Ecography

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Supplementary material

Appendix 1: Zooplankton data handling and sources

Zooplankton data for each site are cumulative records of all species occurrences (1922–2015; Fig. A1). Samples were collected over periods of up to eleven years at some locations, though most lakes were sampled over only one or two years. Historical records were obtained from 30 published articles, 32 government reports, and results from previously unpublished surveys (see Data Sources below). Unpublished results include internal reports communicated by government scientists (Environment Canada, National Park Service, and United States Forest Service) and supplementary records from past surveys.

Records for certain historically revised, hybridizing, or otherwise difficult to distinguish North American taxa were combined to improve consistency among data sources: *Eubosmina hagmanni* was updated to *Bosmina hagmanni* (Kotov et al. 2009); *Bosmina coregoni longispina*, *Bosmina longispina*, *Bosmina obtusirostris*, and *Eubosmina longispina* were merged with *Bosmina coregoni* (WoRMS 2017); *Scapholeberis armata*, *Scapholeberis mucronata*, and *Scapholeberis rammneri* were merged with *Scapholeberis kingi* (Dumont and Pensaert 1983, Quiroz-Vázquez and Elías-Gutiérrez 2009); *Alona affinis ornata* was merged with *Alona affinis* (Van Damm et al. 2010); *Ceriodaphnia affinis* and *Ceriodaphnia dubia* were merged with *Ceriodaphnia reticulata* (Berner 1986); *Diaphanosoma brachyurum* and *Diaphanosoma leuchtenbergianum* were merged with *Diaphanosoma birgei* (Witty 2004); *Daphnia longispina*, *Daphnia longispina hyalina ceresiana*, *Daphnia longispina microcephala*, and *Daphnia rosea* were merged with *Daphnia dentifera* (Glagolev and Severtsov 1986, Petrusek et al. 2008); *Daphnia galeata galeata*, *Daphnia galeata mendotae*, and *Daphnia thorata* were merged with *Daphnia galeata* (Glagolev and Severtsov 1986); *Daphnia obtusa* and *Daphnia pulicaria* were merged with *Daphnia pulex* (Schwartz et al. 1985); *Microcyclops bicolor* and *Microcyclops rubellus* were merged with *Microcyclops varicans* (Gutiérrez-Aguirre and Cervantes-Martínez 2016, U. S. Geological Survey 2017); *Acanthocyclops americanus*, *Cyclops robustus*, and *Cyclops vernalis* were merged with *Acanthocyclops vernalis* (Balcer et al. 1984, Dodson et al. 2003); *Eucyclops serrulatus* was merged with *Eucyclops agilis* (Witty 2004); *Cyclops bicuspidatus* and *Diacyclops bicuspidatus thomasi* were merged with *Diacyclops thomasi* (WoRMS 2017); *Diaptomus pribilofensis* was merged with *Leptodiaptomus angustilobus* (WoRMS 2017); *Diaptomus novamexicanus* was merged with *Leptodiaptomus novamexicanus* (WoRMS 2017); *Diaptomus signicauda* was merged with *Leptodiaptomus signicauda* (WoRMS 2017); *Diaptomus sicilis* was merged with *Leptodiaptomus sicilis* (WoRMS 2017); *Diaptomus nudus* was merged with *Leptodiaptomus nudus* (WoRMS 2017); *Diaptomus oregonensis* was merged with *Skistodiaptomus oregonensis* (WoRMS 2017); *Diaptomus tyrrelli* was merged with *Leptodiaptomus tyrrelli* (WoRMS 2017); *Diaptomus leptopus* was merged with *Aglaodiaptomus leptopus* (WoRMS 2017); and *Diaptomus bakeri* was merged with *Hesperodiaptomus franciscanus* (WoRMS 2017).

Historical body length measurements (Messner et al. 2013, Loewen and Vinebrooke 2016) were supplemented with records presented by Luecke and O’Brien (1981), Balcer et al. (1984), Reid

(1992), Vekhoff et al. (1997), Othman and Pascoe (2001), Berezina (2011), Błędzki and Rybak (2016), and Hébert et al. (2016). For some species where body length measurements were unavailable, estimates were taken from a morphologically similar member of the same genus.

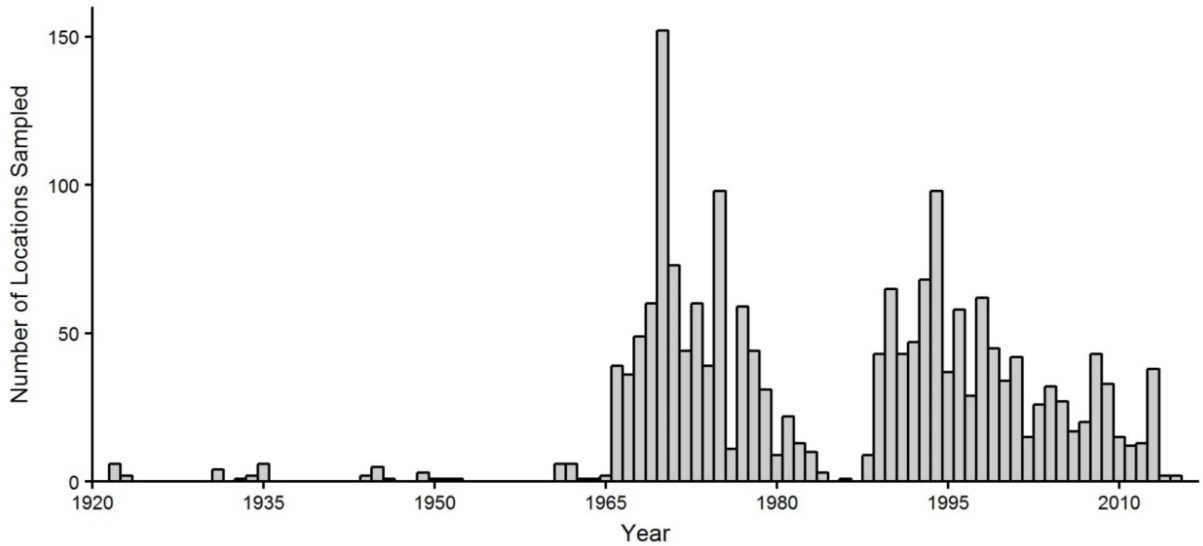

Figure A1. Distribution of zooplankton sampling events. Counts are the number of locations sampled each year (1922–2015). Counts do not indicate duplicate samples collected within a single year. Exact sampling dates were uncertain in some instances and several were inferred from associated water quality monitoring programs.

References

Balcer, M. D. et al. 1984. Zooplankton of the great lakes: a guide to the identification and ecology of the common crustacean species. – Univ. Wisconsin Press.

Berezina, N. A. 2011. Perch-mediated shifts in reproductive variables of *Gammarus Lacustris* (Amphipoda, Gammaridae) in lakes of northern Russia. – Crustaceana 84: 523–542.

Berner, D. B. 1986. Taxonomy of *Ceriodaphnia* (Crustacea: Cladocera) in U.S. Environmental Protection Agency cultures. – Env. Mon. Supp. Lab., Office Res. Devel., USEPA.

Błędzki, L. A. and Rybak, J. I. 2016. Freshwater crustacean zooplankton of Europe: cladocera & copepoda (calanoida, cyclopoida) key to species identification. – Springer Nature.

Dumont, H. J. and Pensaert, J. 1983. A revision of the Scapholeberinae (Crustacea: Cladocera). – Hydrobiologia 100: 3–45.

Dodson, S. I. et al. 2003. Morphological analysis of some cryptic species in the *Acanthocyclops vernalis* species complex from North America. – Hydrobiologia 500: 131–143.

Glagolev, S. M. and Severtsov, A. N. 1986. Species composition of *Daphnia* in Lake Glubokoe with notes on the taxonomy and geographical distribution of some species. – Hydrobiologia 141: 55–82.

Gutiérrez-Aguirre, M. A. and Cervantes-Martínez, A. 2016. Taxonomic evaluation of eleven species of *Microcyclops* Claus, 1893 (Copepoda, Cyclopoida) and description of *Microcyclops inarmatus* sp. n. from America. – Zookeys 603: 33–69.

Hébert, M.-P. et al. 2016. A compilation of quantitative functional traits for marine and freshwater crustacean zooplankton. – Ecol. 97: 1081.

Kotov, A. A. et al. 2009. Revision of the genus *Bosmina* Baird, 1845 (Cladocera: Bosminidae), based on evidence from male morphological characters and molecular phylogenies. – Zool. J. Linn. Soc. 156: 1–51.

Loewen, C. J. G. and Vinebrooke, R. D. 2016. Regional diversity reverses the negative impacts of an alien predator on local species-poor communities. – Ecol. 97: 2740–2749.

Luecke, C. and O'Brien, W. J. 1981. Phototoxicity and fish predaton: selective factors in color morphs in *Heterocope*. – Limnol. Oceanogr. 26: 454–460.

Messner, J. S. et al. 2013. Higher temperatures enhance the effects of invasive sportfish on mountain zooplankton communities. – Freshwater Biol. 58: 354–364.

Othman, M. S. and Pascoe, D. 2001. Growth, development and reproduction of *Hyalella Azteca* (Saussure, 1858) in laboratory culture. – Crustaceana 74: 171–181.

Petrusek, A. et al. 2008. A taxonomic reappraisal of the European *Daphnia longispina* complex (Crustacea, Cladocera, Anomopoda). – Zool. Scripta. 37: 507–519.

Quiroz-Vázquez, P. and Elías-Gutiérrez, M. 2009. A new species of the freshwater cladoceran genus *Scapholeberis* Schoedler, 1858 (Cladocera: Anomopoda) from the semidesert northern Mexico, highlighted by DNA barcoding. – Zootaxa 2236: 50–64.

Reid, J. W. 1992. Copepoda (crustacea) from fresh waters of the Florida Everglades, U.S.A., with a description of *Eucyclops conrowae* n. sp. – Trans. Am. Miscrosc. Soc. 111: 229–254.

Schwartz, S. W. et al. 1985. Morphological separation of *Daphnia pulex* and *Daphnia obtusa* in North America. – Limnol. Oceangr. 30: 189–197.

U. S. Geological Survey. 2017. Free-living and parasitic copepods (including Branchiurans) of the Laurentian Great Lakes: keys and details on individual species. – U. S. Army Corps of Engineers (https://www.glsc.usgs.gov/greatlakescopepods/MainMenu.php).

Van Damm, K. et al. 2010. A checklist of names in *Alona* Baird 1843 (Crustacea: Cladocera: Chydoridae) and their current status: an analysis of the taxonomy of a lump genus. – Zootaxa 2330: 1–63.

Vekhoff, N. V. 1997. Large branchiopod crustacea (anostraca, notostraca, spinicaudata) of the Barents region of Russia. – In: Simovich, M. A. et al. (eds), Studies on large branchiopod biology and conservation. Springer Netherlands, pp. 69–74.

Witty, L. M. 2004. Practical guide to identifying freshwater crustacean zooplankton, 2nd ed. – Coop. Freshw. Ecol. Unit., Dep. Biol., Laurentian University.

WoRMS. 2017. World register of marine species. (www.marine species.org)

Data Sources

Published literature:

Anderson, R. S. 1974. Crustacean plankton communities of 340 lakes and ponds in and near the National Parks of the Canadian Rocky Mountains. – J. Fish. Res. Board Can. 31: 855–869.

Brooks, J. L. 1957. The systematics of North American *Daphnia*. – Mem. Conn. Acad. Arts Sci. 13: 1–180.

Carl, G. C. 1940. The distribution of some Cladocera and free-living Copepoda in British Columbia. – Ecol. Monogr. 10: 55–110.

Carl, G. C. 1953. Limnobiology of Cowichan Lake, British Columbia. – J. Fish. Res. Board Can. 9: 417–449.

Chapman, M. A. et al. 1985. Seasonal dynamics of *Skistodiaptomus pallidus* Herrick and other zooplankton populations in Deer Lake, S.W. British Columbia. – J. Plankton Res. 7: 867–876.

Donald, D. B. et al. 2001. Recovery of zooplankton assemblages in mountain lakes from the effects of introduced sport fish. – Can. J. Fish. Aquat. Sci. 58: 1822–1830.

Fischer, J. M. et al. 2015. Diel vertical migration of copepods in mountain lakes: the changing role of ultraviolet radiation across a transparency gradient. – Limnol. Oceanogr. 60: 252–262.

Foerster, R. E. 1925. No. 16: Studies in the ecology of the sockeye salmon (*Oncorhynchus nerka*). – Contrib. Can. Biol. Fish. 2a: 335–422.

Hammer, U. T. and Forró, L. 1992. Zooplankton distribution and abundance in saline lakes of British Columbia, Canada. – Int. J. Salt Lake Res. 1: 65–80.

Hartman, W. L. and Burgner, R. L. 1972. Limnology and fish ecology of sockeye salmon nursery lakes of the world. – J. Fish. Res. Board Can. 29: 699–715.

Hooper, F. F. 1947. Plankton collections from the Yukon and MacKenzie River systems. – Trans. Am. Microsc. Soc. 66: 74–84.

Larson, G. L. et al. 2009. Zooplankton assemblages in montane lakes and ponds of Mount Rainier National Park, Washington State, USA. – J. Plankton Res. 31: 273–285.

Loewen, C. J. G. and Vinebrooke, R. D. 2016. Regional diversity reverses the negative impacts of an alien predator on local species-poor communities. – Ecol. 97: 2740–2749.

MacLennan, M. M. et al. 2015. Invasive trout increase the climatic sensitivity of zooplankton communities in naturally fishless lakes. – Freshw. Biol. 60: 1502–1513.

Marsh, C. D. 1933. Synopsis of the Calanoid crustaceans, exclusive of the Diaptomidae found in fresh and brackish water, chiefly of North America. – Proc. U. S. Nat. Mus. 82: 1–58.

McMahon, V. H. 1954. The abundance and distribution of entomostracan plankton at Lakelse Lake, B. C., 1949–1952. – J. Fish. Res. Board Can. 11: 479–499.

McMaster, N. L. and Schindler, D. W. 2005. Planktonic and epipelic algal communities and their relationship to physical and chemical variables in alpine ponds in Banff National Park, Canada. – Arct., Antarc., Alp. Res. 37: 337–347.

Neill, W. E. 1978. Experimental studies on factors limiting colonization by *Daphnia pulex* Leydig of coastal montane lakes in British Columbia. – Can. J. Zool. 56: 2498–2507.

Neill, W. E. 1984. Regulation of rotifer densities by crustacean zooplankton in an oligotrophic montane lake. – *Oecologia* 61: 175–181.

Northcote, T. G. and Halsey, T. G. 1969. Seasonal changes in the limnology of some meromictic lakes in southern British Columbia. – J. Fish. Res. Board Can. 26: 1763–1787.

Northcote, T. G. and Lorz, H. W. 1966. Seasonal and diel changes in food of adult Kokanee (*Oncorhunchus nerka*) in Nicola Lake, British Columbia. – J. Fish. Res. Board Can. 23: 1259–1263.

Northcote, T. G. et al. 1964. Some characteristics of Nitinat Lake, an inlet on Vancouver Island, British Columbia. – J. Fish. Res. Board Can. 21: 1069–1081.

Olenick, R. J. 1983. The effects of interspecific competition on *Diaptomus leptopus* in a montane lake: an experimental field study. – Can. J. Zool. 61: 2273–2287.

Patalas, K. and Salki, A. 1973. Crustacean plankton and the eutrophication of lakes in the Okanagan Valley, British Columbia. – J. Fish. Res. Board Can. 30: 519–542.

Rawson, D. S. 1953. The limnology of Amethyst Lake, a high alpine type near Jasper, Alberta. – Can. J. Zool. 31: 193–210.

Ricker, W. E. 1937. The food and the food supply of sockeye salmon (*Oncorhynchus nerka* Walbaum) in Cultus Lake, British Columbia. – J. Biol. Board Can. 3: 450–468.

Ricker, W. E. 1938. Seasonal and annual variations in the quantity of pelagic net plankton, Cultus Lake, British Columbia. – J. Fish. Res. Board Can. 4: 33–47.

Robertson, J. G. 1954. The trophic status of Port John Lake, British Columbia. – J. Fish. Res. Board Can. 11: 624–650.

Swadling, K. M. et al. 2000. Zooplankton community composition of lakes in the Yukon and Northweset Territories (Canada): relationship to physical and chemical limnology. – Hydrobiologia 431: 211–224.

Zyblut, E. R. 1970. Long term changes in the limnology and macrozooplankton of a large British Columbia lake. – J. Fish. Res. Board Can. 27: 1239–1250.

Government reports and data repositories:

Anderson, R. S. 1970a. Limnological studies of high altitude lakes in western Canada. Part 8: a survey of some alpine and subalpine waters in northern Yoho National Park. – Prepared for Parks Can. by CWS.

Anderson, R. S. 1970b. Limnological studies of high altitude lakes in western Canada. Part 10: some shallow mountain lakes and ponds in east-central Jasper National Park. – Prepared for Parks Can. by CWS.

Anderson, R. S. and Donald, D. B. 1976a. Limnological survey of Waterton Lakes National Park. Part 3: small lakes and water chemistry. – Prepared for Parks Can. by CWS.

Anderson, R. S. and Donald, D. B. 1976b. Limnological survey of Waterton Lakes National Park. Part 4: the ponds. – Prepared for Parks Can. by CWS.

Anderson, R. S. and Donald, D. B. 1978a. Limnological studies in Jasper National Park. Part 3: aquatic inventory and fishery survey, Amethyst and Moat Lakes. – Prepared for Parks Can. by CWS.

Anderson, R. S. and Donald, D. B. 1978b. Limnological studies in Jasper National Park. Part 4: aquatic survey and fisheries study, Annette, Beauvert, Edith, Horseshoe, Patricia and Pyramid Lakes. – Prepared for Parks Can. by CWS.

Anderson, R. S. and Donald, D. B. 1978c. Limnological studies in Jasper National Park. Part 5: aquatic survey and reappraisal of the sport fishery in the Maligne River watershed. – Prepared for Parks Can. by CWS.

Anderson, R. S. and Donald, D. B. 1978d. Limnological survey of some lakes in the vicinity of the Cascade Trail, Banff National Park. – Prepared for Parks Can. by CWS.

Anderson, R. S. and Donald, D. B. 1980. Limnological studies in Jasper National Park. Part 7: a limnological survey and study of 24 lakes in the 'west block'. – Prepared for Parks Can. by CWS.

Anderson, R. S. et al. 1976. Limnological survey of Waterton Lakes National Park. Part 2: the main lakes. – Prepared for Parks Can. by CWS.

Clemens, W. A. et al. 1939. A biological survey of Okanagan Lake, British Columbia. – Bull. Fish. Res. Board Can. No. 56.

Clemens, W. A. et al. 1968. A limnological study of Teslin Lake, Canada. – B. C. Fish and Wildl. Branch No. 12.

Donald, D. B. and Alger, D. J. 1984a. Limnological studies in Glacier and Mount Revelstoke national parks. Part 1: the lakes. – Prepared for Parks Can. by CWS.

Donald, D. B. and Alger, D. J. 1984b. Limnological studies in Kootenay National Park. Part 1: the lakes. – Prepared for Parks Can. by CWS.

Donald, D. B. and De Henau, A.-M. 1981. Limnological studies in Jasper National Park. Part 8: a limnological survey and management study of 23 lakes near the icefields parkway. – Prepared for Parks Can. by CWS.

Donald, D. B. et al. 1985. Limnological studies in Jasper National Park. Part 10: the north boundary lakes. – Prepared for Parks Can. by CWS.

Environmental Canada. 2000. Unpublished internal reports, personal communication from Donald, D. B.

Johnson, W. E. 1965. Quantitative studies of the pelagic entomostracan zooplankton of Babin Lake and Nilkitkwa Lake, 1955–1963: methods, stations and basic data. – Fish. Res. Board Can. Manuscr. Rep. Series No. 821.

Kennedy, O. D. and LeBrasseur, R. J. 1972. Zooplankton, species counts for Ash River Drainage Diversion, Stamp River and some lakes surrounding Great Central Lake, 1971. – Fish. Res. Board Canada Manuscr. Rep. Series No. 1173.

Kennedy, O. D. et al. 1971. Primary and secondary productivity data for Great Central Lake, BC, 1970. – Fish. Res. Board Can. Manuscr. Rep. Series No. 1127.

Kubly, D. M. 1983. Plankton of high Sierra lakes. – S. Cali. Edison Res. Develop. Rep. No. 830RD-47.

Lindsey, C. C. et al. 1981. Glaciation and the physical, chemical and biological limnology of Yukon lakes. – Can. Tech. Rep. Fish. Aquat. Sci. No. 966.

Liss, W. J. et al. 2002. Ecological impact of introduced trout on native aquatic communities in mountain lakes: phase III final report. – Prepared for Nat. Park Serv. by US For. Serv.

Manzer, J. I. 1972. Data on catches, size and food of the three-spined stickleback in Great Central Lake, British Columbia, in 1971. – Fish. Res. Board Can. Manuscr. Rep. Series No. 1166.

Mayhood, D. W. and Anderson, R. S. 1976. Limnological survey of the Lake Louise area, Banff National Park. Part 2: the lakes. – Prepared for Parks Can. by CWS.

Mudry, D. R. and Anderson, R. S. 1975. Yoho National Park aquatic resources inventory. – Prepared Parks Can. CWS.

National Park Service. 2016. Unpublished internal reports, personal communication from staff scientists.

Patalas, K. et al. 1994. Planktonic crustaceans in lakes of Canada (distribution of species, bibliography). – Can. Tech. Rep. Fish. Aquat. Sci. No. 1954.

Rankin, D. P. and Ashton, H. J. 1980. Crustacean zooplankton abundance and species composition in 13 sockeye salmon (*Oncorhunchus nerka*) nursery lakes in British Columbia. – Can. Tech. Rep. Fish. Aquat. Sci. No. 957.

Rankin, D. P. et al. 1979. Crustacean zooplankton abundance and species composition in six experimentally fertilized British Columbia lakes. – Fish. Mar. Serv. Tech. Rep. No. 897.

Rankin, D. P. et al. 1983a. Zooplankton abundance in British Columbia lakes sampled by the Lake Enrichment Program in 1977. – Can. Data Rep. Fish. Aquat. Sci. No. 421.

Rankin, D. P. et al. 1983b. Zooplankton abundance in British Columbia lakes sampled by the Lake Enrichment Program in 1978. Part I: Vancouver Island. – Can. Data Rep. Fish. Aquat. Sci. No. 442.

Rawson, D. S. 1934. Productivity studies in lakes of the Kamloops region, British Columbia. – Bull. Biol. Board Can. No. 42.

Stockner, J. G. and Shortreed, K. R. S. 1978. Limnological survey of 35 sockeye salmon (*Oncorhynchus nerka*) nursery lakes in BC and the Yukon Territory. – Fish. Mar. Serv. Tech. Rep. No. 827.

United States Forest Service. 2016. Unpublished internal reports, personal communication from staff scientists.

Appendix 2: Methodological details and data sources for environmental predictors

Catchment boundaries

Watershed delineation and subsequent geoprocessing were conducted using ArcGIS FOR DESKTOP 10.5.0.6491 (Esri 2016). Delineations were based on one arc-second (<30 m) resolution digital elevation maps (DEMs) from the National Elevation Dataset (U. S. Geological Survey 2016a), and the locations of 1:24,000 scale hydrological features (best available data 1944–2016) from the National Hydrography Dataset (U.S. Geological Survey 2016b) and the National Hydrology Network (Natural Resources Canada 2004). Geographic coordinates for sampling locations were spatially joined with waterbody polygons and confirmed/corrected using satellite imagery (Esri 2016). Study areas were projected and analyzed using standard state plane or regional projections to minimize local measurement error.

Terrain preprocessing and watershed delineation procedures were adapted from Esri (2013) for dendritic drainages. DEM manipulation involved filling all sinks to resolve erroneous pits and ensure continuous flow through each hydrological system. DEMs were then reconditioned to emphasize known drainage networks by burning a 10 m trench along stream polylines (AGREE method; Hellweger 1997). Because DEMs lacked bathymetry information, lake polygons were levelled and dropped by 10 m to improve consistency around their perimeters. We then filled any new sinks in the DEMs (created during reconditioning or levelling procedures) and delineated watersheds for each lake polygon from estimated flow direction grids.

Climate and lake/catchment predictors

Catchment and lake boundaries were used to overlay grids of relevant climate and landscape attributes and calculate zonal summaries for each sampling location. Mean catchment aspect, mean catchment slope, and minimum lake elevation were estimated from unprocessed DEMs. Catchment and lake sizes were calculated directly from their feature layers.

Fifty year-mean annual total precipitation at each catchment and annual mean air temperature at each lake surface (1950–2000) were calculated from 30 arc-second (~1 km) grids interpolated from monthly climate records (Hijmans et al. 2005, Commission for Environmental Cooperation 2011).

Mean incoming solar radiation was estimated at each waterbody using the Area Solar Radiation tool (Esri 2016). Direct and diffuse insolation (WH/m^2) was calculated over an 18 week period (May 20–September 23), approximating the open-water season in North American mountain lakes. Calculations were based on geographic positions (latitude and elevation), proximal topography (i.e. shadow cover), and atmospheric conditions (i.e. cloud cover). Waterbody elevations and 20 km upward-looking viewsheds (512 x 512 cells) were estimated from unprocessed DEMs. Mean latitude and cloud cover (1950–2000; University of East Anglia

Climatic Research Unit 2012) were estimated individually for groups of waterbodies occupying cells on a 0.5 degree grid. Cloud cover estimates were used to calculate transmittivity (*t)* as:

$$t = (0.7\ \times P_{clear}) + \left(0.3 \times P_{cloudy}\right)$$

and diffuse proportion (*d*) as:

$$d = (0.2 \times P_{clear}) + (0.7 \times P_{cloudy})$$

where P_{clear} and P_{cloudy} were the estimated proportions of clear and cloudy days, respectively (adapted from Huang et al. 2008). The standard overcast model was used to estimate diffuse radiation (i.e. incoming flux varied with zenith angle). Viewshed calculations used 64 azimuth directions to capture complex topography.

Land cover characteristics at each catchment were calculated from one arc-second (<30 m) resolution grids derived by the Earth Observation for Sustainable Development of Forests (2006) project and the National Land Cover Database (U.S. Geological Survey 2014) from various Landsat imagery and ancillary data (ca. 2000–2001). The data were merged and reclassified to 12 cover classes, including: surface water, perennial ice/snow, developed (non-vegetated), barren land (rock/sand/clay), coniferous/evergreen forest, deciduous/broadleaf forest, mixedwood forest, shrub/scrubland, grassland/herbaceous, agricultural (cropland/pasture), wooded/shrub wetland, and emergent/herbaceous wetland. Undefined areas (including cloud cover and shadows) were subtracted from the total catchment area before calculating the proportional representation of each land cover class.

Catchment lithology was calculated from 7.5 arc-second (<250 m) resolution grids assembled for the Global Ecological Land Unit Map (Sayre et al. 2014; from composition data derived ca. 2004). Lithology classes included acid plutonics, acid volcanics, carbonate sedimentary rock, evaporite, metamorphic rock, mixed sedimentary rock, non-acidic plutonics, non-acidic volcanics, non-carbonate sedimentary rock, pyroclastics, and unconsolidated sediment. As with land cover estimates, undefined areas were subtracted from the total catchment area before calculating the proportional representation of each lithology class.

References and Data Sources

Commission for Environmental Cooperation. 2011. North American Environmental Atlas. – Available from North Am. Agree. Env. Coop. (http://www.cec.org/tools-and-resources/north-american-environmental-atlas).

Earth Observation for Sustainable Development of Forests. 2006. Land Cover Classification. – Available from Can. Forest Serv., Pacific Forest. Centre. (https://pfc.cfsnet.nfis.org/mapserver/cesium1.14/Apps/NFISApps/eosdMap.html).

Esri. 2013. Overview of Arc Hydro Terrain Preprocessing Workflows. – Esri Inc.

Esri. 2016. ArcGIS Desktop, ver. 10.5.0.6491. – Esri Inc.

Huang, S. et al. 2008. Modeling monthly near-surface air temperature from solar radiation and lapse rate: application over complex terrain in Yellowstone National Park. – Phys. Geogr. 29: 158–178.

Hellweger, F. 1997. AGREE – DEM Surface Reconditioning System. – Available from Univ. Texas (http://www.ce.utexas.edu/prof/maidment/GISHYDRO/ferdi/research/agree/agree.html).

Hijmans, R. J. et al. 2005. Very high resolution interpolated climate surfaces for global land areas. – Available from Int. J. Climatol. 25: 1965–1978 (http://worldclim.org/).

Natural Resources Canada. 2004. National Hydro Network. – Available from GeoGratis (http://open.canada.ca/data/en/dataset/87066e9a-94ee-680a-b1ba-591f4688db7d).

Sayre, R. et al. 2014. A new map of global ecological land units – an ecophysiographic stratification approach. – Available from Assoc. Am. Geogr. (https://rmgsc.cr.usgs.gov/ecosystems/).

University of East Anglia Climatic Research Unit. 2012. High resolution gridded data of month-by-month variation in climate (Jan. 1901–Dec. 2009), ver. 3.10. – Available from NCAS Brit. Atmosph. Data Centre (http://www.cgiar-csi.org/data/uea-cru-ts-v3-10-01-historic-climate-database#download).

U. S. Geological Survey. 2014. National Land Cover Database 2001, 2011 ed., amended 2014. – Available from The National Map (https://viewer.nationalmap.gov/launch/).

U. S. Geological Survey. 2016a. National Elevation Dataset. – Available from The National Map at (https://viewer.nationalmap.gov/launch/).

U. S. Geological Survey. 2016b. National Hydrography Dataset, Best Resolution. – Available from The National Map at (https://viewer.nationalmap.gov/launch/).

Appendix 3: Fish introduction data sources

Fish introduction status was estimated at each waterbody following a review of historical salmonid stocking and occurrence records (see below). Zooplankton communities were assumed to be affected by introduced fish where records indicated recent stocking efforts or presence of exotic species prior to the time sampling. Waterbodies were assumed to have not been stocked in the absence of historical accounts of fish introduction, though this does not reject the possible occurrence of native species.

Data Sources

Published literature:

Carl, G. C. 1953. Limnobiology of Cowichan Lake, British Columbia. – J. Fish. Res. Board Can. 9: 417–449.

Donald, D. B. et al. 2001. Recovery of zooplankton assemblages in mountain lakes from the effects of introduced sport fish. – Can. J. Fish. Aquat. Sci. 58: 1822–1830.

Donald, D. B. 1987. Assessment of the outcome of eight decades of trout stocking in the mountain national parks, Canada. – N. Am. J. Fish. Manage. 7: 545–553.

Fischer, J. M. et al. 2015. Diel vertical migration of copepods in mountain lakes: the changing role of ultraviolet radiation across a transparency gradient. – Limnol. Oceanogr. 60: 252–262.

Foerster, R. E. 1925. No. 16: Studies in the ecology of the sockeye salmon (*Oncorhynchus nerka*). – Contrib. Can. Biol. Fish. 2a: 335–422.

Larson, G. L. et al. 2002. Persistence of an unusual pelagic zooplankton assemblage in a clear, mountain lake. – Hydrobiologia 468: 163–170.

Larson, G. L. et al. 2009. Zooplankton assemblages in montane lakes and ponds of Mount Rainier National Park, Washington State, USA. – J. Plankton Res. 31: 273–285.

McMahon, V. H. 1954. The abundance and distribution of entomostracan plankton at Lakelse Lake, B. C., 1949–1952. – J. Fish. Res. Board Can. 11: 479–499.

Neill, W. E. 1978. Experimental studies on factors limiting colonization by *Daphnia pulex* Leydig of coastal montane lakes in British Columbia. – Can. J. Zool. 56: 2498–2507.

Northcote, T. G. and Halsey, T. G. 1969. Seasonal changes in the limnology of some meromictic lakes in southern British Columbia. – J. Fish. Res. Board Can. 26: 1763–1787.

Northcote, T. G. et al. 1964. Some characteristics of Nitinat Lake, an inlet on Vancouver Island, British Columbia. – J. Fish. Res. Board Can. 21: 1069–1081.

Rawson, D. S. 1942. A comparison of some large alpine lakes in Western Canada. – Ecol. 23: 143–161.

Ricker, W. E. 1937. The food and the food supply of sockeye salmon (*Oncorhynchus nerka* Walbaum) in Cultus Lake, British Columbia. – J. Biol. Board Can. 3: 450–468.

Robertson, J. G. 1954. The trophic status of Port John Lake, British Columbia. – J. Fish. Res. Board Can. 11: 624–650.

Walters, C. J. et al. 1990. Comparative population dynamics of *Daphnia rosea* and *Holopedium* in four oligotrophic lakes. – Can. J. Fish. Aquat. Sci. 47: 401–409.

Zyblut, E. R. 1970. Long term changes in the limnology and macrozooplankton of a large British Columbia lake. – J. Fish. Res. Board Can. 27: 1239–1250.

Government reports and data repositories:

Anderson, R. S. 1970. Limnological studies of high altitude lakes in western Canada. Part 10: some shallow mountain lakes and ponds in east-central Jasper National Park. – Prepared for Parks Can. by CWS.

Anderson, R. S. and Donald, D. B. 1976a. Limnological survey of Waterton Lakes National Park. Part 3: small lakes and water chemistry. – Prepared for Parks Can. by CWS.

Anderson, R. S. and Donald, D. B. 1976b. Limnological survey of Waterton Lakes National Park. Part 4: the ponds. – Prepared for Parks Can. by CWS.

Anderson, R. S. and Donald, D. B. 1978a. Limnological studies in Jasper National Park. Part 3: aquatic inventory and fishery survey, Amethyst and Moat Lakes. – Prepared for Parks Can. by CWS.

Anderson, R. S. and Donald, D. B. 1978b. Limnological studies in Jasper National Park. Part 4: aquatic survey and fisheries study, Annette, Beauvert, Edith, Horseshoe, Patricia and Pyramid Lakes. – Prepared for Parks Can. by CWS.

Anderson, R. S. and Donald, D. B. 1978c. Limnological studies in Jasper National Park. Part 5: aquatic survey and reappraisal of the sport fishery in the Maligne River watershed. – Prepared for Parks Can. by CWS.

Anderson, R. S. and Donald, D. B. 1978d. Limnological survey of some lakes in the vicinity of the Cascade Trail, Banff National Park. – Prepared for Parks Can. by CWS.

Anderson, R. S. and Donald, D. B. 1980. Limnological studies in Jasper National Park. Part 7: a limnological survey and study of 24 lakes in the 'west block'. – Prepared for Parks Can. by CWS.

DFO. 2016. Yukon Fisheries Information Summary System (FISS) tool. – Available from Fisheries and Oceans Canada (http://cmnmaps.ca/fiss_yukon/).

Government of Alberta. 2016. Alberta fishing regulations. – Alberta Env. Parks Fish and Wildl. Policy Branch.

Government of British Columbia. 2016. BC freshwater fishing regulations synopsis. – Min. of Forests Lands and Nat. Res. Operations.

Government of British Columbia. 2016. Fisheries Inventory Data Queries (FIDQ) tool. – Available from Min. of Env. B. C. Geogr. Data Wareh. (http://www.env.gov.bc.ca/fish/fidq/).

Government of California. 2016. California Fishing Guide. – Available from Cali. Dep. Fish Wildl. (https://map.dfg.ca.gov/fishing/).

Clemens, W. A. et al. 1939. A biological survey of Okanagan Lake, British Columbia. – Bull. Fish. Res. Board Can. No. 56.

Donald, D. B. and Alger, D. J. 1984a. Limnological studies in Kootenay National Park. Part 1: the lakes. – Prepared for Parks Can. by CWS.

Donald, D. B. and De Henau, A.-M. 1981. Limnological studies in Jasper National Park. Part 8: a limnological survey and management study of 23 lakes near the icefields parkway. – Prepared for Parks Can. by CWS.

Donald, D. B. et al. 1985. Limnological studies in Jasper National Park. Part 10: the north boundary lakes. – Prepared for Parks Can. by CWS.

Lindsey, C. C. et al. 1981. Glaciation and the physical, chemical and biological limnology of Yukon lakes. – Can. Tech. Rep. Fish. Aquat. Sci. No. 966.

Liss, W. J. et al. 2002. Ecological impact of introduced trout on native aquatic communities in mountain lakes: phase III final report. – Prepared for Nat. Park Serv. by U. S. Forest Serv.

Manzer, J. I. 1972. Data on catches, size and food of the three-spined stickleback in Great Central Lake, British Columbia, in 1971. – Fish. Res. Board Can. Manuscr. Rep. Series No. 1166.

Mayhood, D. W. 1995. The fishes of the central Canadian Rockies ecosystem. – Prepared for Parks Can. by Freshwater Res. Ltd. Rep. No. 950408.

Mayhood, D. W. and Anderson, R. S. 1976. Limnological survey of the Lake Louise area, Banff National Park. Part 2: the lakes. – Prepared for Parks Can. by CWS.

Mudry, D. R. and Anderson, R. S. 1975. Yoho National Park aquatic resources inventory. – Prepared for Parks Can. by CWS.

Neave, F. 1949. Game fish populations of the Cowichan River. – Bull. Fish. Res. Board Can. No. 84.

National Park Service. 2007. Final mountain lake fishery management plan environmental impact statement. – N. Cascades Nat. Park Serv. Compl.

National Park Service. 2016. Unpublished internal reports, personal communication from staff scientists.

Oregon Department of Fish and Wildlife. 2016. Unpublished internal reports, personal communication from staff scientists.

Parker, M. S. 2008. Comparison of limnological characteristics and distribution and abundance of littoral macroinvertebrates and zooplankton in fishbearing and fishless lakes of Lassen Volcanic National Park. – Nat. Park Serv. Nat. Res. Tech. Rep. No. 116.

Rankin, D. P. and Ashton, H. J. 1980. Crustacean zooplankton abundance and species composition in 13 sockeye salmon (*Oncorhunchus nerka*) nursery lakes in British Columbia. – Can. Tech. Rep. Fish. Aquat. Sci. No. 957.

Rankin, D. P. et al. 1979. Crustacean zooplankton abundance and species composition in six experimentally fertilized British Columbia lakes. – Fish. Mar. Serv. Tech. Rep. No. 897.

Rawson, D. S. 1934. Productivity studies in lakes of the Kamloops region, British Columbia. – Bull. Biol. Board Can. No. 42.

Stead, J. E. et al. 2005. Census of amphibians and fishes in lentic habitats of Lassen Volcanic National Park: a report to the National Park Service. – USDA Forest Serv. No. LAVO-00717.

Ward, J. C. 1974. The fishes and their distribution in the mountain national parks of Canada. – Prepared for Parks Can. by CWS.

Washington Department of Fish and Wildlife. 2016. Unpublished internal reports, personal communication from staff scientists.

Appendix 4: Detailed results of statistical analyses

All analyses were conducted using R 3.3.2 (R Development Core Team 2016). Hellinger transformation, model selection, redundancy analysis, and variation partitioning analysis were conducted using the *decostand*, *ordi2step*, *rda*, and *varpart* functions, respectively, in the 'vegan' package (Oksanen et al. 2017). Distance-based Moran's eigvenvector maps were computed using the *dbmem* function in the 'adespatial' package (Dray et al. 2017). Connectivity matrices were computed using methods and code from Monteiro et al. (2017). Fisher's exact test was conducted using the *fisher.test* base function in R.

Table A1. Results of variation partitioning of climate, catchment/lake, fish introduction, and spatial correlation explanatory variables.

Fraction	**Overall (*n* = 1,240)**		**Asexual (*n* = 1,120)**		**Sexual (*n* = 1,165)**		**Small (*n* = 1,133)**		**Large (*n* = 1,127)**	
	df	**Adj R^2**	**df**	**Adj R^2**	**df**	**Adj R^2**	**df**	**Adj R^2**	**df**	**Adj R^2**
Total Cli	3	0.1162 *	3	0.1082 *	3	0.1374 *	3	0.1098 *	3	0.1559 *
Total Cat	26	0.1722 *	22	0.1516 *	23	0.1982 *	25	0.1700 *	24	0.2149 *
Total Fis	1	0.0178 *	1	0.0205 *	1	0.0154 *	1	0.0169 *	1	0.0231 *
Total Spa	56	0.2230 *	31	0.1866 *	51	0.2754 *	43	0.2190 *	51	0.2816 *
[a] Unique Cli	3	0.0066 *	3	0.0088 *	3	0.0058 *	3	0.0085 *	3	0.0062 *
[b] Unique Cat	26	0.0252 *	22	0.0215 *	23	0.0272 *	25	0.0238 *	24	0.0315 *
[c] Unique Fis	1	0.0021 *	1	0.0015 *	1	0.0036 *	1	0.0019 *	1	0.0023 *
[d] Unique Spa	56	0.0669 *	31	0.0524 *	51	0.0870 *	43	0.0621 *	51	0.0836 *
[e] Cli + Cat	0	0.0100	0	0.0091	0	0.0090	0	0.0048	0	0.0145
[f] Cat + Fis	0	0.0019	0	0.0040	0	0.0007	0	0.0046	0	0.0009
[g] Cli + Fis	0	0.0002	0	0.0002	0	0.0001	0	0.0002	0	0.0001
[h] Cli + Spa	0	0.0189	0	0.0134	0	0.0265	0	0.0176	0	0.0268
[i] Cat + Spa	0	0.0562	0	0.0429	0	0.0676	0	0.0605	0	0.0631
[j] Fis + Spa	0	0.0014	0	0.0030	0	0 †	0	0.0012	0	0.0015
[k] Cli + Cat + Spa	0	0.0692	0	0.0647	0	0.0851	0	0.0696	0	0.0904
[l] Cli + Cat + Fis	0	0.0019	0	0.0015	0	0.0019	0	0.0010	0	0.0021
[m] Cat + Fis + Spa	0	0.0009	0	0 †	0	0.0009	0	0 †	0	0.0004
[n] Cli + Fis + Spa	0	0.0025	0	0.0023	0	0.0032	0	0.0025	0	0.0037
[o] Cli + Cat + Fis + Spa	0	0.0069	0	0.0083	0	0.0058	0	0.0057	0	0.0121
Residual	0	0.7292	0	0.7667	0	0.6763	0	0.7362	0	0.6608

Notes: Cli, Cat, Fis, and Spa refer to components of variation attributable to climate, catchment/lake, fish introduction, and spatial correlation, respectively; * denotes estimated P (>F) ≤0.01 as determined by permutation testing with 100,000 iterations; and † denotes adjusted R^2 <0.00005.

Table A2. Results of partial redundancy analysis and variation partitioning of individual environmental predictors.

Group / Variable	**Total Adj R^2**	**Unique Adj R^2 Env Conditioned**	**Unique Adj R^2 Env + Spa Conditioned**
Overall (*n* = 1,240)			
Annual Mean Air Temperature [a,b,c]	0.0534 *	0.0096 *	0.0027 *
Annual Total Precipitation [a,b,c]	0.0533 *	0.0061 *	0.0024 *

Group / Variable	Total Adj R^2	Unique Adj R^2 Env Conditioned	Unique Adj R^2 Env + Spa Conditioned
Mixed Sedimentary Rock [a,b,c]	0.0471 *	0.0013 *	0.0003
Barren Land [a,b]	0.0434 *	0.0019 *	0.0006 *
Mean Solar Radiation [a,b,c]	0.0419 *	0.0061 *	0.0013 *
Forest (Coniferous) [a,b]	0.0397 *	0.0009 *	0.0005 ‡
Non-Acidic Volcanics [a,b]	0.0386 *	0.0017 *	0.0003
Forest (Mixedwood) [a,b,c]	0.0313 *	0.0022 *	0.0009 *
Lake Area [a,b,c]	0.0309 *	0.0020 *	0.0005 ‡
Grassland/Herbaceous [a,b,c]	0.0309 *	0.0007 *	0.0003
Perennial Ice/Snow [a,b,c]	0.0301 *	0.0015 *	0.0003
Lake Perimeter [a,b,c]	0.0282 *	0.0014 *	0.0008 *
Catchment Area [a,b,c]	0.0281 *	0.0007 *	0.0002
Forest (Deciduous) [a,b,c]	0.0261 *	0.0018 *	0.0004 ‡
Wetlands (Emergent/Herbaceous) [a,b,c]	0.0226 *	0.0016 *	0.0004 ‡
Catchment Slope [a,b]	0.0183 *	0.0004 ‡	0.0004 ‡
Fish Introduction [a]	0.0178 *	0.0035 *	0.0021 *
Non-Carbonate Sedimentary Rock [a,b,c]	0.0150 *	0.0009 *	0.0006 *
Acidic Plutonics [a,b,c]	0.0111 *	0.0036 *	0.0006 *
Non-Acidic Plutonics [a,b,c]	0.0110 *	0.0011 *	0.0005 ‡
Unconsolidated Sediment [a,b,c]	0.0103 *	0.0023 *	0.0003
Carbonate Sedimentary Rock [a,b,c]	0.0102 *	0.0015 *	0.0007 *
Shrub/Scrubland [a,b,c]	0.0101 *	0.0010 *	0.0006 *
Surface Water [a,b,c]	0.0101 *	0.0006 *	0.0007 *
Wetlands (Wooded/Shrub) [a,b,c]	0.0093 *	0.0011 *	0.0007 *
Metamorphic Rock [a,b,c]	0.0059 *	0.0019 *	0.0007 *
Pyroclastics [c]	0.0059 *	---	---
Developed (Non-Vegetated) [a,b,c]	0.0039 *	0.0008 *	0.0004 ‡
Acidic Volcanics [a,b,c]	0.0032 *	0.0011 *	0.0007 *
Catchment Aspect [b,c]	0.0013 *	---	---
Agricultural [b,c]	0.0007 *	---	---
Evaporite [c]	0.0004 ‡	---	---
Asexual (*n* = 1,120)			
Annual Total Precipitation [a,b,c]	0.0542 *	0.0095 *	0.0039 *
Annual Mean Air Temperature [a,b,c]	0.0487 *	0.0087 *	0.0041 *
Mixed Sedimentary Rock [a,b,c]	0.0410 *	0.0010 *	0.0008 ‡
Mean Solar Radiation [a,b,c]	0.0406 *	0.0047 *	0.0012 *
Non-Acidic Volcanics [a,b]	0.0354 *	0.0016 *	0.0002
Lake Area [a,b,c]	0.0350 *	0.0038 *	0.0010 *
Forest (Coniferous) [a,b]	0.0339 *	0.0012 *	0.0005 ‡
Forest (Mixedwood) [a,b,c]	0.0301 *	0.0025 *	0.0010 *
Lake Perimeter [a,b,c]	0.0299 *	0.0011 *	0 †
Catchment Area [a,b,c]	0.0297 *	0.0009 *	0.0006 ‡
Grassland/Herbaceous [c]	0.0293 *	---	---
Forest (Deciduous) [a,b,c]	0.0289 *	0.0010 *	0.0004
Barren Land [a,b]	0.0281 *	0.0016 *	0.0007 ‡
Perennial Ice/Snow [a,b,c]	0.0222 *	0.0014 *	0.0001
Fish Introduction [a]	0.0205 *	0.0045 *	0.0016 *
Wetlands (Emergent/Herbaceous) [a,b,c]	0.0196 *	0.0011 *	0.0002
Non-Carbonate Sedimentary Rock [b,c]	0.0176 *	---	---
Surface Water [a,b,c]	0.0137 *	0.0013 *	0.0009 ‡
Non-Acidic Plutonics [a,b,c]	0.0125 *	0.0016 *	0.0008 ‡
Shrub/Scrubland [c]	0.0119 *	---	---
Wetlands (Wooded/Shrub) [a,b,c]	0.0105 *	0.0011 *	0.0009 ‡
Acidic Plutonics [a,b,c]	0.0098 *	0.0020 *	0 †
Carbonate Sedimentary Rock [a,b,c]	0.0098 *	0.0012 *	0.0006 ‡

Group / Variable	Total Adj R^2	Unique Adj R^2 Env Conditioned	Unique Adj R^2 Env + Spa Conditioned
Catchment Slope [b]	0.0074 *	---	---
Unconsolidated Sediment [a,b,c]	0.0070 *	0.0029 *	0.0003
Pyroclastics [c]	0.0068 *	---	---
Metamorphic Rock [a,b,c]	0.0063 *	0.0034 *	0.0010 *
Acidic Volcanics [a,b,c]	0.0033 *	0.0010 *	0.0011 *
Developed (Non-Vegetated) [a,c]	0.0024 *	0.0006 ‡	0.0006 ‡
Catchment Aspect [c]	0.0010 ‡	---	---
Agricultural [b,c]	0.0006 ‡	---	---
Evaporite	0.0001	---	---
Sexual (*n* = 1,165)			
Annual Total Precipitation [a,b,c]	0.0593 *	0.0068 *	0.0019 *
Annual Mean Air Temperature [a,b,c]	0.0560 *	0.0125 *	0.0019 *
Mixed Sedimentary Rock [a,b,c]	0.0528 *	0.0023 *	0.0003
Mean Solar Radiation [a,b,c]	0.0503 *	0.0078 *	0.0017 *
Barren Land [a,b]	0.0485 *	0.0031 *	0.0023 *
Non-Acidic Volcanics [a,b,c]	0.0452 *	0.0031 *	0.0003
Forest (Coniferous)	0.0383 *	---	---
Forest (Mixedwood) [a,b,c]	0.0373 *	0.0022 *	0.0009 *
Lake Area [a,b,c]	0.0324 *	0.0014 *	0.0009 *
Grassland/Herbaceous [a,b,c]	0.0323 *	0.0027 *	0.0005 ‡
Catchment Area [a,b,c]	0.0310 *	0.0013 *	0.0001
Lake Perimeter [a,b,c]	0.0304 *	0.0023 *	0.0016 *
Perennial Ice/Snow [a,b,c]	0.0295 *	0.0013 *	0.0008 *
Forest (Deciduous) [a,b,c]	0.0291 *	0.0030 *	0.0007 ‡
Wetlands (Emergent/Herbaceous) [a,b,c]	0.0274 *	0.0029 *	0.0009 *
Catchment Slope [a,b]	0.0260 *	0.0013 *	0.0010 *
Fish Introduction [a]	0.0154 *	0.0028 *	0.0036 *
Non-Carbonate Sedimentary Rock [a,b,c]	0.0155 *	0.0008 *	0 †
Shrub/Scrubland [a,b]	0.0134 *	0.0021 *	0.0010 *
Unconsolidated Sediment [a,b,c]	0.0130 *	0.0014 *	0.0001 *
Acidic Plutonics [a,b,c]	0.0127 *	0.0035 *	0.0006 ‡
Non-Acidic Plutonics [a,b,c]	0.0115 *	0.0008 *	0.0001
Carbonate Sedimentary Rock [a,b,c]	0.0109 *	0.0016 *	0.0006 ‡
Wetlands (Wooded/Shrub) [a,b,c]	0.0106 *	0.0013 *	0.0009 *
Surface Water [c]	0.0084 *	---	---
Metamorphic Rock [a,b,c]	0.0075 *	0.0024 *	0.0010 *
Pyroclastics [c]	0.0060 *	---	---
Developed (Non-Vegetated) [a,b,c]	0.0048 *	0.0009 *	0.0002
Acidic Volcanics [a,b,c]	0.0036 *	0.0011 *	0.0004
Catchment Aspect [c]	0.0018 *	---	---
Agricultural [b,c]	0.0010 *	---	---
Evaporite [c]	0.0006 ‡	---	---
Small (*n* = 1,133)			
Mean Solar Radiation [a,b,c]	0.0550 *	0.0082 *	0.0016 *
Annual Total Precipitation [a,b,c]	0.0513 *	0.0054 *	0.0035 *
Mixed Sedimentary Rock [a,b,c]	0.0468 *	0.0017 *	0.0002
Annual Mean Air Temperature [a,b,c]	0.0401 *	0.0093 *	0.0039 *
Non-Acidic Volcanics [a,b]	0.0398 *	0.0026 *	0.0005
Lake Area [a,b,c]	0.0383 *	0.0025 *	0.0003
Forest (Mixedwood) [a,b,c]	0.0379 *	0.0020 *	0.0008 *
Forest (Deciduous) [a,b,c]	0.0332 *	0.0024 *	0.0006 ‡
Catchment Area [a,b,c]	0.0331 *	0.0008 ‡	0.0003
Grassland/Herbaceous [a,b,c]	0.0305 *	0.0005 ‡	0.0001
Lake Perimeter [a,b,c]	0.0287 *	0.0015 *	0.0006 ‡

Group / Variable	Total Adj R^2	Unique Adj R^2 Env Conditioned	Unique Adj R^2 Env + Spa Conditioned
Forest (Coniferous) [a,b]	0.0267 *	0.0015 *	0.0010 *
Barren Land [a,b]	0.0249 *	0.0024 *	0.0007 ‡
Wetlands (Emergent/Herbaceous) [a,b,c]	0.0227 *	0.0007 ‡	0.0001
Perennial Ice/Snow [b,c]	0.0185 *	---	---
Fish Introduction [a]	0.0169 *	0.0030 *	0.0019 *
Non-Carbonate Sedimentary Rock [a,b,c]	0.0159 *	0.0008 *	0.0004
Non-Acidic Plutonics [a,b,c]	0.0150 *	0.0019 *	0.0012 *
Wetlands (Wooded/Shrub) [a,b,c]	0.0149 *	0.0010 *	0.0008*
Surface Water [a,b,c]	0.0147 *	0.0013 *	0.0014 *
Acidic Plutonics [a,b,c]	0.0129 *	0.0038 *	0.0003
Carbonate Sedimentary Rock [a,b,c]	0.0127 *	0.0024 *	0.0007 ‡
Unconsolidated Sediment [a,b,c]	0.0121 *	0.0031 *	0.0005
Shrub/Scrubland [c]	0.0117 *	---	---
Catchment Slope [a,b]	0.0106 *	0.0008 ‡	0.0004
Metamorphic Rock [a,b,c]	0.0070 *	0.0012 *	0.0010 *
Pyroclastics [b,c]	0.0065 *	---	---
Developed (Non-Vegetated) [a,b,c]	0.0050 *	0.0012 *	0.0005
Acidic Volcanics [a,b,c]	0.0021 *	0.0009 *	0.0006 ‡
Catchment Aspect [c]	0.0014 *	---	---
Agricultural [b,c]	0.0005	---	---
Evaporite [c]	0.0004	---	---
Large (n = 1,127)			
Annual Mean Air Temperature [a,b,c]	0.0770 *	0.0130 *	0.0025 *
Annual Total Precipitation [a,b,c]	0.0727 *	0.0103 *	0.0020 *
Barren Land [a,b]	0.0701 *	0.0039 *	0.0016 *
Forest (Coniferous) [a,b]	0.0602 *	0.0007 ‡	0.0003
Mixed Sedimentary Rock [a,b,c]	0.0587 *	0.0004	0.0006 ‡
Perennial Ice/Snow [a,b,c]	0.0479 *	0.0030 *	0.0008 *
Non-Acidic Volcanics [a,b,c]	0.0468 *	0.0018 *	0.0003
Mean Solar Radiation [a,b,c]	0.0459 *	0.0059 *	0.0013 *
Grassland/Herbaceous [a,b,c]	0.0390 *	0.0010 *	0.0003
Lake Perimeter [a,b,c]	0.0377 *	0.0016 *	0.0010 *
Forest (Mixedwood) [a,b,c]	0.0365 *	0.0032 *	0.0014 *
Lake Area [a,b,c]	0.0346 *	0.0012 *	0.0006 ‡
Catchment Area [a,b,c]	0.0334 *	0.0008 *	0.0003
Wetlands (Emergent/Herbaceous) [a,b,c]	0.0299 *	0.0031 *	0.0010 *
Catchment Slope [a,b]	0.0298 *	0.0005 ‡	0.0008 *
Forest (Deciduous) [a,b,c]	0.0280 *	0.0015 *	0.0010 *
Fish Introduction [a]	0.0231 *	0.0038 *	0.0023 *
Non-Carbonate Sedimentary Rock [a,b,c]	0.0196 *	0.0012 *	0.0009 *
Shrub/Scrubland [a,b,c]	0.0119 *	0.0012 *	0.0007 ‡
Acidic Plutonics [a,b,c]	0.0118 *	0.0048 *	0.0011 *
Carbonate Sedimentary Rock [a,b,c]	0.0114 *	0.0006 ‡	0.0008 *
Unconsolidated Sediment [a,b,c]	0.0113 *	0.0026 *	0 †
Non-Acidic Plutonics [a,b,c]	0.0112 *	0.0008 ‡	0.0001
Surface Water [c]	0.0079 *	---	---
Wetlands (Wooded/Shrub) [a,b,c]	0.0076 *	0.0015 *	0.0013 *
Pyroclastics [c]	0.0075 *	---	---
Metamorphic Rock [a,b]	0.0074 *	0.0040 *	0 †
Acidic Volcanics [a,b,c]	0.0056 *	0.0015 *	0.0010 *
Developed (Non-Vegetated) [c]	0.0029 *	---	---
Catchment Aspect [b]	0.0013 *	---	---
Agricultural [b,c]	0.0009 ‡	---	---
Evaporite [c]	0.0005 ‡	---	---

Notes: Unique variation estimates were obtained conditioning by remaining variables from final selected environment (Env) and spatial correlation (Spa) models; [a] denotes variable was selected for inclusion in group full environment model; [b] denotes variable was selected for inclusion in group climate or catchment/lake model; [c] denotes variable natural log-transformed (variables with non-detect values were natural log(x + (0.5·lowest detected value))-transformed); * denotes estimated P (>F) ≤0.01 as determined by permutation testing with 100,000 iterations; ‡ denotes estimated P (>F) <0.05 and >0.01 as determined by permutation testing with 100,000 iterations; and † denotes adjusted R^2 <0.00005.

Table A3. Results of variation partitioning of environment, spatial correlation, and connectivity explanatory variables.

Fraction	**Overall (*n* = 1,240)**		**Asexual (*n* = 1,120)**		**Sexual (*n* = 1,165)**		**Small (*n* = 1,133)**		**Large (*n* = 1,127)**	
	df	**Adj R^2**	**df**	**Adj R^2**	**df**	**Adj R^2**	**df**	**Adj R^2**	**df**	**Adj R^2**
Total Env	28	0.2033 *	24	0.1805 *	26	0.2364 *	26	0.2005 *	26	0.2547 *
Total Spa	56	0.2230 *	31	0.1866 *	51	0.2754 *	43	0.2190 *	51	0.2816 *
Total Con	2	0.1515 *	2	0.1153 *	2	0.1995 *	2	0.1501 *	2	0.1988 *
[a] Unique Env	28	0.0443 *	24	0.0446 *	26	0.0425 *	26	0.0415 *	26	0.0527 *
[b] Unique Spa	56	0.0495 *	31	0.0418 *	51	0.0591 *	43	0.0497 *	51	0.0573 *
[c] Unique Con	2	0.0059 *	2	0.0055 *	2	0.0077 *	2	0.0077 *	2	0.0061 *
[d] Env + Spa	0	0.0309	0	0.0368	0	0.0298	0	0.0294	0	0.0357
[e] Spa + Con	0	0.0174	0	0.0107	0	0.0278	0	0.0129	0	0.0264
[f] Env + Con	0	0.0029	0	0.0017	0	0.0055	0	0.0026	0	0.0042
[g] Env + Spa + Con	0	0.1252	0	0.0973	0	0.1586	0	0.1270	0	0.1621
Residual	0	0.7238	0	0.7615	0	0.6690	0	0.7293	0	0.6555

Notes: Env, Spa, and Con refer to components of variation attributable to environment, space, and connectivity, respectively; * denotes estimated P (>F) ≤0.01 as determined by permutation testing; and α (connectivity constant) = 69,645 for each group.

References

Dray, S. et al. 2017. adespatial: multivariate multiscale spatial analysis. – R package ver. 0.0-9.

Oksanen, J. et al. 2017. vegan: community ecology package. – R package ver. 2.4-4.

R Development Core Team. 2016. R: a language and environment for statistical computing, ver. 3.3.2. – R Foundation for Statistical Computing.

Appendix 5: Sensitivity analyses

As a quantitative synthesis of multiple historical data sources, there exists potential for our results to reflect biases among individual sampling locations or studies. To evaluate the extent to which our interpretations may be confounded by variations in sampling effort (i.e. number of sampling years integrated for species occurrence estimates), sampling year (i.e. most recent confirmed date), or data source (i.e. research group or taxonomist) we conducted a series of sensitivity analyses (Tables A4–A6). Additionally, we assessed the data collected before and after 1985 independently, to compare the relative importance of connectivity over time and assess the robustness of our results to potential changes in occupancy (Table A7).

Results of the sensitivity analyses suggest that our findings are robust and support our core interpretations. Community variation attributable to geographic position (latitude, longitude, and elevation) was well captured by the environmental and spatial correlation predictor sets, and each explained considerably more variation than differences in sampling effort or sampling year (Table A4–A5). Sampling effort and sampling year each uniquely explain less than 0.5 % of total community variation and impart a negligible influence on the unique contributions of environmental and spatial predictors. These results suggest that unique variation attributed to sampling effort and sampling year is mostly linked to the unexplained residual fraction of variation, and does not influence our interpretation of spatial or environmental factors. Conversely, data source explains a larger amount of total variation, which covaries with spatial correlation, geographic position, and spatially structured environmental variables (Table A6). This result was expected, as different research groups collected data at different geographic locations, which were characterized by different spatially structured environmental conditions. Critically though, the ranking of environmental and spatial structures was unaffected by data source, indicating that our interpretations are generally robust.

Results of variation partitioning for data collected before and after 1985 provide further support for our findings. Foremost, the relative importance of environmental predictors was greater than connectivity for explaining variation in community composition both before and after 1985 (Table A7). Total variation attributable to connectivity in the full dataset (15.15 %; Table A3) was also similar to estimates obtained for before and after 1985 (13.88 and 11.42 %, respectively; Table A7). However, because waterbodies from different regions were sampled at different times, temporal differences also reflect spatial structures. For instance, samples were collected from several southern regions after 1985 (n = 756) where earlier survey data were unavailable. Despite this performance difference for forward selected environmental models with lakes sampled before and after 1985 (25.32 and 14.68 %, respectively), the importance of spatial correlation and connectivity estimates were comparable and appear robust to potential occupancy changes over time. Further, the greater association between environmental predictors and community composition for data collected before 1985 provides evidence that the 50-year mean climate variables and ca. 2001 land cover estimates are no less reflective of the older zooplankton records used in our analysis.

Table A4. Results of variation partitioning of environment, spatial correlation, geography, and sampling effort explanatory variables.

Fraction	Overall (n = 1,240)		Asexual (n = 1,120)		Sexual (n = 1,165)		Small (n = 1,133)		Large (n = 1,127)	
	df	Adj R^2	df	Adj R^2	df	Adj R^2	df	Adj R^2	df	Adj R^2
Total Env	28	0.2033 *	24	0.1805 *	26	0.2364 *	26	0.2005 *	26	0.2547 *
Total Spa	56	0.2230 *	31	0.1866 *	51	0.2754 *	43	0.2190 *	51	0.2816 *
Total Geo	3	0.1347 *	3	0.1178 *	3	0.1613 *	3	0.1477 *	3	0.1569 *
Total Eff	1	0.0068 *	1	0.0057 *	1	0.0089 *	1	0.0082 *	1	0.0057 *
[a] Unique Env	28	0.0324 *	24	0.0332 *	26	0.0342 *	26	0.0349 *	26	0.0382 *
[b] Unique Spa	56	0.0567 *	31	0.0446 *	51	0.0731 *	43	0.0483 *	51	0.0738 *
[c] Unique Geo	3	0.0030 *	3	0.0028 *	3	0.0036 *	3	0.0035 *	3	0.0024 *
[d] Unique Eff	1	0.0022 *	1	0.0023 *	1	0.0017 *	1	0.0023 *	1	0.0021 *
[e] Env + Spa	0	0.0488	0	0.0404	0	0.0577	0	0.0359	0	0.0711
[f] Spa + Geo	0	0.0099	0	0.0080	0	0.0136	0	0.0144	0	0.0097
[g] Env + Geo	0	0.0140	0	0.0127	0	0.0130	0	0.0087	0	0.0180
[h] Env + Eff	0	0.0003	0	0.0002	0	0.0006	0	0.0002	0	0.0004
[i] Spa + Eff	0	0.0004	0	0 †	0	0.0001	0	0 †	0	0.0005
[j] Geo + Eff	0	0.0001	0	0 †	0	0.0002	0	0.0001	0	0.0002
[k] Env + Spa + Eff	0	0 †	0	0 †	0	0.0002	0	0 †	0	0.0001
[l] Env + Spa + Geo	0	0.1038	0	0.09069	0	0.1247	0	0.1152	0	0.1243
[m] Spa + Geo + Eff	0	0 †	0	0 †	0	0.0001	0	0 †	0	0 †
[n] Env + Geo + Eff	0	0.0005	0	0.0003	0	0.0002	0	0.0003	0	0.0002
[o] Env + Spa + Geo + Eff	0	0.0035	0	0.0033	0	0.0058	0	0.0056	0	0.0023
Residual	0	0.7245	0	0.7619	0	0.6711	0	0.7310	0	0.6569

Notes: Env, Spa, Geo, and Eff refer to components of variation attributable to environment, spatial correlation, geography (latitude, longitude, elevation), and sampling effort, respectively; sampling effort is the number of sampling years integrated for species occurrence estimates at each sampling location; * denotes estimated P (>F) ≤0.01 as determined by permutation testing with 100,000 iterations; and † denotes adjusted R^2 <0.00005.

Table A5. Results of variation partitioning of environment, spatial correlation, geography, and sampling year explanatory variables.

Fraction	Overall (n = 1,133)		Asexual (n = 1,032)		Sexual (n = 1,068)		Small (n = 1,050)		Large (n = 1,034)	
	df	Adj R^2	df	Adj R^2	df	Adj R^2	df	Adj R^2	df	Adj R^2
Total Env	28	0.2060 *	24	0.1840 *	26	0.2394 *	26	0.2028 *	26	0.2581 *
Total Spa	56	0.2259 *	31	0.1920 *	51	0.2765 *	43	0.2244 *	51	0.2836 *
Total Geo	3	0.1438 *	3	0.1269 *	3	0.1708 *	3	0.1555 *	3	0.1649 *
Total Yea	1	0.0292 *	1	0.0267 *	1	0.0314 *	1	0.0366 *	1	0.0292 *
[a] Unique Env	28	0.0294 *	24	0.0313*	26	0.0310 *	26	0.0310 *	26	0.0351 *
[b] Unique Spa	56	0.0565 *	31	0.0455 *	51	0.0706 *	43	0.0480 *	51	0.0735 *
[c] Unique Geo	3	0.0028 *	3	0.0021 *	3	0.0040 *	3	0.0028 *	3	0.0021 *
[d] Unique Yea	1	0.0023 *	1	0.0040 *	1	0.0020 *	1	0.0028 *	1	0.0031 *
[e] Env + Spa	0	0.0404	0	0.0351	0	0.0476	0	0.0298	0	0.0620
[f] Spa + Geo	0	0.0070	0	0.0065	0	0.0100	0	0.0121	0	0.0062
[g] Env + Geo	0	0.0152	0	0.0133	0	0.0137	0	0.0095	0	0.0185
[h] Env + Yea	0	0.0011	0	0.0007	0	0.0015	0	0.0016	0	0.0014
[i] Spa + Yer	0	0.0009	0	0.0001	0	0.0016	0	0.0014	0	0.0008

Fraction	Overall (*n* = 1,133)		Asexual (*n* = 1,032)		Sexual (*n* = 1,068)		Small (*n* = 1,050)		Large (*n* = 1,034)	
	df	**Adj R^2**	**df**	**Adj R^2**	**df**	**Adj R^2**	**df**	**Adj R^2**	**df**	**Adj R^2**
[j] Geo + Yea	0	0.0005	0	0.0009	0	0.0010	0	0.0009	0	0.0007
[k] Env + Spa + Yea	0	0.0020	0	0 †	0	0.0036	0	0.0018	0	0.0025
[l] Env + Spa + Geo	0	0.0960	0	0.0822	0	0.1205	0	0.1021	0	0.1167
[m] Spa + Geo + Yea	0	0.0004	0	0 †	0	0.0002	0	0.0012	0	0 †
[n] Env + Geo + Yea	0	0 †	0	0 †	0	0 †	0	0 †	0	0 †
[o] Env + Spa + Geo + Yea	0	0.0226	0	0.0235	0	0.0224	0	0.0282	0	0.0230
Residual	0	0.7235	0	0.7572	0	0.6713	0	0.7281	0	0.6567

Notes: Env, Spa, Geo, and Yea refer to components of variation attributable to environment, spatial correlation, geography (latitude, longitude, elevation), and sampling year, respectively; sampling year is the most recent confirmed sampling year at each sampling location; locations with uncertain sampling dates were excluded from analysis (*n* = 107); * denotes estimated P (>F) ≤0.01 as determined by permutation testing with 100,000 iterations; and † denotes adjusted R^2 <0.00005.

Table A6. Results of variation partitioning of environment, spatial correlation, geography, and data source explanatory variables.

Fraction	Overall (*n* = 1,240)		Asexual (*n* = 1,120)		Sexual (*n* = 1,165)		Small (*n* = 1,133)		Large (*n* = 1,127)	
	df	**Adj R^2**	**df**	**Adj R^2**	**df**	**Adj R^2**	**df**	**Adj R^2**	**df**	**Adj R^2**
Total Env	28	0.2033 *	24	0.1805 *	26	0.2364 *	26	0.2005 *	26	0.2547 *
Total Spa	56	0.2230 *	31	0.1866 *	51	0.2754 *	43	0.2190 *	51	0.2816 *
Total Geo	3	0.1347 *	3	0.1178 *	3	0.1613 *	3	0.1477 *	3	0.1569 *
Total Dat	15	0.1661 *	15	0.1530 *	15	0.1898 *	15	0.1827*	15	0.1857 *
[a] Unique Env	28	0.0262 *	24	0.0279 *	26	0.0260 *	26	0.0277*	26	0.0319 *
[b] Unique Spa	56	0.0378 *	31	0.0332 *	51	0.0482 *	43	0.0311 *	51	0.0540 *
[c] Unique Geo	3	0.0021 *	3	0.0012 ‡	3	0.0026 *	3	0.0022 *	3	0.0025 *
[d] Unique Dat	15	0.0171 *	15	0.0165 *	15	0.0240 *	15	0.0191 *	14	0.0165 *
[e] Env + Spa	0	0.0209	0	0.0161	0	0.0256	0	0.0161	0	0.0275
[f] Spa + Geo	0	0.0016	0	0.0013	0	0.0041	0	0.0023	0	0.0029
[g] Env + Geo	0	0.0136	0	0.0112	0	0.0150	0	0.0085	0	0.0197
[h] Env + Dat	0	0.0066	0	0.0054	0	0.0088	0	0.0074	0	0.0067
[i] Spa + Dat	0	0.0193	0	0.0113	0	0.0250	0	0.0172	0	0.0203
[j] Geo + Dat	0	0.0010	0	0.0016	0	0.0013	0	0.0014	0	0 †
[k] Env + Spa + Dat	0	0.0279	0	0.0240	0	0.0323	0	0.0195	0	0.0438
[l] Env + Spa + Geo	0	0.0223	0	0.0083	0	0.0399	0	0.0152	0	0.0333
[m] Spa + Geo + Dat	0	0.0083	0	0.0067	0	0.0096	0	0.0120	0	0.0066
[n] Env + Geo + Dat	0	0.0009	0	0.0018	0	0 †	0	0.0006	0	0 †
[o] Env + Spa + Geo + Dat	0	0.0850	0	0.0856	0	0.0906	0	0.1055	0	0.0933
Residual	0	0.7096	0	0.7477	0	0.6488	0	0.7142	0	0.6426

Notes: Env, Spa, Geo, and Dat refer to components of variation attributable to environment, spatial correlation, geography (latitude, longitude, elevation), and data source, respectively; data sources are the taxonomist or research group/lab responsible for zooplankton records at each sampling location, and were represented by a set of dummy variables; * denotes estimated P (>F) ≤0.01 as determined by permutation testing with 100,000 iterations; ‡ denotes estimated

P (>*F*) <0.05 and >0.01 as determined by permutation testing with 100,000 iterations; and † denotes adjusted R^2 <0.00005.

Table A7. Results of variation partitioning of environment, spatial correlation, and connectivity explanatory variables for zooplankton data collected before and after 1985.

Fraction	**Before 1985 (*n* = 619)**		**After 1985 (*n* = 756)**	
	df	**Adj R^2**	**df**	**Adj R^2**
Total Env	24	0.2532 *	22	0.1468 *
Total Spa	13	0.1543 *	28	0.1592 *
Total Con	1	0.1388 *	1	0.1142 *
[a] Unique Env	24	0.1013 *	22	0.0378 *
[b] Unique Spa	13	0.0169 *	28	0.0438 *
[c] Unique Con	1	0.0042 *	1	0.0112 *
[d] Env + Spa	0	0.0229	0	0.0227
[e] Spa + Con	0	0.0056	0	0.0168
[f] Env + Con	0	0.0202	0	0.0104
[g] Env + Spa + Con	0	0.1089	0	0.0759
Residual	0	0.7201	0	0.7815

Notes: Env, Spa, and Con refer to components of variation attributable to environment, spatial correlation, and connectivity, respectively; * denotes estimated *P* (>*F*) ≤0.01 as determined by permutation testing; and α (connectivity constant) = 104,466 and 58,533 before and after 1985, respectively.

Appendix 6: Water chemistry and temperature conditions

Regional climate, catchment/lake morphometry, land cover, and lithology variables were selected based on their expected importance driving local environmental conditions and community composition. To evaluate covariance between these predictors and local water quality, we calculated summary statistics for several indictor parameters and performed a series of variation partitioning analyses (Tables A8–A17). Available open-water season water quality data were generally collected from the water surface during zooplankton sampling events, to characterize the pelagic environments. Further details on sampling and analytical methods are available from their source documents (see Appendix 1). Maximum mid-summer temperatures were used where multiple measurements were collected at varying depths or over a single sampling season. Laboratory results were deemed more reliable and preferred over field-measured pH and electrical conductivity. Total phosphorous and nitrogen concentrations below laboratory detection limits were omitted.

For each selected water quality indicator (surface temperature, electrical conductivity, pH, total phosphorous, and total nitrogen), we obtained a subset of lakes with available data and estimated individual environmental models, as per our model selection procedures. Environmental models were then used to evaluate the unique variation and shared covariation in community composition attributable to each water quality variable (*varpart* function in the 'vegan' package; Oksanen et al. 2017). Mean water quality values were estimated and used for lakes where multiple years of data were available. Environmental variables were natural log-transformed where doing so improved model fit.

To evaluate potential changes in water quality over time, we plotted available annual data as a function of sampling year (Figures A2–A6). We also conducted a series of linear mixed-effects models (*lme* function in the 'nlme' package; Pinheiro et al. 2018) to test relationships between water quality variables and sampling year, treating location as a random effect (i.e. random intercepts) to account for repeated measures (Table A18). Note that some data points were omitted from regression analysis where exact sampling dates could not be verified.

We found that our environmental models performed well in capturing the variation in community composition attributable to local water quality indicators. For instance, electrical conductivity explained the most total variation in community composition among selected chemistry parameters (4.93 %; Table A11); however, only 0.68 % was uniquely attributable, indicating that our environmental model (with selected regional climate and catchment variables) covaried strongly with electrical conductivity and could account for 86.21 % of the variation linked to it. Findings were similar for surface temperature (Table A9), pH (Table A13), total phosphorous (Table 15), and total nitrogen (Table A17). Available water quality time-series data also indicate that local environmental conditions have not changed significantly over the course of our study (Figures A2–A6; Table A18).

Table A8. Summary statistics of mean surface water temperatures across sampling locations ($n = 848$).

Statistic	Estimate
Minimum	4.0
1st quartile	12.10
Median	15.62
Mean	15.49
3rd quartile	18.90
Maximum	27.50

Notes: Estimate units are °C.

Table A9. Results of variation partitioning for environmental model and mean summer surface water temperatures ($n = 848$).

Fraction	df	Adj R^2
Total Env	28	0.2139 *
Total Temp	1	0.0206 *
[a] Unique Env	28	0.1945 *
[b] Unique Temp	1	0.0012 *
[c] Env + Temp	0	0.0194
Residual	0	0.7849

Notes: Env and Temp refer to components of variation attributable to environment and summer surface water temperature, respectively; temperature values were natural log-transformed; and * denotes estimated P (>F) ≤0.01 as determined by permutation testing with 100,000 iterations.

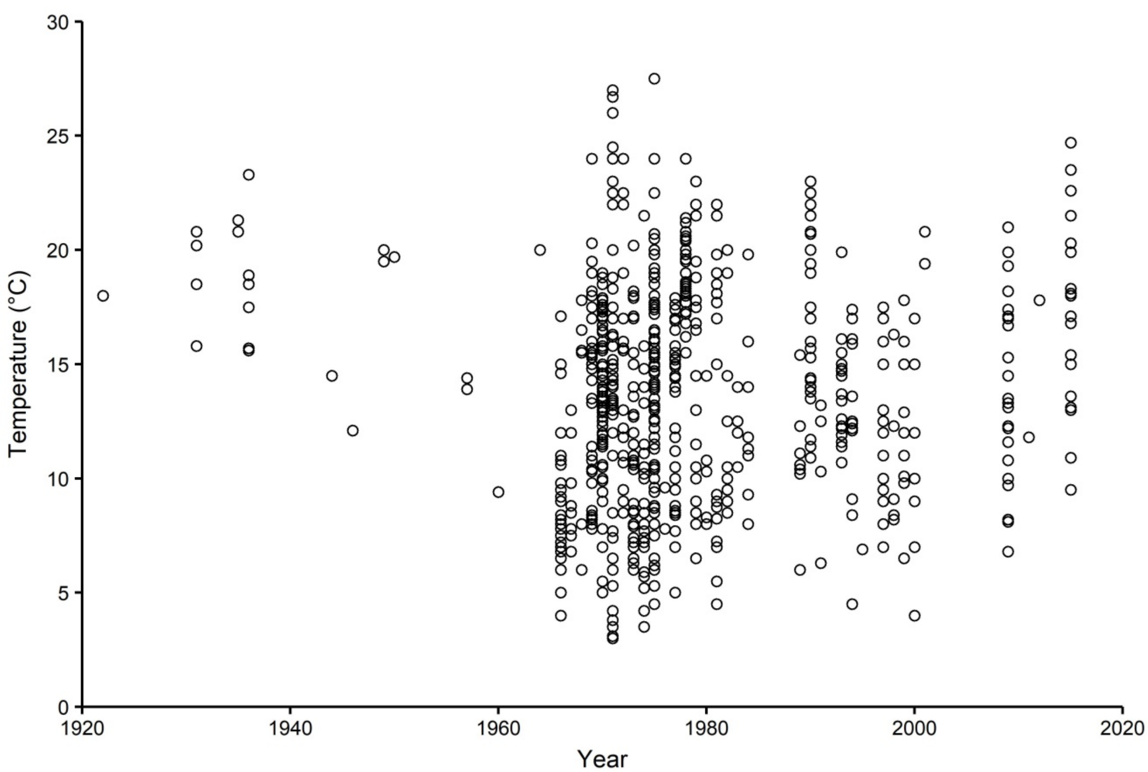

Figure A2. Summer surface water temperatures over time (1922–2015; $n = 676$). Records were omitted where exact sampling date could not be verified.

Table A10. Summary statistics of mean electrical conductivity across sampling locations ($n = 873$).

Statistic	Estimate
Minimum	0.003
1st quartile	7.300
Median	24.700
Mean	205.836
3rd quartile	129.000
Maximum	16,500.00

Notes: Estimate units are µS/cm units.

Table A11. Results of variation partitioning for environmental model and mean electrical conductivity ($n = 873$).

Fraction	df	Adj R^2
Total Env	27	0.1891 *
Total EC	1	0.0493 *
[a] Unique Env	27	0.1465 *
[b] Unique EC	1	0.0068 *
[c] Env + EC	0	0.0426
Residual	0	0.8041

Notes: Env and EC refer to components of variation attributable to environment and electrical conductivity, respectively; electrical conductivity values were natural log-transformed; and * denotes estimated P ($>F$) ≤ 0.01 as determined by permutation testing with 100,000 iterations.

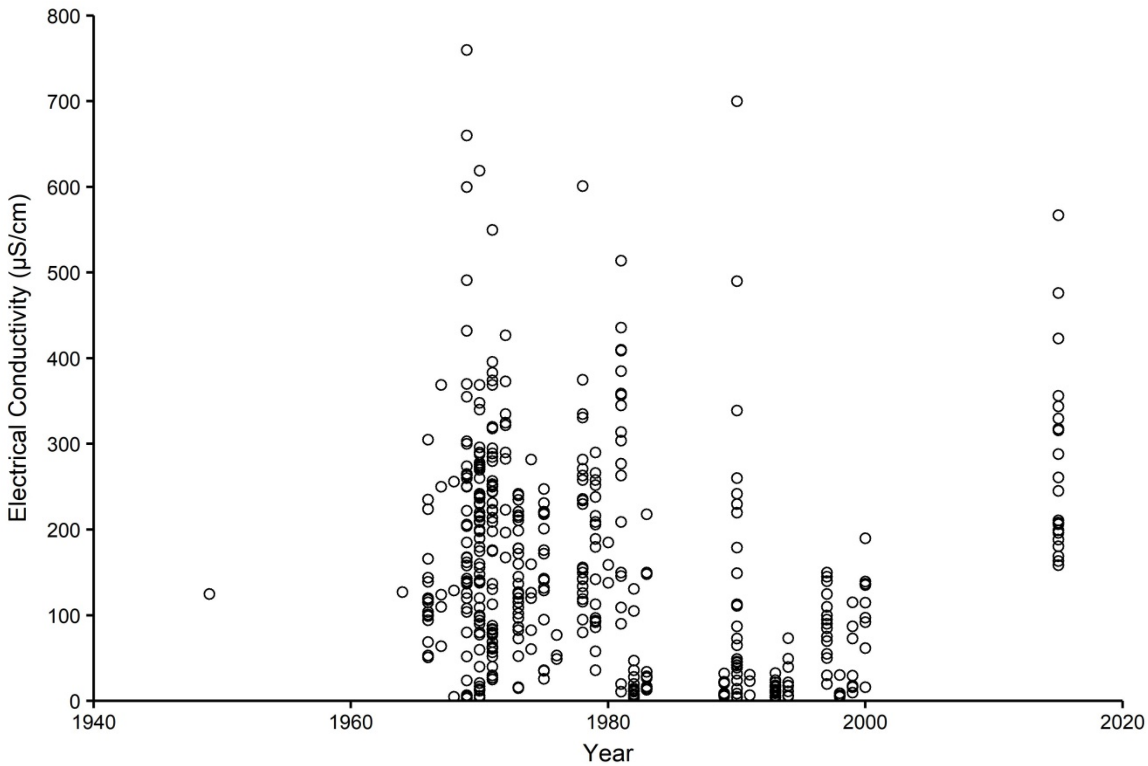

Figure A3. Surface water electrical conductivity over time (1949–2015; n = 480). Nineteen outlier records > 800 µS/cm are not visible in current plot. Records were omitted where exact sampling date could not be verified.

Table A12. Summary statistics of mean surface water pH across sampling locations (n = 1,054).

Statistic	Estimate
Minimum	4.80
1st quartile	6.61
Median	7.47
Mean	7.39
3rd quartile	8.10
Maximum	10.90

Notes: Estimate units are pH units.

Table A13. Results of variation partitioning for environmental model and mean surface water pH (n = 1,054).

Fraction	df	Adj R^2
Total Env	28	0.1916 *
Total pH	1	0.0488 *
[a] Unique Env	28	0.1468 *
[b] Unique pH	1	0.0040 *
[c] Env + pH	0	0.0449
Residual	0	0.8044

Notes: Env and pH refer to components of variation attributable to environment and mean surface water pH, respectively; and * denotes estimated P ($>F$) $\leq$0.01 as determined by permutation testing with 100,000 iterations.

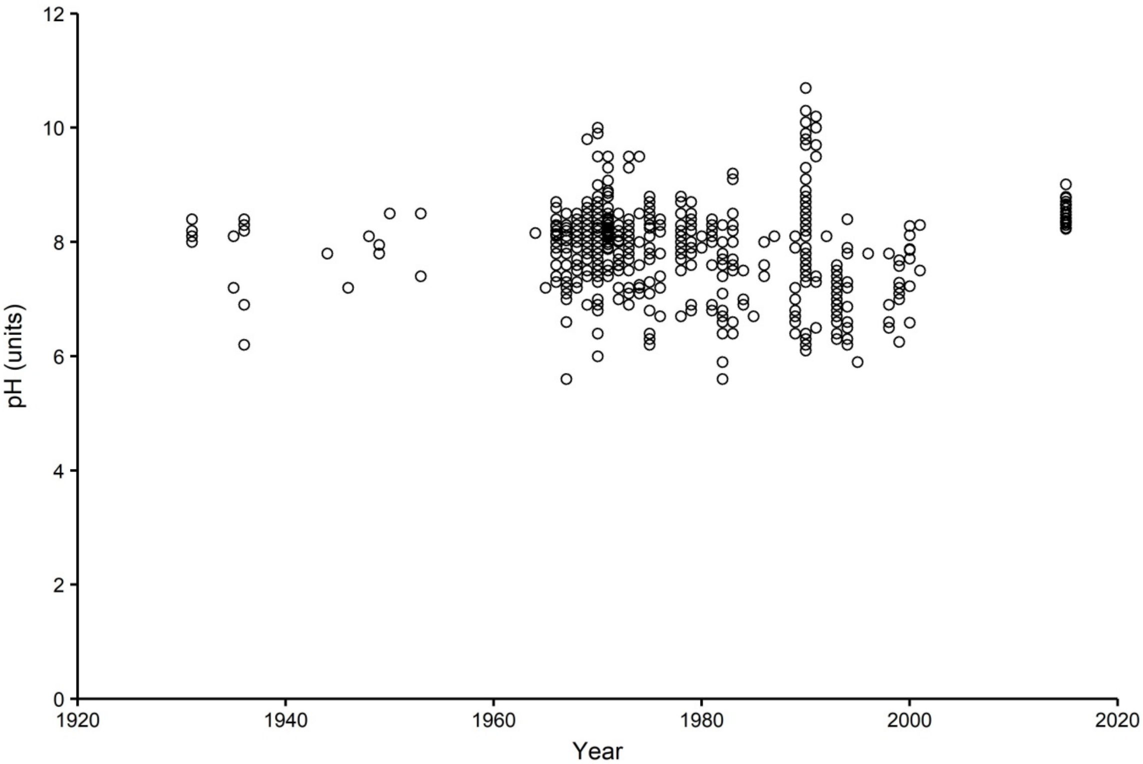

Figure A4. Surface water pH over time (1931–2015; n = 737). Records were omitted where exact sampling date could not be verified.

Table A14. Summary statistics of mean surface water total phosphorous across sampling locations (n = 192).

Statistic	Estimate
Minimum	0.0010
1st quartile	0.0040
Median	0.0060
Mean	0.0105
3rd quartile	0.0100
Maximum	0.1410

Notes: Estimate units are mg/L.

Table A15. Results of variation partitioning for environmental model and mean surface water total phosphorous (n = 192).

Fraction	df	Adj R^2
Total Env	15	0.2808 *
Total Ptot	1	0.0176 *
[a] Unique Env	15	0.2639 *

[b] Unique Ptot	1	0.0006
[c] Env + Ptot	0	0.0170
Residual	0	0.7186

Notes: Env and Ptot refer to components of variation attributable to environment and mean surface water total phosphorous, respectively; total phosphorous concentrations were natural log-transformed; and * denotes estimated P (>F) ≤0.01 as determined by permutation testing with 100,000 iterations.

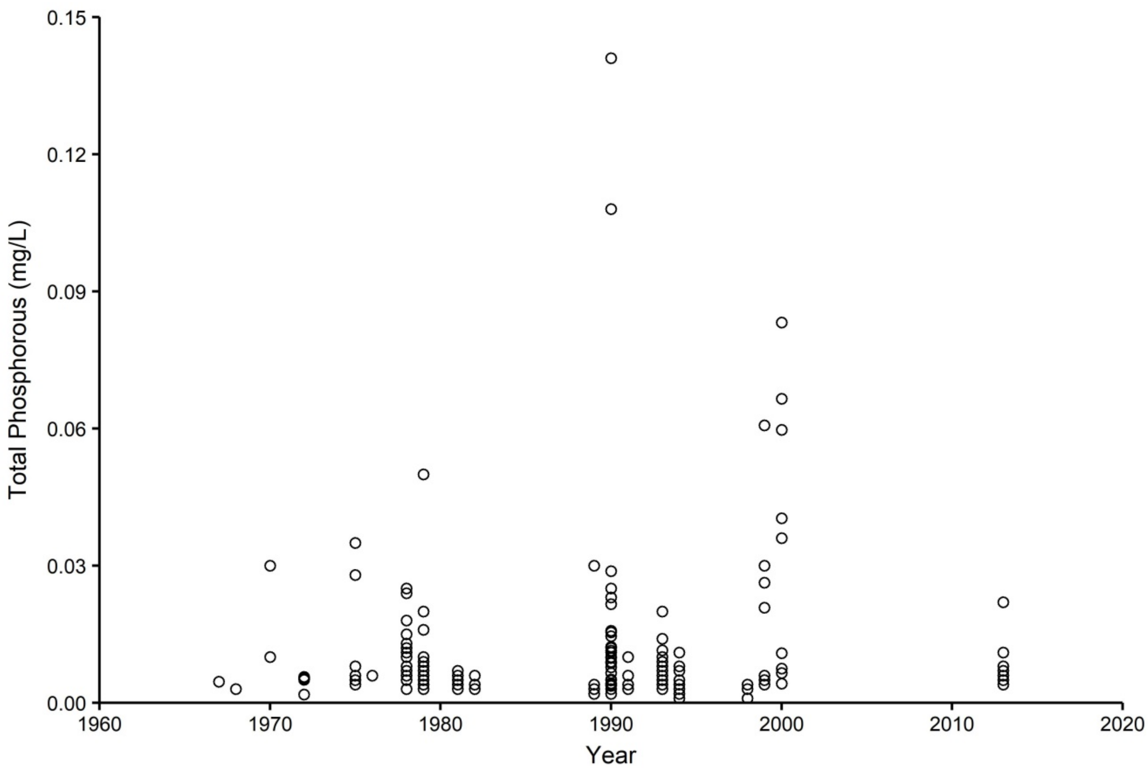

Figure A5. Surface water total phosphorous over time (1967–2013; n = 192). Records were omitted where exact sampling date could not be verified.

Table A16. Summary statistics of mean surface water total nitrogen across sampling locations (n = 101).

Statistic	Estimate
Minimum	0.0100
1st quartile	0.0745
Median	0.1360
Mean	0.2789
3rd quartile	0.4065
Maximum	1.5850

Notes: Estimate units are mg/L.

Table A17. Results of variation partitioning for environmental model and mean surface water total nitrogen (n = 101).

Fraction	df	Adj R^2
Total Env	9	0.2312 *
Total Ntot	1	0.0385 *
[a] Unique Env	9	0.1979 *
[b] Unique Ntot	1	0.0052
[c] Env + Ntot	0	0.0333
Residual	0	0.7636

Notes: Env and Ntot refer to components of variation attributable to environment and mean surface water total nitrogen, respectively; total nitrogen concentrations were natural log-transformed; and * denotes estimated P (>F) ≤0.01 as determined by permutation testing with 100,000 iterations.

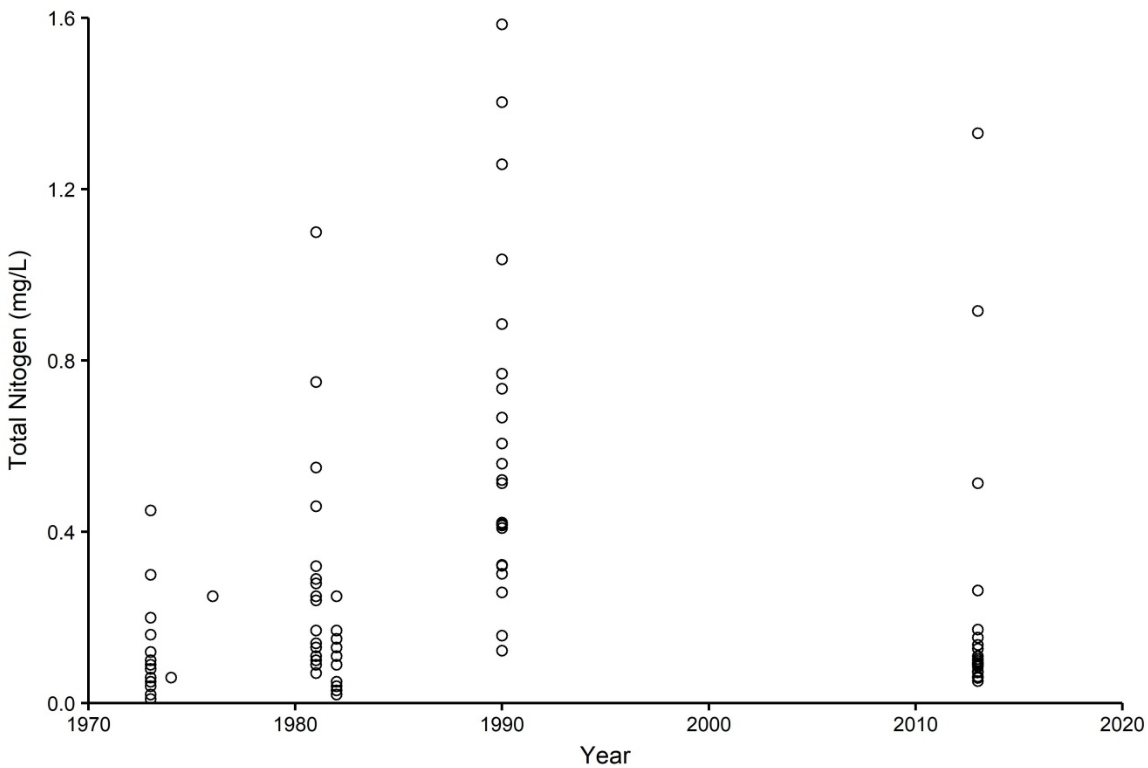

Figure A6. Surface water total nitrogen over time (1973–2013; n = 98). Records were omitted where exact sampling date could not be verified.

Table A18. Estimates of fixed effects from linear mixed-models for selected water quality variables as a function of sampling year.

Linear model	Variable	Coefficient	Std. error	df	*t*-value	*P*-value
Surface temperature [a]	Intercept	0.0902	1.8925	463	0.0477	0.9620
	Year	0.0013	0.0010	211	1.3174	0.1891
Electrical conductivity [a]	Intercept	11.5687	4.6457	379	2.4902	0.0132
	Year	-0.0035	0.0023	99	-1.4852	0.1407
pH	Intercept	6.7439	3.1318	563	2.1534	0.0317
	Year	0.0006	0.0016	172	0.3811	0.7036
Total phosphorous [a]	Intercept	-11.7712	9.3178	169	-1.2633	0.2082
	Year	0.0034	0.0047	9	0.7298	0.4841

Linear model	Variable	Coefficient	Std. error	df	*t*-value	*P*-value
Total nitrogen [a]	Intercept	-13.2385	12.7252	90	-1.0403	0.3010
	Year	0.0057	0.0064	6	0.8964	0.4046

Notes: Sampling year was treated as a fixed effect; location was treated as a random effect (with random intercept); records were omitted where exact sampling date could not be verified; [a] denotes variable natural log-transformed prior to analysis; and * denotes coefficient significance at $\alpha = 0.01$ (Bonferroni-adjusted alpha), based on restricted maximum likelihood.

References

Oksanen, J. et al. 2017. vegan: community ecology package. – R package ver. 2.4-4.

Pinheiro, J., et al. 2018. nlme: linear and nonlinear mixed effects models. – R package ver. 3.1-131.1.