Henrys Lake water quality and limnology investigation

Idaho Fish and Game Commission

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Preliminary Report

By

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Abstract

Henrys Lake is among the most popular and economically important lentic fisheries in Idaho. Henrys Lake is managed as a trophy fishery, maintained primarily through fall stocking of trout fingerlings. Since 2015, trout stockings have increased by about 250,000 fish per year, but trout abundances observed in recent gillnet catches in 2017 (5.5 trout per net) and 2018 (4.3 trout per net) were well below the management target of 11 trout per net. The reduction of trout abundances has fisheries managers concerned that abiotic (e.g. temperature, oxygen) or biotic (e.g. food availability, competition) factors may be limiting the current trout population. The objectives of this study were to assess suitability of summer temperatures for trout growth and survival, suitability of winter oxygen conditions (and potentially also summertime conditions) for trout survival, short-term and long-term trends in nitrogen and phosphorus concentrations and ratios, and sufficiency of zooplankton abundances in summer and fall to provide forage for young trout (age-0, age-1). Five sampling locations were established around the lake, representing conditions in the north, east, south, west, and center areas of the lake. Weekly water-quality sampling was conducted at each site from August to October of 2018 and from May to July of 2019. Sampling consisted of Secchi depth measurement, collection of water samples for total nitrogen and total phosphorus concentrations, and depth profiles of temperature, dissolved oxygen, and relative indices of cyanobacteria and algae concentrations. Nutrient samples and depth profiles of temperature and dissolved oxygen were collected at all but the center location during each of January, February and March, under ice cover. Zooplankton samples were collected biweekly during the open-water season.

Over the course of this study, primary and secondary productivity peaked in late summer and early fall of 2018, and zooplankton quality index (ZQI) was high enough at this time to support the high densities of fingerling trout typically stocked by IDFG in September. However, measures of zooplankton abundance and quality varied substantially around the lake. Ratios of nitrogen to phosphorus indicated phosphorus limitation, but seasonality of phosphorus concentrations appeared to be driven by seasonal cycles of primary production, not the other way around. Phosphorus concentrations were similar to those observed in Island Park Reservoir in recent years, and high internal phosphorus loading observed by previous researchers suggests that internal cycling, rather than input from external sources, is the primary mechanism for release of phosphorus into the water column. Water-quality characteristics indicated that low dissolved oxygen under ice cover is likely to be the single abiotic factor limiting trout survival. By the end of winter, dissolved oxygen concentrations remained above 5 mg/L only in the top 0.5-1.0 m of the water column at all sampling sites, although oxygen concentrations remained higher at depth in the north and east locations longer into the winter than at the other sampling locations. During this study, summertime dissolved oxygen concentrations were suitable for trout growth and survival throughout most of the water column, and water temperatures remained below 20°C. However, summertime air temperatures during this study were at 30-year averages. In 2017, when summertime temperatures were above average, water temperatures exceeded 25°C, suggesting that under warmer conditions, thermal stress may reduce condition factor of trout going into the winter period. Continued fine-scale monitoring of water quality and plankton could inform changes in timing and location of fingerling stockings to maximize survival and growth, if hatchery operations can be adapted to allow stocking at times of year other than early fall.

Acknowledgments

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Introduction

Henrys Lake is among the most the popular lentic waters for angling in the state. In 2013, angling effort accounted for 191,000 hours (High et al. 2015). Economically, Henrys Lake is also very important to the state, with angler expenditures of 12 million dollars in 2003 (Grunder et al. 2008). Henrys Lake is managed as a trophy fishery and provides a stronghold for native Yellowstone Cutthroat Trout *Oncorhynchus clarkii bouvieri*. The fishery is maintained primarily through fall stocking of trout fingerlings, although some wild-trout recruitment does occur. Since 2015, trout stockings have increased by about 250,000 fish per year. Despite increased stocking rates, trout abundances observed in recent gillnet catches in 2017 (5.5 trout per net) and 2018 (4.3 trout per net) were lower than expected and well below the management target of 11 trout per net. The reduction of trout abundances has fisheries managers concerned that abiotic (e.g. temperature, oxygen) or biotic (e.g. food availability, competition) factors may be limiting the current trout population. Understanding potential factors that may be causing poor trout survival and recruitment is key to establishing a stable trout population for anglers in this particularly high-profile fishery.

Factors that may directly impact trout survival include higher summer temperatures and/or lower winter oxygen availability. Over the last five years, ice-off has occurred earlier than in the previous ten years based on the timing of gillnet sets at ice-off. This earlier ice-off increases the summer solar radiation period and likely has increased summer water temperatures. Due to the shallow nature of the lake, temperature stratification does not occur. Thus, there is little thermal refuge available to trout in Henrys Lake, and higher water temperatures in the summer may be metabolically stressful. Also, high water temperatures and increased solar radiation may have increased frequency of cyanobacteria blooms, which occurred in the summers of 2016 and 2017. Due to the biological oxygen demand during and after these blooms, it is possible that blooms in 2017 contributed to dissolved oxygen levels during the 2017-2018 winter that were the second lowest observed over the last two decades, likely resulting in low trout survival.

Indirect factors that could be affecting trout survival include changes in primary and secondary productivity, probably also driven by warmer spring and summer temperatures. Increased occurrence of cyanobacteria blooms could be shifting primary production away from beneficial phytoplankton than can serve as forage for zooplankton and macroinvertebrates, which ultimately contribute to trout growth. In addition to increased water temperatures and solar radiation, ratio of nitrogen to phosphorus (N:P) is an indicator of physical conditions that contribute to production of unusable phytoplankton such as cyanobacteria rather than beneficial phytoplankton (Levich 1996). At the level of secondary production, zooplankton provides the forage base for aquatic food webs in lakes and reservoirs and influences fish growth in lentic environments for planktivorous fish (Luecke et al. 1990). In Idaho lakes and reservoirs, Dillon and Alexander (1996) observed that the presence of large zooplankton was directly linked to the success and survival of fall hatchery trout fingerling stocking. However, fish stocking programs often fail to provide basic zooplankton monitoring data in evaluations of stocking rates. In this case, warmer spring air temperatures may be shifting timing of primary and secondary production cycles. If production of usable phytoplankton and zooplankton is beginning—and potentially ending—earlier, this may limit forage for stocked trout introduced each fall, potentially impacting their over-winter survival. Estimates of zooplankton abundances can be used to help evaluate hatchery trout stocking programs by providing an indication of the relative production potential of a water body and potential availability of preferred zooplankton as a food source for stocked fish.

Despite the need to understand the role of water-quality, phytoplankton, and zooplankton in potentially regulating trout abundances, limited water-quality monitoring has previously occurred in Henrys Lake. The last water-quality assessment in the lake occurred over two decades ago (Hill and Mebane 1998). Currently there is a need to conduct a more in-depth water quality assessment to determine temperature and oxygen constraints for trout in Henrys Lake as well as the role of nutrient availability as it affects primary production, from a bottom-up perspective in the food web.

Objectives

The objectives of this study are to assess:

1. Suitability of summer temperatures for trout growth and survival,
2. Suitability of dissolved oxygen under ice cover and also potentially in the summer for trout survival,
3. Short-term and long-term trends in nitrogen, phosphorus, and N:P ratios, and
4. Sufficiency of zooplankton abundances in summer and fall to provide forage for young trout (age-0, age-1).

Methods

Data collection aimed at determining current seasonal and spatial variation in primary production and water quality in Henrys Lake including nutrient concentrations, continuous data on total algae biomass and relative cyanobacteria concentration, plankton tows to determine community structure, and photic zone measurement. Sampling began on 7 August 2018 and continues as of the writing of this report.

Sampling site selection:

The lake was divided into four uniform quadrats to denote north, south, east, west and center. Sites were then randomly selected by overlaying a grid system (100x 100 m) in each quadrat using the TOPO! Mapping software. Two additional sites were also randomly selected to generate a total of seven zooplankton sampling sites (Figure 1).

Water Quality

Physical and biological parameters

During the open-water season (August-October 2018 and May-July 2019), a vertical profile of the lake at each of the 5 sampling locations was taken once a week using a YSI EXO3 multi-parameter water-quality sonde. The sonde was outfitted with optical dissolved oxygen, conductivity/temperature and total algae probes. The output from the total algae probe on the EXO3 yields an index of cyanobacteria concentration (phycocyanins) as well as chlorophyll-a concentration. The sonde was lowered from a stationary boat at approximately 0.25 m/s to the bottom of the reservoir, then retrieved at the same speed to the surface. Temperature and depth measurements were recorded 1/s by the sonde. Data from a single sampling event consisted of data recorded when the sonde was being lowered and data recorded when the sonde was being raised. The two sets of data (up-going and down-going) were averaged at 100 equally-spaced elevations within the profile to obtain the complete depth profile.

During the ice-on season the YSI EXO3 multi-parameter water-quality sonde was suspended 3 meters below the surface from a fixed buoy at the North sampling location. This sonde was outfitted to record data every 15 minutes. Due to human error during sonde deployment, a continuous record was available only from 8 February to 27 March 2019. Vertical profiles of dissolved oxygen and temperatures were collected once during each of January, February and March with a YSI Pro 20 handheld probe by lowering the probe through a hole drilled in the ice. Measurements were recorded every 0.5 m from immediately underneath the ice to the bottom of the lake. These winter profiles were collected at all water-quality sampling sites except the center site.

Nutrients

During the ice-free period (roughly 24 April to 15 November), water samples for analysis of total phosphorus (TP) and total nitrogen (TN) were collected weekly using a Van Dorn sampler at 1 m depth at each location. Each time nutrient samples were collected, the depth of the photic zone was also measured and recorded via a Secchi depth reading. During periods of ice cover, TN and TP samples were collected once each month at each sampling location. Analysis of variance was used to test for differences in TN, TP, and TN:TP ratio across the five sites, using each sampling event as a replicate within each site. Mixed-effects linear modeling was used to test for temporal differences in TN, TP, and TN:TP across the year. Site was considered a random effect within sampling dates, and regression coefficients for constant, linear, and quadratic trends were fit as fixed effects. The likelihood ratio test was used to test for temporal trends. Level of significance was set at $\alpha = 0.05$ for a family of 6 hypothesis tests (one test each for difference across site and time for each of TN, TP and TN:TP). Using Bonferroni's correction, this is equivalent to a significance level of 0.0083 for any individual test.

Zooplankton

Zooplankton samples were collected from Henrys Lake following the protocol described by Teuscher (1999). Zooplankton samples were collected on a bi-weekly basis throughout the open water season (7 August 2018- 20 October 2018; 5 June 2019-present). At each sampling event samples were collected from seven different locations spread around the lake. This included the 5 water quality sites and an additional 2 locations (Figure 1). Three samples were collected at each site using a small (153 µm), medium (500 µm) and large (750 µm) mesh nets. Zooplankton were preserved in denatured ethyl alcohol at a concentration of 1:1 (sample volume:alcohol). After ten days in alcohol, phytoplankton were removed from the samples by re-filtering through a 153 µm mesh sieve. The remaining zooplankton were blotted dry with a paper towel and weighed to the nearest 0.1 g. Biomass estimates were corrected for tow depth and reported in g/m. Relative production potential was estimated using the overall zooplankton biomass collected from the 153 µm net. Competition for food (or cropping impacts by fish) was determined using the zooplankton productivity ratio (ZPR) which is the ratio of preferred (750 µm) to usable (500 µm) zooplankton. The zooplankton quality index (ZQI) was estimated to account for overall abundance of zooplankton using the formula developed by Teuscher (1999) where ZQI = (500 µm + 750 µm) × ZPR.

Results

Water quality

Physical and biological parameters

Open-water depth profiles of physical and biological parameters varied across the five sampling locations but were similar between the north and center locations and between south and west locations (Figure 2). Profiles were much different at the east site than at the others. Thus, to limit redundancy, we have omitted plots from the north and west locations. Little to no thermal stratification was present at any of the sites during open-water sampling in 2018 and 2019, and little spatial variability in temperature was apparent (Figure 3). Water temperatures dropped from around 20°C in early August 2018 to 3°C by the end of October. In the spring of 2019, temperatures increased from 9°C in late May to 20°C by the end of July. No temperatures over 20°C were observed over the course of the study. Open-water dissolved oxygen (DO) concentrations varied substantially across locations, depth, and time (Figure 4). The highest DO concentrations, in the range of 8-10 mg/L, were observed near the lake surface in October 2018 and May and early June 2019. DO decreased with depth at the center (shown in Figure 4) and north locations during the summer months in both years but showed vertical variability in the south and west sites only on a few sampling events in August 2018. At the north and center sites, DO concentration was less than 5 mg/L in the bottom 2 m of the water column for most of August and September 2018 and July 2019. DO at the east site showed no vertical variability and was consistently higher than 8 mg/L during late summer of fall of 2018 and higher than 6 mg/L during spring and early summer 2019.

Phycocyanin concentrations in the upper and middle of the water column were lowest at the east site relative to the other four sites and were highest during September of 2018 (Figure 5). A pronounced cyanobacteria bloom was observed at about 3 m depth on 1 October 2018. At all but the east site, phycocyanin concentrations were consistently high in the bottom 2 m of the lake throughout late summer and fall 2018. Chlorophyll-a concentrations varied widely across sampling dates at all locations (Figure 6). Concentrations were highest during September and October 2018 and lowest during spring and early summer of 2019. As with phycocyanins, chlorophyll-a concentrations were generally higher near the bottom of the lake than near the surface. Secchi depths mirrored presence of phycocyanins and chlorophyll-a; the bottom of the photic zone was only 1-2 m below the lake surface during September 2018 but 4-6 m below the surface in June and early July of 2019. Secchi depths were highly correlated across the five sampling sites, although the shallowest Secchi depths were observed at the south site, in both September 2018 and July 2019.

Winter profiles showed expected density-determined thermal stratification under ice cover at all but the north site, where temperature at the bottom of the water column was consistently warmer than expected based on density alone (Figure 8). Bottom temperature there was between 4°C and 5°C during all three winter sampling events. At all sites and on all sampling dates, DO concentrations dropped from 6-10 mg/L immediately under the ice to 0-2 mg/L near the bottom of the lake. Little spatial variability in winter DO profiles was observed except in January, when DO remained above 5 mg/L down to a depth of 3 m at the east and north sites. However, in February and March, DO was above 5 mg/L only in the top 0.5-1.0 m of the lake at all sampling locations. Because of the relatively short, late-winter timing of data collected by the stationary sonde, little temporal change in any of the parameters was observed.

Nutrients

Concentrations of TN ranged from 0.4 mg/L to 2.1 mg/L and averaged 0.91 mg/L over all sites and sampling dates (Figure 9). There was no significant difference in TN across sites (ANOVA, $F_{4,84} = 1.11$, $P = 0.36$) or across time (LRT, $\chi_1^2 = 0.04$, $P = 0.84$). Concentrations of TP ranged from <0.01 mg/L to 0.06 mg/L and averaged 0.026 mg/L over all sites and dates (Figure 10). There was no significant difference in TP across sites (ANOVA, $F_{4,85} = 2.05$, $P = 0.10$). However, TP concentrations showed significant seasonal variability, described by a quadratic trend (LRT, $\chi_2^2 = 52.2$, $P < 0.001$). TP concentrations were highest in late summer and fall and lowest in winter and early spring. TN:TP ratios ranged from 6.7 to 250.0, with a mean of 55.6 (Figure 11). TN:TP showed no significant difference across sites (ANOVA, $F_{4,72} = 0.84$, $P = 0.51$). However, driven by the seasonal variability in TP, TN:TP ratio also showed a significant quadratic trend over time (LRT, $\chi_2^2 = 29.8$, $P < 0.001$). Overall, TN:TP ratios fell into the range considered in the literature to indicate phosphorus limitation (Hellström 1996).

Zooplankton

Zooplankton biomass varied across all sampling sites on each sampling date and seasonally. Overall zooplankton biomass was the highest across all sampling sites on 1 October 2018 and lowest on 18 June 2019. When averaged across all sites zooplankton biomass showed an increasing trend from the onset of sampling, peaking on 1 October 2019, crashing in the following 2 weeks and rebounding slightly before ice-on (Figure 12). Both ZPR and ZQI indices mirrored one another at each site throughout the study. Cycling of zooplankton densities was apparent at 2 week to a month time intervals between sites. Starting in August 2018 we tracked the highest ZPR and ZQI in the East site followed by the Center and South before ice on. Subsequently, during the spring and early summer 2019 the highest numbers were present in the West and North locations (Figure 13). During the week directly proceeding fingerling stocking in Henrys Lake (18 September 2018), an average ZQI rating of 1.68 was found across all sampling sites.

Discussion and Management Implications

Just over 1.5 million fingerling trout were stocked in to Henrys Lake during the last week of September 2018. As outlined by Teusher (1999), a recommended ZQI of >1.0 is needed during this time to stock high densities of fingerling trout (Table 1). On average we calculated a ZQI of 1.68 in the lake during the week directly proceeding stocking. This indicates Henrys Lake has a large enough zooplankton forage base to accommodate the stocking of fingerling trout in high densities during late September, at least under conditions we observed in 2018. Based on patterns of productivity in the lake indicated by our water-quality data, zooplankton forage base is likely to be sufficient to support high stocking densities in the fall every year, with year-to-year variability determined by hydro-meteorological conditions within a particular year.

Table 1. Zooplankton quality index (ZQI) ratings and the recommended hatchery trout stocking rates as outlined by Teuscher (1999).

ZQI	Stocking recommendation
<0.1	Low density fingerlings (< 75 per acre) or stock catchables
0.1-1.0	Moderate density fingerlings (75 - 150 per acre)
>1.0	High density fingerlings (150 - 300 per acre)

Over the course of our study, water temperature did not appear to be a factor affecting survival or growth of trout in Henrys Lake. Water temperatures did not exceed 20°C at any site, depth or time during the study. Mean air temperature in Island Park during August and September 2018 was equal to the 1989-2018 average, and mean July temperature in 2019 was also equal to the 1989-2018 average, suggesting that under average summertime conditions, water temperature in Henrys Lake is likely to be suitable for trout growth and survival through the entire summer. However, during 2017, when mean July air temperature was 1.4°C warmer than average, IDFG measured water temperatures in excess of 25°C near the hatchery. Thus, during summers when air temperatures are above average, water temperatures may reduce summertime growth and survival in at least portions of the lake. Although summertime temperatures do not affect fall-stocked fingerlings, thermal stress on older trout during summer could reduce condition going into the stressful ice-on period, leading to lower winter survival.

During the year of this study, DO had the potential to limit trout survival only during winter. Although late-summer DO concentrations fell below optimal levels for trout survival near the bottom of the lake, DO remained above 5 mg/L in the top 4-5 m of the water column throughout the lake. Low DO during late summer and early autumn coincided with the highest concentrations of phycocyanins and chlorophyll-a near the bottom of the lake, indicating that decay of cyanobacteria and algae is most likely the cause of low DO at that time. No decrease in DO with depth was observed at the east location, where inflow from Targhee Creek apparently maintained sufficient mixing to keep DO high. During winter, DO remained suitable for trout survival only near the top of the lake, and the depth of this suitable layer narrowed throughout the winter at all sites. During January, DO remained above 5 mg/L at the north and east sites down to 3 m depth under the ice, providing a larger volume of suitable habitat for fish than at the other sites. However, by the end of February, DO was no different at the north and east sites than at the other sites. Thus, low DO reduced the total volume of the lake suitable for trout survival in late winter of 2018-2019. Low winter-time DO in Henrys Lake was described over two decades ago (Hill and Mebane 1998).

Secchi depth, nutrient, algae/cyanobacteria, and plankton data displayed a seasonal pattern of high productivity from late July through early October, with much lower productivity the remainder of the year. Seasonal cycling of internal TP is most likely produced by seasonality in primary productivity rather than the other way around. During periods of low productivity—likely limited by sunlight and temperature—little TP is present in the water column. Conversely, when primary productivity is high during late summer and fall, TP concentrations in the water column are much higher due to high biomass of phytoplankton present at that time. Restoration of tributary streams and their riparian areas initiated in the 1980s had already limited external loading of P by the early 1990s (Hill and Mebane 1998). In 1994, an estimated 66% of the total P load in the lake was internal, and that fraction has probably increased since then. Anoxic conditions during winter release P from lake-bottom sediments, and this P remains near the bottom until the lake mixes after ice-off. Wind-driven mixing is high on Henrys Lake, as evidenced by lack of thermal stratification during summer, because the lake is very shallow in relation to its surface area. Once mixed into the water column, P is then available to support primary productivity in the water column once sunlight and water temperature are suitable. Spatial consistency in TP across the lake provides additional evidence for internal cycling of TP, since an external point source would likely produce higher TP concentrations in areas of the lake near the source versus other areas. Nutrient concentrations and ratios in Henrys Lake during this study were very similar to those observed in Island Park Reservoir in recent years by the Henry's Fork Foundation. However, changes in TN:TP ratio driven by seasonal productivity could affect the type of primary productivity—algae versus cyanobacteria—observed during the late summer and fall (Levich 1996). Again, we note that air and water temperatures during this study were lower than in recent years, likely reducing occurrences of cyanobacteria blooms compared to 2015, 2016, and 2017.

Zooplankton biomass and ZPR tracked indicators of primary productivity well, reaching maximum values in late September and early October, coincident with the highest chlorophyll-a concentrations and shallowest Secchi depths. The highest ZQI value observed in this study also occurred at this time, but ZQI showed high spatial variability at this time. In particular, the large peak in ZQI in October 2018 was observed only at the south site, suggesting the need for zooplankton sampling prior to stocking times at specific stocking locations. IDFG is currently collaborating with a University of Idaho graduate student who is tracking Henrys Lake fish. That study, in conjunction with continuation of zooplankton sampling, could determine whether trout move around the lake to forage in locations where zooplankton abundance and ZQI are highest at a given time.

This study suggests that stocking trout at times of the year other than early fall—and in locations where ZQI is high—could increase condition factor of juvenile trout going into the winter. This would require adaptations to IDFG's current stocking regime. However, regular sampling of the entire water column through this study allowed IDFG to stock Hybrid Trout fingerlings in June 2019, before water temperature became too high for stocking. This helped free up hatchery space for other projects. Furthermore, continuing this project for another winter, with emphasis on more frequent sampling between ice-on and ice-off, will help inform the timing and success of IDFG's egg take facility located on Henrys Lake.

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Figures

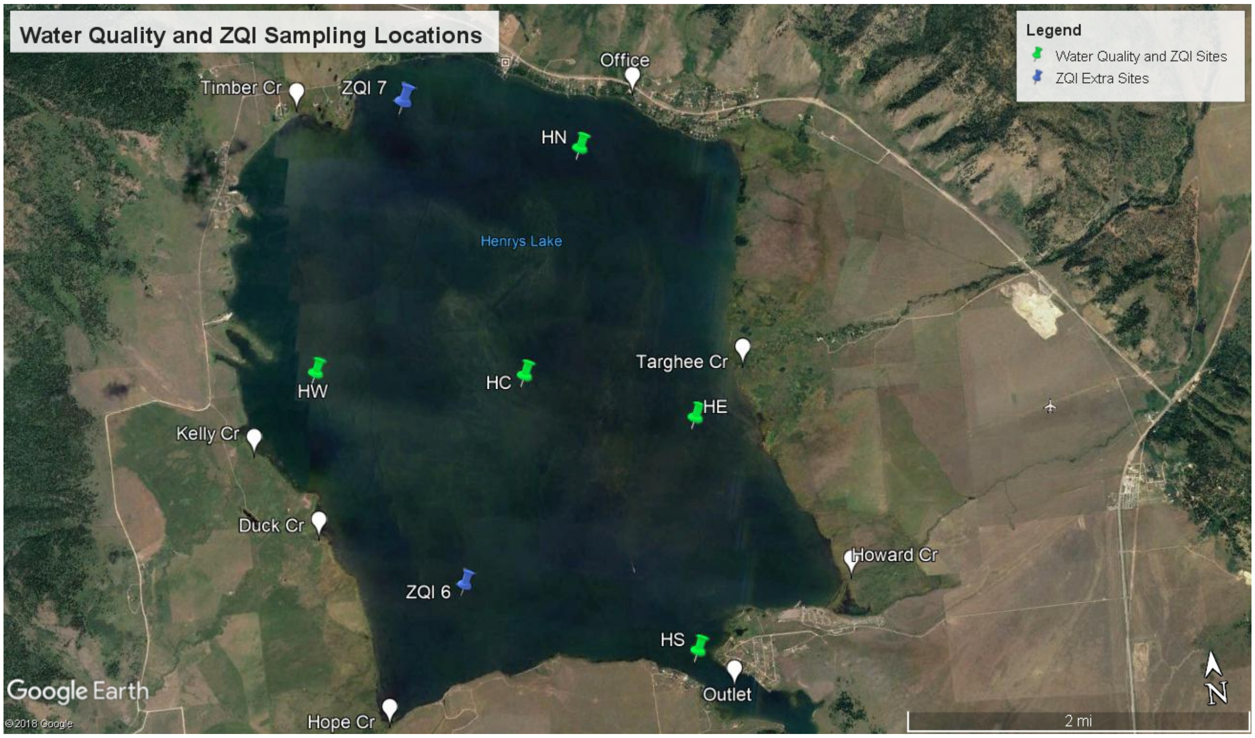

Figure 1. Map of Henrys Lake, showing sampling locations

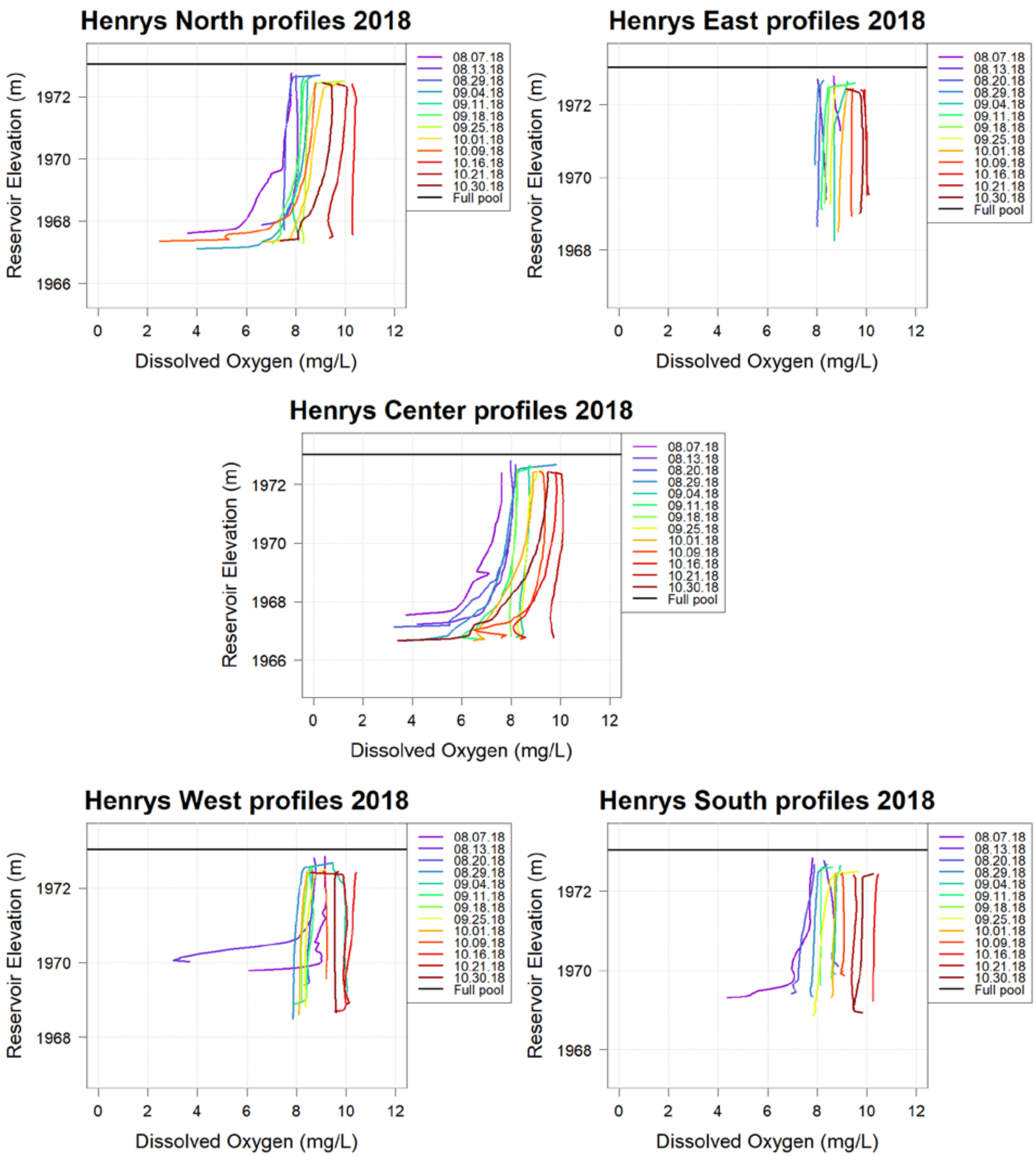

Figure 2. Dissolved oxygen profiles at all sites, 7 August 2018 – 30 October 2018.

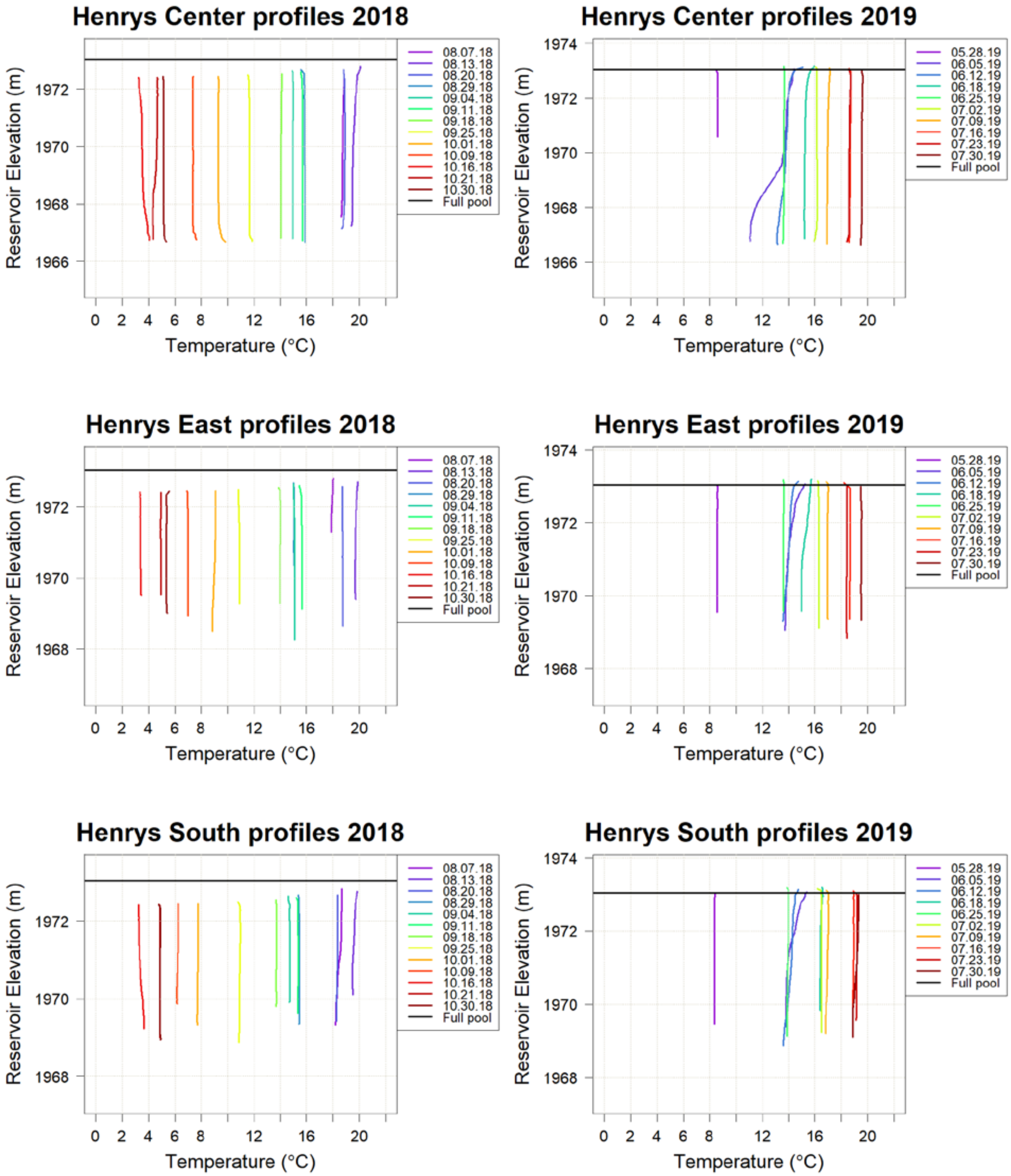

Figure 3. Open-water temperature profiles, 08-07-2018 through 10-30-2018 (left panels) and 05-28-2018 through 07-30-2019.

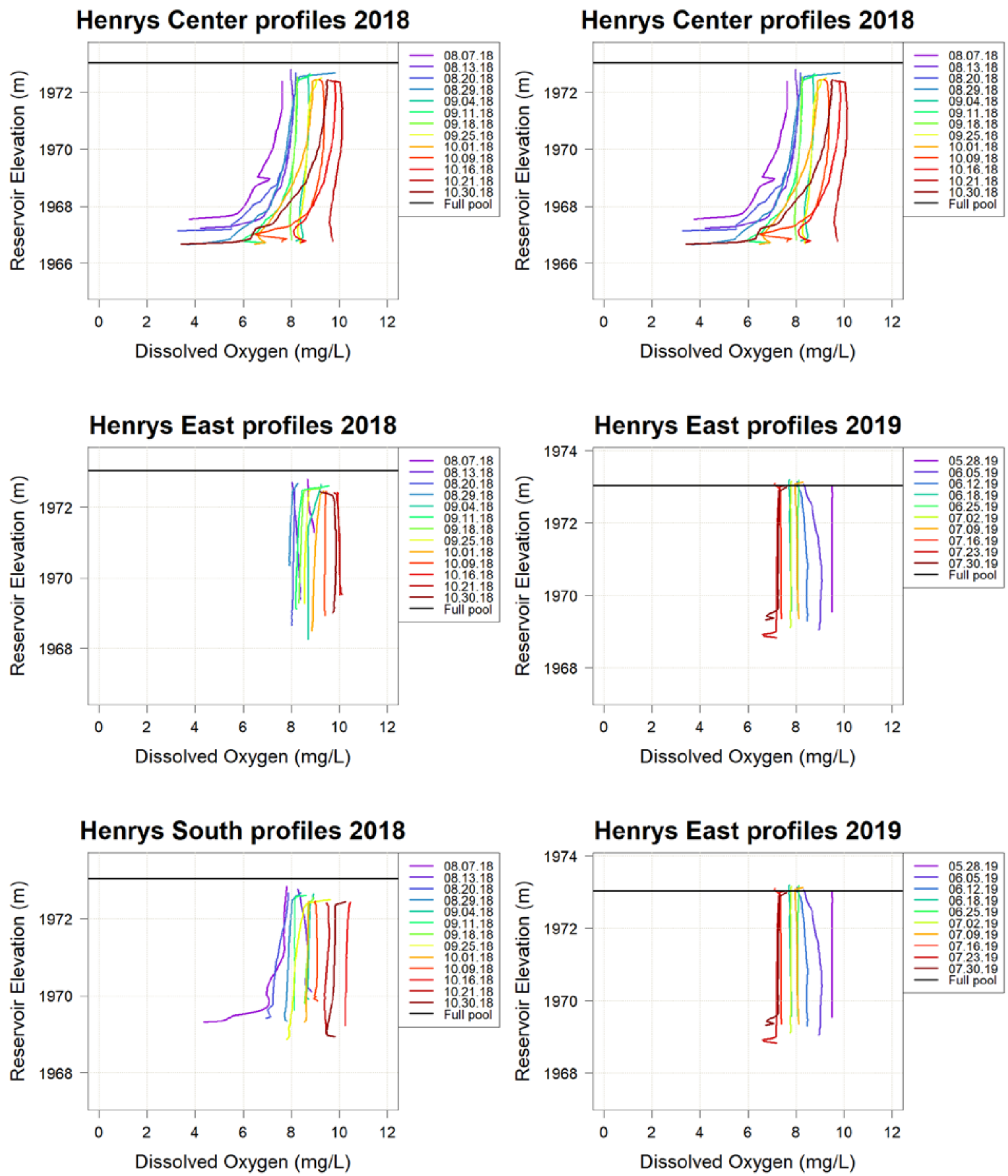

Figure 4. Open-water dissolved oxygen profiles, 08-07-2018 through 10-30-2018 (left panels) and 05-28-2018 through 07-30-2019 (right panels).

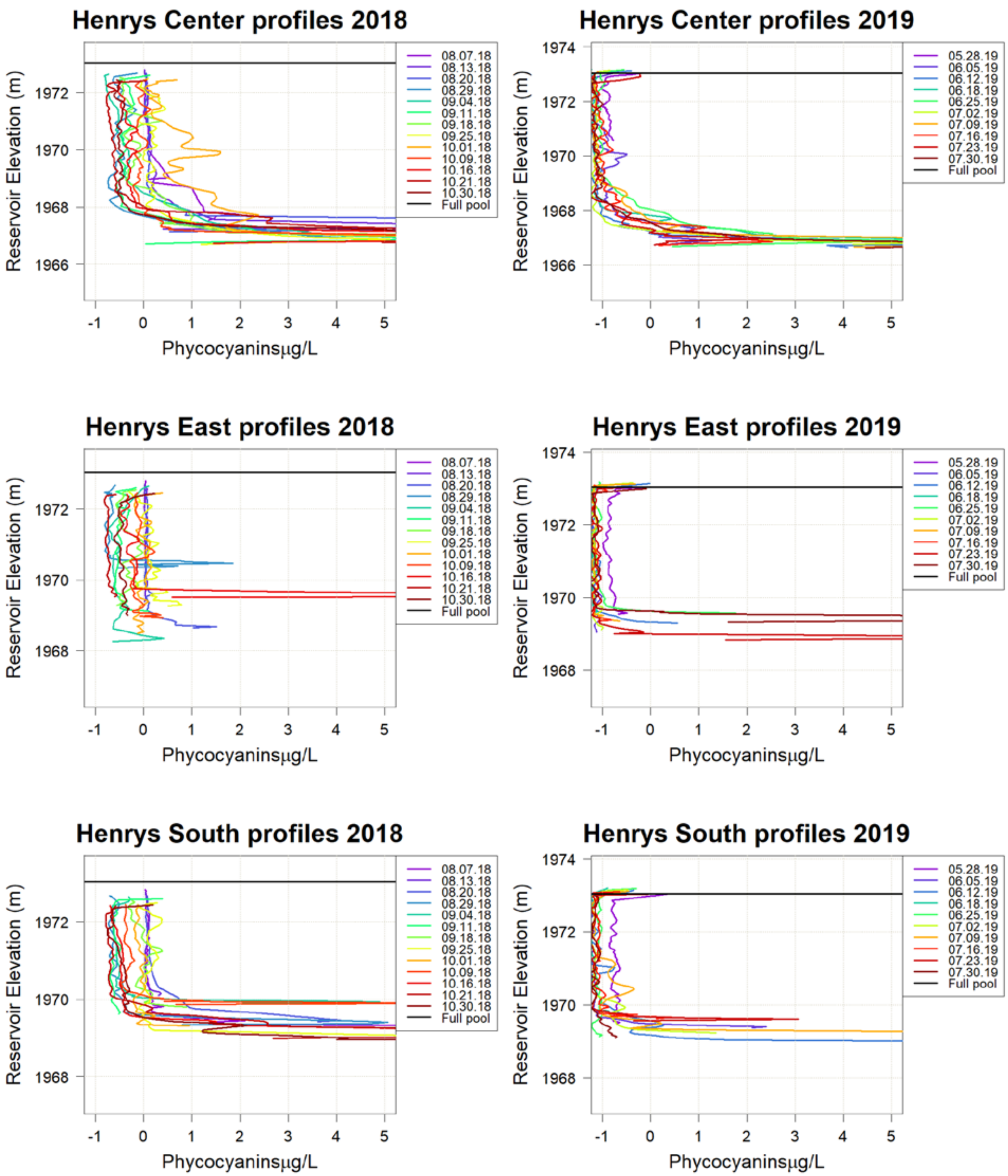

Figure 5. Open-water cyanobacteria index profiles, 08-07-2018 through 10-30-2018 (left panels) and 05-28-2018 through 07-30-2019 (right panels).

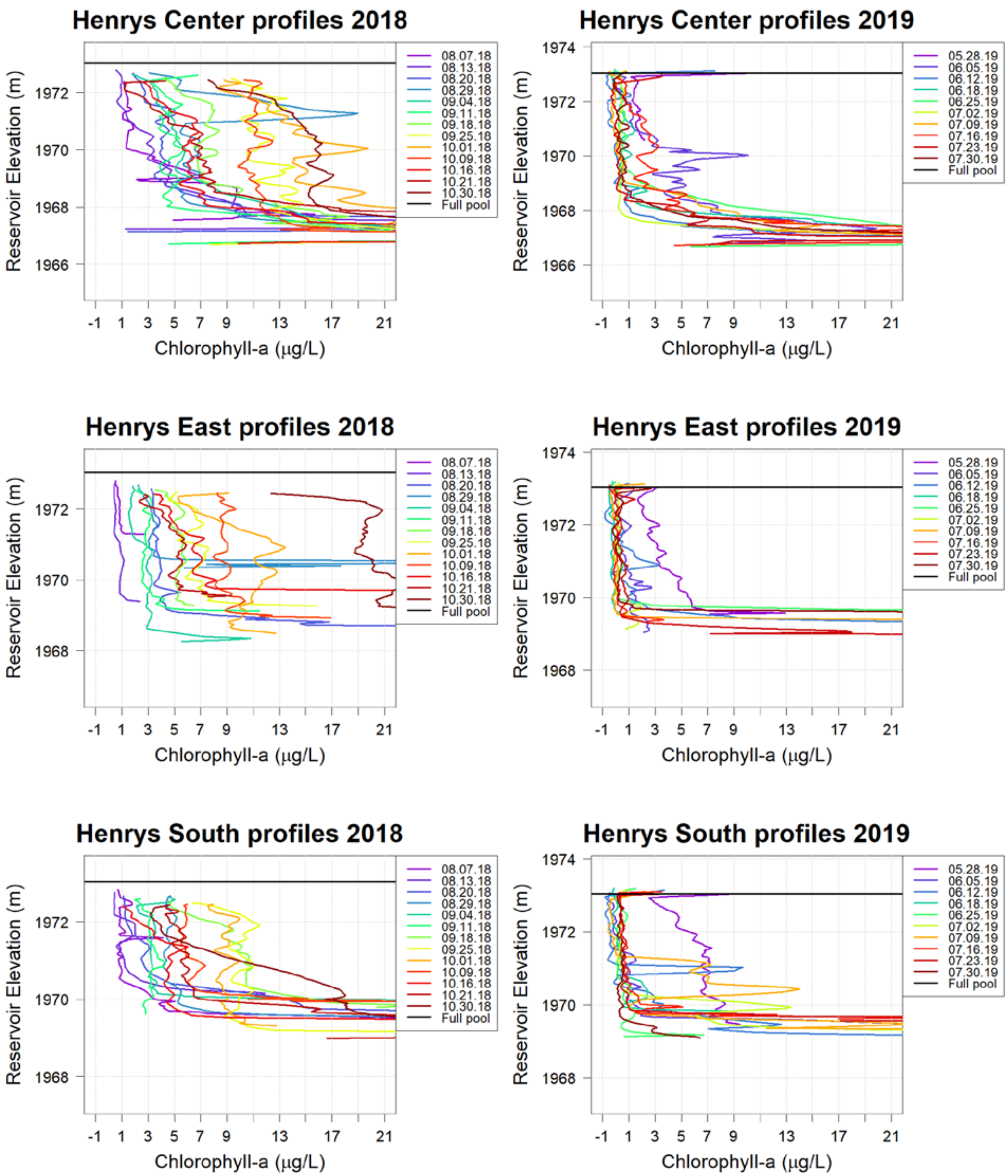

Figure 6. Open-water chlorophyll-a index profiles, 08-07-2018 through 10-30-2018 (left panels) and 05-28-2018 through 07-30-2019 (right panels).

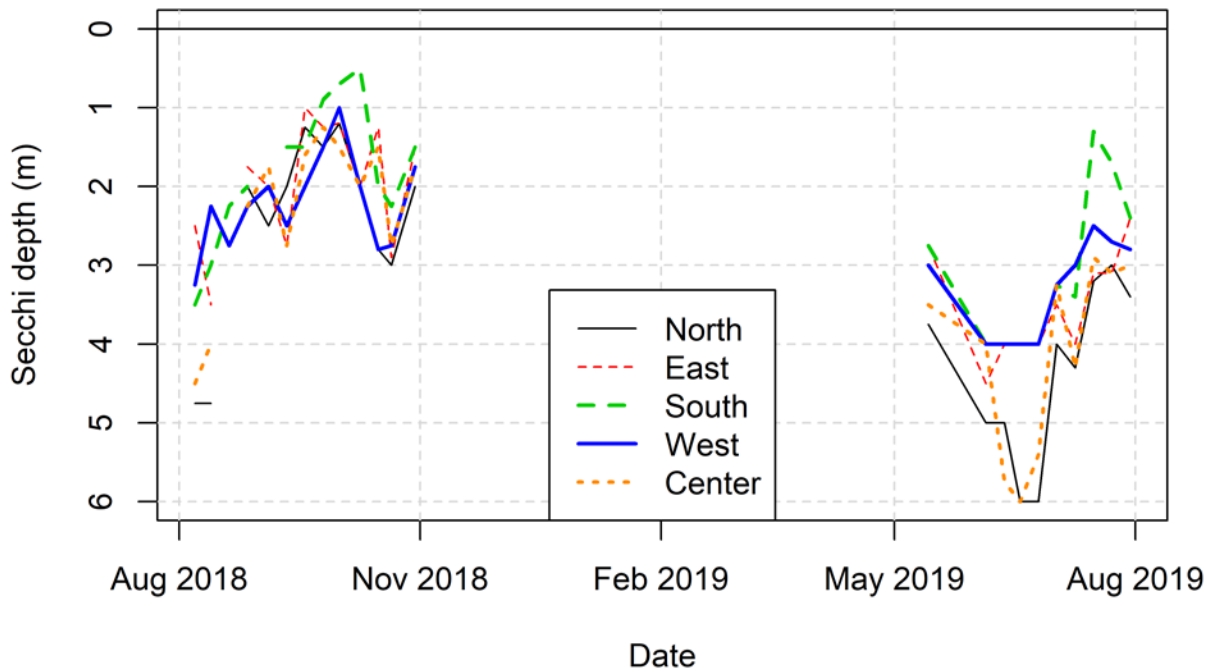

Figure 7. Secchi depth (bottom of photic zone) at all sites on all open-water sampling dates.

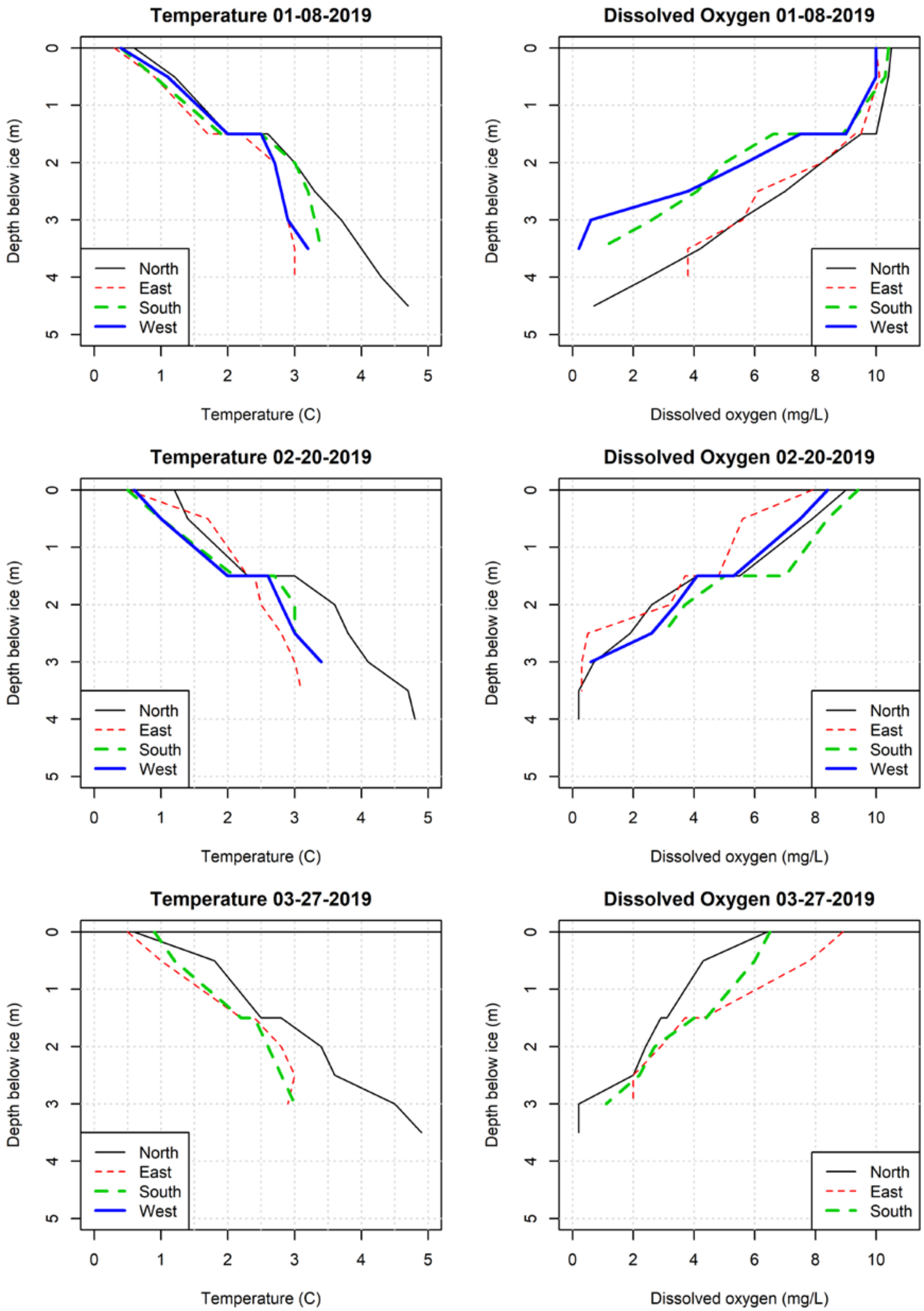

Figure 8. Winter temperature (left) and dissolved oxygen (right) profiles at the North, East, South and West sampling locations.

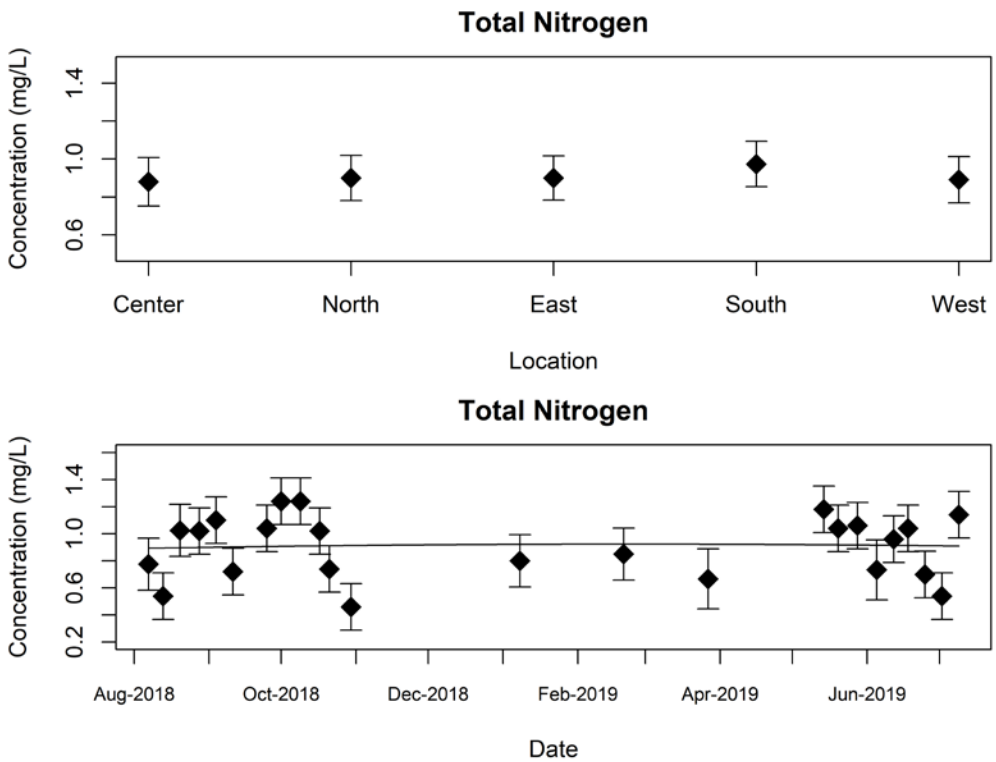

Figure 9. Total nitrogen concentrations by site and date, with 95% confidence intervals.

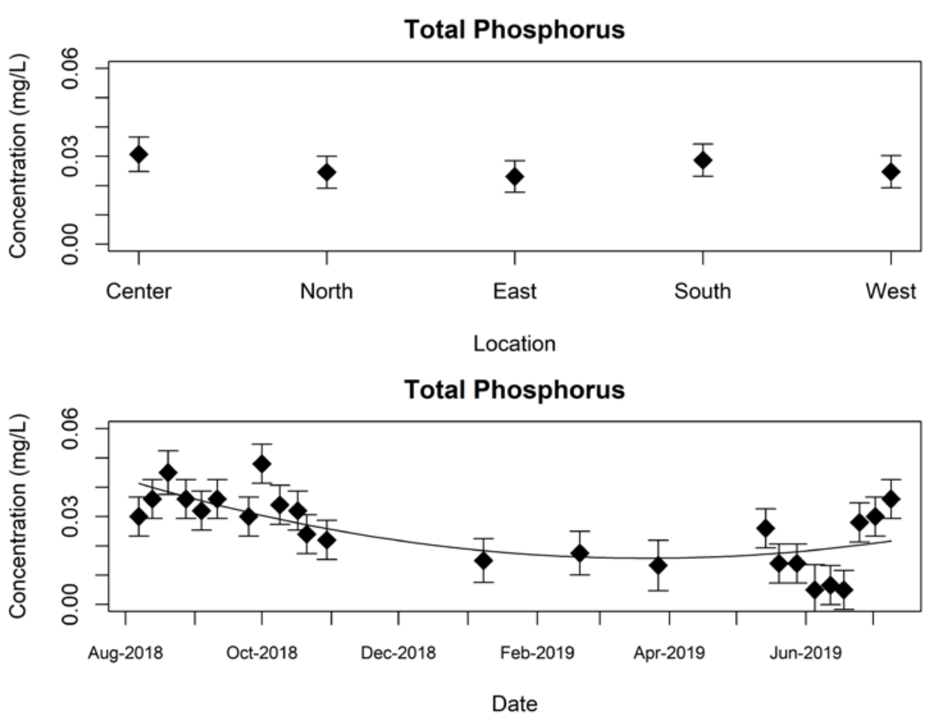

Figure 10. Total phosphorus concentrations by site and date, with 95% confidence intervals.

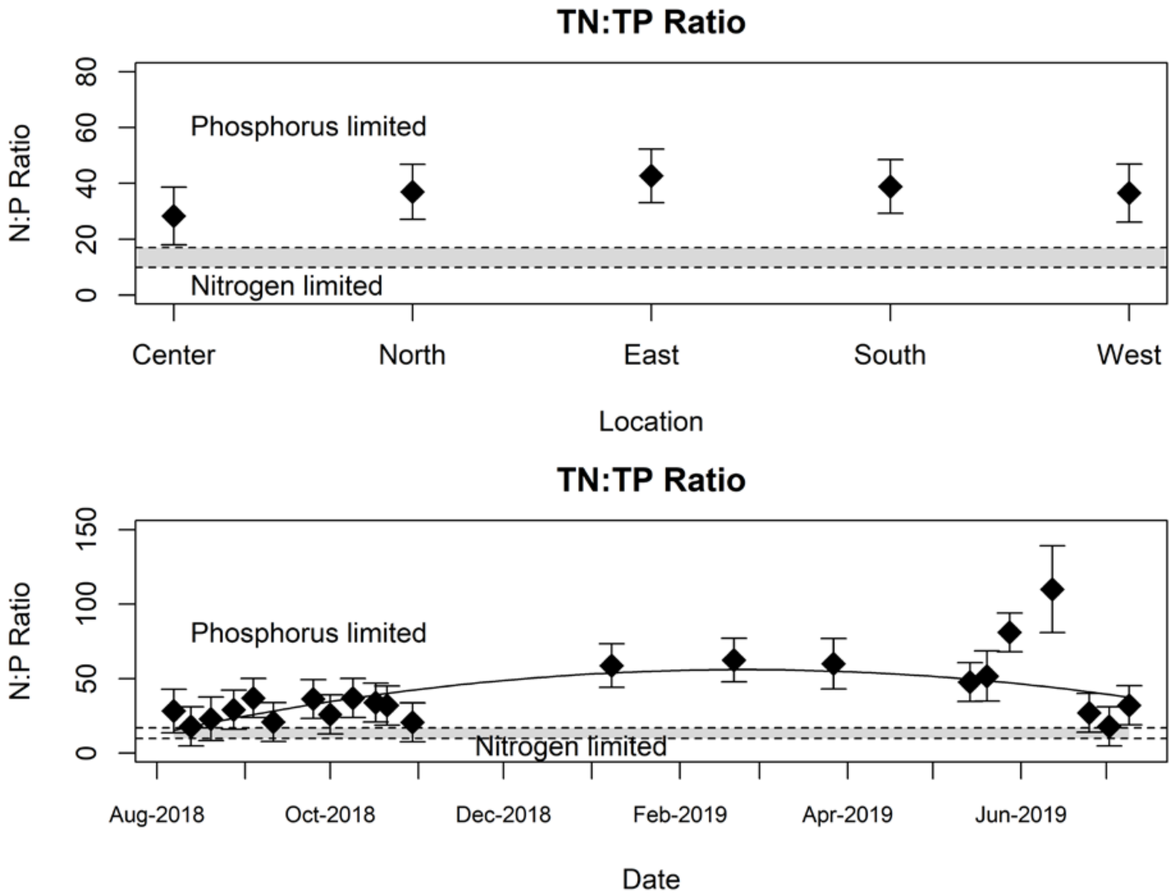

Figure 11. Ratio of total nitrogen to total phosphorus by site and date, with 95% confidence intervals.

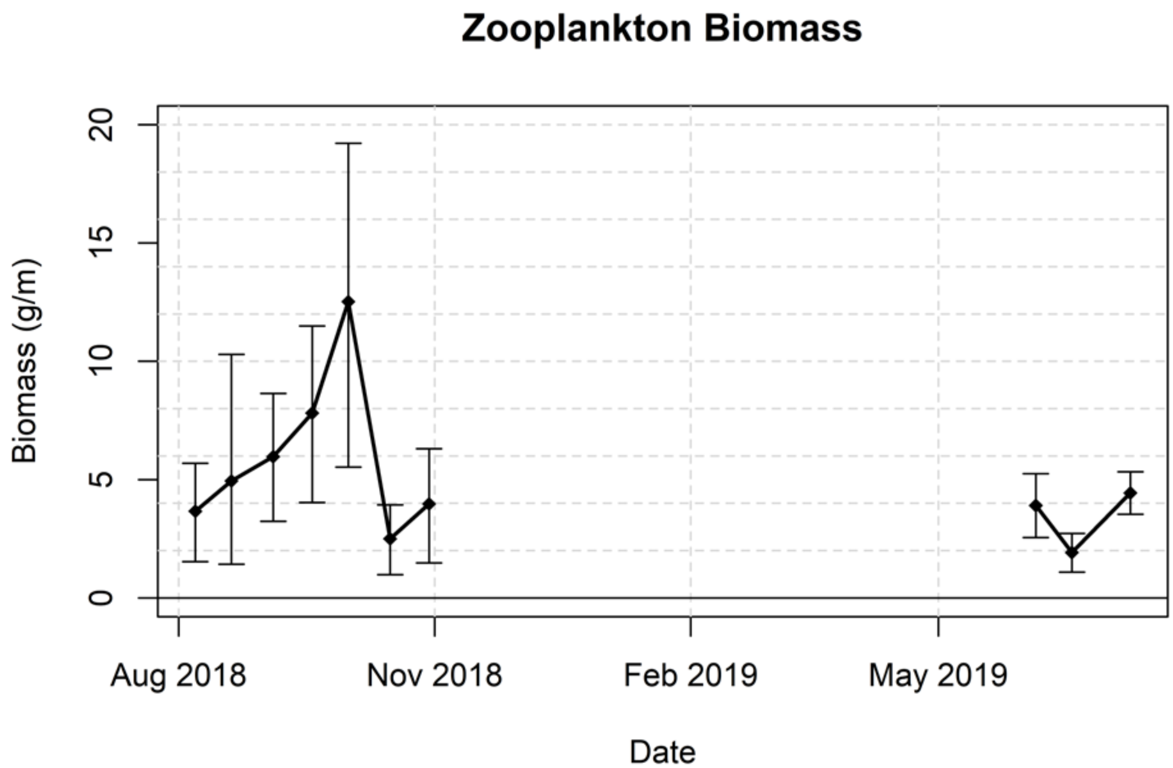

Figure 12. Mean zooplankton biomass across all sample sites, with 95% confidence intervals.

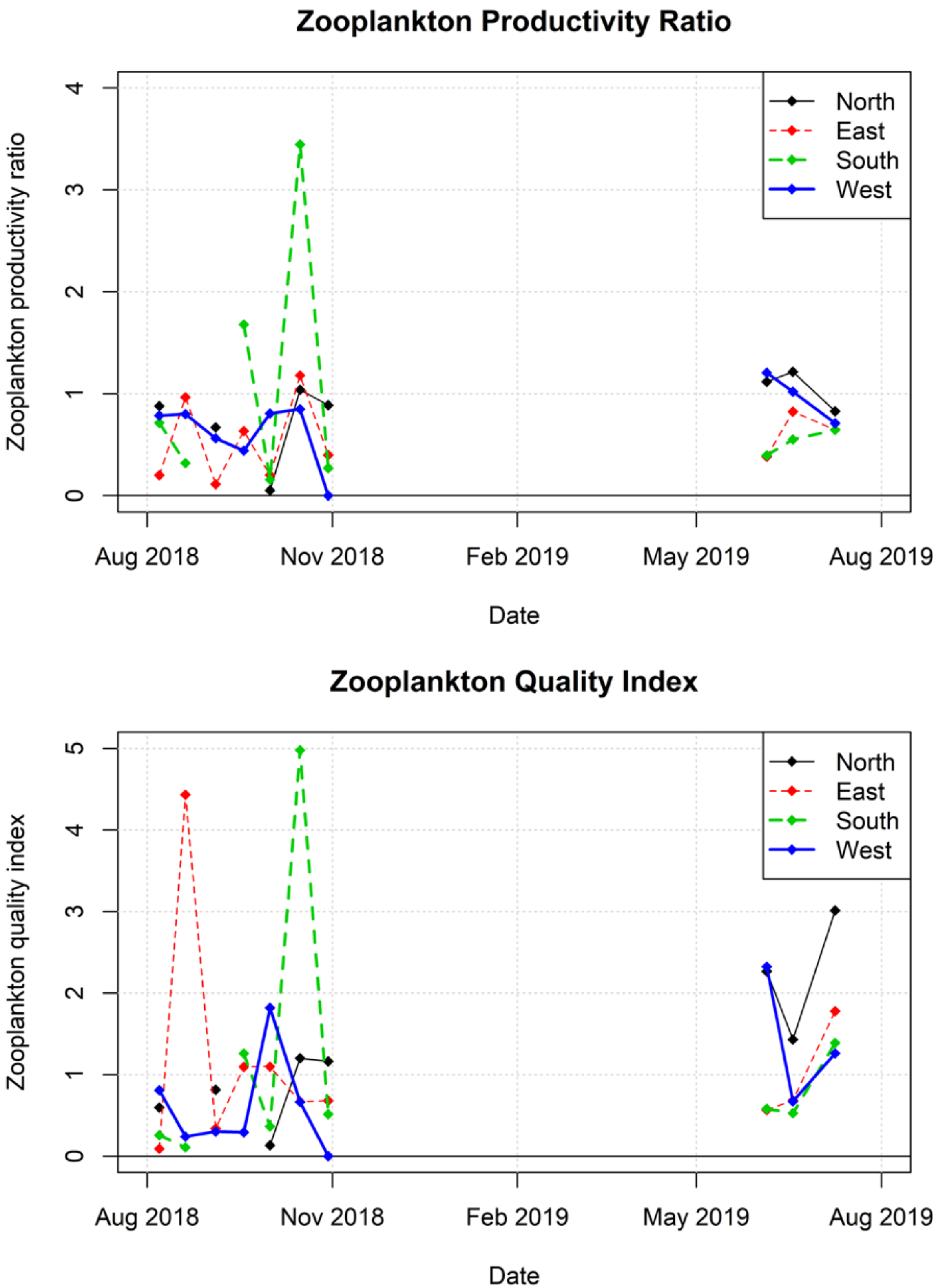

Figure 13. Zooplankton quality index (top) and productivity ratio (bottom).