Supplementary Tables, Figures, and Code

This file contains:

- Supplementary tables 1-4, which include information about the ^{210}Pb, ^{214}Pb, and ^{137}Cs activities measured in Kelly Lake surface sediments (1), the revised chronology for Ager's (1983) pollen zone transitions in Hidden Lake (2), the information used to perform bias corrections for the modern mass balance modeling experiments (3), and information about the visible tephra deposits in Hidden and Kelly lake sediments.
- Supplementary figures 1-6, which include information about the ^{210}Pb, ^{214}Pb, and ^{137}Cs activities measured in Kelly Lake surface sediments (1), an example of a purified sedimentary diatom sample used for oxygen isotope analysis (2), modeled/inferred shifts in lake level at Kelly Lake during past intervals (3), correlations between various productivity proxies at Hidden and Kelly lakes (4 and 5), and the principal components analysis performed on the diatom flora data from Kelly Lake (6).
- R code used for the mass balance modeling experiments.

Supplementary Table 1. ^{210}Pb, ^{214}Pb, and ^{137}Cs activities and analytical errors (±1σ) used to model the age-depth profile for surface core KLY18-2C. Depths are given as the midpoint of each 1-cm interval sampled. Activities of each isotope (^{210}Pb, ^{214}Pb, and ^{137}Cs) and analytical errors are given in becquerels per kilogram (Bq/kg). Modeled ages shown here (in yr BP) were used in the Bacon age model for KLY18-2.

KLY18-2C midpoint depth (cm)	**^{210}Pb (Bq/kg)**	**^{210}Pb_err (Bq/kg)**	**^{214}Pb (Bq/kg)**	**^{214}Pb_err (Bq/kg)**	**^{137}Cs (Bq/kg)**	**^{137}Cs_err (Bq/kg)**	**Modeled age (yr BP)**
0.5	2.03E-03	3.05E-04	1.50E-03	4.35E-04	6.25E-04	2.39E-04	–68 ± 1
1.5	1.37E-03	3.08E-04	1.34E-03	4.46E-04	2.89E-04	2.43E-04	–67 ± 1
2.5	1.40E-03	3.19E-04	1.90E-03	4.27E-04	3.13E-04	2.58E-04	–66 ± 1
5.5	1.20E-03	2.95E-04	4.75E-04	4.21E-04	0.00E+00	0.00E+00	–63 ± 1
8.5	2.05E-03	3.22E-04	7.18E-04	4.10E-04	1.50E-04	2.41E-04	–49 ± 1
11.5	1.04E-03	3.00E-04	1.67E-03	4.14E-04	1.13E-03	2.54E-04	–23 ± 5
14.5	7.99E-04	2.98E-04	2.15E-03	4.56E-04	7.41E-04	2.87E-04	–13 ± 8
15.5	6.02E-04	2.80E-04	1.27E-03	4.15E-04	1.76E-03	2.86E-04	–10 ± 5
16.5	1.17E-03	2.85E-04	1.26E-03	4.38E-04	2.57E-03	2.69E-04	–5 ± 6
17.5	7.99E-04	3.18E-04	1.82E-03	4.35E-04	1.24E-03	2.53E-04	5 ± 2
20.5	5.21E-04	2.76E-04	3.81E-03	4.01E-04	3.59E-04	2.70E-04	27 ± 4
23.5	9.72E-04	2.96E-04	1.70E-03	4.40E-04	1.39E-04	1.65E-04	35 ± 6
26.5	9.03E-04	2.75E-04	2.31E-03	4.26E-04	4.51E-04	2.32E-04	53 ± 11
29.5	1.18E-03	2.67E-04	8.45E-04	4.30E-04	5.56E-04	2.54E-04	104 ± 60
31.5	4.63E-05	2.65E-04	2.48E-03	4.18E-04	1.16E-05	2.13E-04	–
33.5	7.64E-04	2.87E-04	1.38E-03	3.99E-04	6.37E-04	2.50E-04	–
35.5	2.43E-04	2.78E-04	4.86E-04	4.26E-04	1.62E-04	2.56E-04	–
39.5	1.39E-04	2.64E-04	3.01E-04	4.32E-04	0.00E+00	0.00E+00	–
45.5	2.31E-04	2.73E-04	5.09E-04	4.21E-04	6.94E-04	2.25E-04	–
49.5	1.27E-04	2.60E-04	1.66E-03	4.23E-04	4.51E-04	1.73E-04	–

Supplementary Table 2. Pollen zone transitions identified and dated by Ager (1983), and the corresponding revised ages from Hidden Lake core HD14-2. All depths and ages are reported for the beginning of the zone (i.e., the stratigraphically lower and older limit).

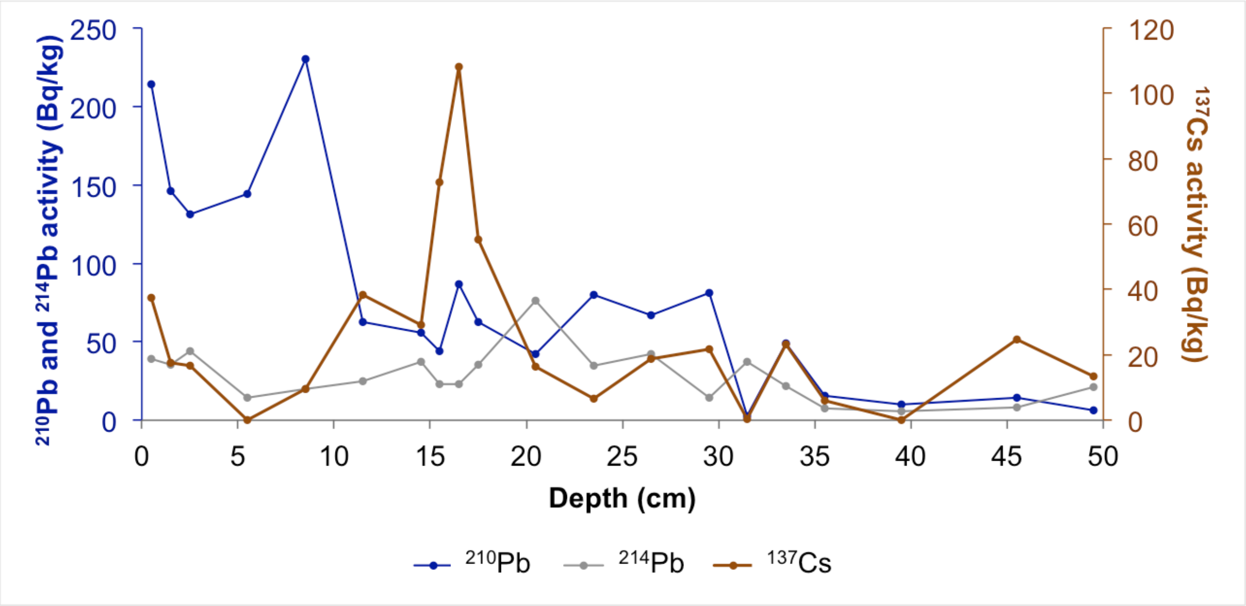
Pollen zone (Ager, 1983)	**Depth (blf cm) (HD14-2)**	**Age (cal yr BP) (Ager, 1983)**	**Age (cal yr BP) (HD14-2)**
Picea-Alnus-Betula	161.7	8,851 ± 635	8,541 ± 356
Alnus	177.7	10,818 ± 652	9,245 ± 198
Populus-Salix	201.7	12,246 ± 670	11,271 ± 803
Betula	225.7	16,636 ± 681	12,970 ± 605

Supplementary Table 3. Observed 20th century climate data recorded at Kenai airport (air temperature; http://climate.gi.alaska.edu/acis_data), the Kenai Moose Pens SNOTEL station in Soldotna (precipitation; https://www.wcc.nrcs.usda.gov/index.html), and the Western Regional Climate Center station in Gateway (evaporation; https://wrcc.dri.edu/Climate/comp_table_show.php?stype=pan_evap_avg), compared to simulated values from the 0 ka, 4 ka, and 9 ka HadCM3 snapshots. The difference between the observed data and the 0 ka simulation is applied as a bias correction to the 4 ka and 9 ka values.

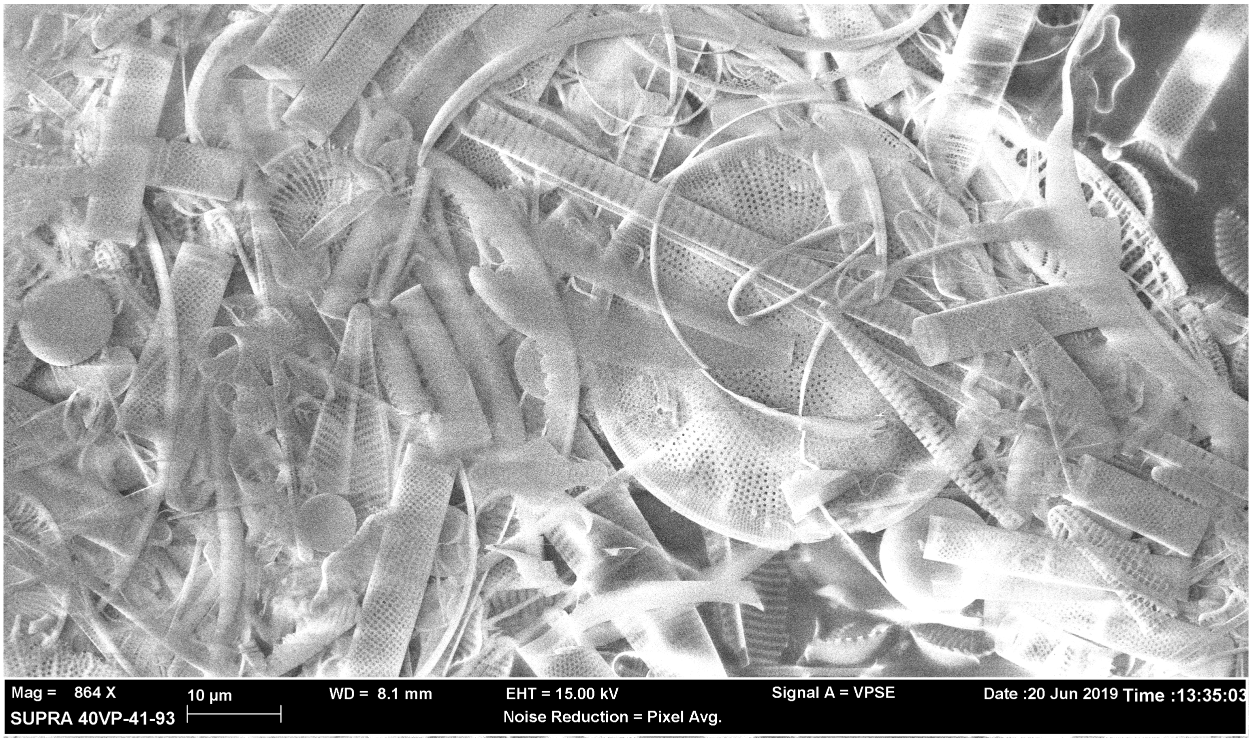
Time period	Air temperature (°C)	Precipitation rate (m/year)	Evaporation rate (m/year)	Relative humidity (%)
20th–21st century (measured)	0.9 (for ~1950 CE)	0.59	0.44	89
0 k (1850 CE) HadCM3 (modeled)	–1.9	0.64	0.35	91
4 k HadCM3 (modeled)	–1.9	0.66	0.36	91
9 k HadCM3 (modeled)	–2.4	0.55	0.23	93
Difference (measured – HadCM3 0 k)	2.0	–0.05	0.09	2
4 k corrected	1.0	0.61	0.45	89
9 k corrected	0.5	0.50	0.32	91

Supplementary Table 4. Depths, thicknesses, and ages for visible tephra (volcanic ash deposits) in HD14-2 and KLY18-2.
*Calibrated age is the median of the calibrated age probability density function. Uncertainty is one half of the two-sigma calibrated age range.

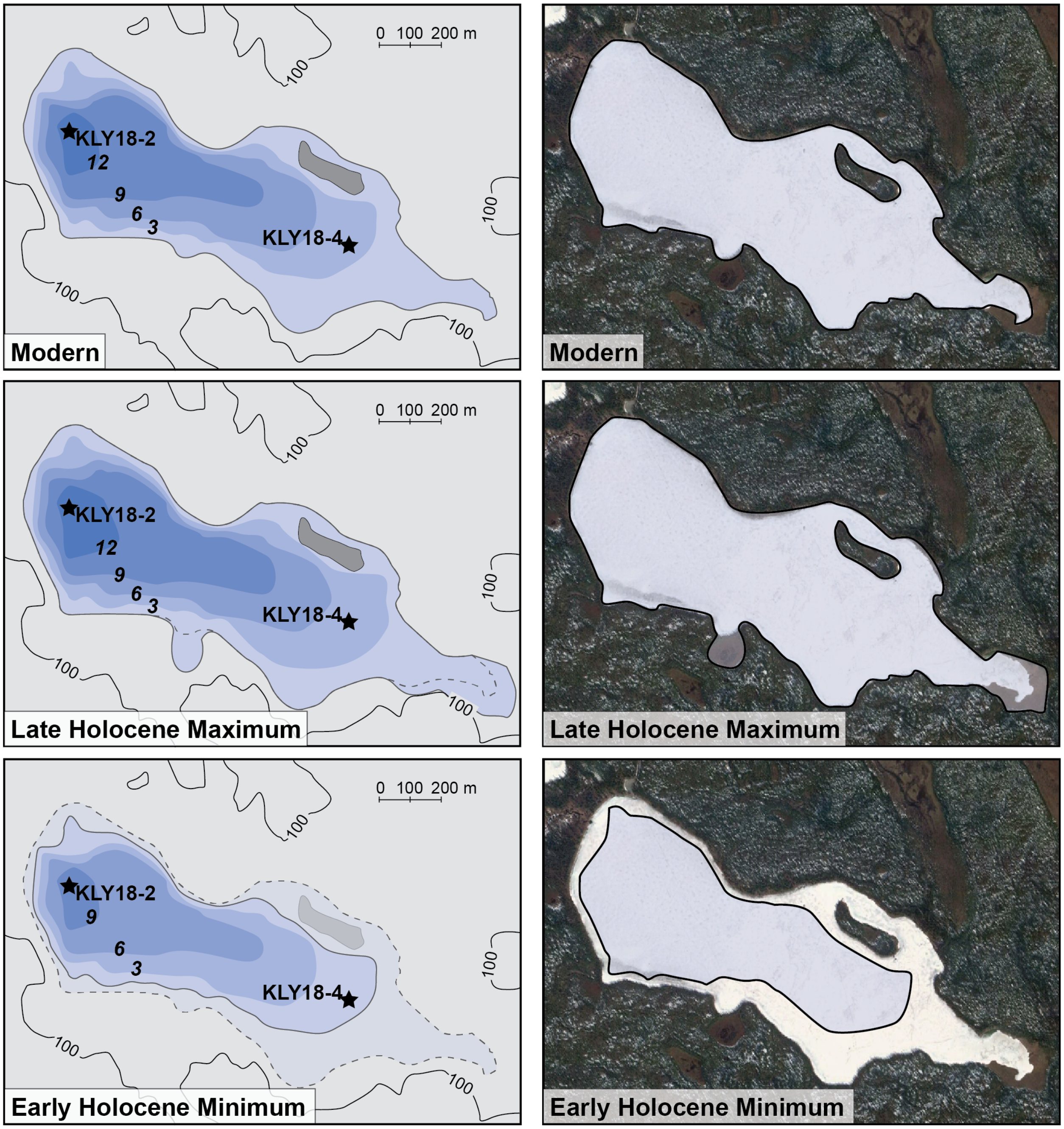
Core and section ID	**Section depth (cm)**	**Depth blf (cm)**	**Thickness (mm)**	**Age (cal yr BP)***
HD14-2C	13.3	4.8	1	-32 ± 31
HD14-2C	18.2	9.7	2	136 ± 274
HD14-2C	20.0	11.5	1	233 ± 305
HD14-2C	22.5	14.0	4	338 ± 352
HD14-2A-1	26.5	48.2	4	2052 ± 212
HD14-2A-1	57.5	79.2	10	3837 ± 302
HD14-2A-1	79.0	100.7	1	5114 ± 491
HD14-2A-1	89.5	111.2	2	5780 ± 574
HD14-2A-1	103.0	124.7	4	6635 ± 201
HD14-2A-1	105.0	126.7	2	6737 ± 304
HD14-2A-2	17.0	150.2	5	8038 ± 111
HD14-2A-2	33.5	167.2	1	8791 ± 380
HD14-2A-2	37.0	169.7	5	8878 ± 371
HD14-2A-2	72.0	205.7	5	11583 ± 755
HD14-2A-2	97.5	231.2	5	13212 ± 714
KLY18-2C	22.5	13.5	2	-16 ± 4
KLY18-2A-1	67.3	102.8	2	881 ± 171
KLY18-2A-2	10.0	118.5	20	994 ± 183
KLY18-2A-3	62.0	316.0	5	2700 ± 162
KLY18-2A-3	87.7	341.7	2	2869 ± 138
KLY18-2A-4	64.0	473.0	30	4234 ± 180
KLY18-2A-4	130.1	539.1	2	4877 ± 101
KLY18-2A-4	151.8	560.8	6	5089 ± 128
KLY18-2B-2	54.5	608.5	25	5613 ± 269
KLY18-2B-2	67.5	621.5	5	5749 ± 262
KLY18-2B-2	89.6	643.6	2	5964 ± 236
KLY18-2B-2	101.9	655.9	2	6270 ± 337
KLY18-2B-3	35.9	686.4	3	7146 ± 180
KLY18-2B-3	37.4	687.9	2	7174 ± 218
KLY18-2B-3	42.2	692.7	12	7239 ± 228
KLY18-2B-3	43.6	694.1	4	7258 ± 238
KLY18-2B-3	57.7	708.2	3	7507 ± 280
KLY18-2B-3	61.8	712.3	2	7585 ± 272
KLY18-2B-3	71.6	722.1	2	7765 ± 264
KLY18-2B-3	74.5	725.0	3	7811 ± 234
KLY18-2B-3	75.4	725.9	2	7823 ± 228
KLY18-2B-3	85.7	736.2	2	8012 ± 107
KLY18-2B-3	94.0	744.5	4	8264 ± 269
KLY18-2B-3	95.0	745.5	2	8290 ± 299
KLY18-2B-3	96.8	747.3	2	8338 ± 360
KLY18-2B-4	51.2	774.2	2	9192 ± 191
KLY18-2B-4	54.8	777.8	5	9315 ± 148



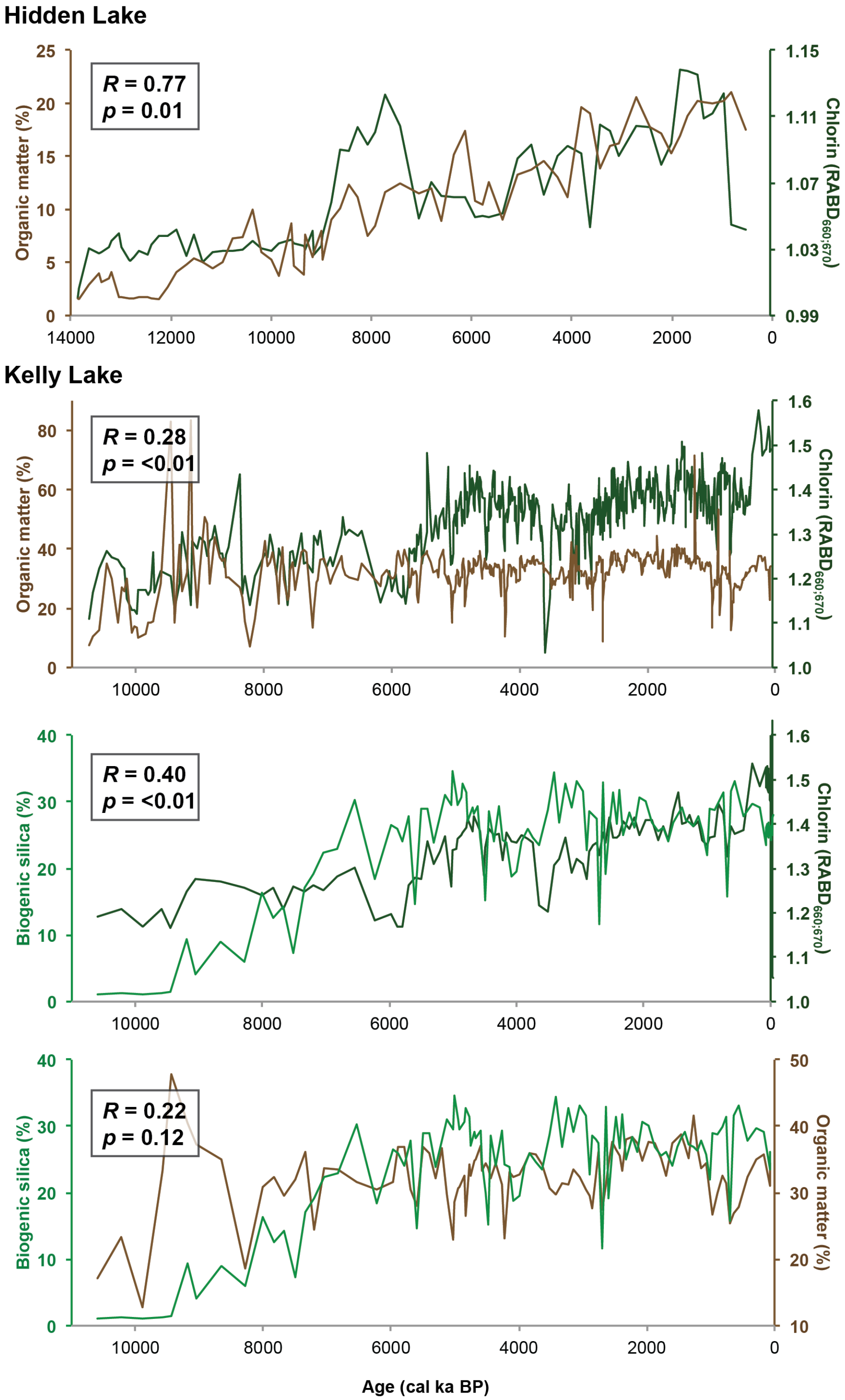
Supplementary Figure 1. ^{210}Pb, ^{214}Pb, and ^{137}Cs activity profiles from Kelly Lake surface core KLY18-2C. Activities (on the y-axes) are given in becquerels per kilogram (Bq/kg). Data used in this graph are given in Supplementary Table 1.



Supplementary Figure 2. Purified sedimentary diatom sample from 364 cm below lake floor (3,054 ± 170 cal yr BP) in Kelly Lake core KLY18-2.



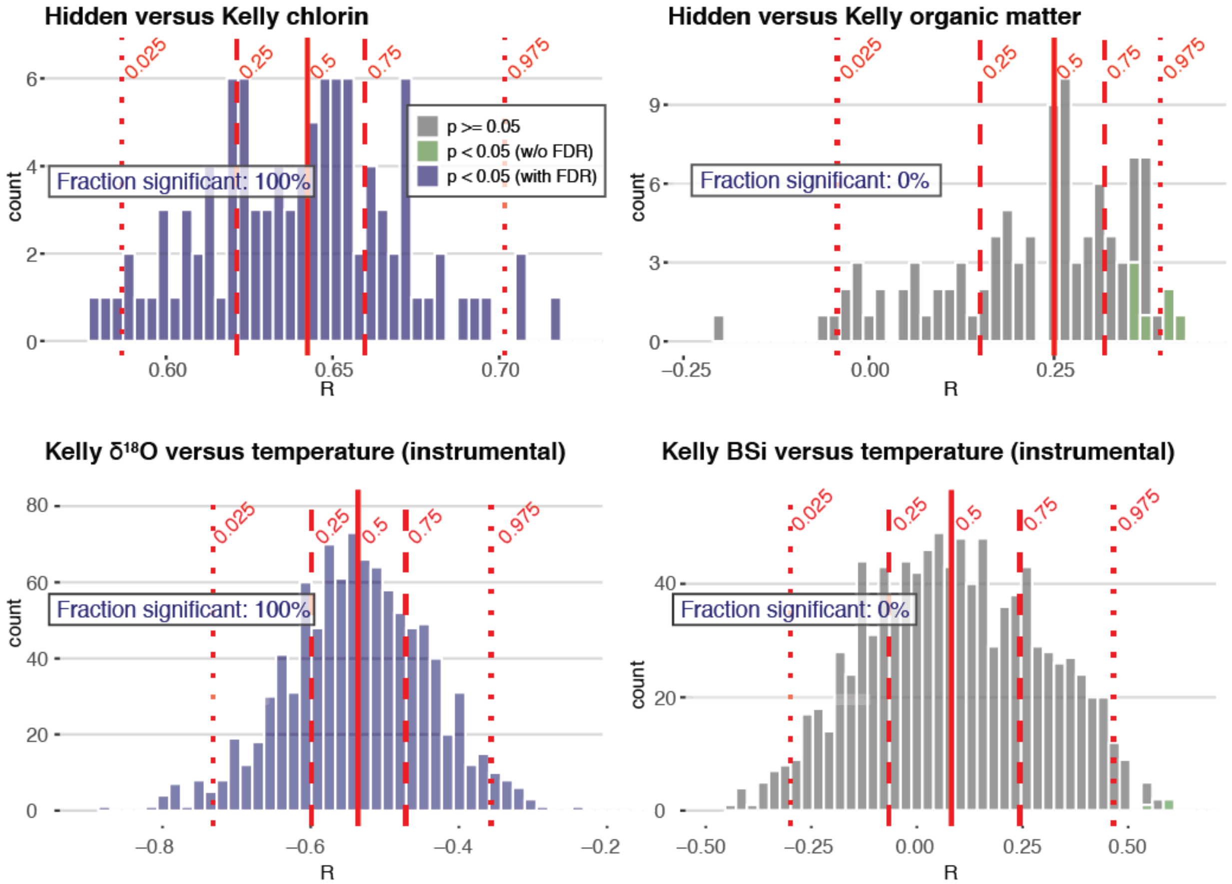
Supplementary Figure 3. Inferred late Holocene maximum and early Holocene minimum lake levels. Maximum elevation encompasses adjacent fens, and minimum elevation is constrained by the documented continual Holocene sedimentation at site KLY18-4 (Wrobleski, 2021). These lake level fluctuations are shown alongside their corresponding bathymetric profiles (left column), illustrating the extent to which lowered lake level brings shallow water closer to the coring location described in this study (KLY18-2). Satellite imagery from Google Earth (2019).



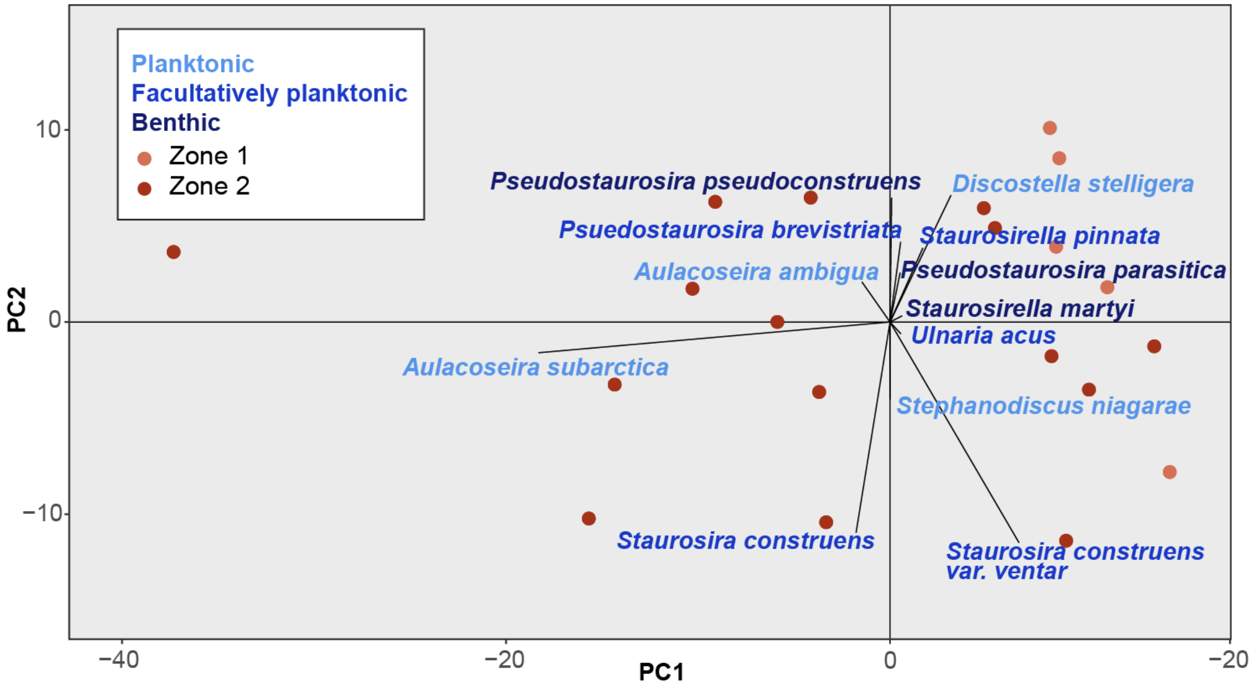
Hidden Lake

Kelly Lake

Supplementary Figure 4. Correlations between productivity proxy datasets at Hidden Lake (top panel) and Kelly Lake (bottom three panels). Correlations are shown for organic matter and chlorin content in the top two panels, followed by biogenic silica and chlorin, and biogenic silica and organic matter in the bottom panel. Prior to calculating *r* and *p* values, the higher resolution dataset was binned into intervals corresponding to those of the lower resolution dataset, and the *p* values were corrected for auto-correlation.



Supplementary Figure 5. Frequency distribution of age-uncertain correlations. Top two panels show correlations between chlorin (left) and organic matter (right) proxy datasets between the two lakes. Bottom two panels show correlations between $\delta^{18}O_{\text{diatom}}$ (left) and BSi (right) data at Kelly Lake from 1940 – 2018 CE, versus temperature recorded at Kenai airport over this time period (http://climate.gi.alaska.edu/acis_data). *R* and *p* values were calculated using all ensemble members from the Bacon age models for Hidden and Kelly Lakes. Purple indicates a correlation that is significant ($p < 0.05$) after applying a 5% false discovery rate (FDR); green indicates a correlation that is only significant before applying the FDR (i.e., a less robust correlation); and gray indicates a correlation that is not significant.



Supplementary Figure 6. Principal component analysis (PCA) of diatom assemblages by sample. CONISS zone is indicated by dot color (see Figure 8 in main text), and habitat types (after Spaulding et al., 2020) are indicated by text color. PC1 explains 52% of the variance in the dataset, and PC2 explains 13%.

Code for the hydrologic and isotope mass balance model (in R)

```
#Code used in the simple isotope mass balance model after Krabbenhoft et al. (1990)

#PART 1: a function to calculate groundwater inflow in m^3/year (without uncertainty):

Krabbenhoft = function(dL,SA,E,P,dP,TA,TL,RH,dG){
  #where:
  #dL is the isotope composition of the lake water in per mil
  #SA is the lake's surface area in m^2
  #E is the evaporation rate in m^2/year
  #dP is the isotope composition of precipitation in per mil
  #P is the precipitation rate in m^2/year
  #TA is the air temperature in °C
  #TL is the water surface temperature in °C
  #RH is relative humidity in %
  #dG is the isotope composition of the groundwater inflow in per mil

  #first, calculate on-lake precip and evap (in m^3):
  precip = P*SA
  evap = E*SA

  #empirically derive d18O of evaporated water vapor (per mil):
  TA = TA+273.15
  TL = TL+273.15
  esa = 6.108*(2.71828^((17.27*TA)/(TA+237.7)))
  lnalpha = (0.35041*(10^6/TA^3)) - (1.6664*(10^3/TA^2)) + (6.7123*(1/TA)) - (7.685*10^-3)
  alpha = exp(1)^lnalpha
  h = RH*(TA/TL)
  epsilonP = 1000*(1-alpha)
  dA = dP - epsilonP
  epsilonK = 14.2*(1-h)
  epsilon = epsilonK + epsilonP
  dE = ((alpha*dL) - (h*dA) - epsilon) / (1-h+(0.001*epsilonK))

  #and finally calculate the amount of groundwater inflow:
  X = (precip*(dL-dP)+evap*(dE-dL))/(dG-dL)
  return(X)
}
#output is a number for groundwater inflow rate in m^3/year
```

```
#PART 2: a function to calculate groundwater inflow in m^3/year, considering ranges of possible values for precipitation and evaporation rate, as well as multiple scenarios for precipitation and groundwater isotopes:

KrabbenhoftB = function(dL,SA,E,dP,P,TA,TL,RH){
  #where:
  #dL is the isotope composition of the lake water in per mil
  #SA is the lake's surface area in m^2
  #E is the evaporation rate in m^2/year
  #dP is the isotope composition of precipitation in per mil
  #P is the precipitation rate in m^2/year
  #TA is the air temperature in °C
  #TL is the water surface temperature in °C
  #RH is relative humidity in %

  #first, convert P and E to volume, with a range of possibilities for increased/decreased P and E:
  P = c(P*1.25, P, P*0.75)
  E = c(E*1.25, E, E*0.75)
  precip = P*SA
  evap = E*SA

  #empirically derive d18O of evaporated water vapor (per mil), for 3 different d18O scenarios:
  TA = TA+273.15
  TL = TL+273.15
  esa = 6.108*(2.71828^((17.27*TA)/(TA+237.7)))
  lnalpha = (0.35041*(10^6/TA^3)) - (1.6664*(10^3/TA^2)) + (6.7123*(1/TA)) - (7.685*10^-3)
  alpha = exp(1)^lnalpha
  h = RH*(TA/TL)
  epsilonP = 1000*(1-alpha)
  epsilonK = 14.2*(1-h)
  epsilon = epsilonK + epsilonP
  dA = dP - epsilonP
  dE = ((alpha*dL) - (h*dA) - epsilon) / (1-h+(0.001*epsilonK))

  #calculate groundwater d18O as related to d18Oprecip:
  dG = c(dP-1.5, dP, dP+1.5)

  #calculate groundwater inflow based off ranges of dP and dG:
  G1 = matrix(NA, length(dG),length(evap))
  G2 = matrix(NA, length(dG),length(evap))
  G3 = matrix(NA, length(dG),length(evap))
  for (g in 1:3) {
    for (e in 1:3) {
      G1[g,e] = ((precip[1]*(dL-dP)+evap[e]*(dE-dL))/(dG[g]-dL))
    }
  }
```

```
  for (g in 1:3) {
    for (e in 1:3) {
      G2[g,e] = ((precip[2]*(dL-dP)+evap[e]*(dE-dL))/(dG[g]-dL))
    }
  }
  for (g in 1:3) {
    for (e in 1:3) {
      G3[g,e] = ((precip[3]*(dL-dP)+evap[e]*(dE-dL))/(dG[g]-dL))
    }
  }
  G = cbind(G1,G2,G3)
  row.names(G) = dG
  colnames(G) = c(rep(precip[1],times = 3), rep(precip[2],times = 3),rep(precip[3],times = 3))
  G = as.data.frame(cbind(dG,G))

  #make a plot:
  library(ggplot2)
  library(scales)
  plot = ggplot()+
    geom_ribbon(aes(x=G[,1], ymax=G[,2], ymin = G[,4],colour = "PMax", fill = "Pmax"), size
=1,alpha = 0.1, linetype = 2)+
    geom_line(aes(x=G[,1], y=G[,3], colour = "PMax"),size =1)+
    geom_ribbon(aes(x=G[,1], ymax=G[,5], ymin = G[,7],colour = "P", fill = "P"), size =1,alpha =
0.1, linetype = 2)+
    geom_line(aes(x=G[,1], y=G[,6], colour = "P"),size =1)+
    geom_ribbon(aes(x=G[,1], ymax=G[,8], ymin = G[,10],colour = "Pmin", fill = "Pmin"), size
=1,alpha = 0.1, linetype = 2)+
    geom_line(aes(x=G[,1], y=G[,9], colour = "Pmin"),size =1)+
    geom_hline(aes(yintercept = 0), colour = "black")+
    geom_hline(aes(yintercept = 118000), linetype = "dotted", size = 1, colour = "black")+
    xlab("Groundwater d18O")+
    ylab("Groundwater inflow")+
    scale_color_discrete(name = "Precipitation rate", labels = c("P","PMax","PMin"))+
    coord_cartesian(ylim = c(0, 500000)) +
    theme(axis.text = element_text(size = 18), axis.title = element_text(size = 18), legend.position
= "none", legend.text = element_text(size = 18), legend.title = element_text(size = 18),
panel.background = element_rect(fill = 'white', colour = 'black'))
  return(plot)
}
#output is a plot that looks like one of the panels in Figure 9, but with units in meters^3.
```