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Executive summary

- Sediment accumulation rate (SAR) is one of the most important physical parameters affecting the functioning of lake systems. In many lakes across the world an increase in SAR has been observed over the last c.100 years. Reasons for this include changes in land-use and land-management, causing accelerated catchment soil erosion, and eutrophication. Climate change can influence these processes and is likely to play a progressively more important role in future.

- The EU Water Framework Directive (WFD) requires that biological, hydromorphological and chemical elements of water quality should be based on the degree to which present day conditions deviate from those expected in the absence of significant anthropogenic influence, termed reference conditions. Currently however, the reference condition for a 'basal sediment accumulation rate' for lakes of different types is undefined, and the main driving factors remain unidentified. It is therefore necessary to improve our understanding of the controls on SARs, including changing climate, to determine which are the most susceptible lake types and what the biological consequences might be. This is one of the aims of Euro-limpacs WP2 Task 1.2.

- SAR data were compiled for 337 sediment cores from 278 lakes. However, data on latitude, longitude, alkalinity, altitude, maximum depth and lake area were only available for 207.

- The 207 lake dataset includes sites in 19 countries. 60% are from the UK and smaller clusters exist in Italy, Finland, Estonia, Svalbard, Spain and Denmark. Major gaps occur in mainland central Europe, from the Low Countries eastwards, in south-east Europe and in mid-northern latitudes including central Norway and Sweden and southern Finland. European Russia is particularly poorly represented. In terms of climatic zones, most sites fall within a humid-oceanic zone, while humid-continental and sub-arctic regions are under-represented.

- Consideration of the sites with >3 dated cores shows that where multiple cores are taken from representative deep-water areas then there is good agreement in terms of general SAR trends and in 'basal' SARs. We conclude that SAR data from sediment cores taken from deep water areas are likely to be representative of that lake sediment basin.

- 66% of the sediment cores showed surface SARs higher than basal rates. 19% showed no change while 15% showed a decline. For classes showing SAR increases, little change occurred prior to 1900. Most increases seemed to occur in more recent periods in particular 1950 – 1975 and post-1975. It may be that this observation identifies a general acceleration in SAR in European lakes.

- Lakes were classified into lake-types using four parameters: alkalinity (3 classes), altitude (3 classes), maximum depth (2 classes) and lake area (2 classes). This generated a possible 36 lake classes of which 25 were represented in the dataset. Nine classes contained >10 lakes in them. The largest class (1221) includes many upland sites in the UK used in the Surface Water Acidification Project and those now forming part of the UK Acid Waters Monitoring Network.

- Reference SARs were estimated for 8 lake classes. Mountain lakes had the lowest reference SAR (0.005 ± 0.003 g cm^{-2} yr^{-1}) while large, lowland, high alkalinity sites had the highest (0.03 – 0.04 g cm^{-2} yr^{-1}). Others range between 0.012 and 0.024 g cm^{-2} yr^{-1}. All would benefit from further data.

- Next steps include: (i) addition of further SAR and typology data (ii) further statistical analysis (iii) more detailed sedimentological work to identify those components of the sediment responsible for SAR increases in key lake classes and determining the causes of these increases.

Sediment accumulation rate changes in European lakes: A first report (WP2; Task 1.2)

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Background

Sediment accumulation rate (SAR) is one of the most important physical parameters affecting the functioning of lake systems. It affects lake morphology, physical and chemical stratification, the availability of habitats and hence distribution of aquatic flora and fauna particularly in littoral areas. In shallower lakes rapid accumulation can raise the sediment surface into the zone of resuspension thus affecting light penetration and plant growth, and ultimately lead to complete terrestrialisation.

In many lakes across the world an increase in SAR has been observed over the last c.100 years. Reasons for this include changes in land-use and land-management causing accelerated catchment soil erosion, and eutrophication. Climate change can influence both these processes and is likely to play a progressively more important role in future. For example, temperature increases may lead to enhanced lake productivity and elevated rainfall and increased frequency of extreme events (both drought and winter storms) could result in an increase in catchment erosion. However, increases in sediment accumulation rate have also been observed in upland lakes where catchment scale changes are more limited and hence the causes more uncertain.

The European Union's Water Framework Directive (WFD) (2000/60/EC) establishes an integrated approach to the protection, improvement and sustainable use of Europe's rivers, lakes, estuaries, coastal waters and groundwater and aims to achieve good ecological quality in all relevant waters within 15 years. It requires that biological, hydromorphological and chemical elements of water quality should be based on the degree to which present day conditions deviate from those expected in the absence of significant anthropogenic influence, termed reference conditions. The WFD specifically requires the determination of reference conditions for different waterbody types in order to identify sites of 'High' status, i.e. those where the various elements correspond to undisturbed conditions. The four categories of 'Good', 'Moderate', 'Poor' and 'Bad' status are defined according to the degree of deviation from the reference state. In the absence of long-term data, the WFD states that reference conditions based on modelling may be derived using hindcasting methods, and palaeolimnology is one such technique (Pollard and Huxham, 1998; European Union, 2000). Currently however, the reference condition for a 'basal sediment accumulation rate' for lakes of different types is undefined, and the main driving factors remain unidentified. It is therefore necessary to improve our understanding of the controls on sediment accumulation rates, including changing climate, to determine which are the most susceptible lake types and what the biological consequences might be. This is one of the aims of Euro-limpacs WP2 Task 1.2.

This report

In order to attempt to address these questions it has been necessary to compile a database of historical trends in sediment accumulation rates from as many European lakes as possible. Only by bringing together these data will it be possible to try and identify SAR changes for different lake types.

This report is divided into two parts. The first describes the compilation and content of this SAR database, the distribution of sites for which data were available and highlights gaps in this dataset. It also considers the availability of data required to divide sites included in the SAR database into lake-types and how this further restricts the number of sites available for consideration. Finally, we consider within-lake variability of SAR and to determine whether sediment cores taken from the deepest areas may be considered representative of that lake and therefore whether the data from single cores can be used in subsequent analysis.

The second part of this report is concerned with the historical trends in SAR within the various lake types. Although all lake types are considered, this section is primarily focussed on those for which more than ten lakes exist in the database.

Part 1: Database compilation

Due to the nature of palaeolimnological research in Europe over the last few decades most studies which include sediment accumulation rate data only consider the period back to the mid-19th century. The reasons for this are two-fold. First, many of the problems which palaeolimnological techniques have been used to address (e.g. acidification, eutrophication, contamination of metals and persistent organic pollutants (POPs) from industrial sources) are products of, or have become greatly exacerbated during, the industrial period. Second, the development of ^{210}Pb-dating since the 1970s has allowed reliable and high resolution chronologies to be constructed, but these are restricted to c.150 years due to the 22.23 year half-life of this isotope.

As a consequence, and in order that as much data as possible can be included in reference condition considerations, a reference date of 1850 is used here for SAR. It is almost certain that for many lakes an 1850 SAR does not reflect a ‘natural’ rate of accumulation and in the few instances where recent chronologies are successfully combined with longer dating estimates from techniques such as ^{14}C this would appear to be the case (e.g. Bukkehammarstjoern data; Rose and Hughes, in press). However, such studies are rare and restricting this report to them would preclude any estimate of a consensus for a reference SAR for any lake-type. Therefore, while pre-1850 SAR may have been lower and ‘more natural’ at many of the sites considered in this report, we use 1850 where possible, as a best practicable reference date. For some lake types where ^{210}Pb-dating is further curtailed, more recent reference dates (e.g. 1875) are used. These instances are described more fully later in the report.

(i) SAR database

A database of available SAR was compiled from original dating reports, data published in the literature and from personal communications from researchers around Europe. For each site, where available, the SAR for every 25 years from 1850 (e.g. 1850, 1875, 1900, 1925, 1950, 1975, 2000) were recorded as were the most recent SAR, and the rate and date of maximum sediment accumulation through the core. In total, data from 337 cores have been compiled from 278 lakes, the discrepancy in these numbers resulting from multiple cores from the same site (see below). Of these cores 204 had no data available for 1850, while 146 also had no data for 1875; 74 for 1900; 33 for 1925 and 11 for 1950. Any sites with shorter records than this (i.e. c. 50 years) are not included here.

Of the sites with multiple dated sediment cores Lago Tovel (Italy) and Lough Neagh (UK; Northern Ireland) had 7, Brotherswater (UK; England) 6, Albano (Italy) 5; Friary Lough (UK; Northern Ireland) 4 while Loch Coire nan Arr, Loch Fleet, Lochnagar (all UK; Scotland) and Øvre Neådalsvatn (Norway) all had three cores. Data for two cores were obtained from each of an additional 22 sites.

(ii) Full typology database

It is expected that a comparison of reference SARs and SAR changes through time can only meaningfully be done when lakes of a similar type are considered together. Therefore, in order to classify the lakes included within this database into types a range of additional data were required. The classification used here was based upon a simplified version of the Geographical Intercalibration Group (GIG) scheme and, after discussion at the Euro-limpacs Palaeoecology Cross-cutting Theme workshop (held in London in May 2005), included altitude, alkalinity, maximum depth and lake area. In addition, locational data (latitude and longitude) were also required. However, not all these data were available for all sites and therefore further analysis was not possible on the full 337 core / 278 lake database. One of the 4 classification variables was not available for 34 sites, data on 2 variables was not available for an additional 12 sites, data on only one variable was available for 6 sites while none of the variables are currently available for 19 sites. While we still hope that additional data may be forthcoming, allowing a more complete analysis at a later stage, the current classification was undertaken on the 207 lakes for which the full dataset was available. The remainder of this report is concerned with these 207 lakes.

Figure 1 shows the distribution of these 207 sites. Clearly there is a strong bias towards lakes in the UK although there are other clusters of sites in Svalbard, north Finland, Estonia and northern Italy. In fact the UK represents over 60% of the sites in this database and only Italy (5.3%), Finland (4.8%), Estonia (4.4%), Svalbard (3.9%), Spain (2.9%) and Denmark (2.4%) contribute more than 2% despite a total of 19 European countries being included (Figure 2). Apart from these clusters, site locations are scattered thinly across the remainder of Europe. Major gaps exist in mainland central Europe, from the Low Countries eastwards, in south-east Europe and in mid-northern latitudes including central Norway and Sweden and southern Finland. Russia is particularly poorly represented with only a single site in the Kola Peninsula and three in the northern Urals for the whole of the European area. In terms of climatic zones, the majority of sites fall within a humid-oceanic climate zone, while humid-continental and sub-arctic regions are under-represented.

Figure 1. Distribution of lakes for which sediment accumulation rate and all typology data exist.

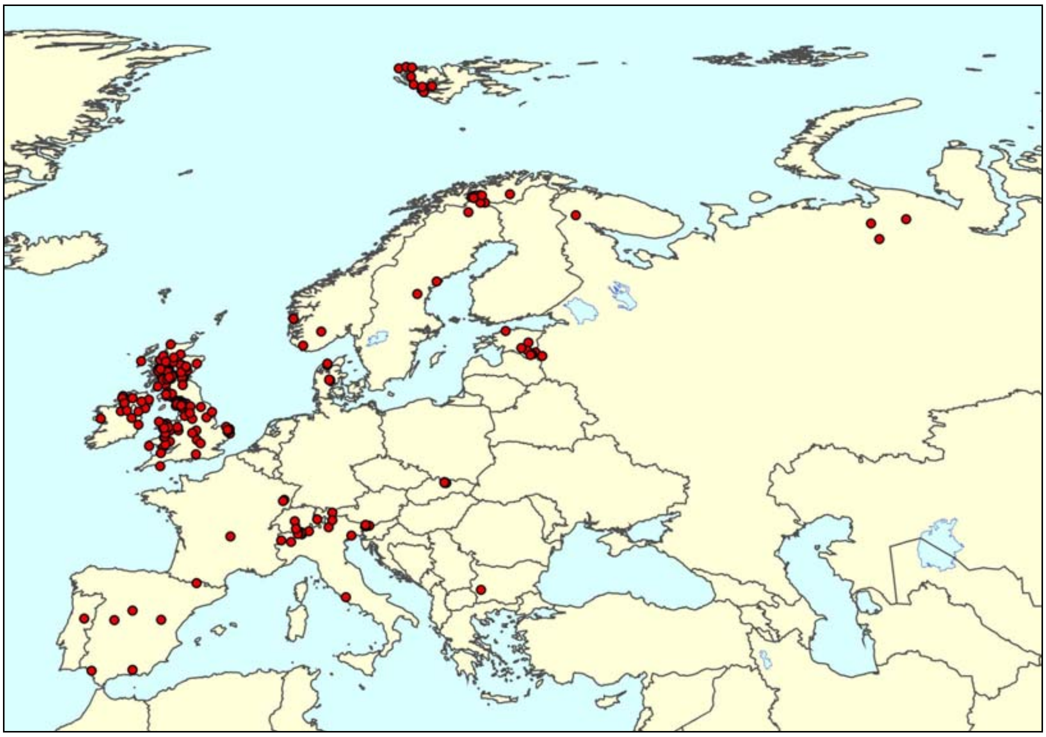
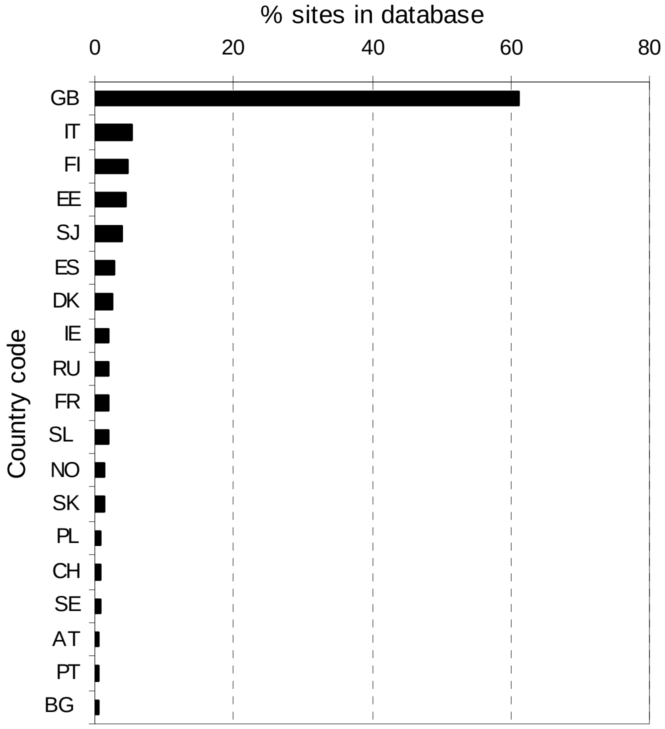


Figure 2. Distribution of sites in the 207 lake database, by country.



(iii) Lake classification

Once the database of 207 sites had been constructed the lakes could be classified into types. The four typology parameters were divided as follows:

Alkalinity:	3 classes	< 0.2 μeq l^{-1}	0.2 – 1.0 μeq l^{-1}	> 1.0 μeq l^{-1}
Altitude:	3 classes	< 200 m a.s.l.	200 – 800 m a.s.l.	>800 m a.s.l.
Maximum depth:	2 classes	< 5 m	> 5m	
Lake area:	2 classes	< 50 ha	> 50 ha.	

These sub-divisions result in 36 possible lake-type classes. Each class was allocated a number based upon this classification and defined as shown in Table 1. Of the 36 possible classes, 25 are represented in the database while nine include ten or more lakes.

The missing lake-types are reasonably well distributed between the alkalinity classes with four in the lowest class, five in the middle class and three in the upper class, but the same is not true for the other parameters where of the eleven missing classes, ten are in the shallowest depth class, eight are in the largest area class and seven are in the highest altitude range. Furthermore, only one of the missing classes is in the lowest altitude range suggesting a skewed distribution away from high altitude lakes. The relationship between lake size and depth is also demonstrated by the low numbers of lakes in the classes where area is larger than 50 ha and depth is less than 5 m, regardless of the other parameters (i.e. larger lakes tend to be deeper). This is especially true in the highest altitude class where only two lakes are present for this lake-type regardless of alkalinity.

The classes with larger (>10) numbers of lakes in them are determined by research activities undertaken over the last few decades rather than the greater prevalence lakes of these types. Five of the nine classes are in the low alkalinity range reflecting the palaeolimnological work on sites sensitive to acidification. In particular class 1221 includes many upland sites in the UK used in the Surface Water Acidification Project and those now forming part of the UK Acid Waters Monitoring Network. Class 1321 includes high altitude lakes from 11 different countries and includes lakes studied as part of the EU funded research projects AL:PE, AL:PE2; MOLAR and EMERGE. Similarly, the sites in classes 1122, 1222 and 2122 are all large, deep lakes, many in Scotland, as a result of research projects directed towards lakes of this type, while the three high alkalinity classes with more than ten sites result from studies in the UK, Denmark and Estonia particularly in the area of lake eutrophication.

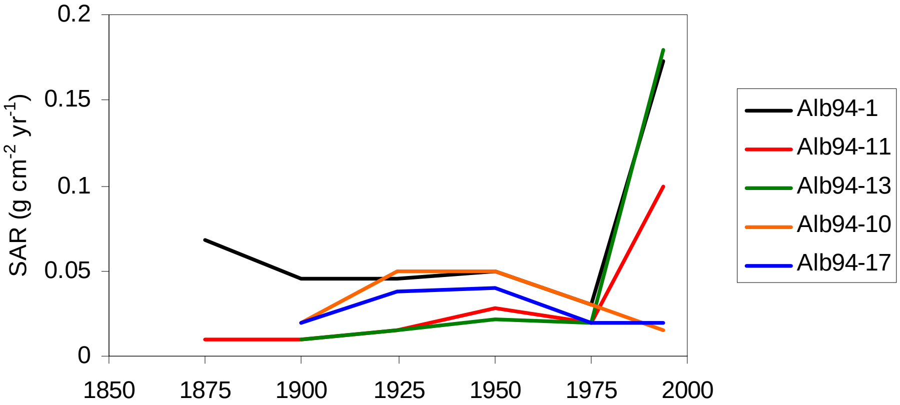
Table 1. List of possible lake-type classes and their associated class numbers.(Units for parameters as descibed above; N = number of lakes in this class)

Class	Alkalinity	Altitude	Depth	Area	N
1111	< 0.2	<200	< 5	< 50	2
1112	< 0.2	<200	< 5	> 50	0
1121	< 0.2	<200	> 5	< 50	10
1122	< 0.2	<200	> 5	> 50	16
1211	< 0.2	200 – 800	< 5	< 50	5
1212	< 0.2	200 – 800	< 5	> 50	0
1221	< 0.2	200 – 800	> 5	< 50	32
1222	< 0.2	200 – 800	> 5	> 50	13
1311	< 0.2	>800	< 5	< 50	2
1312	< 0.2	>800	< 5	> 50	0
1321	< 0.2	>800	> 5	< 50	17
1322	< 0.2	>800	> 5	> 50	0
2111	0.2 – 1.0	<200	< 5	< 50	5
2112	0.2 – 1.0	<200	< 5	> 50	2
2121	0.2 – 1.0	<200	> 5	< 50	7
2122	0.2 – 1.0	<200	> 5	> 50	19
2211	0.2 – 1.0	200 – 800	< 5	< 50	0
2212	0.2 – 1.0	200 – 800	< 5	> 50	0
2221	0.2 – 1.0	200 – 800	> 5	< 50	4
2222	0.2 – 1.0	200 – 800	> 5	> 50	2
2311	0.2 – 1.0	>800	< 5	< 50	0
2312	0.2 – 1.0	>800	< 5	> 50	0
2321	0.2 – 1.0	>800	> 5	< 50	2
2322	0.2 – 1.0	>800	> 5	> 50	0
3111	> 1.0	<200	< 5	< 50	17
3112	> 1.0	<200	< 5	> 50	7
3121	> 1.0	<200	> 5	< 50	16
3122	> 1.0	<200	> 5	> 50	10
3211	> 1.0	200 – 800	< 5	< 50	0
3212	> 1.0	200 – 800	< 5	> 50	1
3221	> 1.0	200 – 800	> 5	< 50	5
3222	> 1.0	200 – 800	> 5	> 50	4
3311	> 1.0	>800	< 5	< 50	0
3312	> 1.0	>800	< 5	> 50	0
3321	> 1.0	>800	> 5	< 50	6
3322	> 1.0	>800	> 5	> 50	2

(iv) Additional considerations

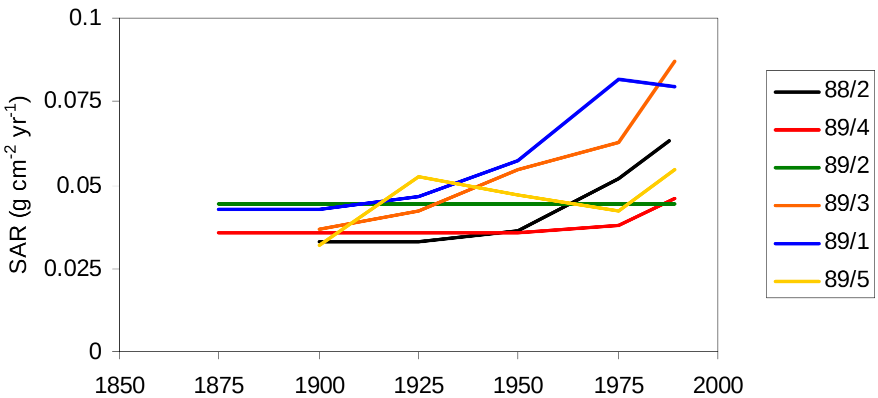
While the attempt in this Task of Euro-limpacs is to try and determine trends and possible reference SARs for different lake types, the availability of multiple core data from single sites provides an opportunity to consider within lake variability and how this may effect the interpretation of reference SARs within lake-types. For example, if within-lake variability is very high can we have confidence in reference conditions determined from single cores from a large number of sites? Multiple core SAR data exist for five lakes within the SAR database: Albano (5), Brotherswater (6), Friary Lough (4), Lough Neagh (7) and Lago Tovel (7).

Albano(3222)



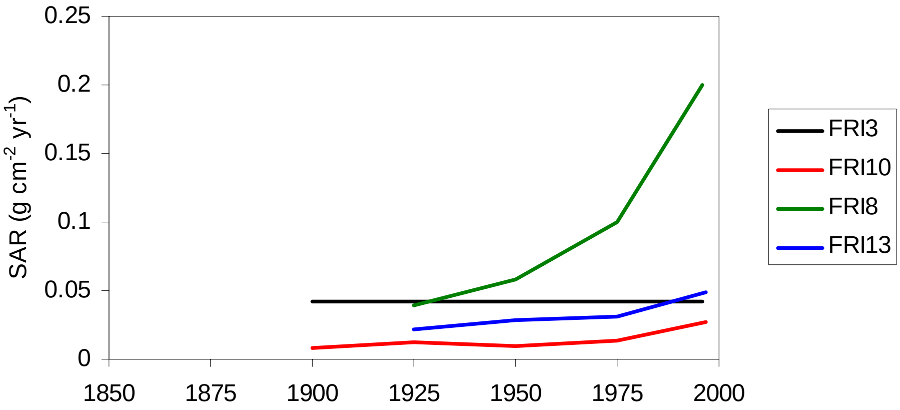
The five cores from Albano show considerable within-site variability with Alb94-1, Alb94-13 and Alb94-11 showing rapid SAR increases in the last 25 years while the other two cores (Alb94-10 and Alb94-17) show similar trends, much smaller scale changes in SAR and declines from 1950 to the uppermost sediments. However, the cores were all taken in different water depths. The three which show major increases at the surface are from 30 m, 70 m and 90 m while Alb94-10 and Alb94-17 are from 170 m and 120 m respectively. It would therefore appear that the cores taken from deepest water show repeatable temporal trends and similar SARs throughout the record and the shallow cores, while exhibiting some level of agreement in recent decades show greater variability and quite different temporal trends to those cores from the deeper water depths.

Brotherswater(1121)



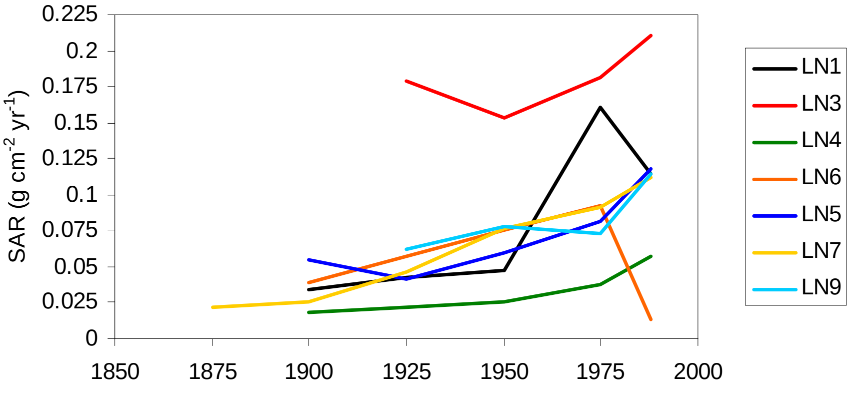
The six Brotherswater cores show a greater level of agreement than those from Albano. Apart from 89/2, which shows no change throughout the profile, all cores show an increase through time, although 89/5 shows a more variable profile. None of the cores extend back to 1850 although three have values for 1875 and all have SAR values for 1900. The mean SAR for the three 1850 values is 0.041 g cm^{-2} yr^{-1} with a standard deviation of 0.0047, while the 1900 values are 0.0374 and 0.0051respectively. Thus there is reasonable agreement between the SARs of the cores especially in these earlier periods.

Friary Lough (no class)



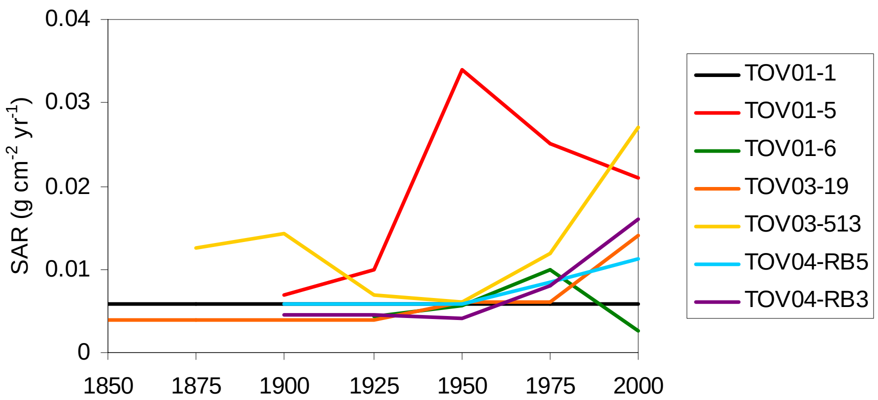
Although it has not yet been possible to place Friary Lough in a lake-type class as not all typology data are available, there are four dated sediment cores from the site so it provides information on within-lake variability of SARs. As with Albano there is considerable variability in trends and SARs through time. FRI3 shows no change, and while the other three cores all show increases in SAR through time, FRI8 shows a considerably higher rate of accumulation than the other cores, especially in recent sediments. However, as with Albano, these cores are again taken from across the lake basin. FRI3 is taken from the deepest water (8m) while FRI8 and FRI10 are littoral cores (2.5 m) and FRI13 is intermediate. This may explain the variety of profiles, but the elevated levels in the shallower cores with respect to the SAR in the deep water raises questions regarding implications for lake-infilling (i.e. accumulation at the lake margins or focussing in deeper areas).

Lough Neagh (3122)



Seven cores were taken from Lough Neagh in 1988 as part of a study looking at the distribution of trace metals across the sediment basin. Seven of these cores were taken from representative areas of the basin between 9 – 12m water depth, while LN3 was taken from a 'deep-water' trench at 18 m. This deep area is small and is therefore not representative of the basin as a whole. No cores were taken from the lake margins as sediment accumulation is not reliable in these areas. As shown above, all seven of the 9 – 12m cores show increases in SAR from 1900 to the uppermost sediments although there are differences in absolute SARs and trends especially in the most recent data where SAR declines in LN1 and LN6. The record for the deep-water core LN3 is quite different to the remainder of the cores showing different temporal trends and considerably higher rates. This is probably due to sediment focussing in this small deep area. The record is short in these Lough Neagh cores and a record back to 1875 is only obtained from one. However, values for 1900 are available for five of the cores from the main basin and these show a mean SAR of 0.0343 g cm^{-2} yr^{-1} and a standard deviation of 0.0138. Therefore, where sediment cores are taken from representative areas of a lake basin, trends and early SARs appear to give reasonable agreement even though core-specific changes vary quite considerably later on.

Lago Tovel (3321)



There is considerable variability in the SAR records of the seven cores taken from across the basin of Lago Tovel as part of the SALTO-BEST project. There is good agreement in temporal trends and SARs for the shallow water cores TOV03-19, TOV04-RB3 and TOV04-RB5 although the fourth shallow core TOV01-1 shows no change. There is also good agreement in 1875 and 1900 SARs for those cores with data with the exception of TOV03-513. However, the deep-water cores TOV03-513 (33m) and TOV01-5 (40m) show quite differing SARs and trends. Unfortunately, unlike those cores from the shallower areas, there are no 'duplicates' for the deep water cores (i.e. they were taken from quite different depths) and therefore little consensus can be drawn about the site apart from the substantial variability and that for cores taken from similar areas (i.e. the shallow cores) there are reasonably repeatable SAR values and trends.

In summary, there is considerable variability in SARs from multiple cores taken across full lake sediment basins. However, where cores are taken from representative deep-water areas (and even comparable shallow water areas in some cases e.g. Tovel), then there is good agreement between multiple cores in terms of general trends and more particularly an 'early' SAR which might be used for a reference. Consequently, we conclude that SAR data from sediment cores taken from deep water areas are likely to be representative of that lake sediment basin and therefore, single sediment cores from a site can be used in subsequent SAR data analysis.

Part 2: Sediment Accumulation Rates for lake-types

(i) Classes with >10 sites

Nine lake-type classes include more than 10 sites and the data from these are shown and described in the following section. These data are presented in two ways. First a table of the SARs (in g cm^{-2} yr^{-1}) for each 25 years are shown for each core together with the surface SAR (where this is not 2000). These are then colour coded to show the percentage change in SAR from the previous 25 year value. The colour codes are as follows:

> 50% increase
10 - 50% increase
<10%>
10 - 50% decrease
>50% decrease

To allow for some natural variability, SAR which varies by ± 10% are coloured green. Thus, a core completely shaded green does not necessarily mean no change throughout the core. Where SAR increases by 10 – 50% and by more than 50% over the previous 25-year value these are shaded orange and red respectively. Similar SAR decreases are shaded pale blue and dark blue. Consequently, sites changing from green to orange through time are showing continued SAR increases e.g. Lochnagar (NAG3):

1875	1900	1925	1950	1975	1986
0.0068	0.0068	0.0068	0.0083	0.0157	0.0289

while a site which shows an increase in SAR and then remains at this higher level will show orange and / or red followed by green showing the SAR has stabilised at the higher level e.g. Lough Maam (MAAM3):

1850	1875	1900	1925	1950	1975	1988
0.0076	0.0076	0.0076	0.0076	0.0076	0.014	0.014

and sites which show significant increases and decreases through time show both orange/red and blues e.g. Burnmoor Tarn (BURN 1):

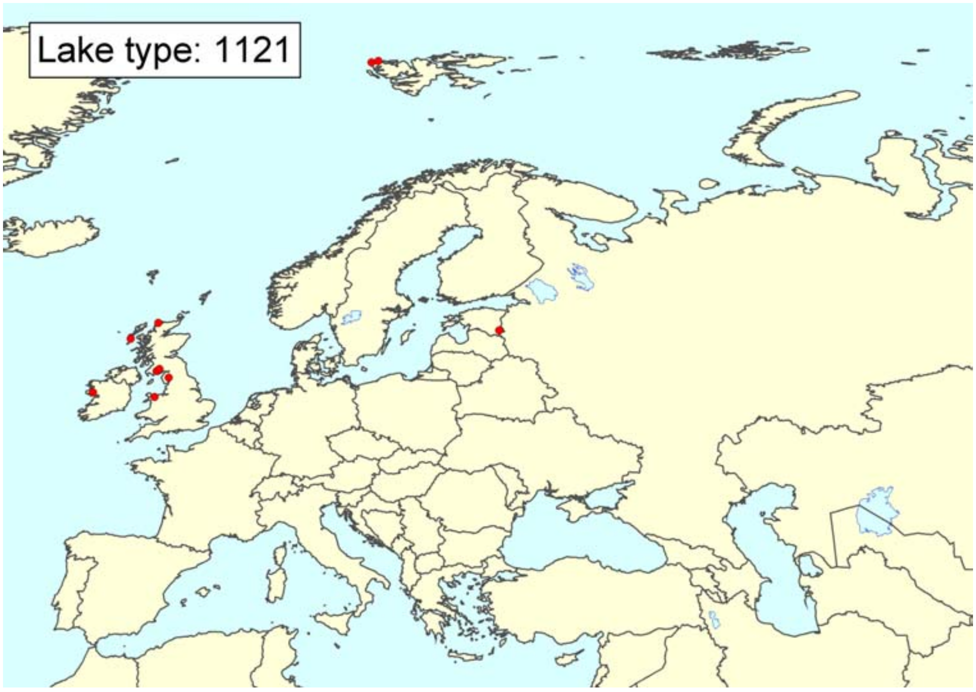
1850	1875	1900	1925	1950	1975	1989
0.0159	0.0302	0.0388	0.0252	0.1044	0.0338	0.0604

In this way it is rapidly clear which sites have shown little or no change, which sites have shown continued increases over the 150 period and which have shown variable rates.

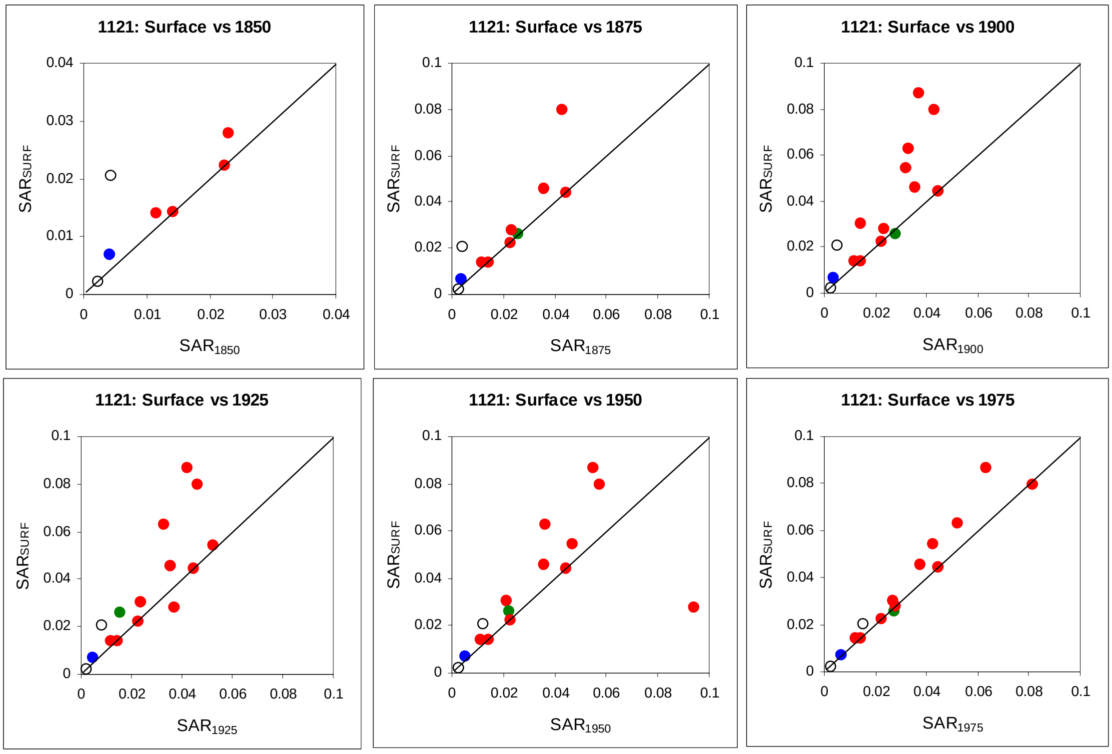
Secondly, the values for each 25 year period are shown scattered against the surface sediment SAR together with a 1:1 line. Thus, sites above the line show a higher surface SAR than that for the 25 year value and those below the line a SAR decrease in the surface sediments. Looking through the sequence of figures therefore provides an indication of the period at which SARs changed for this lake type as the data points will move closer to the line as they approach the surface SAR value. For example, Class 1121 shows a shift towards the line when comparing the 1950 and 1975 values suggesting that an increase in SAR generally occurred for this class between these dates. For these Figures, the sites are coloured by country.

Finally, the mean and standard deviation of the basal SAR is provided for each class and some assessment as to whether this may be considered a reasonable reference SAR for this lake-type included.

Class:	**1121**						
Alkalinity:	< 0.2 μeq l⁻¹	*Altitude:*	<200 m	*Max. depth:*	> 5 m	*Lake area:*	<50 ha
No. lakes:	10	*No. cores:*	15				
Description: Small, low-lying, deep lakes mainly situated on western seaboard of UK, Ireland and Svalbard							



Site name	Country	1850	1875	1900	1925	1950	1975	2000	SURFACE
Arresjøen	SJ	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023		0.0023
Birgervatnet	SJ	0.0043	0.0042	0.0049	0.0081	0.012	0.0152		0.0206
Brotherswater	GB			0.033	0.033	0.0361	0.0519		0.0631
Brotherswater	GB		0.0429	0.0429	0.0463	0.0573	0.0815		0.0797
Brotherswater	GB		0.0444	0.0444	0.0444	0.0444	0.0444		0.0444
Brotherswater	GB			0.0368	0.0423	0.0547	0.0629		0.0868
Brotherswater	GB		0.0356	0.0356	0.0356	0.0356	0.0376		0.0458
Brotherswater	GB			0.0319	0.0522	0.0469	0.0424		0.0546
Llyn Geirionydd	GB			0.0139	0.0234	0.0213	0.027		0.0304
Loch na Larach	GB	0.0142	0.0142	0.0142	0.0142	0.0142	0.0142		0.0142
Lough Maumwee	IE		0.0256	0.0277	0.0154	0.0223	0.0271		0.026
Loch Skerrow	GB	0.023	0.023	0.023	0.037	0.094	0.028		0.028
Loch Teanga	GB	0.0115	0.0115	0.0115	0.0119	0.0112	0.012		0.0141
Loch Urr	GB	0.0224	0.0224	0.0224	0.0224	0.0224	0.0224		0.0224
Nohipalu Valgjärv	EE	0.004	0.0037	0.0033	0.0047	0.0051	0.0068	0.0076	0.0069



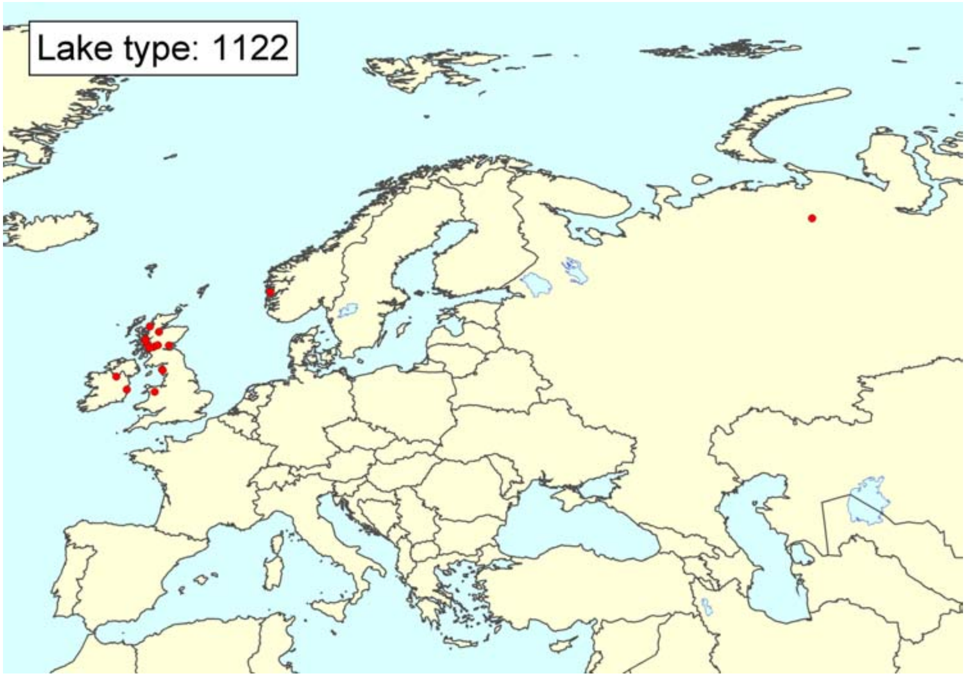
Red = GB; Green = IE; White = SJ; Blue = EE.

In general SARs increase through time for this class. There are only very few instances of SAR declines and this is confirmed by the scatter plots where almost all datapoints lie above the 1:1 line for all time periods. Four of the 15 cores show no SAR change throughout the period while four cores show peak SAR in the surface sediments. Little change in SAR occurs at these sites prior to 1900. However, from this time, and in all subsequent periods, 5 – 7 cores show SAR increases of 10 – 50% or > 50% over the previous 25 year period. Most of these increases are by 10 – 50% suggesting steady rather than dramatic SAR increases at these sites.

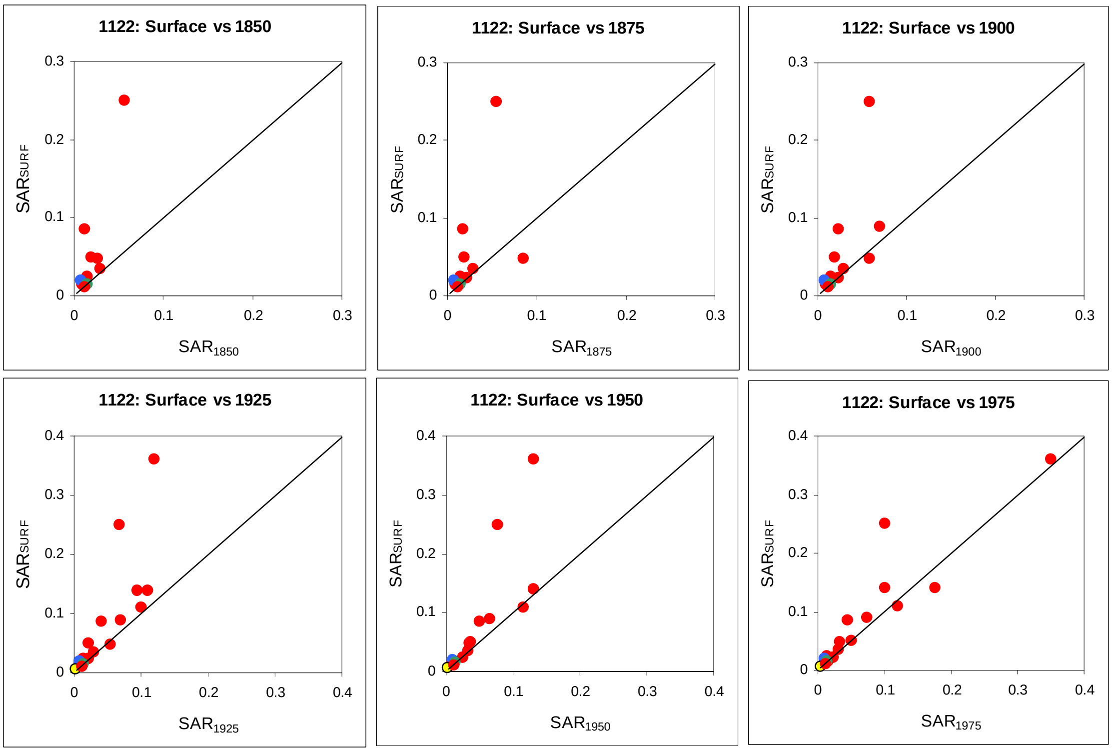
The mean SAR for 1850 is 0.0117 g cm^{-2} yr^{-1} with a standard deviation of 0.0087 g cm^{-2} yr^{-1} (N = 7). However, these 1850 SAR values vary by more than an order of magnitude. It is therefore not possible to estimate an 1850 reference SAR with any confidence for this lake class. Rather, the variability appears to be more geographical with lakes in Estonia and Svalbard showing the lowest SAR in each time period and those from the UK the highest.

Class:	**1122**						
Alkalinity:	< 0.2 µeq l^{-1}	*Altitude:*	<200 m	*Max. depth:*	> 5 m	*Lake area:*	>50 ha
No. lakes:	16	*No. cores:*	17				

Description: Large, low-lying deep lakes situated in western areas of UK. Few sites in Norway, Ireland and Russia.



Site name	Country	1850	1875	1900	1925	1950	1975	2000	SURFACE
Loch Awe	GB	0.019	0.019	0.019	0.022	0.036	0.051		0.05
Castle Loch	GB				0.1	0.115	0.12		0.11
Loch Chon	GB	0.008	0.008	0.008	0.0084	0.0104	0.0161		0.0143
Loch Chon	GB	0.014	0.014	0.014	0.014		0.014		0.025
Loch Doilet	GB	0.0119	0.0179	0.0238	0.0405	0.0507	0.0438		0.0863
Loch Eck	GB				0.11	0.13	0.1		0.14
Ennerdale Water	GB		0.022	0.0225	0.022	0.0255	0.024		0.023
Kalandsvatenet	NO	0.0076	0.0076	0.0078	0.008	0.0103	0.0105		0.02
Loch Lubnaig	GB			0.07	0.07	0.066	0.074		0.09
Loch Maree	GB	0.056	0.055	0.058	0.067	0.076	0.1		0.25
Loch Ness	GB	0.0253	0.0844	0.0586	0.053	0.0346	0.0338		0.0485
Oughter Lough	GB				0.12	0.13	0.35		0.36
Llyn Tegid	GB				0.095	0.13	0.175		0.14
Loch Uisge	GB	0.0287	0.0287	0.0287	0.0287	0.0329	0.0313		0.0343
Vankarat	RU				0.002	0.0022	0.0029		0.0056
Lough Veagh	IE	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143		0.0143
Wastwater	GB	0.011	0.011	0.011	0.011	0.011	0.011		0.011



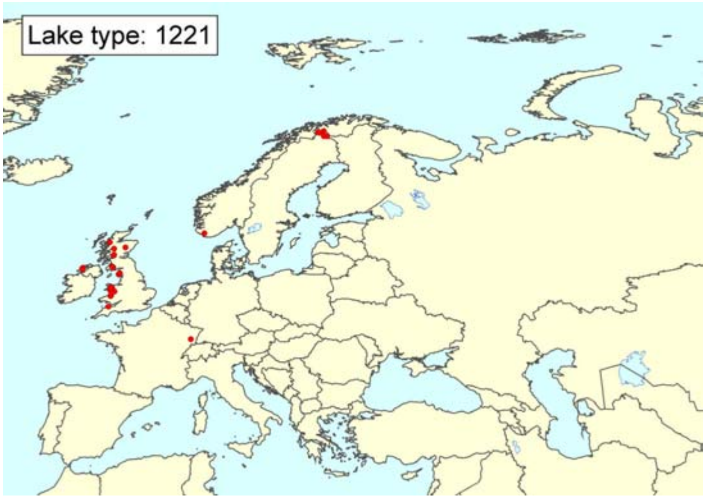
Red = GB; Green = IE; Blue = NO; Yellow = Russia.

In general SARs increase through time for this class and there are only a few instances of SAR declines. This is confirmed by the scatter plots where almost all data points lie above the 1:1 line for all time periods. Only two of the 15 cores show no SAR change throughout the period while four cores show peak SAR in the surface sediments. With the exception of Loch Doilet which shows some large increases from the earliest periods and Loch Ness which shows considerable variability through time, most of the increases in SAR occur post-1925. In particular, 11 of the 15 cores show at least a 10 – 50% increase in SAR between 1925 and 1950. However, the most dramatic period of SAR increase appears to occur post-1975, i.e. in the most recent sediments, where SAR increases of > 50% occur in five cores.

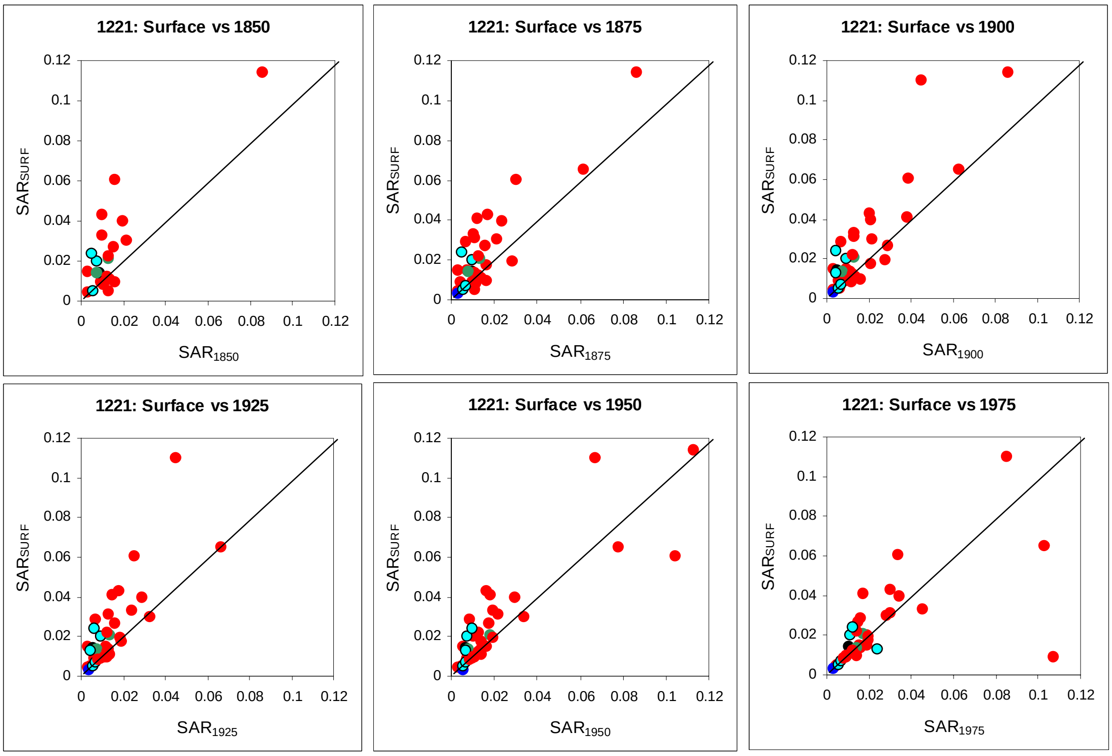
The mean SAR for 1850 is 0.0196 g cm^{-2} yr^{-1} with a standard deviation of 0.0146 g cm^{-2} yr^{-1} (N = 10). The range for these ten 1850 values is 0.008 – 0.0287 g cm^{-2} yr^{-1} which although considerable is by no means the order of magnitude variability observed in Class 1121. Therefore, it may be that a SAR of 0.0196 ± 0.0146 is not an unreasonable reference 1850 SAR for this lake class.

Class:	**1221**						
Alkalinity:	< 0.2 μeq l^{-1}	*Altitude:*	200-800 m	*Max. depth:*	> 5 m	*Lake area:*	<50 ha
No. lakes:	31	*No. cores:*	37				

Description: Small, deep, mid-altitude lakes mainly situated in upland areas of the UK. Additonal sites in NE Finland, NW Ireland, E France and S Norway. Sites used for SWAP and UK AWMN.



Site name	Country	1850	1875	1900	1925	1950	1975	2000	SURFACE
Llyn Berwyn	GB		0.0616	0.0625	0.0666	0.0776	0.1029		0.0655
Burnmoor Tarn	GB	0.0159	0.0302	0.0388	0.0252	0.1044	0.0338		0.0604
Llyn Clyd	GB	0.003	0.003	0.003	0.003	0.0056	0.015		0.015
Loch Coire an Lochan	GB	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094		0.0094
Loch Coire Fionnaraich	GB		0.007	0.009	0.0115	0.016	0.019	0.015	0.015
Llyn Conwy	GB	0.0213	0.0213	0.0217	0.0329	0.0339	0.0284		0.0303
Lac des Cordeaux	FR	0.0084	0.0095	0.0051	0.0055	0.0068	0.0102		0.0145
Llyn Cwm Mynach	GB	0.0028	0.0028	0.0028	0.0028	0.0028	0.004		0.0047
Llyn Dulyn	GB		0.0043	0.0058	0.0062	0.0075	0.107		0.0091
Loch Fleet	GB	0.086	0.086	0.086	0.274	0.113	0.786		0.114
Llyn Glas	GB		0.011	0.013	0.013	0.022	0.03		0.031
Llyn Gynon	GB	0.0193	0.0233	0.0211	0.0288	0.0295	0.0345		0.0397
Llyn Hir	GB	0.0131	0.0108	0.006	0.0046	0.0049	0.0049		0.0049
Llyn Irddyn	GB	0.0155	0.0155	0.0288	0.0159	0.0175	0.0149		0.027
Ljosvatn	NO		0.0029	0.00305	0.0038	0.0056	0.0033		0.0031
Llyn Llagi	GB		0.0165	0.0212	0.0191	0.0138	0.0196		0.0177
Llyn Llagi	GB		0.011	0.011	0.0128	0.0141	0.016		0.0135
Llyn Llygad Rheidol	GB	0.01	0.017	0.02	0.018	0.0165	0.03		0.043
Llyn Llygad Rheidol	GB	0.01	0.01	0.013	0.024	0.019	0.0455		0.033
Lochnagar	GB		0.0068	0.0068	0.0068	0.0083	0.0157		0.0289
Lochnagar	GB		0.0095	0.0095	0.0095	0.01	0.019		0.0201
Lochnagar	GB		0.012	0.038	0.015	0.018	0.017		0.041
Lough Maam	IE	0.0076	0.0076	0.0076	0.0076	0.0076	0.014		0.014
Mallajarvi	FI	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054
Masehjarvi	FI		0.0069	0.0069	0.0069	0.0069	0.0069		0.0069
Lough Muck	IE	0.0131	0.0131	0.0131	0.0137	0.018	0.0169		0.021
Loch Narroch	GB	0.016	0.016	0.016	0.012	0.011	0.014		0.01
Pinkworthy Pond	GB			0.045	0.045	0.067	0.085		0.11
Round Loch of Glenhead	GB	0.0103	0.0115	0.0115	0.0082	0.0082	0.0082		0.0082
Round Loch of Glenhead	GB	0.0124	0.0124	0.0124	0.0124	0.0124	0.0124		0.0124
Scoat Tarn	GB	0.0136	0.0136	0.0136	0.0136	0.0136	0.0118		0.0108
Somas	FI	0.0076	0.0098	0.0094	0.0093	0.0074	0.011	0.02	0.02
Loch Tinker	GB		0.0284	0.0278	0.0184	0.0193	0.0194		0.0193
Loch Tinker	GB	0.0126	0.0126	0.0126	0.0126	0.0126	0.0142		0.0223
Tsuolbmajarvi	FI			*0.004*	0.004	0.0065	0.024	0.013	0.013
Loch Valley	GB	0.0111	0.0111	0.0111	0.0111	0.01	0.009		0.01
Vallijarvi	FI	0.0046	0.0046	0.0046	0.0064	0.0098	0.012	0.024	0.024



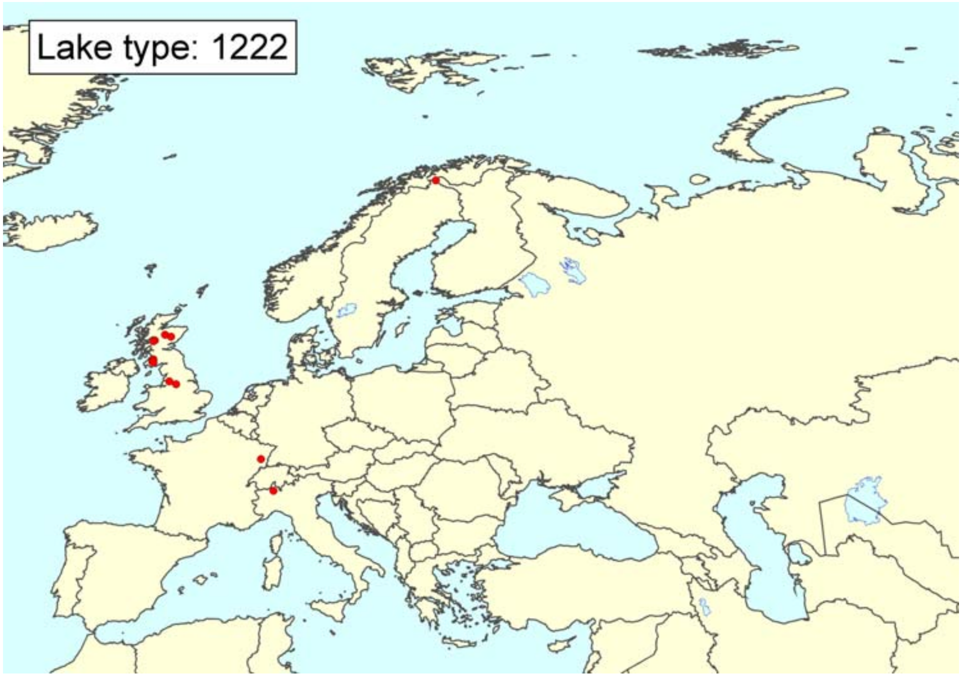
Red = GB; Green = IE; Blue = NO; Light blue = FI

This class represents the largest group in this dataset as it corresponds to upland sites, mainly in the UK and Scandinavia, that have been used for acidification studies. While trends in SAR appear to be more variable than the previous two classes, much of this variability is confined to a few sites (e.g. Loch Fleet; Llyn Dulyn; Burnmoor Tarn) and SARs still generally increase through time at most sites. This is supported by the scatter-plots where most points lie above the 1:1 lines although more datapoints are now observed below. Only four of the 37 cores show no SAR change throughout the period while 11 cores show peak SAR in the surface sediments. Although SAR increases (and to a lesser extent decreases) are observed in all time periods, most of the major (> 50%) SAR increases occur post-1950. In particular, the period between 1950 and 1975 shows 12 instances of SAR increases between 10 – 50% and an additional 9 increases in SAR of > 50%.

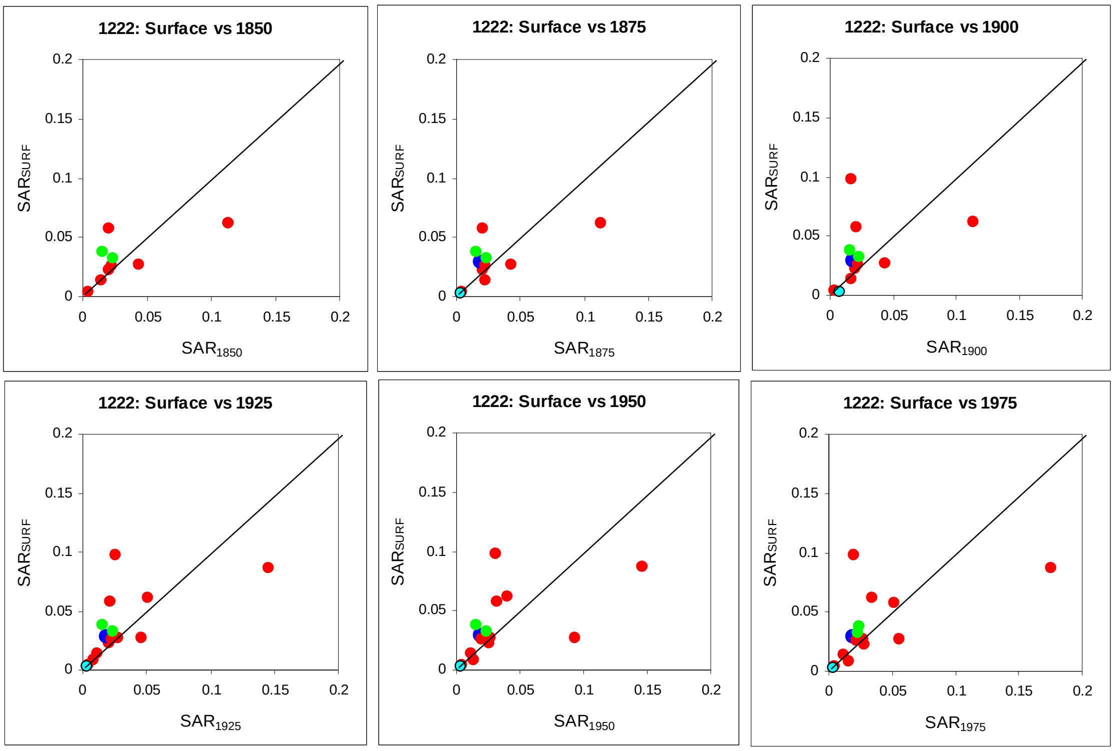
The mean SAR for 1850 is 0.0143 g cm^{-2} yr^{-1} with a standard deviation of 0.0163 g cm^{-2} yr^{-1} (N = 23) while the range for these values is 0.003 – 0.0213 g cm^{-2} yr^{-1}. This range of almost an order of magnitude emphasises the observed variability but this may be elevated by a few highly variable sites. Given the large number of sites in this class and the variable nature of some individual sites, this mean is perhaps not an unreasonable reference for an 1850 SAR for this lake class.

Class:	**1222**						
Alkalinity:	< 0.2 μeq l^{-1}	*Altitude:*	200-800 m	*Max. depth:*	> 5 m	*Lake area:*	>50 ha
No. lakes:	13	*No. cores:*	16				

Description: Large, deep, mid-altitude lakes mainly situated in northern UK. Additonal sites in NE Finland, N Italy, E France



Site name	Country	1850	1875	1900	1925	1950	1975	2000	SURFACE
Loch Dee	GB	0.113	0.113	0.113	0.051	0.04	0.034		0.062
Loch Dee	GB	0.02	0.02	0.02	0.02	0.026	0.028		0.023
Loch Doon	GB	0.043	0.043	0.043	0.046	0.093	0.055		0.027
Loch Einich	GB				0.0082	0.0135	0.015		0.0086
Loch Enoch	GB				0.027	0.027	0.027		0.027
Lac de Gerardmer	FR		0.018	0.018	0.018	0.018	0.018		0.029
Loch Grannoch	GB	0.052	0.052	0.052	0.082	0.033	0.309		0.301
Loch Grannoch	GB	0.0207	0.0207	0.0207	0.0213	0.0313	0.0517		0.0584
Howden Reservoir	GB				0.1452	0.1455	0.175		0.087
Loch Laidon	GB	0.014	0.022	0.016	0.011	0.011	0.011		0.014
Loch Muick	GB	0.022	0.022	0.022	0.022	0.019	0.022		0.026
Loch na h'Achlaise	GB	0.0036	0.0036	0.0036	0.0036	0.0038	0.004		0.004
Orta	IT	0.015	0.015	0.015	0.015	0.015	0.024		0.038
Orta	IT	0.023	0.023	0.023	0.023	0.023	0.023		0.033
Tsahkaljarvi	FI		0.0031	0.0069	0.0034	0.0034	0.0034		0.0034
Turton & Entwistle Res.	GB			0.017	0.025	0.031	0.019		0.098



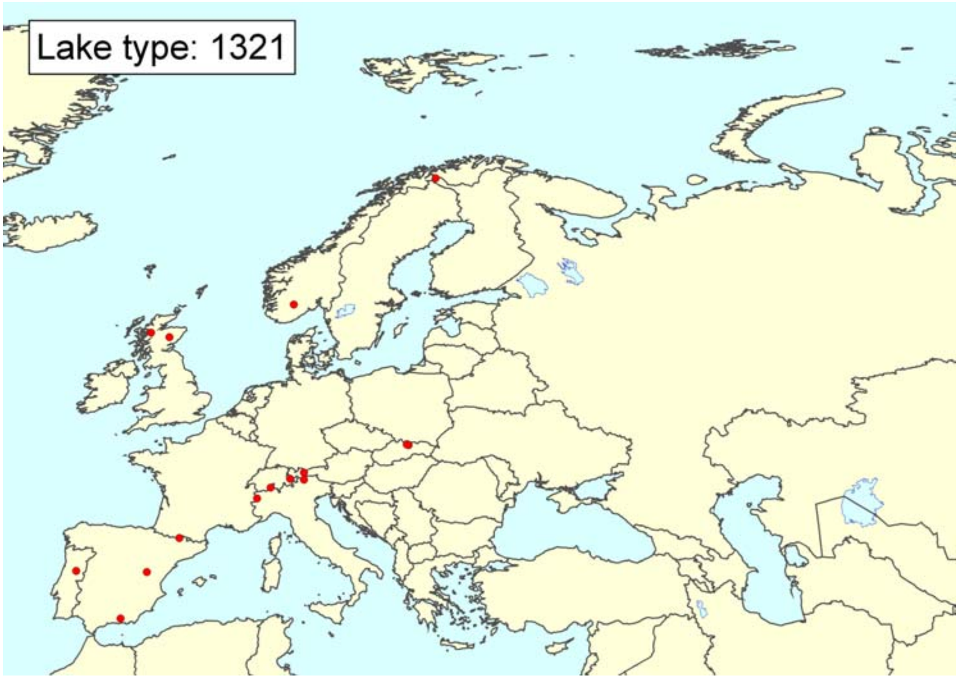
Red = GB; Light Green = IT; Blue = FR; Light blue = FI

SARs appear to be more variable for this class and the number of periods for which SAR increases and decreases occur are more equal, although there are fewer dramatic decreases (> 50% reduction) than increases. This is also observed in the scatter-plots. Some of the sites for which considerable variability occurs (e.g. Loch Dee and Loch Grannoch) have afforested catchments and this process will certainly have affected the SAR of these sites, a situation that is also observed in other classes (see for example Class 1221 – Loch Fleet). Only one of the 16 cores shows no SAR change throughout the period. Most SAR increases > 10% occur after 1925 while 5 cores show peak SAR in the surface sediments.

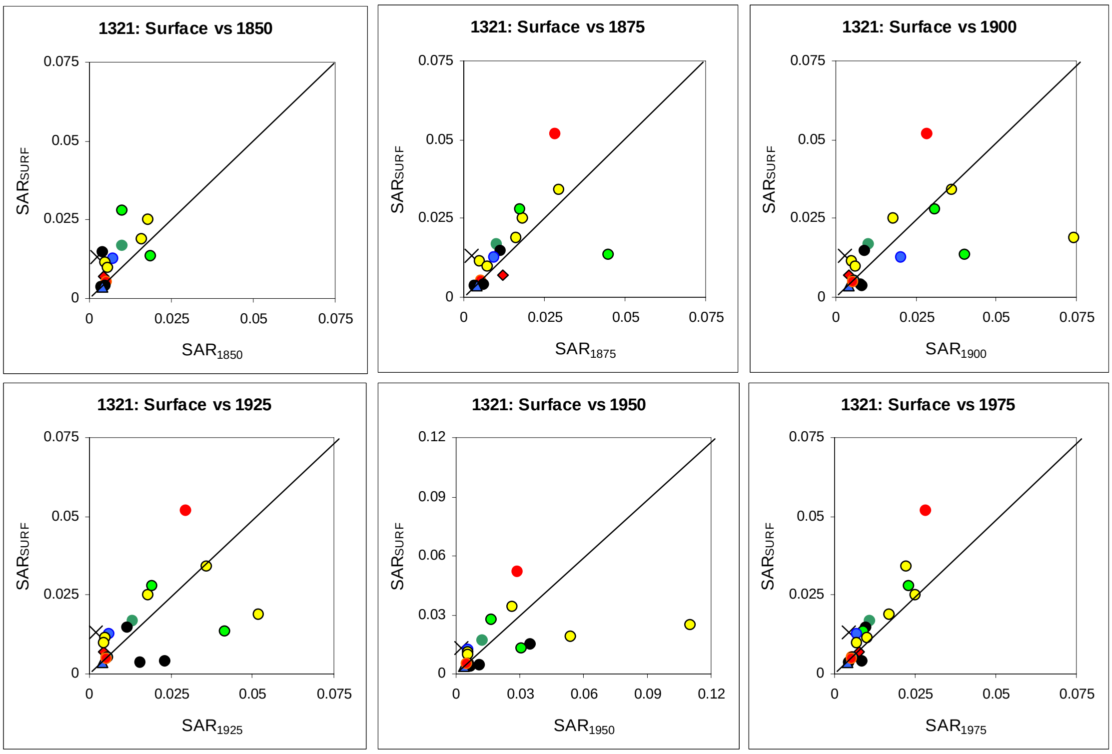
The mean SAR for 1850 is 0.0326 g cm^{-2} yr^{-1} with a standard deviation of 0.0315 g cm^{-2} yr^{-1} (N=10) These values are considerably higher than those for the classes described above but are undoubtedly affected by a single high value for Loch Dee (0.113 g cm^{-2} yr^{-1}) without which the range for these nine 1850 values is 0.02 – 0.052 g cm^{-2} yr^{-1}, the mean is 0.0237 g cm^{-2} yr^{-1} and the standard deviation is 0.0149g cm^{-2} yr^{-1} (N = 9). While this value remains higher than the other classes, this value appears more representative of this class and therefore it may be that a SAR of 0.0237 ± 0.0149 g cm^{-2} yr^{-1} is not an unreasonable reference 1850 SAR for this lake-type.

Class:	**1321**						
Alkalinity:	< 0.2 μeq l^{-1}	*Altitude:*	> 800 m	*Max. depth:*	> 5 m	*Lake area:*	< 50 ha
No. lakes:	16	*No. cores:*	20				

Description: Small, deep, mountain lakes. Sites for EU AL:PE, AL:PE2, MOLAR and EMERGE projects



Site name	Country	1850	1875	1900	1925	1950	1975	2000	SURFACE
Laguna Caldera	ES	0.018	0.018	0.018	0.018	0.11	0.025		0.025
Laguna Cimera	ES		0.0295	0.036	0.036	0.0265	0.022		0.034
Laguna Cimera	ES	0.016	0.016	0.074	0.052	0.054	0.017		0.019
Dlugi Staw Gasiencowy	PL	0.0044	0.0122	0.004	0.0043	0.0058	0.0078		0.0068
Laguna Escura	PT	0.01	0.01	0.01	0.013	0.012	0.011		0.017
Loch nan Eun	GB	0.0053	0.0053	0.0053	0.0053	0.0053	0.0053		0.0053
Gossenköllesee	AT	0.0022	0.0023	0.0027	0.0019	0.0026	0.0044		0.0132
Jörisee	CH	0.006	0.006	0.0066	0.0094	0.017	0.03		0.13
Ladove	SK	0.0041	0.0114	0.0089	0.0117	0.035	0.0097	0.0149	0.0149
Milchsee	IT	0.0188	0.0447	0.0403	0.0415	0.0306	0.009		0.0134
Nizné Terianske Pleso	SK	0.0048	0.0062	0.0076	0.0232	0.0111	0.0084		0.0043
Nizné Terianske Pleso	SK	0.0034	0.0034	0.0083	0.0154	0.0067	0.0044		0.0038
Lac Noir	FR	0.007	0.0092	0.0201	0.006	0.0053	0.007		0.0127
Paione Superiore	IT	0.0101	0.0175	0.0307	0.019	0.0163	0.0231		0.0279
Estany Redó	ES	0.0048	0.0048	0.0048	0.0048	0.0056	0.0099		0.0114
Estany Redó	ES	0.0054	0.0072	0.0059	0.0045	0.0056	0.0069		0.0099
Stavsvatn	NO	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039		0.0039
Stuoramohkki	FI			0.0055	0.0055	0.0055	0.0055	0.0055	0.0055
Lochan Uaine	GB		0.0283	0.0283	0.0294	0.0288	0.0283		0.052
Lochan Uaine	GB			0.0051	0.0051	0.0051	0.0051		0.0051



○: Red = GB; Yellow = ES; light blue = FI; light green = IT; white = CH; black = SK; dark green = PT; dark blue = FR; ◇: Red = PL; △: Blue = NO: ×= AT.

This class includes those lakes studied as part of EU funded mountain lake research projects and represents the largest geographical diversity of any SAR class covering 11 countries. There is considerable variability within this class and this maybe due to small changes to low SARs i.e. in these mountain lakes small changes in SAR equate to higher percentage changes. However, SARs in these small lake systems may also be greatly affected by in-washes from steep and rocky catchments and this may account for sites where major increases in SAR are followed by major decreases (e.g. Nizne Terianske Pleso). This variability is also observed in the scatter plots. Increases and decreases occur throughout the period although it is notable that in the most recent data 12 out of the 20 cores show SAR increases >10% and of these 5 are > 50%. Only four of the 20 cores show no SAR change throughout the period while three cores show peak SAR in the surface sediments.

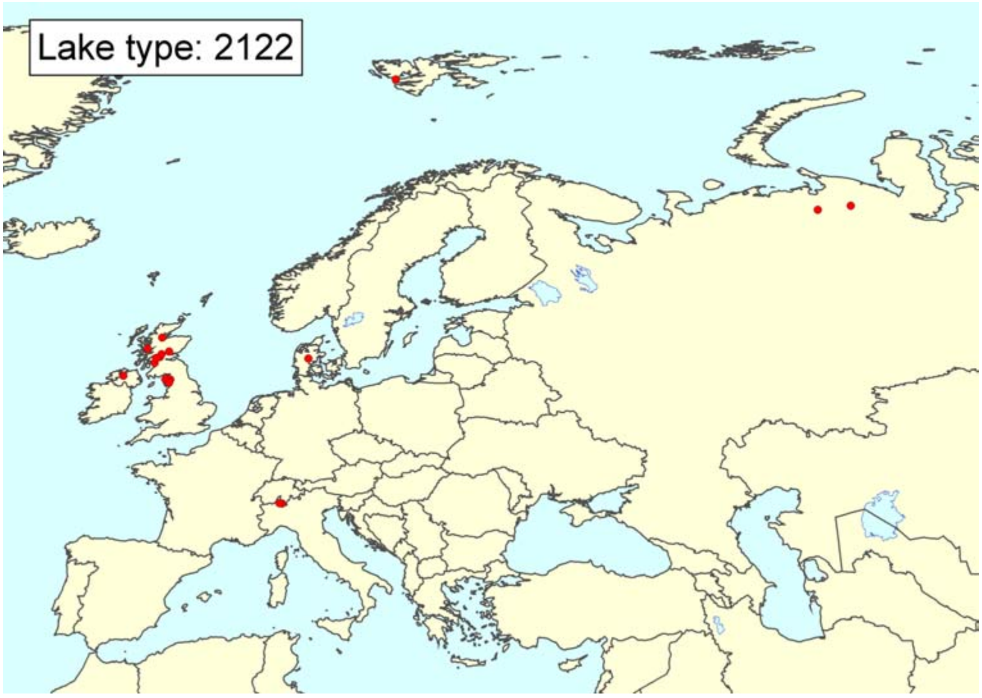
As might be expected SARs are also generally lower for this class than for any other although the recent SAR in Jorisee reaches 0.13 g cm^{-2} yr^{-1}, more than 20 times higher than its 1850 value. The mean SAR for 1850 is 0.0077 g cm^{-2} yr^{-1} with a standard deviation of 0.0053 g cm^{-2} yr^{-1} (N = 16). While this mean value is considerably higher than some of the individual 1850 SARs, it is of interest to note that the SAR for those cores which show no change throughout (i.e. Loch nan Eun 0.0053 g cm^{-2} yr^{-1}; Stavsvatn 0.0039 g cm^{-2} yr^{-1}; Lochan Uaine 0.0051 g cm^{-2} yr^{-1}; Stuoramohkki 0.0055 g cm^{-2} yr^{-1}) are quite consistent. Therefore it may be that a SAR of around 0.005 ± 0.003 g cm^{-2} yr^{-1} is not an unreasonable reference 1850 SAR for this lake class.

Class: **2122**

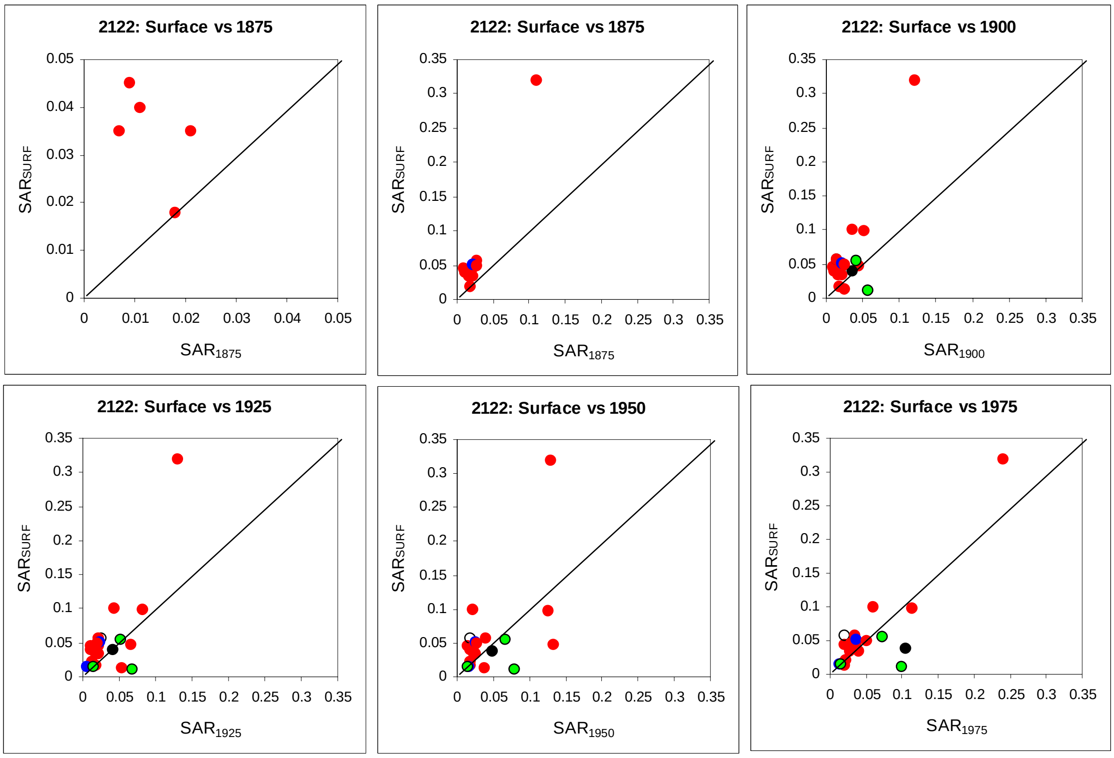
Alkalinity: 0.2 - 1 μeq l^{-1} *Altitude:* < 200 m *Max. depth:* > 5 m *Lake area:* > 50 ha

No. lakes: 18 *No. cores:* 21

Description: Large, deep, lowland lakes situated mainly in northern UK with additional sites in Denmark, N. Italy, Svalbard and Russia.



Site name	Country	1850	1875	1900	1925	1950	1975	2000	SURFACE
Lough Ash	GB	0.009	0.009	0.009	0.01	0.014	0.02	0.045	0.045
Bassenthwaite Lake	GB			0.052	0.083	0.126	0.114		0.098
Loch Earn	GB			0.045	0.066	0.133	0.036		0.047
Esthwaite Water	GB			0.036	0.043	0.022	0.06		0.1
Kilbirnie Loch	GB	0.018	0.018	0.018	0.018	0.018	0.018		0.018
Knud Soe	DK			0.036	0.041	0.049	0.104		0.039
Kongresvatnet	SJ			0.0135	0.025	0.017	0.019	0.057	0.057
Loch Lomond	GB			0.024	0.054	0.038	0.02		0.013
Loch Lomond	GB				0.013	0.018	0.022		0.022
Loch of the Lowes	GB	0.011	0.011	0.01	0.011	0.018	0.03		0.04
Loweswater	GB		0.022	0.022	0.022	0.0235	0.0285		0.046
Maggiore	IT			0.056	0.067	0.079	0.099		0.0119
Maggiore	IT			0.041	0.051	0.066	0.072		0.056
Malinkaya	RU				0.006	0.016	0.012		0.015
Lake of Menteith	GB	0.022	0.027	0.015	0.022	0.04	0.034		0.057
Mergozzo	IT				0.015	0.015	0.015		0.015
Podvaty	RU	0.022	0.022	0.022	0.0235	0.0245	0.036		0.051
Loch Shiel	GB	0.021	0.021	0.021	0.022	0.024	0.027		0.035
Loch Ussie	GB		0.11	0.12	0.13	0.13	0.24		0.32
Windermere	GB	0.007	0.016	0.0155	0.0185	0.026	0.039		0.035
Windermere	GB		0.027	0.025	0.0205	0.0275	0.051		0.05



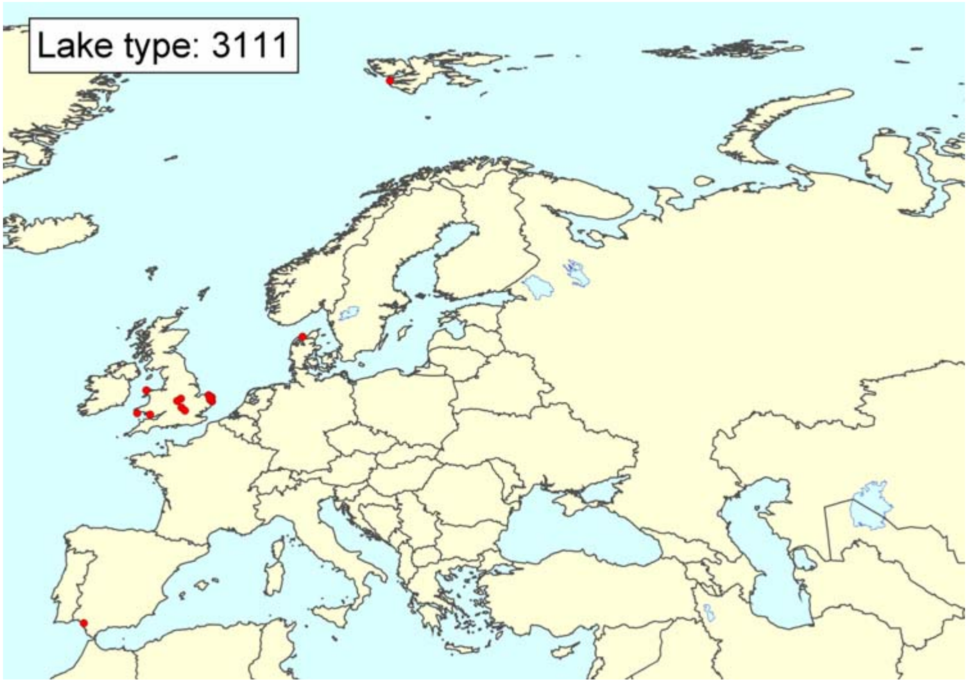
Red = GB; Black = DK; white = SJ; light green = IT; Blue = RU

SARs generally increase through time at most sites although there is considerable variability at a few (e.g. Loch Earn, Lago Maggiore, Knud Soe). This is supported by the scatter-plots where most points lie above the 1:1 lines particularly in the earlier plots. Only 2 of the 21 cores show no SAR change throughout the period while 8 of the 21 cores show peak SAR in the surface sediments. Little SAR change occurs prior to 1900 but after this there are considerable increases (and to a lesser extent decreases) observed in all time periods.

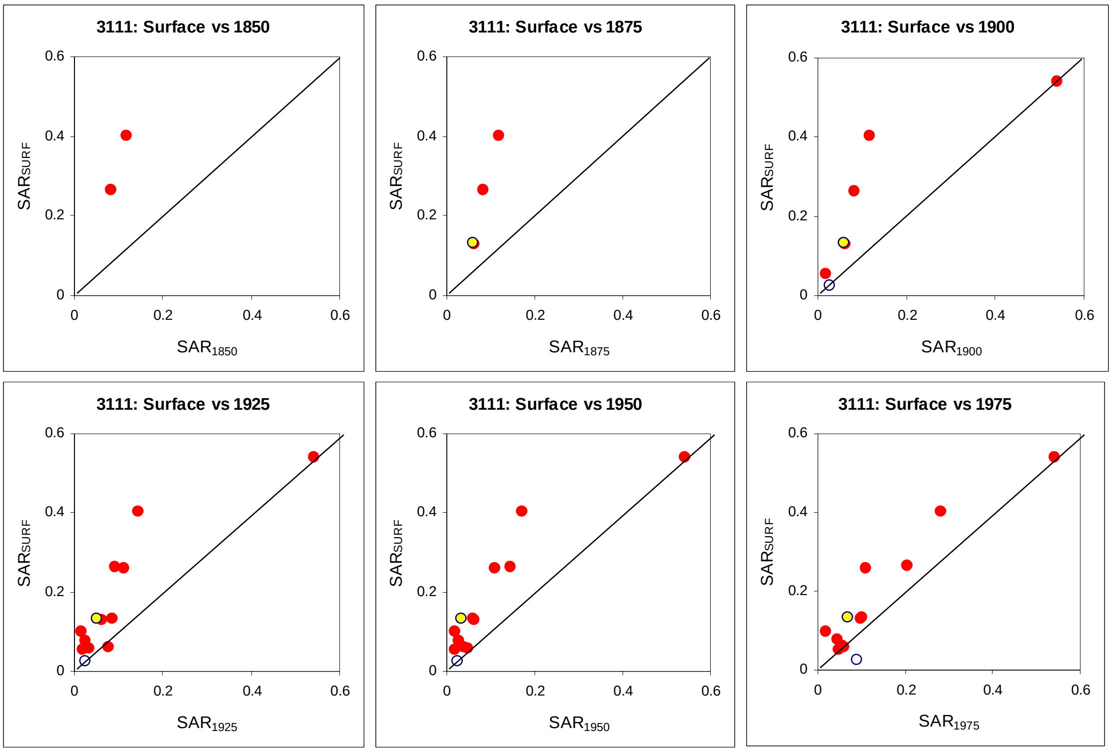
The mean SAR for 1850 is 0.0157 g cm^{-2} yr^{-1} with a standard deviation of 0.0065 g cm^{-2} yr^{-1} (N = 7) while the range for these values is 0.007 – 0.022 g cm^{-2} yr^{-1}. While this range is reasonably small the number of sites is also low and therefore, while 0.0157 ± 0.0065 may represent a reasonable reference for an 1850 SAR for this lake class, further data are required to confirm this value.

Class:	**3111**						
Alkalinity:	> 1 μeq l^{-1}	*Altitude:*	< 200 m	*Max. depth:*	< 5 m	*Lake area:*	> 50 ha
No. lakes:	12	*No. cores:*	13				

Description: Small, shallow, lowland lakes situated mainly in southern UK with additional sites in Denmark, Svalbard and S. Spain.



Site name	Country	1850	1875	1900	1925	1950	1975	2000	SURFACE
Barnby Broad	GB				0.022	0.026	0.043		0.078
Bosherston Lake	GB				0.11	0.11	0.11	0.23	0.26
Calthorpe Broad	GB				0.014	0.017	0.017	0.1	0.1
Eleven Acre Lake	GB			0.057	0.0858	0.0587	0.0997		0.1331
Felbrigg Hall Lake	GB		0.062	0.062	0.062	0.062	0.099		0.13
Kenfig Pool	GB				0.0764	0.038	0.057	0.065	0.062
Marsworth Reservoir	GB			0.54	0.54	0.54	0.54		0.54
Llyn Penrhyn	GB			0.017	0.017	0.017	0.047		0.054
Laguna Santa Ollala	ES		0.058	0.057	0.0506	0.0337	0.0688	0.1345	0.1345
Seeswood Pool	GB	0.081	0.081	0.081	0.09	0.143	0.205		0.265
Seeswood Pool	GB	0.117	0.117	0.117	0.144	0.17	0.282		0.403
Upton Broad	GB				0.033	0.046	0.06		0.06
Vassauga	SJ			0.027	0.022	0.023	0.089		0.025



Red = GB; Yellow = ES; white = SJ

With the exception of Vassauga on Svalbard, and Marsworth Reservoir in the UK, all sites in this class show considerable SAR increases. Marsworth Reservoir is the only core for which there is no SAR change throughout the dated period, while Vassauga shows major SAR increases and decreases such that the earliest and most recent SARs (1875 and 1995) are very similar. For the other sites, little change in SAR occurs prior to 1900 but 10 out of 13 cores show > 10% SAR increase between 1950 and 1975 and 9 of the 13 show the same increase between 1975 and the surface. In summary, it may be that not only are SARs increasing in lakes of this type, but that this increase in SAR is also accelerating. Given that this is a shallow lake class this could suggest a significant move towards lake-infilling.

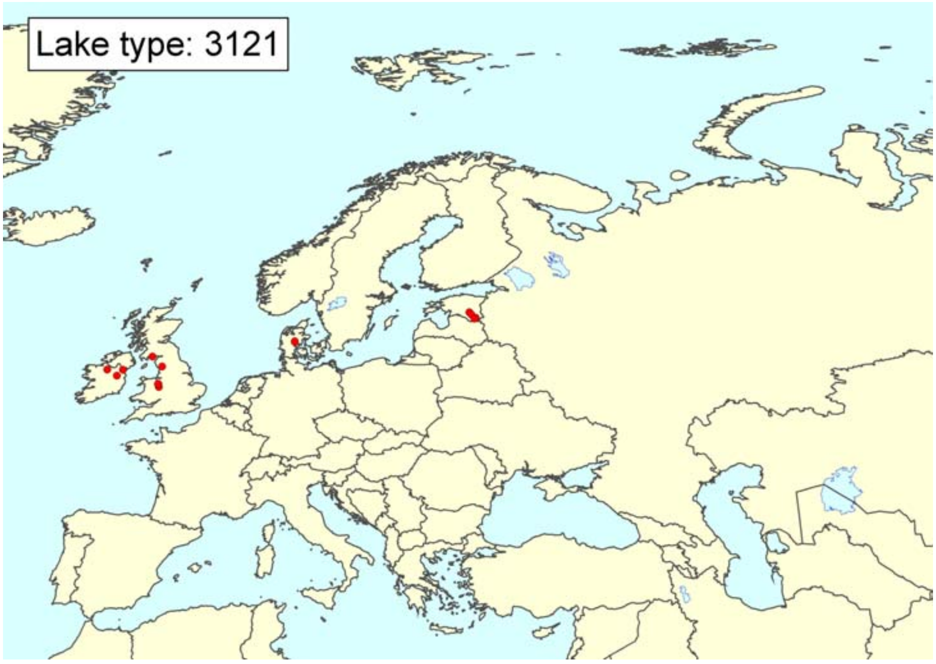
The mean SAR for 1850 is 0.099 g cm^{-2} yr^{-1} with a standard deviation of 0.0254 g cm^{-2} yr^{-1}. However, these data represent only two cores. The mean SAR for 1875 is slightly lower at 0.0795 g cm^{-2} yr^{-1} with a standard deviation of 0.0269 g cm^{-2} yr^{-1} but this also only considers four cores. Therefore although these values may represent a reasonable reference for the SAR for this lake class, further data are required to have any confidence in this value.

Class: **3121**

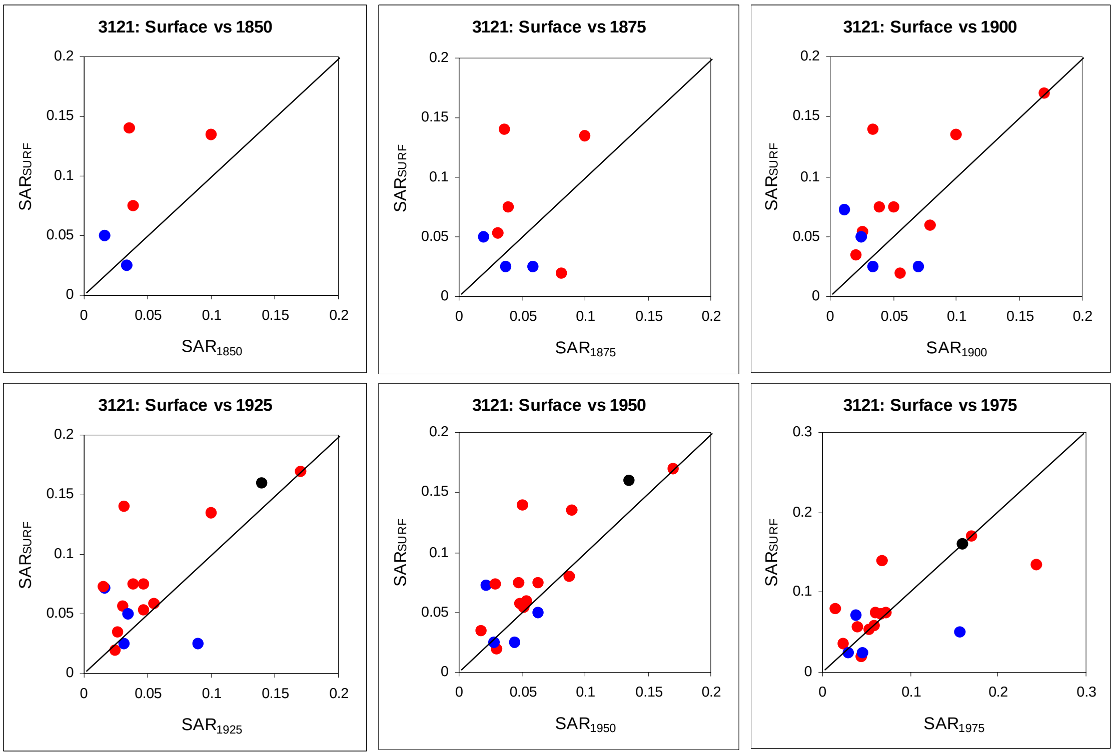
Alkalinity: > 1 μeq l^{-1} *Altitude:* < 200 m *Max. depth:* > 5 m *Lake area:* < 50 ha

No. lakes: 16 *No. cores:* 17

Description: Small, deep, lowland lakes situated in western UK, Ireland, Denmark and Estonia



Site name	Country	1850	1875	1900	1925	1950	1975	2000	SURFACE
Lough Ballywillin	GB					0.088	0.015		0.08
Betton Pool	GB	0.1	0.1	0.1	0.1	0.09	0.244		0.135
Bryrup Langsoe	DK				0.031	0.048	0.04		0.057
Carlingwark Loch	GB				0.14	0.135	0.16		0.16
Cole Mere	GB			0.021	0.027	0.018	0.023		0.035
Lough Corbet	GB			0.17	0.17	0.17	0.17		0.17
Lough Creeve	GB		0.0311	0.0258	0.0473	0.0515	0.0528		0.0538
Crose Mere	GB	0.039	0.039	0.039	0.039	0.063	0.061		0.075
Hawes Water	GB	0.036	0.036	0.034	0.032	0.05	0.068		0.14
Lough Heron	GB			0.05	0.047	0.047	0.073		0.075
Otepää Pikajärv	EE		0.0817	0.0552	0.0244	0.0304	0.0448	0.0183	0.0199
Pappjärv	EE	0.034	0.037	0.034	0.032	0.028	0.046	0.06	0.025
Rõuge Tõugjärv	EE		0.0585	0.0698	0.0901	0.0439	0.0293	0.0246	0.0246
Verevi	EE	0.016	0.02	0.025	0.035	0.063	0.156	0.073	0.05
White Lough	GB			0.011	0.016	0.022	0.039		0.072
White Lough	GB				0.015	0.029	0.067		0.073
White Mere	GB			0.079	0.055	0.054	0.059		0.059

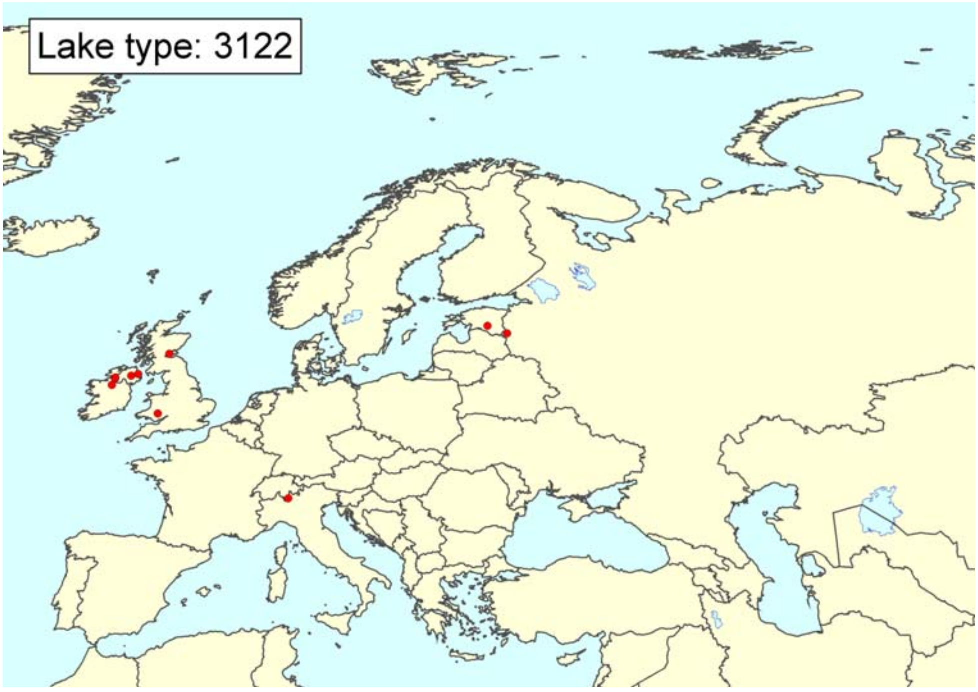


Red = GB; Black = DK; Blue = EE

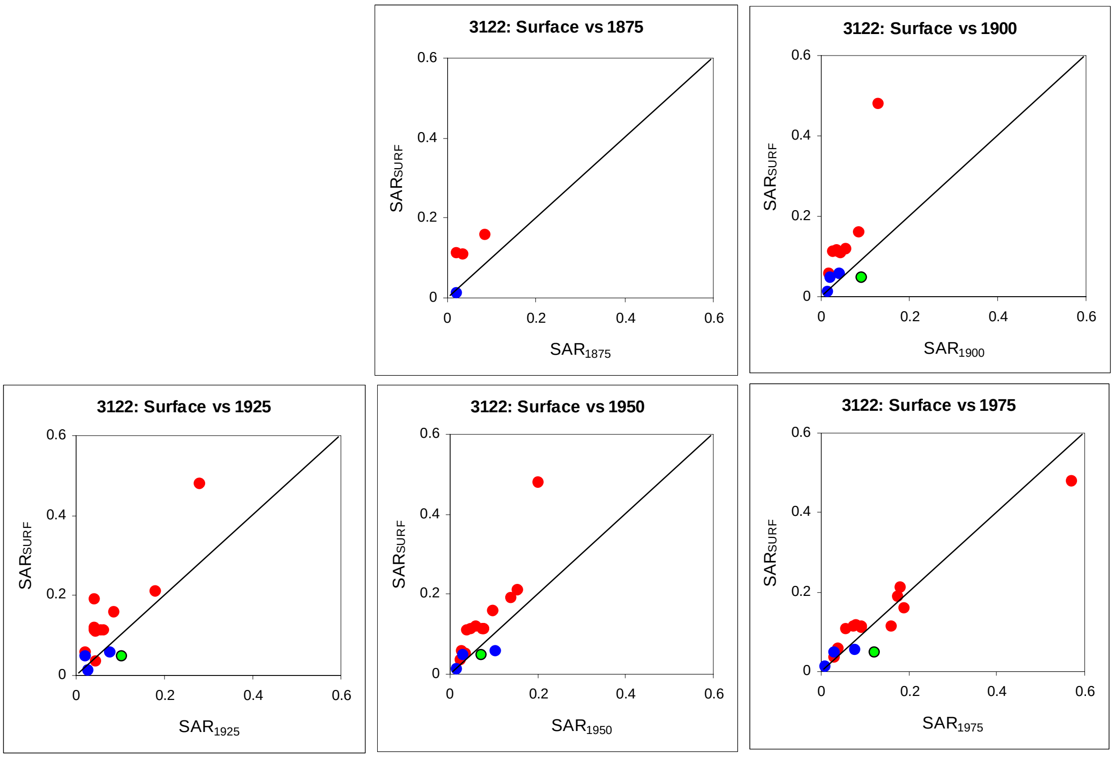
SARs generally increase through time at most sites although there is considerable variability at some. This is supported by the scatter-plots where there is considerable scatter about the 1:1 line. Only one of the 17 cores show no SAR change throughout the period and only one of the 21 cores shows a peak in SAR in the surface sediments. While increases and decreases occur in all periods, most of the major increases in SAR occur between 1925 - 1950 and 1950 -1975.

The mean SAR for 1850 is 0.045 g cm^{-2} yr^{-1} with a standard deviation of 0.0286 g cm^{-2} yr^{-1} (N = 5) but this is undoubtedly affected by the 1850 SAR for Betton Pool (0.1 g cm^{-2} yr^{-1}). Without Betton Pool the mean SAR for 1850 is 0.0312 g cm^{-2} yr^{-1} with a standard deviation of 0.0104 g cm^{-2} yr^{-1}. While 0.0312 ± 0.0104 g cm^{-2} yr^{-1} may represent a reasonable reference for an 1850 SAR for this lake class, the number of sites is low and further data are required to confirm this value.

Class:	**3122**						
Alkalinity:	> 1 µeq l^{-1}	*Altitude:*	< 200 m	*Max. depth:*	> 5 m	*Lake area:*	> 50 ha
No. lakes:	10	*No. cores:*	17				
Description: Large, deep, lowland lakes situated in UK (especially Northern Ireland), Ireland, N. Italy and Estonia							



Site name	Country	1850	1875	1900	1925	1950	1975	2000	SURFACE
Lough Brantry	GB		0.036	0.045	0.043	0.039	0.057		0.109
Como	IT			0.091	0.104	0.071	0.121		0.049
Lower Lough Erne	GB		0.084	0.084	0.084	0.097	0.19		0.16
Leven	GB					0.034	0.036		0.051
Llangorse Lake	GB			0.13	0.28	0.2	0.57		0.48
Lough Melvin	GB				0.044	0.024	0.0285		0.037
Lough Mourne	GB				0.04	0.14	0.175	0.19	0.19
Lough Neagh	GB		0.0213	0.0258	0.0465	0.0771	0.091		0.1124
Lough Neagh	GB			0.0386	0.0573	0.0749	0.0924		0.1134
Lough Neagh	GB			0.0548	0.0418	0.0595	0.0809		0.1184
Lough Neagh	GB			0.0341	0.0421	0.0475	0.1609		0.1149
Lough Neagh	GB			0.0183	0.0218	0.0253	0.0372		0.0574
Lough Neagh	GB				0.1788	0.1534	0.1816		0.2104
Lough Neagh	GB				0.062	0.0776	0.0729		0.1138
Peipsi järv	EE			0.02	0.02	0.03	0.03	0.05	0.05
Peipsi järv	EE		0.0218	0.0158	0.0261	0.0149	0.0097	0.0138	0.0127
Võrtsjärv	EE			0.0402	0.075	0.1049	0.077	0.0613	0.057



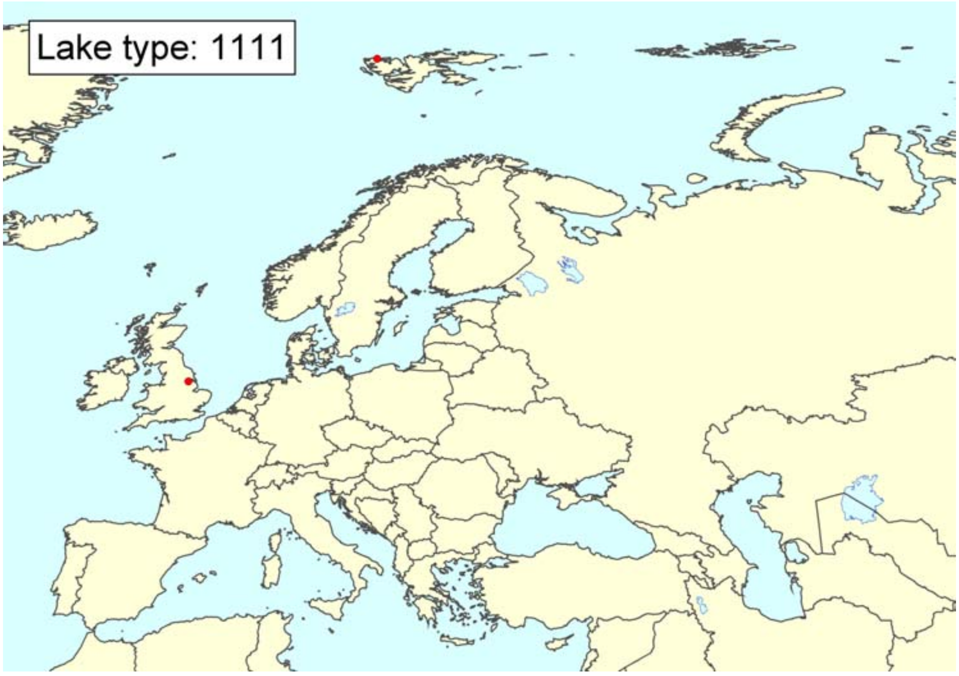
Red = GB; Light green = IT; Blue = EE

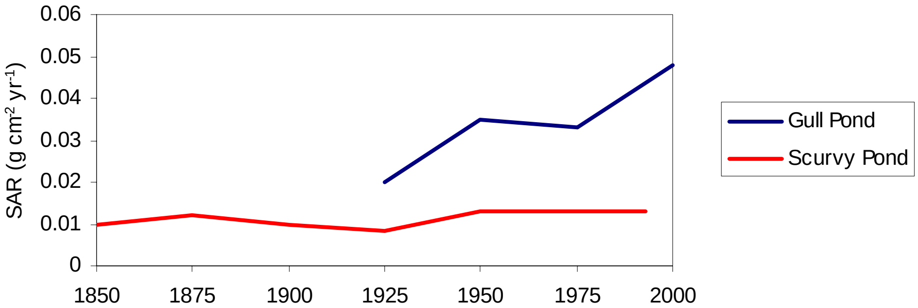
SARs generally increase through time at most sites although there is some variability. This is supported by the scatter-plots. None of the 17 cores show no SAR change throughout the period and only four of the 17 show a peak in SAR in the surface sediments. While increases and decreases occur in all periods, most of the major increases (>50%) in SAR occur post-1950.

The dateable chronologies for these sites are short and there are no values for 1850 and only four for 1875. However, the mean SAR for 1875 is 0.0408 g cm^{-2} yr^{-1} with a standard deviation of 0.0296 g cm^{-2} yr^{-1} (N = 4). For 1900, the mean SAR is 0.0498 g cm^{-2} yr^{-1} with a standard deviation of 0.0349 g cm^{-2} yr^{-1} (N = 11) but this is undoubtedly affected by the SAR for Llangorse Lake (0.13 g cm^{-2} yr^{-1}). Without Llangorse Lake the mean SAR for 1900 is 0.0425 g cm^{-2} yr^{-1} with a standard deviation of 0.0253 g cm^{-2} yr^{-1}. This rate, while lower, remains the highest for all the lake-types. While 0.04 ± 0.02 g cm^{-2} yr^{-1} may represent a reasonable reference for an 1875 - 1900 SAR for this lake class, the number of sites is very low and there can be little confidence in such a value without further confirmation. Furthermore, whether a reference SAR for such a date is useful, when other classes are defined for 1850, remains debateable.

(ii) Classes with <10 sites

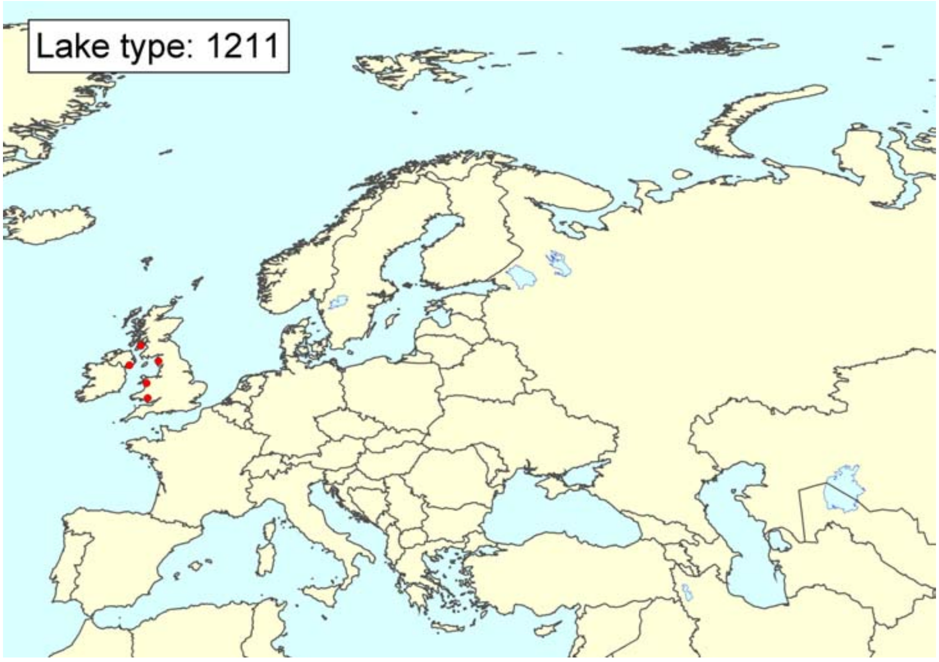
Class:	**1111**						
Alkalinity:	< 0.2 μeq l^{-1}	*Altitude:*	< 200 m	*Max. depth:*	< 5 m	*Lake area:*	< 50 ha
No. lakes:	2	*No. cores:*	2				
Description: Small, shallow lowland lakes							

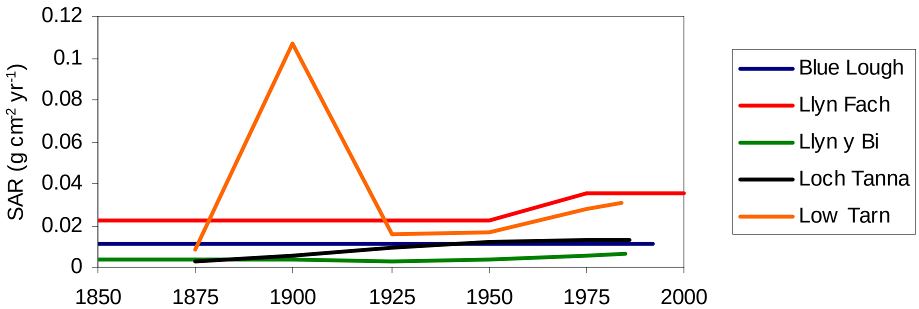




Only two sites represent this small, shallow, lowland class and only one, on northern Svalbard, has a chronology extending back beyond 1925. The SAR line for Gull Pond in the UK shows an increase through time to the present while that of Scuvy Pond shows little change. While the trajectory of the Gull Pond SAR line suggests it may reach the Scurvy Pond value further back in time, there is insufficient data to draw any firm conclusions about SAR trends or a reference SAR for this lake-type.

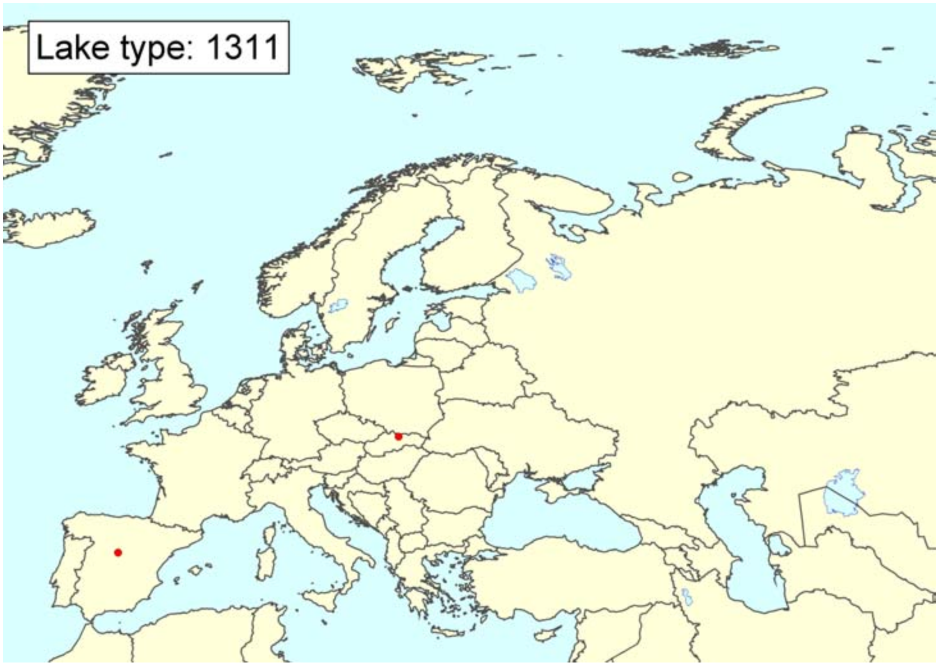
Class:	**1211**						
Alkalinity:	< 0.2 μeq l^{-1}	*Altitude:*	200-800 m	*Max. depth:*	< 5 m	*Lake area:*	< 50 ha
No. lakes:	5	*No. cores:*	5				
Description: Small, shallow, mid-altitude lakes							

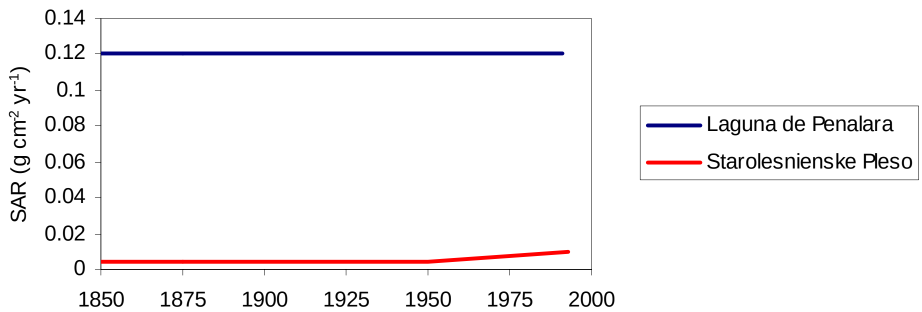




Five sites represent this small, shallow, mid-altitude class, all in the UK. There is considerable variability in the temporal trends, with Llyn Fach, Loch Tanna and Llyn y Bi showing increases through time, Blue Lough showing no SAR change and Low Tarn showing a significant increase in SAR at the start of the 20th century. There is also considerable variability in the 1850 SAR values (N = 3) and therefore there is insufficient data to draw any firm conclusions about a reference SAR for this lake-type, even on this small geographical scale.

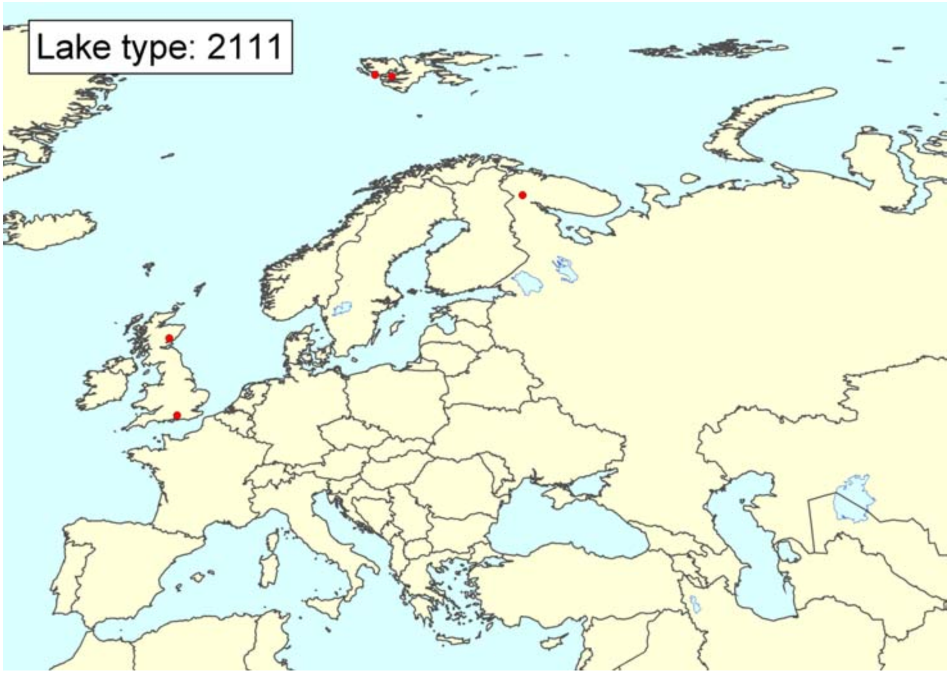
Class:	**1311**						
Alkalinity:	< 0.2 μeq l^{-1}	*Altitude:*	> 800 m	*Max. depth:*	< 5 m	*Lake area:*	< 50 ha
No. lakes:	2	*No. cores:*	2				
Description: Small, shallow, high altitude lakes							

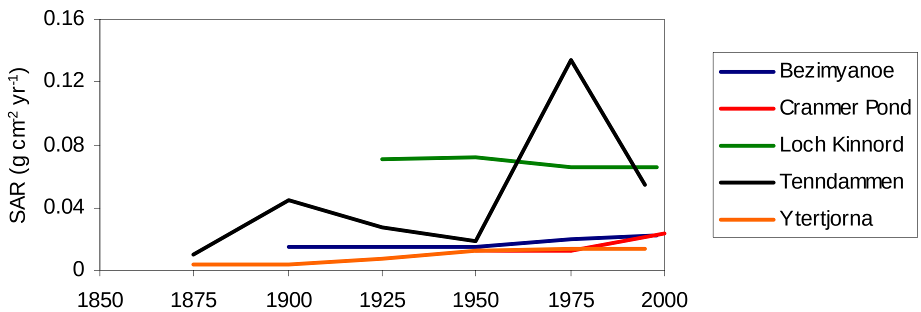




Only two sites represent this small, shallow, high altitude class. Both show little variability in SAR through time but large differences between the sites. Therefore there is insufficient data to draw any firm conclusions about SARs or reference conditions for this lake-type.

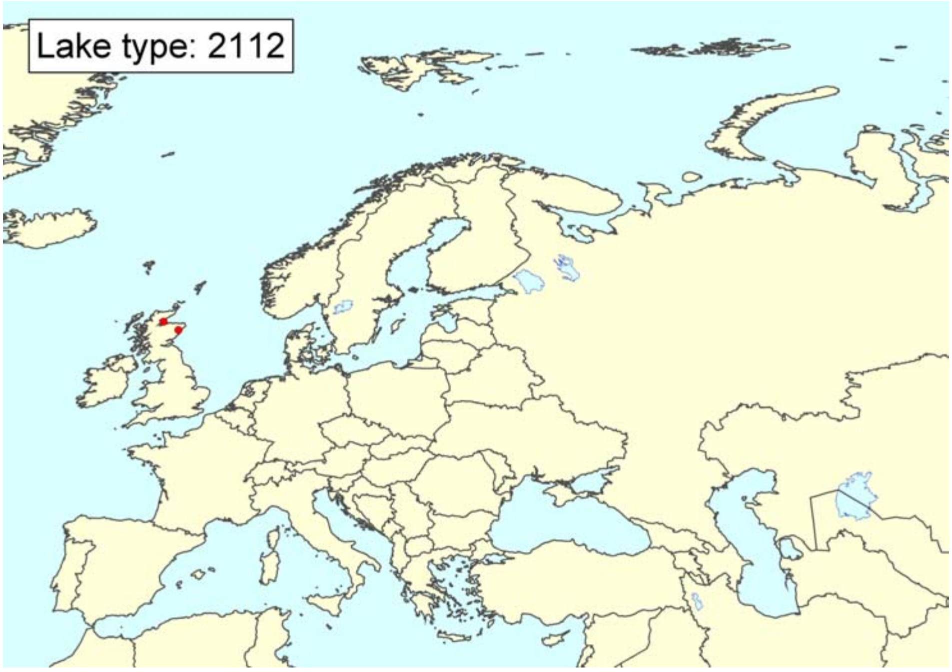
Class:	**2111**						
Alkalinity:	0.2 –1 µeq l^{-1}	*Altitude:*	< 200 m	*Max. depth:*	< 5 m	*Lake area:*	< 50 ha
No. lakes:	5	*No. cores:*	5				
Description: Small, shallow, lowland lakes							

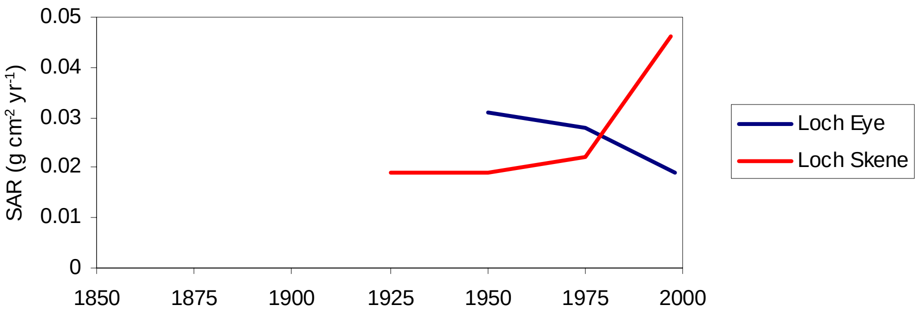




Five sites represent this small, shallow, lowland class. There is considerable variability in the temporal trends, with Ytertjorna and Bezimyanoe showing increases through time, while Loch Kinord shows a decline and Tenndammen a highly variable record as a result of human activities in the catchment. The record for Cranmer Pond is short but shows an increase in recent decades. There are no data for 1850 and, while the two SAR available for 1875 appear to show a reasoable agreement (mean = 0.007 g cm^{-2} yr^{-1}) these sites are both on Svalbard and it is therefore unknown whether this represents a good value for this lake-type as a whole. However, the SAR record for Bezimyanoe would appear to suggest that this value would also not be unreasonable for this site. Despite this there is insufficient data to draw any firm conclusions about a reference SAR for this lake-type.

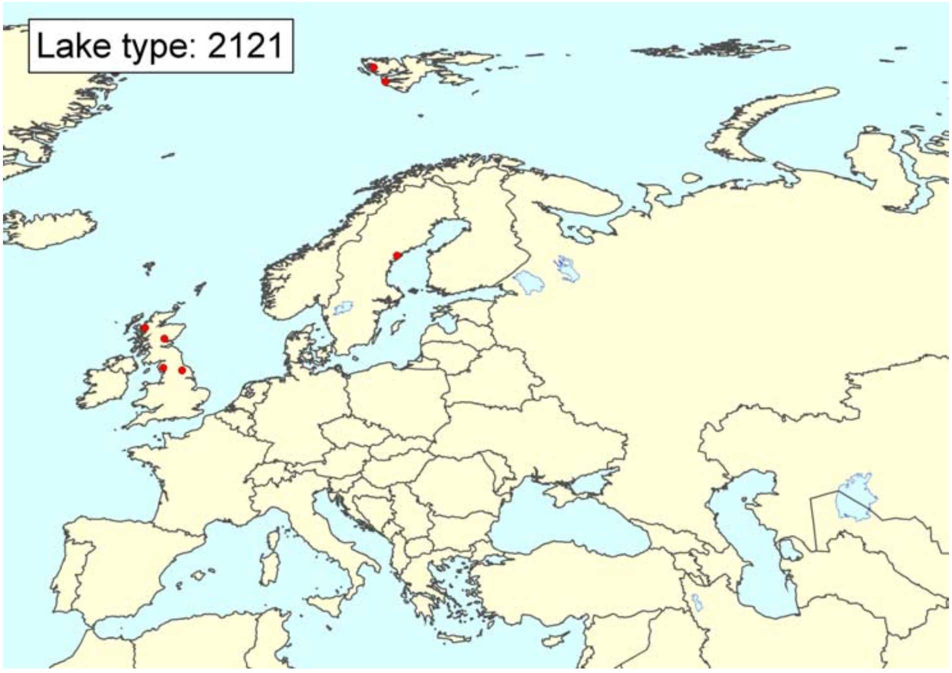
Class:	**2112**						
Alkalinity:	0.2 –1 µeq l^{-1}	*Altitude:*	< 200 m	*Max. depth:*	< 5 m	*Lake area:*	> 50 ha
No. lakes:	2	*No. cores:*	2				
Description: Large, shallow, lowland lakes							

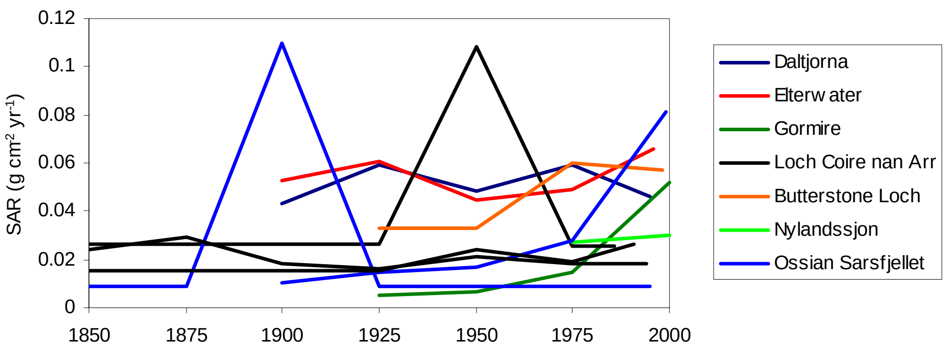




Only two sites represent this large, shallow, lowland class and both of these are in the UK. Both records are short and show conflicting trends even over this period. Therefore there is insufficient data to draw any firm conclusions about SARs or SAR reference conditions for this lake-type.

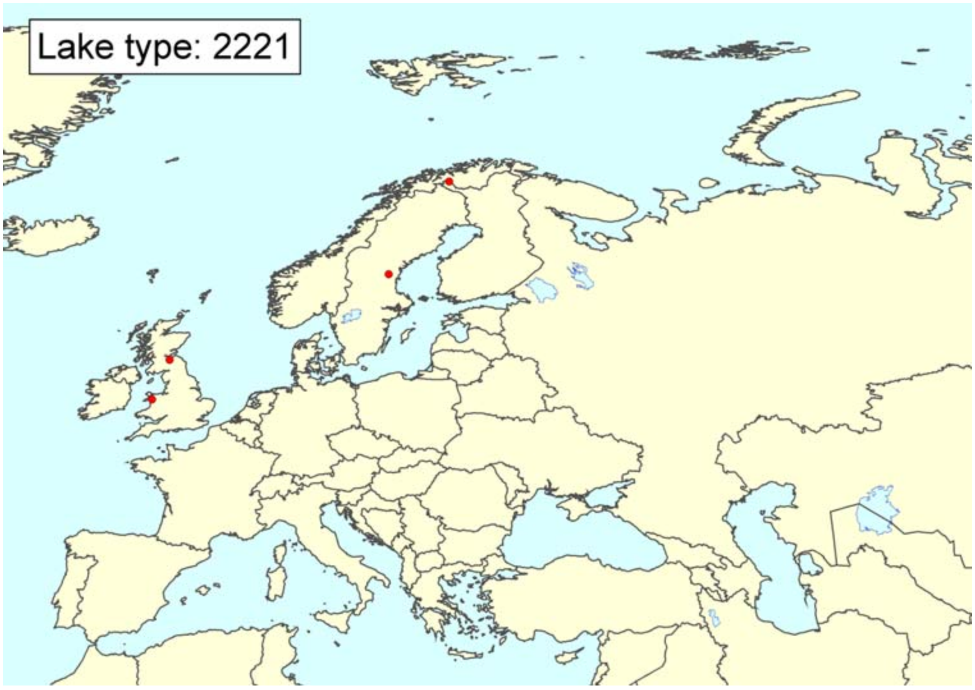
Class:	**2121**						
Alkalinity:	0.2 –1 μeq l^{-1}	*Altitude:*	< 200 m	*Max. depth:*	> 5 m	*Lake area:*	< 50 ha
No. lakes:	7	*No. cores:*	10				
Description: Small, deep, lowland lakes							

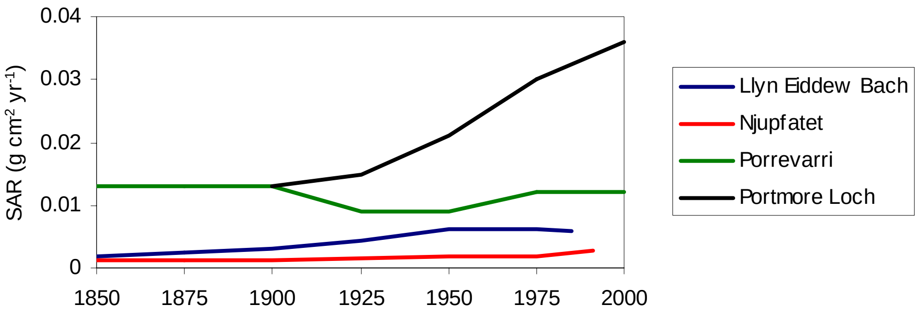




Seven sites represent this small, deep, lowland class. There is considerable variability in the temporal trends at most of these sites with the two Svalbard lakes showing major increases in SAR at various times through their records. Furthermore, the two records from Ossian Sarsfjellet show little agreement in trends or rates. Data for most other sites only extend back to 1900, but even for those with chronologies back to 1850 there is considerable variability in the SAR values ranging from 0.0088 – 0.0262 g cm^{-2} yr^{-1}. Therefore, there is insufficient data to draw any firm conclusions about SAR trends or a reference SAR for this lake-type.

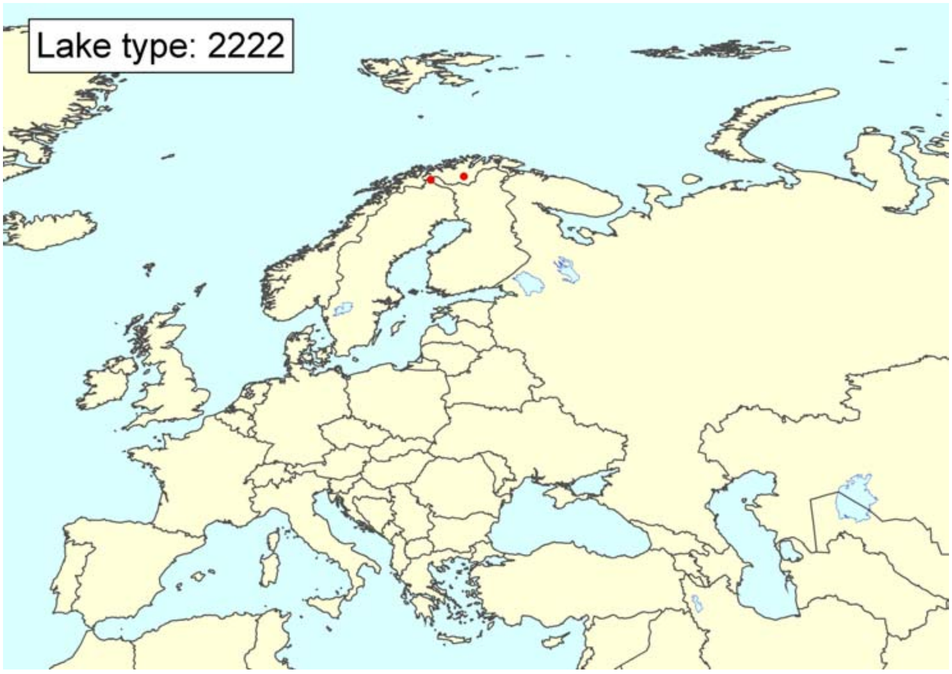
Class:	**2221**						
Alkalinity:	0.2 –1 μeq l^{-1}	*Altitude:*	200-800 m	*Max. depth:*	> 5 m	*Lake area:*	< 50 ha
No. lakes:	4	*No. cores:*	4				
Description: Small, deep, mid-altitude lakes							

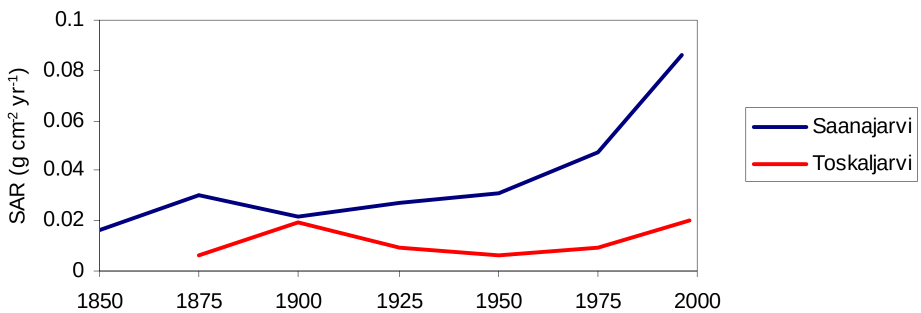




Four sites represent this small, deep, mid-altitude class. Apart from Porrevarri which shows little long-term trend, all sites show an increase in SAR over the period. However, that of Portmore Loch only extends back to 1900. Of the three sites for which data extends back to 1850 two, Llyn Eiddew Bach and Njupfatet show good agreement in 1850 SAR values (mean = 0.00106 g cm^{-2} yr^{-1}) while that of Porrevarri is an order of magnitude higher. Consequently, while it may be true to say that in general there has been a SAR increase for this lake type, there is insufficient data to draw any firm conclusions about real SAR trends or a reference SAR.

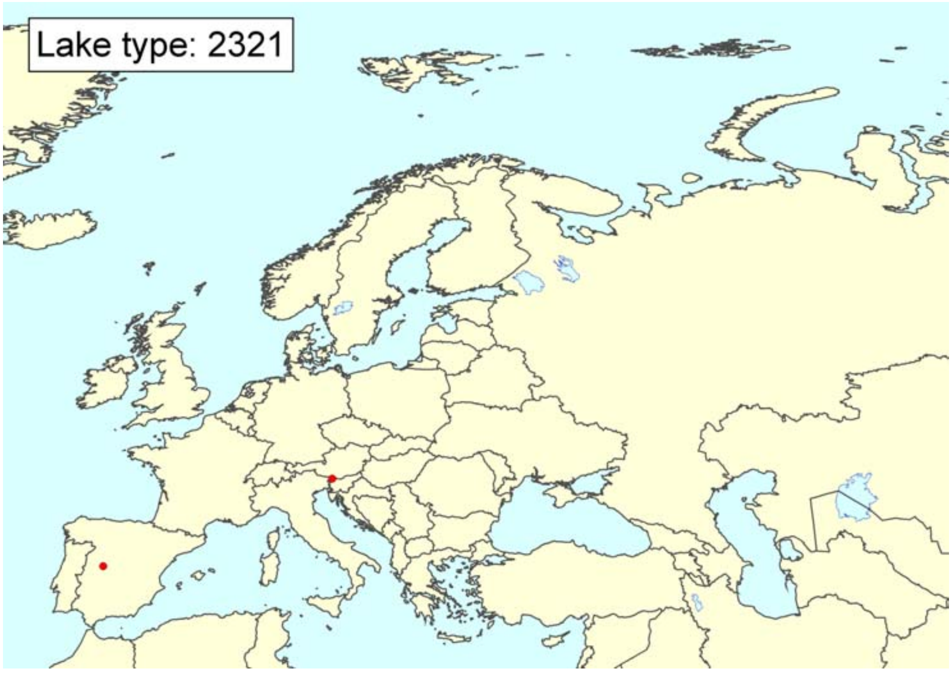
Class:	**2222**						
Alkalinity:	0.2 –1 μeq l^{-1}	*Altitude:*	200-800 m	*Max. depth:*	> 5 m	*Lake area:*	> 50 ha
No. lakes:	2	*No. cores:*	2				
Description: Large, deep, mid-altitude lakes							

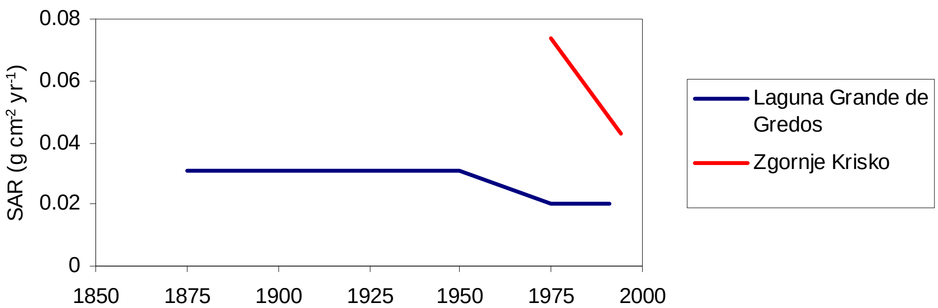




Only two sites represent this large, deep, mid-altitude class, both in northern Finland. The SAR line for Saanajarvi extends back to 1850 and shows a considerable and continuing increase through time up to the present while that of Toskalijarvi shows little long-term trend since 1875. Therefore, there is insufficient data to draw any firm conclusions about SAR trends or a reference SAR for this lake-type.

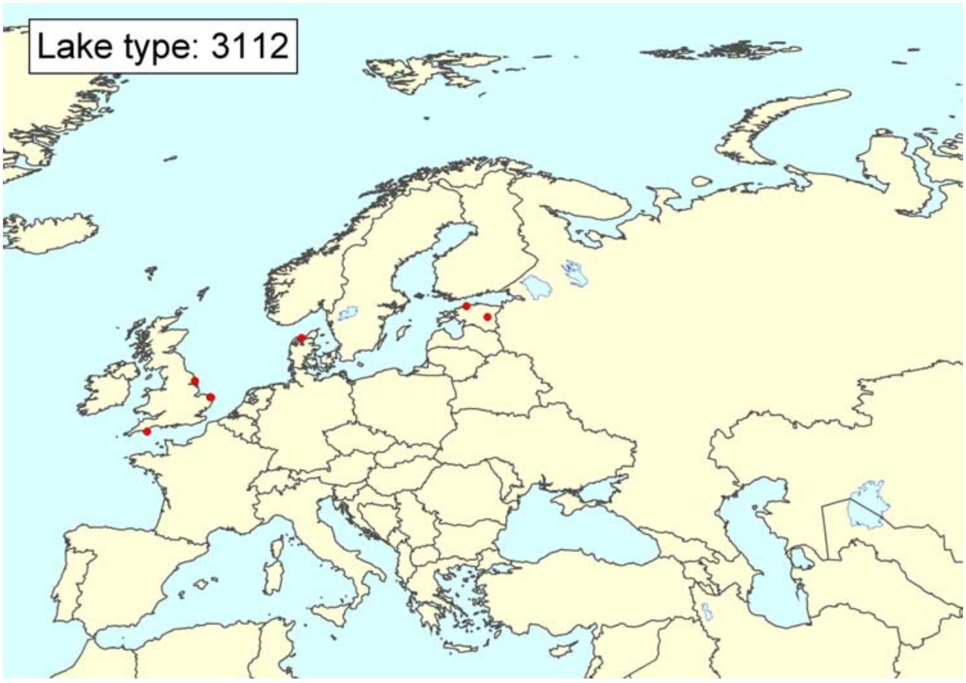
Class:	**2321**						
Alkalinity:	0.2 –1 μeq l^{-1}	*Altitude:*	> 800 m	*Max. depth:*	> 5 m	*Lake area:*	< 50 ha
No. lakes:	2	*No. cores:*	2				
Description: Small, deep, high-altitude lakes							

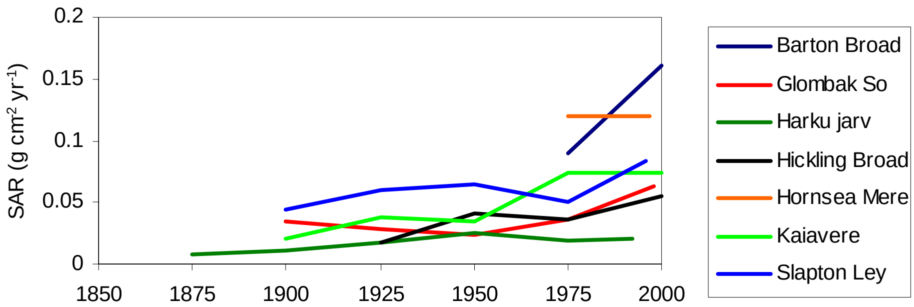




Only two sites represent this small, deep, high altitude class. Both records are short and show conflicting trends even over this period. Therefore there is insufficient data to draw any firm conclusions about SARs or SAR reference conditions for this lake-type.

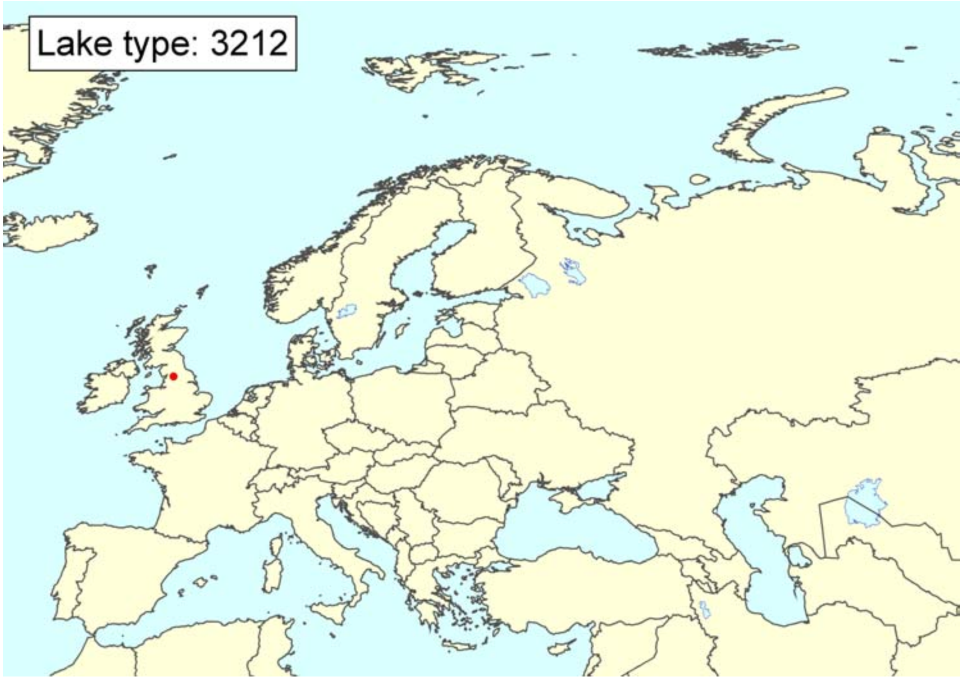
Class:	**3112**						
Alkalinity:	>1 μeq l^{-1}	*Altitude:*	< 200 m	*Max. depth:*	< 5 m	*Lake area:*	> 50 ha
No. lakes:	7	*No. cores:*	7				
Description: Large, shallow, lowland lakes							

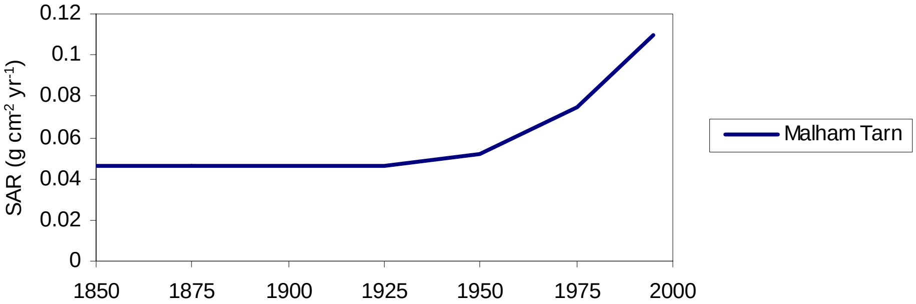




Seven sites represent this large, shallow, lowland class. Many of the records are short but most show an increase in SAR over the available data period with maximum increases occuring over recent decades. However, agreement on SAR values in the early part of the record is poor and only one site has a record extending back prior to 1900. Therefore, while we may conclude that this lake-type appears to be exhibiting increases in SAR and that this incease may be accelerating (cf. Class 3111) further data are required in order to confirm this.

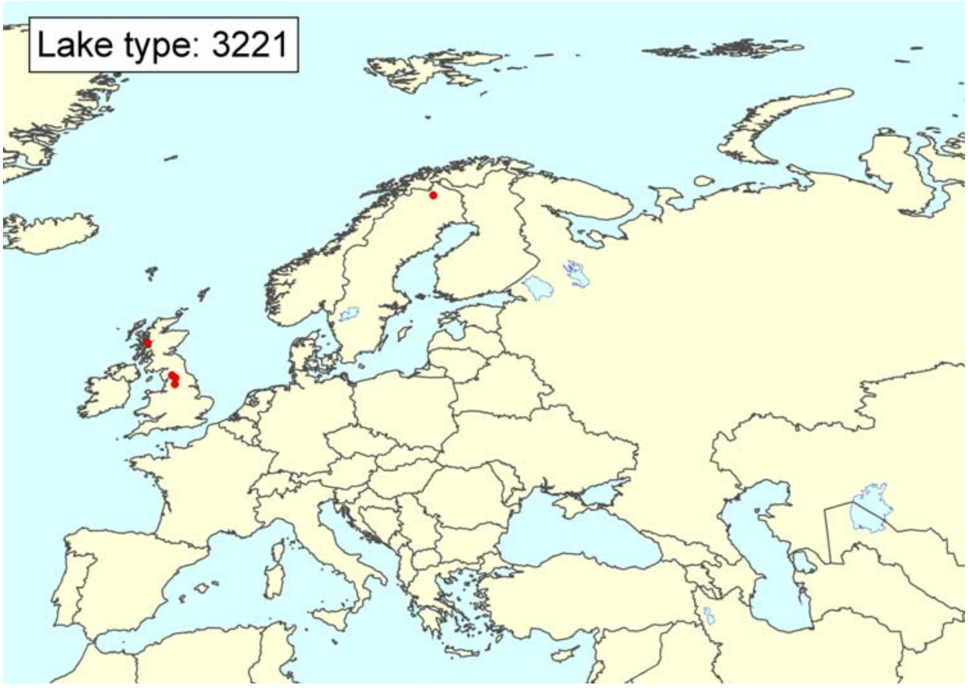
Class:	**3212**						
Alkalinity:	>1 μeq l^{-1}	*Altitude:*	200-800 m	*Max. depth:*	< 5 m	*Lake area:*	> 50 ha
No. lakes:	1	*No. cores:*	1				
Description: Large, shallow, mid-altitude lakes							

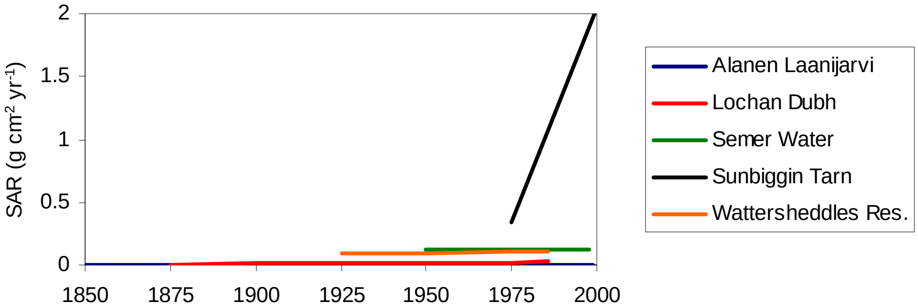




Only Malham Tarn in the UK represents this large, shallow, mid-altitude class. SARs for this site show no change until 1925 after which there is a continuing increase to the most recent sediments. However, as there is only one site it is not possible to know how this trend or the 1850 SAR of 0.046 g cm^{-2} yr^{-1} represent this lake class as a whole.

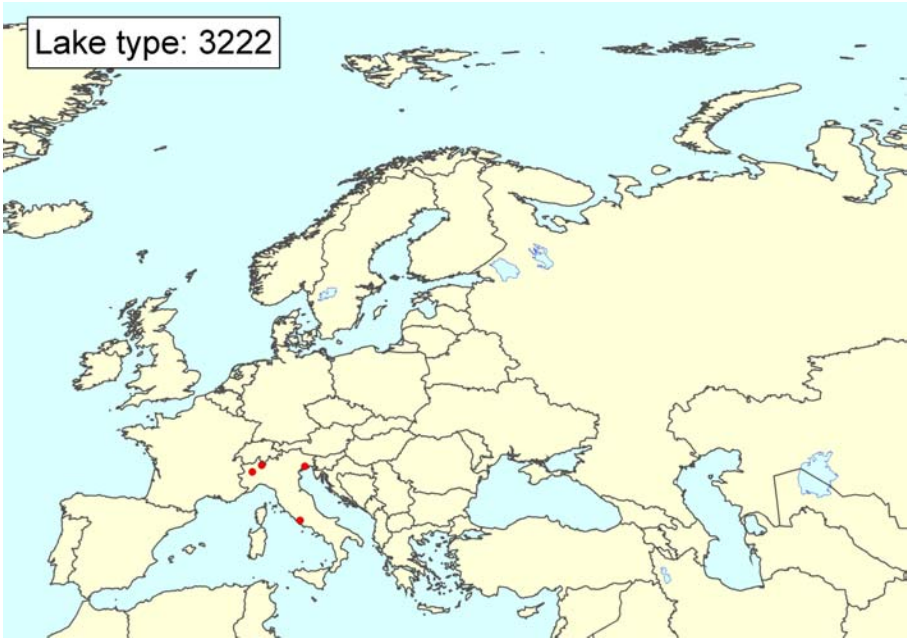
Class:	**3221**						
Alkalinity:	>1 μeq l^{-1}	*Altitude:*	200-800 m	*Max. depth:*	> 5 m	*Lake area:*	< 50 ha
No. lakes:	5	*No. cores:*	5				
Description: Small, deep, mid-altitude lakes							

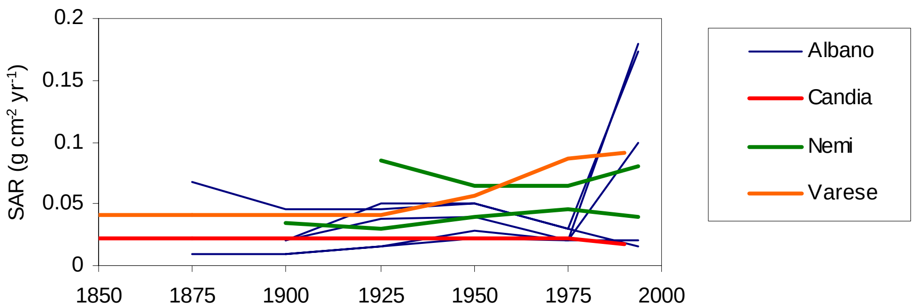




Five sites represent this small, deep, mid-altitude class. Only the data for Alanen Laanijarvi extend back to 1850. Apart from Sunbiggin Tarn which has SARs much higher than the other sites as well as an enormous increease between 1975 and 2000, the remaining sites show either little change through time (Alanen Laanijarvi, Semer Water) or minor increases in the surface sediments (Lochan Dubh, Wattersheddles). There is such variability in both trends and SAR rates that it is currently not possible to determine any consensus for this lake-type.

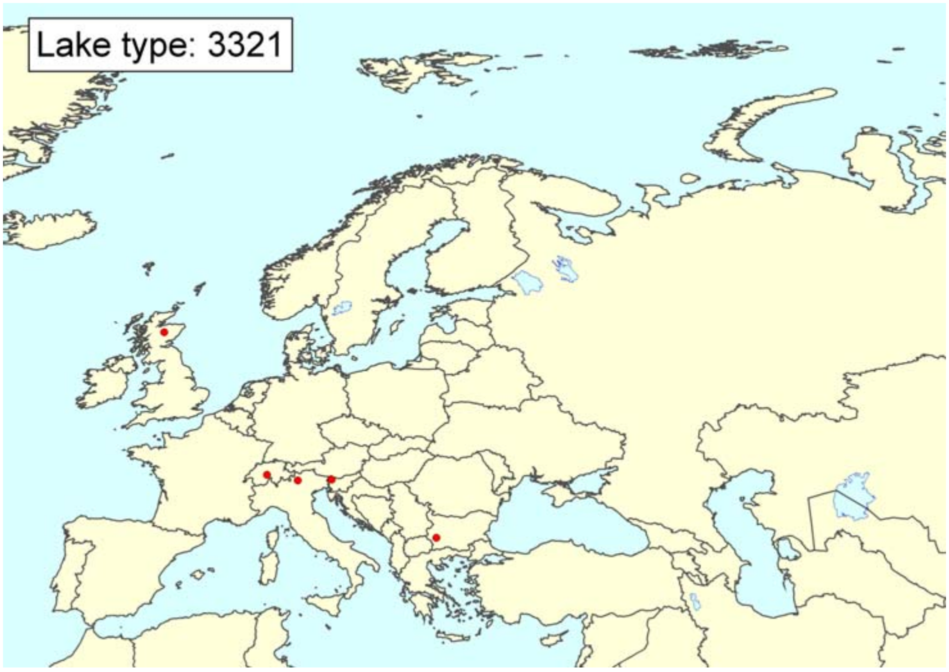
Class:	**3222**						
Alkalinity:	>1 μeq l^{-1}	*Altitude:*	200-800 m	*Max. depth:*	> 5 m	*Lake area:*	> 50 ha
No. lakes:	4	*No. cores:*	9				
Description: Large, deep, mid-altitude lakes							

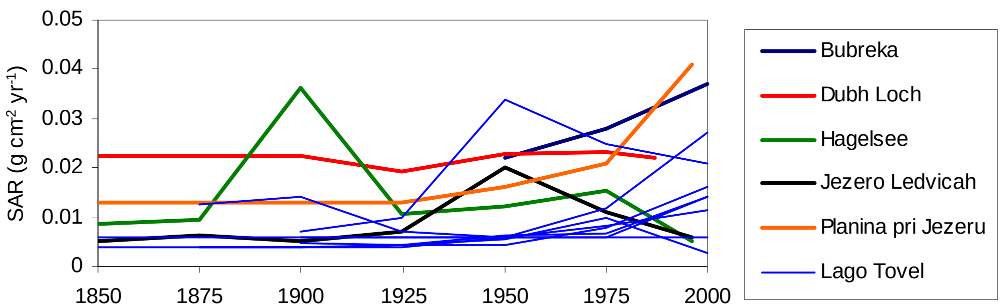




Four lakes from northern and central Italy represent this large, deep, mid-altitude class. However, there are multiple cores from Albano and Nemi. There is considerable variability in temporal trends both between and within-lakes (see above) with three of the five Albano cores showing a very rapid increase in SAR in the most recent sediments while, apart from the Varese core, none of the others show increasing trends. Only the cores from Varese and Candia have records back to 1850 and there is significant variability in SAR values between these sites. As a consequence, it is not possible to draw any firm conclusions about SARs or SAR reference conditions for this lake-type.

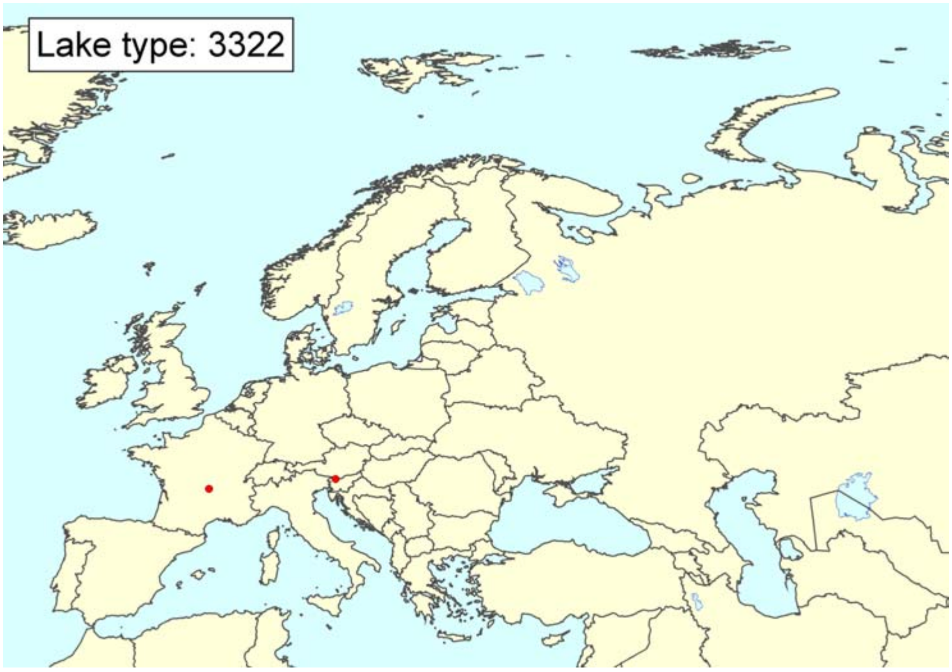
Class:	**3321**						
Alkalinity:	>1 µeq l^{-1}	*Altitude:*	> 800 m	*Max. depth:*	> 5 m	*Lake area:*	< 50 ha
No. lakes:	6	*No. cores:*	13				
Description: Small, deep, high-altitude lakes							

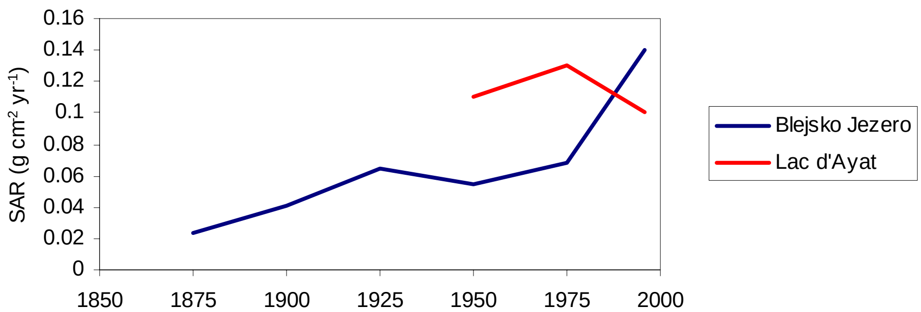




Six lakes represent this small, deep, high-altitude lake class. However, there are multiple cores from Lago Tovel. There is considerable variability in temporal trends here, with Dubh Loch showing little change in SAR through time, increases in the short Bubreka record and most of the Tovel cores while the SAR for Hagelsee and Jezero Ledvicah show considerable variability through time. Although data for six cores extend back as far as 1850 there is a large range in these values 0.0039 – 0.024 g cm^{-2} $yr^{-1}$and consequently it is not currently possible to draw any firm conclusions about SARs or SAR reference conditions for this lake-type.

Class:	**3322**						
Alkalinity:	>1 μeq l^{-1}	*Altitude:*	> 800 m	*Max. depth:*	> 5 m	*Lake area:*	> 50 ha
No. lakes:	2	*No. cores:*	2				
Description: Large, deep, high-altitude lakes							





Only two sites represent this large, deep, high altitude class. Only the record of Lac d'Ayat extends back beyond 1950 and even in the post-1950 period there are conflicting trends. Therefore there is insufficient data to draw any firm conclusions about SARs or SAR reference conditions for this lake-type.

Part 3: Conclusions

The dataset

Sediment accumulation rate (SAR) data has been compiled for 337 sediment cores from 278 lakes. Of these 278 data on latitude, longitude, alkalinity, altitude, maximum depth and lake area were only available for 207. While we hope to gain more data in future, and thereby expand this number for later reports, these 207 form the basis of our SAR analysis.

Spatial and climatic coverage.

The 207 lake dataset includes sites in 19 countries although more than 60% are from lakes in the UK. Small clusters of sites also exist in Italy, Finland, Estonia, Svalbard, Spain and Denmark but otherwise sites are scattered thinly. Major gaps exist in mainland central Europe, from the Low Countries eastwards, in south-east Europe and in mid-northern latitudes including central Norway and Sweden and southern Finland. European Russia is particularly poorly represented. In terms of climatic zones, the majority of sites fall within a humid oceanic climate zone, while humid-continental and sub-arctic regions are under-represented.

Use of single cores

31 lakes have multiple core data although 22 have only two. Consideration of the five lakes in the database with >3 dated cores shows there is considerable variability in SARs in cores taken across full lake basins. However, where multiple cores are taken from representative deep-water areas (and even comparable shallow water areas in some cases e.g. Tovel), then there is good agreement between multiple cores in terms of general trends and in 'basal' SARs. Consequently, we conclude that SAR data from sediment cores taken from deep water areas are likely to be representative of that lake sediment basin and therefore, single sediment cores from a site can be used in subsequent SAR data analysis.

General SAR trends

66% of the sediment cores included in the analysis showed surface SARs higher than basal (i.e. earliest reliable data) rates. 19% showed no change while 15% showed a decline in surface SAR with respect to basal rates.

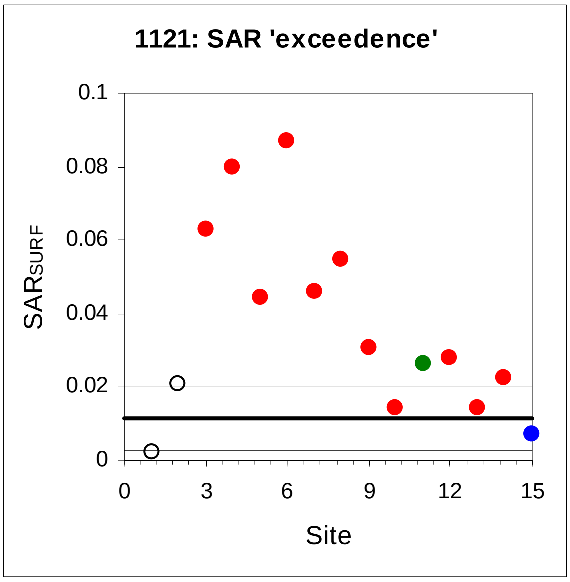
Typologies and lake classes.

Lakes were classified into lake-types using four parameters: alkalinity (3 classes), altitude (3 classes), maximum depth (2 classes) and lake area (2 classes). This generated a possible 36 lake classes of which 25 were represented in the dataset. The missing lake-types are reasonably well distributed between the alkalinity classes but the same is not true for the other parameters where of the eleven missing classes, ten are in the shallowest depth class, eight are in the largest area class and seven are in the highest altitude range. Furthermore, only one of the missing classes is in the lowest altitude range. The classes with >10 lakes in them are determined by research activities undertaken over the last few decades rather than the greater prevalence of lakes of these types. Five of the nine classes are in the low alkalinity range reflecting the palaeolimnological work on sites sensitive to acidification. In particular, the largest class (1221) includes many upland sites in the UK used in the Surface Water Acidification Project and those now forming part of the UK Acid Waters Monitoring Network. Class 1321 includes high altitude lakes from 11 different countries and includes lakes studied as part of the EU funded research projects AL:PE, AL:PE2; MOLAR and EMERGE. Similarly, the sites in classes 1122, 1222 and 2122 are all large, deep lakes, many in Scotland, as a result of research projects directed towards lakes of this type, while the three high alkalinity classes with more than ten sites result from studies in the UK, Denmark and Estonia particularly in the area of lake eutrophication.

SAR trends within lake classes

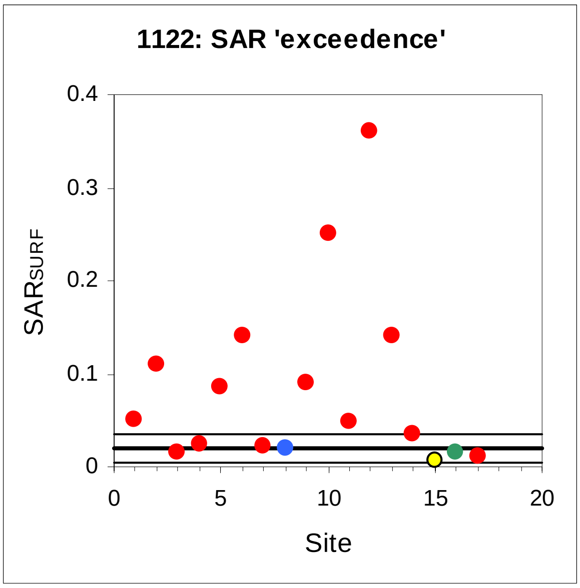
1121 (Small, low alkalinity, low altitude, deep lakes)

Little change in SAR occurs prior to 1900 but in all subsequent periods, 5 – 7 cores show SAR increases of 10 – 50% or > 50% over the previous 25 year period. Most of these increases are by 10 – 50% suggesting steady rather than dramatic SAR increases. Mean SAR for 1850 is 0.0117 g cm^{-2} yr^{-1} with a standard deviation of 0.0087 g cm^{-2} yr^{-1} (N = 7). However, these 1850 SAR values vary by more than an order of magnitude and there can be little confidence in this value as a 'reference SAR'. Variability appears to be geographical with lakes in Estonia and Svalbard showing the lowest SAR and those from the UK the highest. This is emphasised if surface SARs are plotted against the mean 1850 SAR to show a surface SAR 'exceedence' over this value. The Svalbard and Estonian sites fall within the 'reference' SAR boundaries while most of the UK and Ireland sites would require a reduction in SAR of 0.01 – 0.066 g cm^{-2} yr^{-1} to attain this 1850 value.



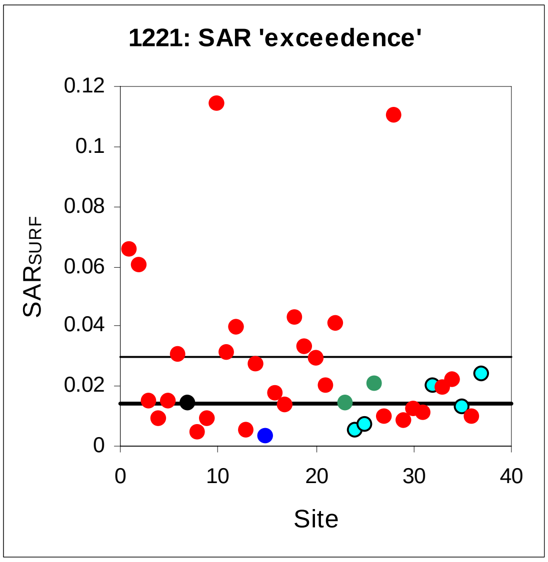
1122 (Large, low alkalinity, low altitude, deep lakes)

In general SARs increase through time and there are only a few instances of SAR declines. Most of the increases in SAR occur post-1925. In particular, 11 of the 15 cores show at least a 10 – 50% increase in SAR between 1925 and 1950. However, the most dramatic period of SAR increase appears to occur post-1975. Mean SAR for 1850 is 0.0196 g cm^{-2} yr^{-1} with a standard deviation of 0.0146 g cm^{-2} yr^{-1} (N = 10). It may be that a SAR of 0.02 ± 0.015 is not an unreasonable reference 1850 SAR (SAR_{1850}) for this lake class. The plot shows that such a reference SAR would indicate a high level of SAR 'exceedence' for the surface sediments of many of the lakes in this class. Reductions of up to 0.33 g cm^{-2} yr^{-1} would be required to lower the SAR of Oughter Lough to this level.



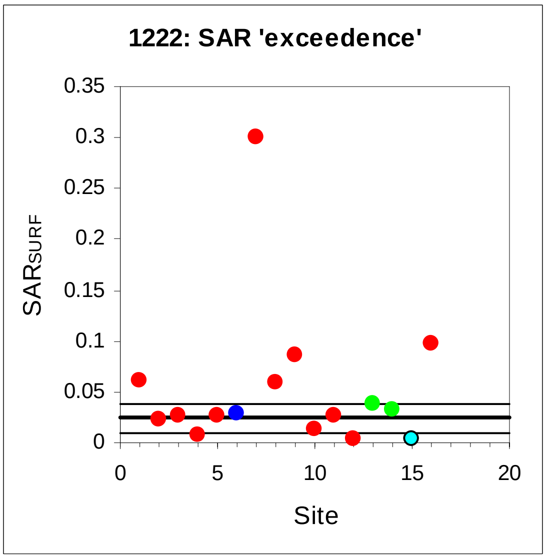
1221 (Small, low alkalinity, deep, mid-altitude lakes)

Trends in SAR appear to be quite variable but much of this variability is confined to a few sites (e.g. Loch Fleet; Llyn Dulyn; Burnmoor Tarn) and SARs generally increase through time at most. Although SAR increases (and to a lesser extent decreases) are observed in all time periods, most of the major (> 50%) SAR increases occur post-1950 and in particular, the 1950 – 1975 period. The mean SAR for 1850 is 0.0143 g cm^{-2} yr^{-1} with a standard deviation of 0.0163 g cm^{-2} yr^{-1} (N = 23). The 1850 range of 0.003 – 0.0213 g cm^{-2} yr^{-1} emphasises the class variability. If 0.014 ± 0.016 g cm^{-2} yr^{-1} is taken as a SAR_{1850} reference value then most sites fall within the limits. This suggests SAR increases are not as significant for this lake class, but could also be a consequence of the SAR variability within the lake type.



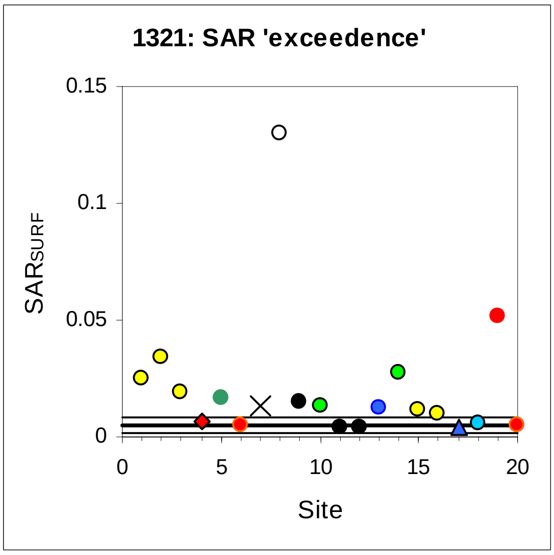
1222 (Large, low alkalinity, deep, mid-altitude lakes)

SARs appear to be variable for this class and some of the sites for which considerable variability occurs (e.g. Loch Dee and Loch Grannoch) have afforested catchments and this process will certainly have had an effect. The mean SAR for 1850 is 0.0326 g cm^{-2} yr^{-1} with a standard deviation of 0.0315 g cm^{-2} yr^{-1} (N=10) These 1850 values are undoubtedly affected by a single high value for Loch Dee (0.113 g cm^{-2} yr^{-1}) without which the range for these nine 1850 values is 0.02 – 0.052 g cm^{-2} yr^{-1}, the mean is 0.0237 g cm^{-2} yr^{-1} and the standard deviation is 0.0149g cm^{-2} yr^{-1} (N = 9). Therefore, a SAR of 0.024 ± 0.015 g cm^{-2} yr^{-1} may be a reasonable reference 1850 SAR for this lake class. As with class 1222, the variability in this class may result in most sites falling within the SAR_{1850} reference limits although Loch Grannoch would requires substantial SAR reduction to attain this value.



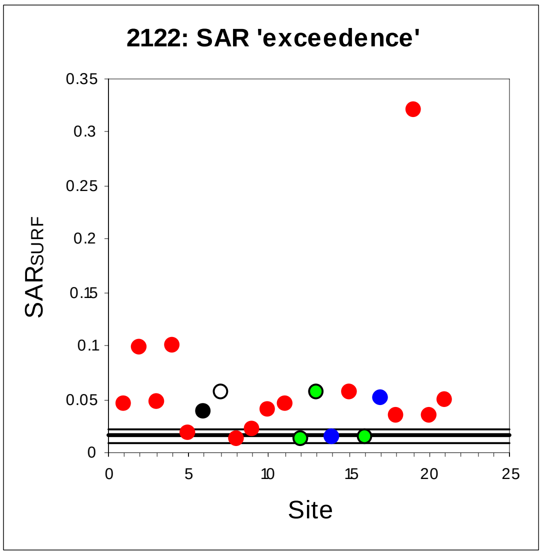
1321(Low alkalinity, small, deep, high altitude lakes)

SARs are also generally low for this class although the recent SAR in Jorisee reaches 0.13 g cm^{-2} yr^{-1}, more than 20 times higher than its 1850 value. The mean SAR for 1850 is 0.0077 g cm^{-2} yr^{-1} with a standard deviation of 0.0053 g cm^{-2} yr^{-1} (N = 16). This mean value is considerably higher than some of the individual 1850 SARs and it is of interest to note that the SAR for those cores which show no change throughout are quite similar (i.e. Loch nan Eun 0.0053 g cm^{-2} yr^{-1}; Stavsvatn 0.0039 g cm^{-2} yr^{-1}; Lochan Uaine 0.0051 g cm^{-2} yr^{-1}; Stuoramohkki 0.0055 g cm^{-2} yr^{-1}). Therefore a SAR of 0.005 ± 0.003 g cm^{-2} yr^{-1} may not be an unreasonable reference 1850 SAR for this lake class. If this is the case then most sites in this class require a reduction in SAR to attain this reference value. Apart from Jorisee, SAR 'exceedence' is up to 0.044 g cm^{-2} yr^{-1}.



2122 (Mid-alkalinity, large, deep, lowland lakes)

SARs generally increase through time at most sites although there is considerable variability at a few (e.g. Loch Earn, Lago Maggiore, Knud Soe). Little SAR change occurs prior to 1900 but after this there are considerable increases (and to a lesser extent decreases) observed in all time periods. The mean SAR for 1850 is 0.0157 g cm^{-2} yr^{-1} with a standard deviation of 0.0065 g cm^{-2} yr^{-1} (N = 7) while the range for these 1850 values is 0.007 – 0.022 g cm^{-2} yr^{-1}. While this range is reasonably small the number of sites is also low and therefore, while 0.016 ± 0.007 may represent a reasonable reference for an 1850 SAR for this lake class, further data are required to confirm it. However, if this accepted, then most sites show an exceedence in their surface SARs. Except for the very high value for Loch Ussie reductions of up to 0.0775 g cm^{-2} yr^{-1} are required to attain the SAR_{1850} value.

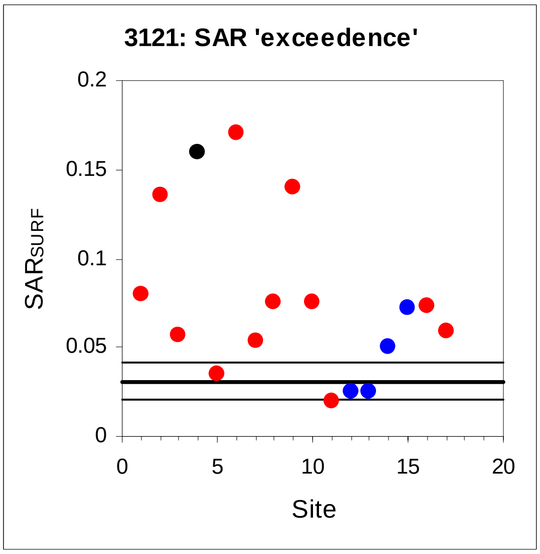


3111 (Small, high alkalinity, shallow, lowland lakes)

With the exception of two lakes all sites in this class show considerable SAR increases. Little change in SAR occurs prior to 1900 but 10 out of 13 cores show > 10% SAR increase between 1950 and 1975 and 9 of the 13 show the same increase between 1975 and the surface. Therefore, not only are SARs increasing in lakes of this type, but it would appear that SAR is also accelerating. The same situation may also be true for lake class 3112 (i.e. all high alkalinity, shallow lowland lakes). Given that this is a shallow lake class this could suggest a significant move towards lake-infilling. As so few sites have 1850 or 1875 data, no reference SAR has been identified.

3121 (Small, deep, high alkalinity, lowland lakes)

SARs generally increase through time at most sites although there is considerable variability at some. Most of the major increases in SAR occur between 1925 - 1950 and 1950 -1975. The mean SAR for 1850 is 0.045 g cm^{-2} yr^{-1} with a standard deviation of 0.0286 g cm^{-2} yr^{-1} (N = 5) but this is undoubtedly affected by the 1850 SAR for Betton Pool (0.1 g cm^{-2} yr^{-1}). Without this site the mean SAR for 1850 is 0.0312 g cm^{-2} yr^{-1} with a standard deviation of 0.0104 g cm^{-2} yr^{-1}. While 0.031 ± 0.01 g cm^{-2} yr^{-1} may represent a reasonable reference for an 1850 SAR for this lake class, the number of sites is low and further data are required to confirm this value. However, if this SAR_{1850} is accepted then considerable reductions in SAR are required at most sites in order to attain this reference condition.



3122 (Large, deep, high alkalinity lowland lakes)

SARs generally increase through time at most sites. However, chronologies are short and there are no values for 1850 and only four for 1875. The mean SAR for 1875 is 0.0408 g cm^{-2} yr^{-1} with a standard deviation of 0.0296 g cm^{-2} yr^{-1} (N = 4). For 1900, the mean SAR is 0.0498 g cm^{-2} yr^{-1} with a standard deviation of 0.0349 g cm^{-2} yr^{-1} (N = 11) but this is undoubtedly affected by the SAR for Llangorse Lake (0.13 g cm^{-2} yr^{-1}). Without Llangorse the mean SAR for 1900 is 0.0425 g cm^{-2} yr^{-1} with a standard deviation of 0.0253 g cm^{-2} yr^{-1}. While 0.04 ± 0.02 g cm^{-2} yr^{-1} may represent a reasonable reference for an 1875 - 1900 SAR for this lake class, the number of sites is low and there can be little confidence in such a value without further confirmation.

Reference SAR summary

It has been possible to estimate potential reference SARs for only 8 classes. As might be expected the mountain lake class have the lowest reference SAR while the large, lowland high alkalinity sites have the highest. The others range between 0.012 and 0.024 g cm^{-2} yr^{-1}. While we have greater confidence in some of these estimates than others (see Table) all would benefit from further data and therefore the values in the Table should be considered preliminary. We will continue to try and add further sites to these classifications and refine our estimates throughout the Euro-limpacs project.

Lake class	Reference SAR (g cm^{-2} yr^{-1})	Date
1121	0.012 ± 0.009 *	1850
1122	0.02 ± 0.015	1850
1221	0.014 ± 0.016	1850
1222	0.024 ± 0.015	1850
1321	0.005 ± 0.003	1850
2122	0.016 ± 0.007 *	1850
3121	0.031 ± 0.01 *	1850
3122	0.04 ± 0.02 *	1875 / 1900

* More uncertain; further data required.

SAR summary
For lake classes showing SAR increases, little change occurred prior to 1900. Most increases seemed to occur in more recent periods in particular 1950 – 1975 and post-1975. It may be that this observation identifies a general acceleration in SAR in European lakes.

4. Further work

The next steps for this SAR work fall into two categories:

(i) *Further analysis of the SAR database.*

We will continue to improve the SAR database by adding new SAR and typology data as it becomes available, either from new sites / cores or where we have data gaps in the current dataset. This will give more sites in the various lake classes allowing greater confidence in their interpretations and / or data for analysis of new lake classes.

We will also consider the possibility of including data from other dating techniques (e.g. Spheroidal Carbonaceous Particles) into the database.

Cluster analysis will be used to group the SAR profiles into clusters of sites with common profiles. This classification will be compared with the lake typology to investigate whether common patterns of SAR change are found within lake-types. To determine which processes may be contributing to the different SAR changes across the clusterings a classification analysis using a linear discriminant analysis or a classification tree method will be performed with available explanatory variables. Selection of the most important variables accounting for the between cluster differences will be based upon the results of these analyses.

(ii) *More detailed sediment analysis.*

We will select a small number of lake classes upon which to undertake more detailed sedimentological work. This will include identifying those components of the sediment record responsible for the SAR increases in key lake classes and determining the causes of these increases. This will be the subject of a PhD dissertation being offered at University College London.

Acknowledgements

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