and calcareous, although an organic category (peat) is important in Northern Ireland. Lake sizes (Fig. 2) were placed in two categories: smaller than 2 ha and larger than 2 ha. Johnson & Goedkoop (2000) used size categories of 1-10, 10-100 ha and larger size ranges. Johnes et al. (1994) (ref for Pond Action) consider that very small lakes (ponds) are less than 2 ha.

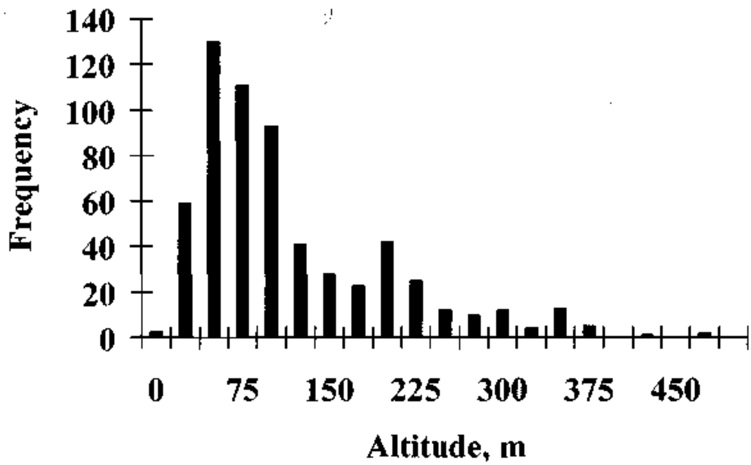

FIG. 1. Frequency distribution for altitude (m) of 566 lakes in Northern Ireland.

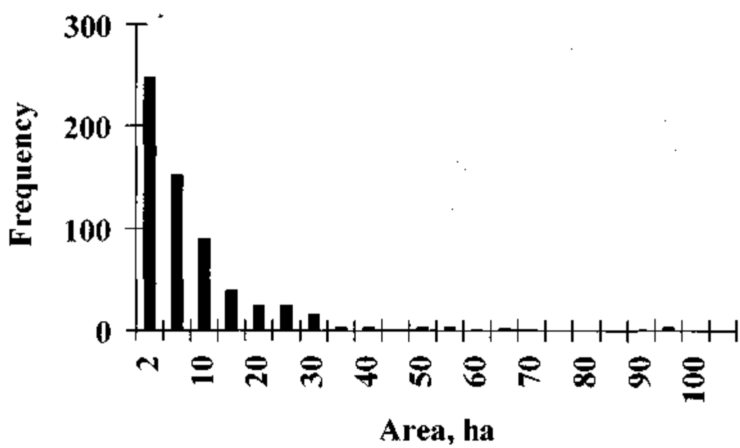

FIG. 2. Frequency distribution for surface areas (ha) of 566 lakes in Northern Ireland.

System B in Annexe II of the WFD lists ten optional descriptors that may be used for typing lakes. Of these, acid neutralising capacity (ANC) was most useful (Fig. 3) and two categories were chosen: low ANC (lakewater alkalinity <0.05 milliequivalents per litre) and high ANC (alkalinity >0.05 mequivalents per litre), based on the sensitivity of water to acidification (Henriksen 1979).

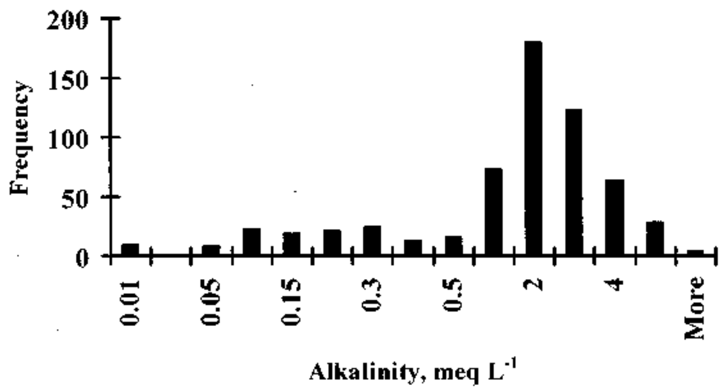

FIG. 3. Frequency distribution for alkalinity (milliequivalents per litre) of 566 lakes in Northern Ireland.

Of the remaining nine optional descriptors listed in Annexe II, we did not use mean substratum composition, background nutrient status and water-level fluctuation, as we have no information on these characteristics. We did not include hydraulic residence time as practically all of the lakes, even the largest ones, are rapidly flushed (hydraulic residence time around or less than one year), and we excluded shape, as almost all of the lakes have simple shapes. We tried to include depth and mixing characteristics. For this we used an empirical relationship (n = 32) to infer maximum depth from area (Ruiz 1999) and then used maximum depth to allocate lakes to either a polymictic or monomictic category depending on whether the inferred maximum depth was less than or greater than 6 m, respectively. While mixing characteristics may influence the natural biological communities, all lakes in our sample were allocated to the monomictic category (i.e. an annual cycle of thermal stratification).

Preliminary classification of lakes in Northern Ireland

Our preliminary classification of the 566 lakes in Northern Ireland is based on four major descriptors: altitude, geology, size (lake surface area) and lakewater alkalinity - representing acid neutralising capacity. Early analysis of the data was assisted by using TWINSPAN (Hill et al. 1975; Hill 1979), where each descriptor was treated as equivalent to a biological "species". This approach has been used for the classification of land cover (Barr 1993; Cooper et al. 1997).

The lakes were split first into two categories: 457 at low altitude and 109 at medium altitude. (Note: two of these lakes actually were in the high altitude category but were included in the medium class for further analysis by TWINSPAN). From further analysis we distinguished seven lake types or classes (Fig. 4), enumerated below.

Type (Class) 7. 18 lakes at medium altitudes, with small, siliceous catchments and low ANC.

Type (Class) 8. 56 lakes at low altitudes, with small, calcareous catchments and high ANC.

Type (Class) 9. 113 lakes at low altitudes, with large, calcareous catchments and high ANC.

Type (Class) 10. 174 lakes at low altitudes, with large, siliceous catchments and high ANC.

Type (Class) 11. 114 lakes at low altitudes, with small, siliceous catchments and high ANC.

Type (Class) 12. 47 lakes at medium altitudes (including one at higher altitude), with large, siliceous catchments and high ANC.

Type (Class) 13. 44 lakes at medium altitudes (including one at higher altitude), with small, siliceous catchments and high ANC.

Table 1 gives the number of lakes in each of the seven types of waterbody and the arithmetic mean values for three major lake descriptors: altitude, surface area and alkalinity. In addition, we assessed the degree of homogeneity between lakes in each of the seven types by assigning indices to the categories used to describe the lakes. When a lake occurs in a particular category, medium altitude for example, it was allocated an index value of 1, whereas if it does not occur in that particular category it was allocated a value of 0. Therefore, the arithmetic mean value for indices in each category describes the homogeneity of descriptors for lakes in each

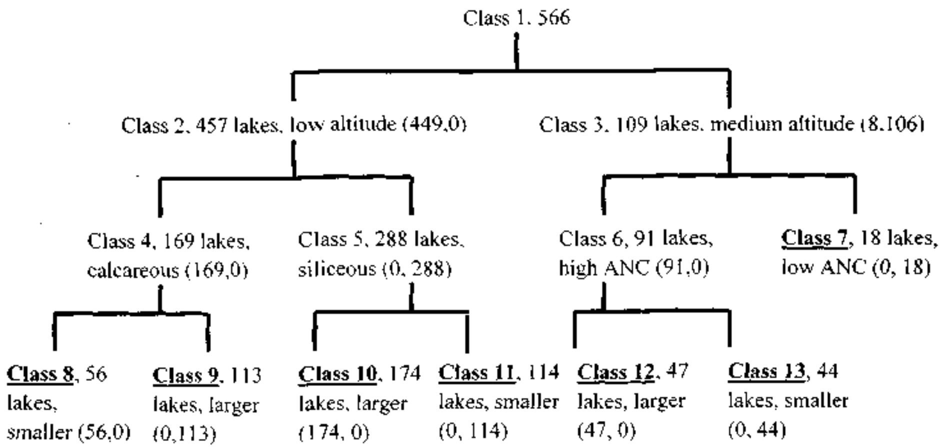

Fig. 4. The classification of 566 lakes in Northern Ireland, made using altitude, geology, size and acid neutralizing capacity (ANC) categories. (x, y) displays the number of lakes in a category of waterbody descriptor that are classified to the negative group (x) and to the positive group (y) at a division, e.g. low altitude (449, 0) displays that 449 lakes in the low altitude category of waterbody descriptor are classified to the negative group and 0 are classified to the positive group at the first division.

Table 1. The numbers of lakes and the arithmetic mean values for altitude, area and alkalinity. Homogeneity of the lake types is given by the mean values* for indices (1 or 0) allocated to categories of each descriptor. When all lakes in a class or type fall within one particular category, the index is 1, and when all lakes do not fall within the same category, the index is 0.

Lake types:	7	8	9	10	11	12	13
Number of lakes:	18	113	56	174	114	47	44
Descriptor:							
Mean altitude (m)	263	71	64	72	75	247	250
Categories:							
*Low	0	0.96	0.95	1	1	0	0
*Medium	1	0.04	0.05	0	0	0.96	0.98
*High	0	0	0	0	0	0.04	0.02
Descriptor:							
Mean area (ha)	2	1	11	11	1	11	1
Categories:							
*Small (<2 ha)	0.89	1	0	0	1	0	1
*Large (>2 ha)	0.11	0	1	1	0	1	0
Descriptor:							
Mean HCO_3 (mE l^{-1})	0.02	3.14	2.35	1.67	1.79	0.39	0.25
Categories:							
*Low ANC	1	0	0	0	0.03	0	0
*High ANC	0	1	1	1	0.97	1	1
Descriptor:							
Catchment geology							
Categories:							
*Siliceous	0.94	0	0	1	1	1	1
*Calcareous	0.06	1	1	0	0	0	0

type (Table 1). For example, as all 18 lakes in Type 7 were in the medium altitude category, the mean index for this category is 1, whereas if most were in the medium category but a few were in the low altitude category, the mean index would then have been less than 1.

A perfect classification of lakes would have mean values of either 1 or 0 for each category. Table 1 shows that this is almost achieved. Many of the mean values for the categories are either 1 or values down to 0.89, or 0 up to 0.11.

Future work on lake classification

Our preliminary classification of 566 of Northern Ireland's lakes into seven waterbody types has been achieved by using just four major descriptors: altitude, surface area, catchment geology and acid neutralising capacity. Nevertheless, there are some limitations to this classification that will be addressed in future work. The categories for catchment geology used here were "calcareous" and "siliceous". However, an "organic" category needs to be included as many Irish lakes have peat in their catchments, sufficient to affect the characteristics of the water and sediment and thus influence the natural biological communities living in them. Our attempt to include depth and mixing characteristics of lakes was unsuccessful, but this could be remedied by lowering the maximum depth below which polymictic behaviour is expected.

The development of lake types, based on physical and chemical descriptors, is only sensible if they correlate with natural biological communities in the lakes, i.e. the classification must be ecologically relevant. Johnson & Goedkoop (2000) found that the littoral macroinvertebrate communities in Swedish lakes were correlated with the biogeographic regions of lilies (1966), but lake surface area and altitude within a particular region had only a weak influence. This implies, at least for the lake descriptors which they employed, that the littoral macroinvertebrate communities could not be easily divided much below the level of ecoregions.

Work has already started to establish if lake classifications made using the natural communities of phytoplankton, macrophytes, macro-invertebrates and fish are similar to each other and to that made using the physico-chemical lake descriptors. Agreement is important if the approach to measuring the ecological status of lakes using discrete biological communities is to be successful. During 2000, the communities of fourteen lakes, two of the least impacted in each of the seven lake types, were investigated. Visits were made in spring, summer and autumn, when oxygen-temperature profiles and the concentrations of chlorophyll-α, total phosphorus and bicarbonate were obtained. Phytoplankton was identified and counted, macrophytes were surveyed from the shoreline and from a boat, and littoral and profundal samples were taken for benthic macroinvertebrates. A single survey of each lake using gill and fyke nets was completed and the numbers and size of fish species were established.

In subsequent fieldwork, impacted lakes will be sampled and their biota will be examined to see how the communities change as a result of impacts such as nutrient enrichment, contamination with biodegradable organic matter and acidification.

References

Barr, C. (1993). *Countryside Survey 1990: main report.* Department of the Environment.

Cooper, A., Murray, R. & McCann, T. (1997). *The Northern Ireland Countryside Survey.* Environment and Heritage Service.

Gibson, C. E., Wu, Y., Smith, S. J., & Wolfe-Murphy, S. A. (1995). Synoptic limnology of a diverse geological region: catchment and water chemistry. *Hydrobiologia* **306,** 213-227.

Henriksen, A. (1979). A simple approach for identifying and measuring lake acidification. *Nature, London* **278,** 542-545.

Hill, M. O. (1979). TWINSPAN - a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Ecology and Systematics, Cornell University, Ithaca, New York.

Hill, M. O., Bunce, R. G. H. & Shaw, M. W. (1975). Indicator species analysis, a divisive polythetic method of classification, and its application to a survey of native pinewoods in Scotland. *Journal of Ecology* **63,** 597-613.

lilies, J. (1966). Verbreitung der Susswasserfauna Europas. *Verhandlungen Internationale Vereinigung fur theroetische und angewandte Limnologie* 16, 287-296.

Johnes, P., Moss, B. & Phillips, G. (1994). Lakes - classification and monitoring: a strategy for the classification of lakes. National Rivers Authority R&D Note 253.

Johnson, R. K. & Goedkoop, W. (2000). The use of biogeographical Regions for partitioning variance of littoral macroinvertebrate communities. *Verhandlungen Internationale Vereinigung fur theroetische und angewandte Limnologie* 27, 333-339

Ruiz, Z. (1999). *The physical limnology and dissolved oxygen regimes of small eutrophic lakes.* Unpublished DPhil thesis, University of Ulster.

Smith, S. J., Wolfe-Murphy, S. A., Enlander, I. & Gibson, C. E. (1991). *The lakes of Northern Ireland; and annotated inventory.* HMSO.

Whittier, T. R., Hughes, R. M. & Larsen, D. P. (1988). Correspondence between ecoregions and spatial patterns in stream ecosystems in Oregon. *Canadian Journal of Fisheries and Aquatic Sciences* 45, 1264-1278.

Wright, J, F., Furse, M. T. & Moss, D. (1998). River classification using invertebrates: RIVP ACS applications. *Aquatic Conservation* 8, 617-31.

Wright, J. F., Sutcliffe, D. W. & Furse, M. T. (2000). *Assessing the biological quality of fresh waters: RIVP ACS and other techniques.* Freshwater Biological Association, Ambleside, xxiv + 373 pp.