

Lake Auburn Lake Watershed-based Protection Plan

REPORT



November 2022 (Draft)

August 2023 (Final)

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- Appendix B Watershed Survey
- Appendix C Perimeter Water Quality Plots
- Appendix D Profile and Isopleth Plots
- Appendix E Algal Count and Biovolume Plots

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Section 1

Background Information

1.1 Document Purpose and Scope

Lake Auburn is the drinking water supply for the communities of Lewiston and Auburn, Maine; in addition to drinking water supply, Lake Auburn is also used for non-contact recreation and fishing, and is stocked with lake trout and landlocked salmon by the Maine Department of Inland Fisheries and Wildlife. The lake is a typical northern temperate dimictic lake, with a mean depth of 40 feet (12.2 m), a maximum depth of 120 feet (36.5 m), a surface area of 2,260 acres (915 hectares), and a residence time of 4.8 years (Dudley, 2014). Historically, Lake Auburn has been known for its excellent water quality, and the Auburn Water District and Lewiston Water Division (AWD/LWD) were granted a filtration avoidance waiver for Lake Auburn from Maine Division of Environmental Health in 1991.

About a decade ago, Lake Auburn experienced unusual, likely climate-change driven, events that resulted in a brief period of degraded water quality, threatening the coldwater fishery and AWD/LWD's filtration avoidance waiver. In 2011 and 2012, turbidity increased due to a combination of factors, including cyanobacteria blooms; in 2012 nearly the entire bottom water (hypolimnion) was anoxic, leading to a fish kill. Subsequent to the 2011 and 2012 water quality degradation, additional, periodic episodes of elevated turbidity and algal blooms have occurred. In 2018, a cyanobacteria bloom in the fall led to a copper sulfate algaecide treatment in September, followed by a low dose aluminum sulfate (alum) treatment in 2019. While water quality has improved following the alum treatment – as measured by lower phosphorus concentrations, deeper Secchi depths, and lower turbidities – increased turbidity has been observed in fall 2021 and 2022, likely the result of a combination of algal growth and sediment in the water column (either resuspended from the bottom or introduced to the lake from tributary inflows).

This document is an update to the Lake Auburn Watershed-Based Plan, developed by Comprehensive Environmental and the Lake Auburn Watershed Protection Commission (LAWPC) in 2013. The purpose of this plan is to identify sources of non-point source pollution that may impact water quality in the lake, identify structural and non-structural best management practices (BMPs) that will enhance water quality protection of Lake Auburn and its watershed, and establish an implementation schedule.

This plan is designed to meet the requirements of the Maine Lake Watershed-based Protection Plan guidance, an alternative to the Environmental Protection Agency (EPA) required nine-element watershed-based plan that Maine Department of Environmental Protection (MDEP) allows for unimpaired lakes that are on the Nonpoint Source (NPS) Priority Watersheds List with a recent non-point source pollution survey. Lake Auburn is not listed as impaired by MDEP and is on the NPS Priority Watersheds List for Lakes. AWD/LWD maintain a strong watershed protection program that includes frequent watershed surveys to identify potential pollution

sources throughout the watershed; in addition, an updated NPS pollution survey was completed as a component of the development of this plan (see **Appendix B**).

1.2 Watershed Background

Lake Auburn’s watershed is 9,650 acres (excluding the 2,260-acre surface area of Lake Auburn). Most of the watershed is located in the City of Auburn (5,804 acres or 60 percent), with smaller areas in Turner (2,620 acres or 27 percent), Minot (885 acres or 9 percent), Hebron (184 acres or 2 percent) and Buckfield (159 acres or 2 percent). The Lake Auburn watershed is divided into six sub-watersheds: Spring Road, Upper Watershed, Townsend Brook, Route 4, Lower Watershed, and Lake Shore Drive (**Figure 1-1, Table 1-1**). LAWPC owns most of the land immediately adjacent to Lake Auburn as well as a large amount of land within the watershed in Auburn. In addition, LAWPC holds life estates and conservation easements on additional parcels in the watershed; the life estates are properties that have been sold to LAWPC, but the owner is permitted to occupy the land. These are shown on **Figure 1-1**. In total, LAWPC owns or controls 1,975 acres of land within the watershed and 80 percent of the Lake Auburn shoreline.

Table 1-1 Subwatersheds in the Lake Auburn Watershed

Subwatershed	Area (ac)	Description
Upper Watershed	4,940	Upper watershed, north of the northern inlet to the lake; includes the Basin, Little Wilson Pond, and Mud Pond
Lake Shore Drive	1,140	Tributaries that discharge across Lake Shore Drive west of Townsend Brook
Townsend Brook	1,540	Townsend Brook watershed, including the portions of Route 4 that are located in the Townsend Brook watershed
Route 4	290	Direct drainage along Route 4 in Auburn
Lower Watershed	750	Direct drainage south of Lake Auburn
Spring Road	990	Drainage along Whitman Spring Road, comprised of a number of small tributaries that drain a steep slope on the western shore of Lake Auburn
Total	9,650	

The City of Auburn recently completed a study (FB Associates et al., 2021) to review current water quality and regulatory conditions in the Lake Auburn watershed and evaluate potential future conditions accounting for both climate change and population growth. As a component of this study, FB Associates reexamined the watershed boundary in the Lower Watershed using historical groundwater monitoring data and 2-ft surface contours. The area evaluated in this study contains two sand and gravel operations and a decommissioned landfill. FB Associates’ review indicated that this 148-acre area should be removed from the watershed. LAWPC subsequently commissioned a review of the proposed change, which suggested areas of uncertainty regarding the groundwater contributing area (CDM Smith, 2022). Because the change in the watershed boundary has not yet been adopted by the LAWPC, the previous watershed boundary is used as the basis for the watershed area calculations in **Table 1-1** and the remainder of this plan.

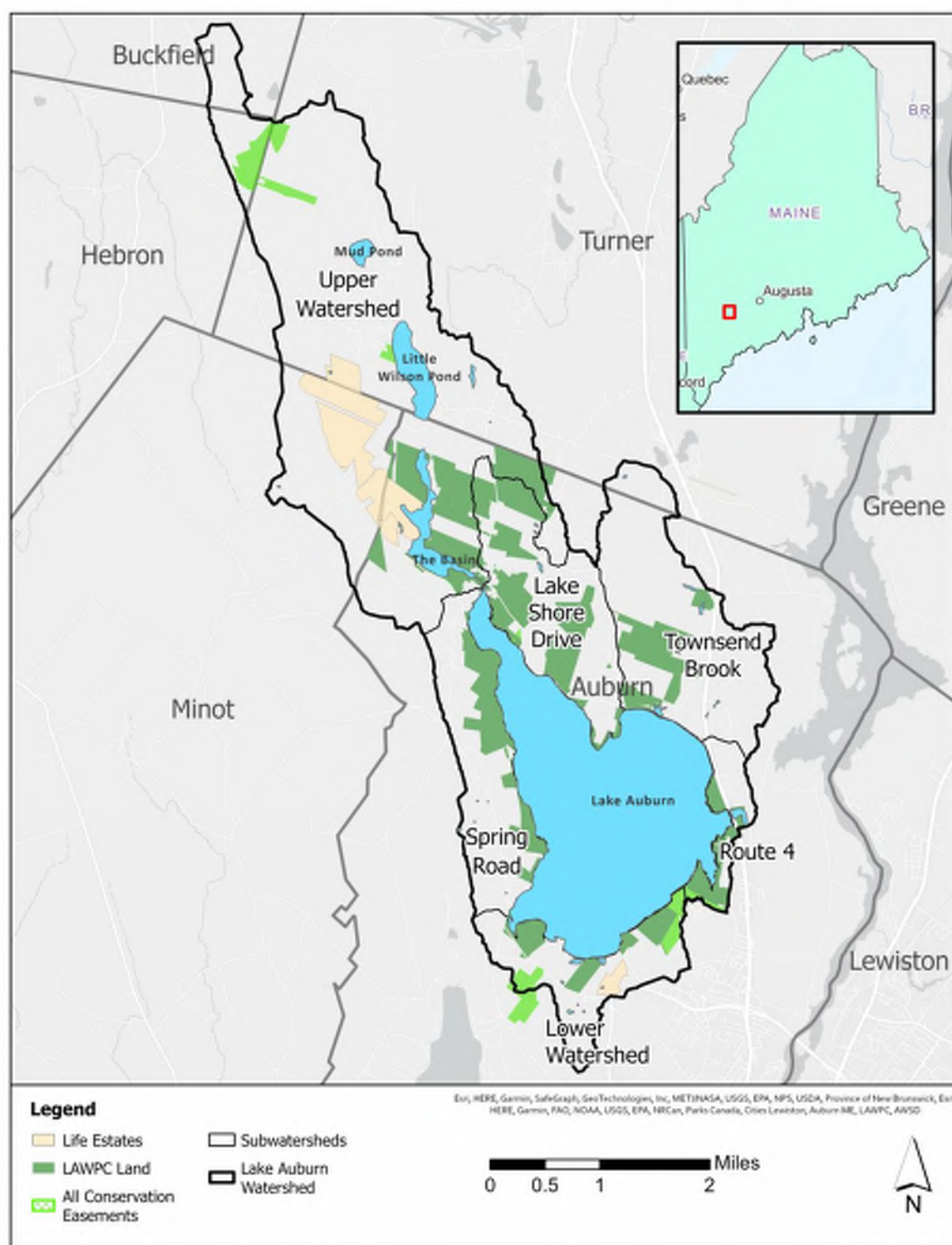


Figure 1-1
Lake Auburn Watershed Overview Map and Boundaries

1.2.1 Land Use and Changes

The Lake Auburn watershed is characterized by mostly forested land use (78 percent), with smaller portions of agriculture (6.2 percent), urban (9.7 percent), and water (5.5 percent) land uses. FB Associates (2021) completed a land use assessment by municipality, analyzing current land use and changes in the watershed since 1997. Their land use analysis used the 2013 City of Auburn land cover (updated in 2018) and the 2001 Maine Land Cover Database as a baseline, and manually updated the baseline data to determine the 2010 and 2020 land use using a detailed assessment of satellite imagery.

The FB Associates analysis is summarized in **Table 1-2** and **Figure 1-2**; CDM Smith did not independently verify these results, but the overall patterns in land use are consistent with the land use calculations in the previous watershed management plan (CEI, 2013). However, the FB Associates land use analysis omitted the 148-acre area described above; therefore, CDM Smith added this area to the FB Associates watershed area in Auburn and recalculated the land use change by year. This analysis found that land use in the watershed was largely unchanged since 1997, with little added development – overall, an increase of 181 acres of urban land, or about 2 percent of the total Lake Auburn watershed. Most of the development occurred in Turner in the Upper Watershed, with forest area converted to urban land uses (generally residential). Notable changes include:

- Additional development in Turner, including a residential development to the west of Little Wilson Pond, additional residential development to the southwest of Little Wilson Pond, and development to the east of Mud Pond
- A conversion of row crops to pastureland in Minot and Turner, which could change the nutrient export potential from these land uses

Additional town-by-town land use maps are in Appendix 3 of FB Associates (2021).

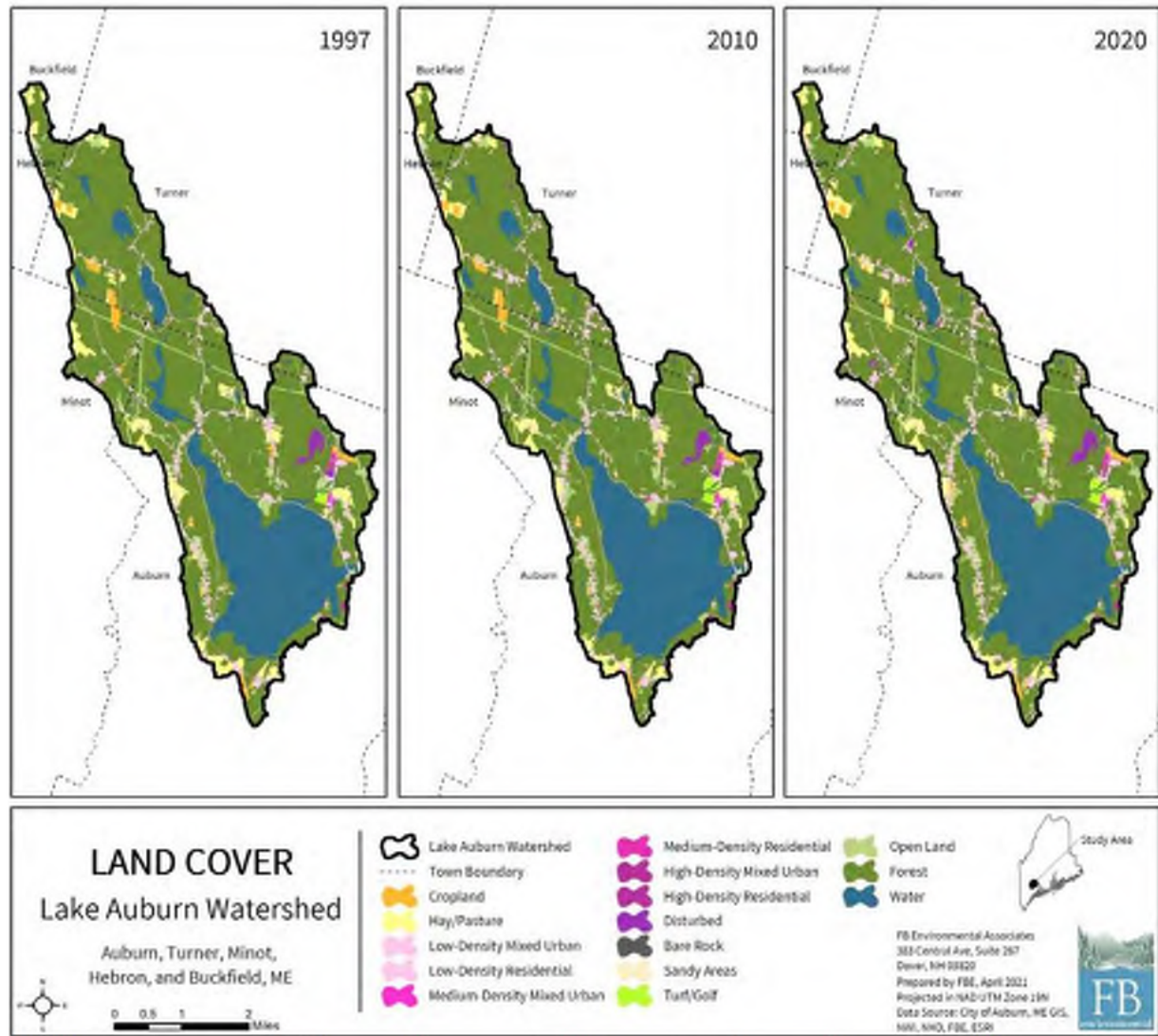


Figure 1-2
Land Cover in the Lake Auburn Watershed
Reproduced from Figure 2-2 in FB Associates (2021)

Table 1-2 Land Use Analysis by City/Town Comparing 1997, 2010, and 2020

Year	Land Use Category	Auburn	Turner	Minot	Hebron	Buckfield
1997	Agriculture	358.5	145.4	85.1	6	49.6
	Forest	4,521	2,112.5	740.1	153	105.3
	Urban	696.2	123.6	53.5	23.7	3.2
	Water/Wetland	2,488.1	232.1	7.5	2.2	
2010	Agriculture	319.2	130.1	76.2	6	49.9
	Forest	4,510.7	2,042	734.8	151.3	104.9
	Urban	745.8	209.3	67.7	25.4	3.2
	Water/Wetland	2,488.1	232.1	7.5	2.2	
2020	Agriculture	324.6	143	74.8	6	49.9
	Forest	4,488.5	2,024	727.9	151.3	104.9
	Urban	762.5	214.4	76	25.4	3.2
	Water/Wetland	2,488.1	232.1	7.5	2.2	
1997 - 2020	Agriculture	-33.9	-2.4	-10.3	0	0.3
	Forest	-32.5	-88.5	-12.2	-1.7	-0.4
	Urban	66.3	90.8	22.5	1.7	0
	Water/Wetland	0	0	0	0	0

Note: Modified from Table 2-2 in FB Associates (2021) to include the additional 148 acres contained in the current Lake Auburn Watershed Overlay District. Positive areas represent an increase and negative areas a decrease from 1997.

1.2.2 Point Sources and Wastewater Disposal

There are no known point sources within the Lake Auburn watershed. Most of the Lake Auburn watershed is unsewered, with properties served by on-site septic systems. Properly functioning septic systems contribute a nutrient load and failing septic systems can additionally contribute high levels of bacteria to surrounding waterbodies. Phosphorus is typically adsorbed to sediment in the shallow groundwater, so phosphorus loads from septic systems to surface waterbodies are typically limited to a small distance from the leach field. Conventionally, phosphorus contributions from properly functioning septic systems are more likely to occur from systems located within 300 feet of a waterbody (either a tributary stream or Lake Auburn), though in some geologic settings, septic systems in use for many decades can contribute nutrients from farther away. Robertson et al. (1998) completed a field investigation of ten groundwater plumes from septic systems in Ontario, Canada, evaluating the fate and transport of phosphorus in shallow groundwater for a spectrum of geologic settings. This study found that the extent of phosphorus attributable to septic systems was greatest in coarse, calcareous sand. Phosphorus was least mobile in fine-grained, non-calcareous sediments. Coarse grained sediments have a smaller surface area relative to volume when compared with finer-grained sediments, reducing the adsorption capacity, and the elevated calcium carbonate composition of calcareous sediment results in increased pH. However, a follow-up study (Robertson et al., 2019) that expanded this assessment to 24 septic systems found that significant phosphorus reduction (69 percent) occurs even in coarse-grained, calcareous settings. Failing septic systems pose a greater risk of elevated nutrient and bacteria loading to Lake Auburn and its tributaries, and the impacts of such systems may extend far beyond the 300-foot buffer zone.

Septic system locations within the Lake Auburn watershed were determined for each city and town. AWD maintains an inventory of septic systems by address in Auburn with the year installed and year upgraded (if applicable). No data on septic systems were available for the towns of Hebron, Buckfield, Turner, and Minot; for these municipalities, septic tank locations were approximated to unique street addresses from the Maine E911 Addresses Feature (MaineGIS, 2021). For all septic systems, the leach field was assumed to be located adjacent to the building. Counts of all septic systems and those within 300 feet of Lake Auburn and nearby waterbodies within the Lake Auburn watershed are shown in **Figure 1-3** and **Table 1-3**. No data are available on failing septic systems within the Lake Auburn watershed.

Table 1-3 Inventory of Septic Systems Within the Lake Auburn Watershed

Town	Count	<300 ft to Waterbody
Hebron	14	0
Buckfield	2	0
Turner	193	29
Minot	55	1
Auburn	194	25
Totals	458	55

Since the City of Auburn maintains detailed records of the location and installation/upgrade date of septic systems within the city limits, an assessment was completed to determine the likely age of each system within the City of Auburn. These are shown graphically in **Figure 1-4** and are enumerated in **Table 1-4**. There are 13 septic systems within 300 feet of Lake Auburn, and an additional 12 septic systems within 300 feet of another waterbody or tributary to Lake Auburn.

Table 1-4 Date of Construction or Upgrade for Septic Tanks in the City of Auburn

Most Recent Year Built/Upgraded	Count	<300ft to Lake Auburn	<300 ft to another waterbody
1970-1979	23	2	0
1980-1989	32	2	2
1990-1999	53	4	2
2000-2009	61	4	8
2010-2019	16	1	0
> 2020	9	0	0
Totals	194	13	12

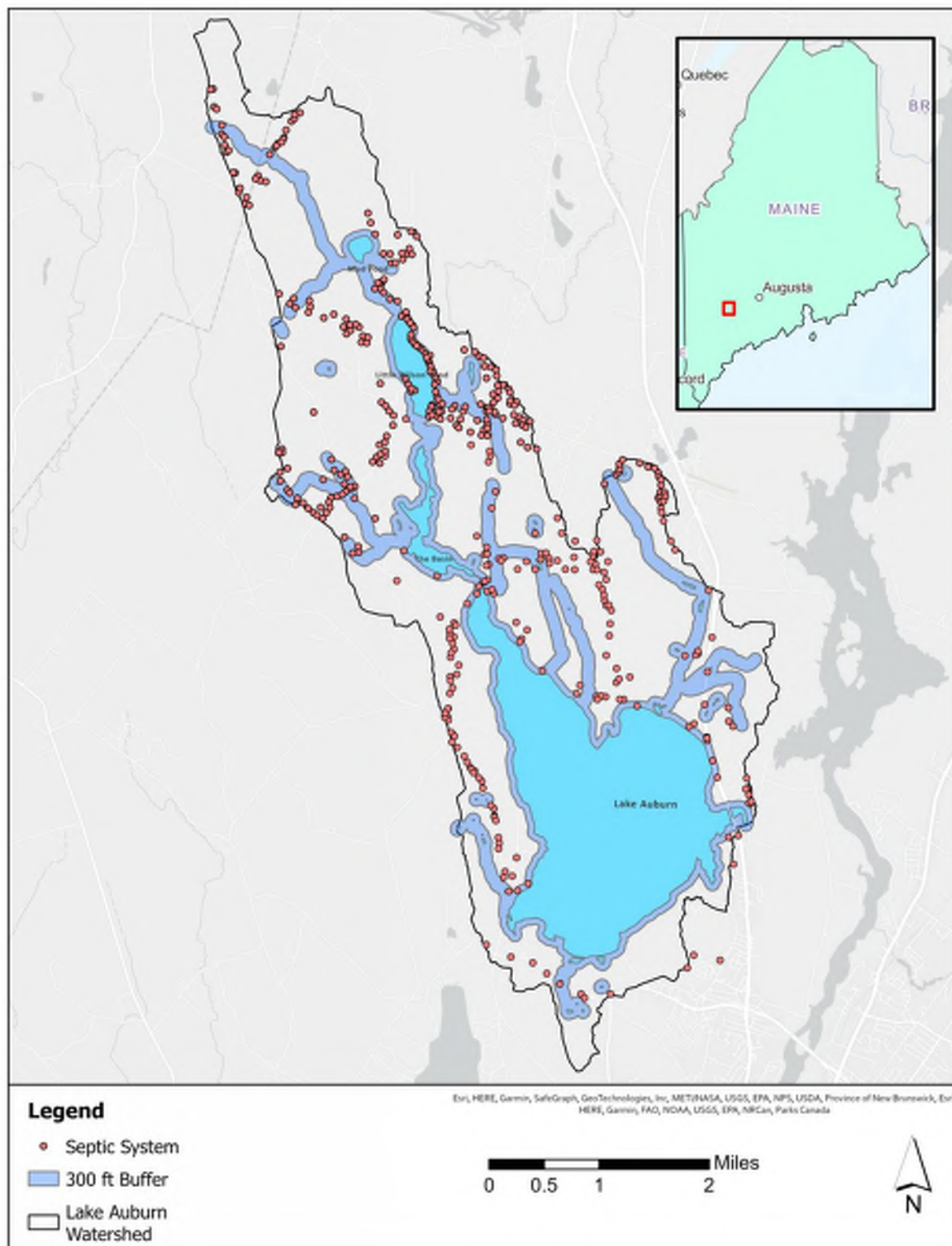


Figure 1-3
Septic Systems Within the Lake Auburn Watershed

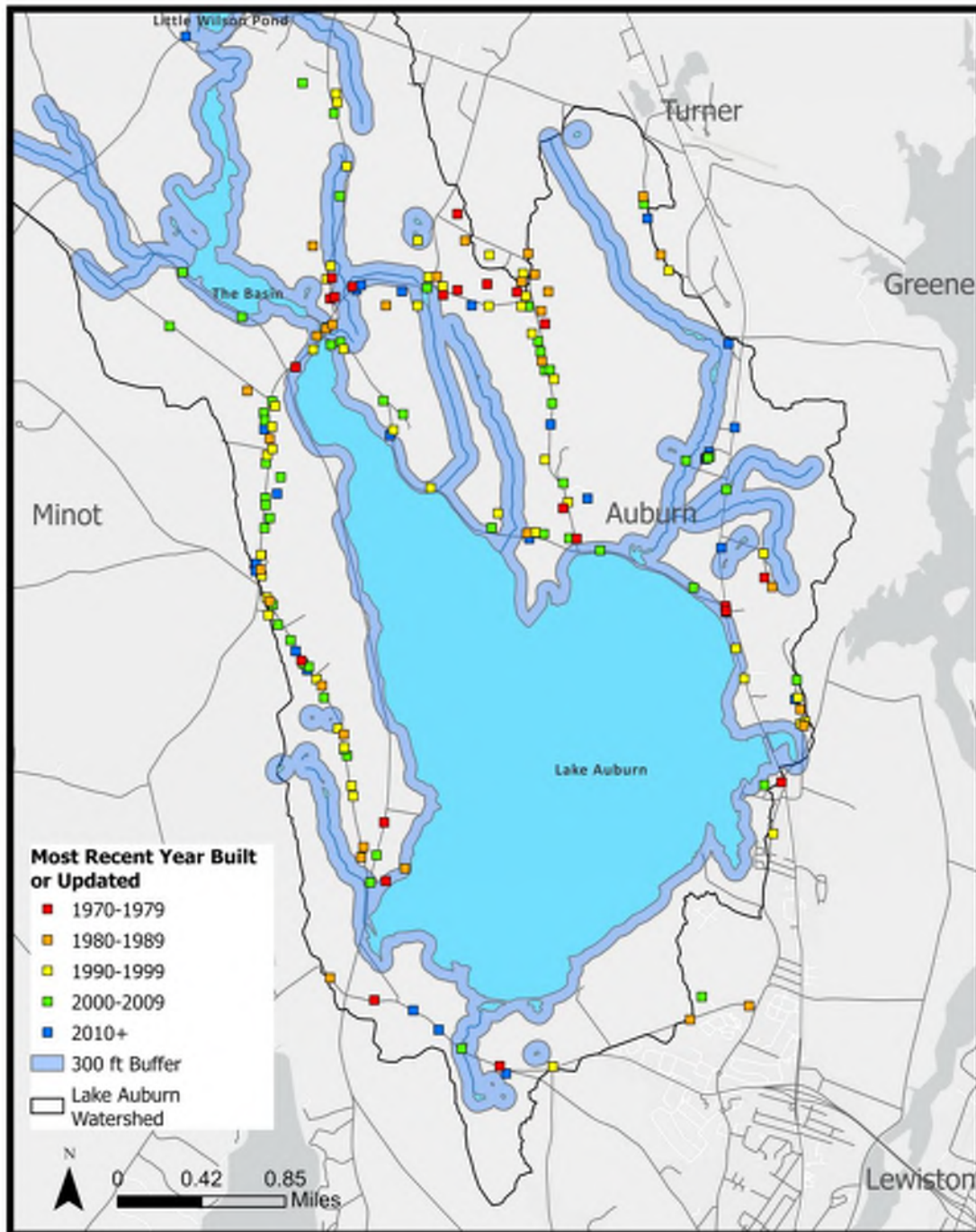


Figure 1-4
Septic Systems in the City of Auburn in the Lake Auburn Watershed Identified by the Most Recent Year Built or Upgraded

1.3 BMPs Installed and Actions Taken Since Previous Watershed-based Plan

Between 2010 and 2014, several studies were completed with recommendations on improving the water quality of Lake Auburn. LAWPC, AWD, and LWD have installed or partnered with surrounding municipalities, the Maine Department of Transportation (MDOT), and landowners to implement many of these recommendations; recommendations implemented since 2010 are listed in **Table 1-5**.

Table 1-5 BMPs Implemented Since Last Watershed Plan

Issue / Recommendation	Steps Taken
Address direct stormwater discharges on Route 4 and within other areas of the watershed	5 vortex separators were installed in catch basins along Route 4 that drain to the lake. Units are maintained twice a year.
Restrictions on future residential and agricultural development	- Several LAWPC land purchases - City of Auburn imposes restrictions on development through the Phosphorus Control Ordinance, Lake Auburn Watershed Overlay District, and the Shoreland Overlay District zoning regulations
Wildlife management	Contract with USDA Wildlife Services for a gull management program and beaver removal
Work with city and town DPWs to address drainage issues in watershed	- Coordinated with Turner (2016/2017) and Minot DPW (2020) to replace culverts - Ongoing coordination with Auburn DPW and MDOT about drainage projects.
Set aside funds for maintenance of watershed lands	Added a Source Protection line item in LAWPC budget
Increase vegetated buffers around the lake: replace Route 4 paved turnaround with vegetation	MDOT removed the Route 4 paved turnaround and replaced it with vegetation in 2022. The project also includes traffic changes to the Route 4 boat launch.
Public education	Recommendations completed: enhance website, develop and distribute educational materials, school education program, and residential vegetated buffer education program.
Continue with invasive species controls	Courtesy Boat Inspection funding through MDEP
Begin planning for an algaecide application for use as a contingency plan if turbidity levels rise in 2013 or beyond while implementing measures to reverse the degradation of the lake water quality.	Algaecide permit was secured in 2013 for a 5-year term and renewed in 2018 prior to the application on 9/11/2018.
Spring Road erosion	BMPs installed: armored swales, plunge pools, and culvert replacements for most culverts along Spring Road. Four historical, granite box culverts were not addressed.
Holbrook Road erosion	Minot DPW replaced a culvert on Simeon Rd in 2020. LAWPC removed a failed culvert and placed riprap to stabilize stream bed and banks on the old Lunn Road in 2019.
Little Wilson Pond Road erosion	Culverts replaced under 319 grant (2016/2017).

Issue / Recommendation	Steps Taken
Route 4 drainage	▪ Culvert for First Brook: removed sediment, stabilized banks, replaced pipe; Completed in 2021 ▪ Culvert near church: repaired side slopes of drainage channel and armored outfall
Townsend Brook	Gammon's detention pond repaired to manage flow with reinforced outlet; purchased the property on Townsend Brook Road in 2019 that previously had livestock that was an issue.

In addition to these improvements, several in-lake management measures were implemented. An algal bloom (*Dolichospermum*) occurred in 2018 that caused turbidity at the intake to rise rapidly. In response to this event, AWD/LWD decided to apply a copper sulfate algaecide to 300 acres around the intake pipe at a target dose of 0.075 milligrams per liter (mg/L). Turbidity decreased following the algaecide treatment.

Following the algaecide treatment, AWD/LWD followed up with a low-dose alum treatment in 2019. The target dose was 2 mg/L across 1,250 acres, equivalent to a dose of 18 grams per square meter (g/m²). The primary goal was to reduce water column phosphorus, with a secondary goal of sediment inactivation. The 18 g/m² dose is estimated to be approximately half of the dose projected to inactivate all of the sediment phosphorus in Lake Auburn (WRS, 2019).

Section 2

Identification of the Causes and Sources of the NPS Threat

2.1 Introduction

The causes and sources of non-point source (NPS) threat were identified several ways:

- Field inspection of the watershed conducted in September 2022
- Review of changes in land use patterns (**Section 1.2.1**)
- Review of satellite images
- Review of water quality data for both the tributaries and the lake
- Discussion of water quality concerns and best management practice (BMP) implementation with Auburn Water District (AWD) and Lewiston Water Division (LWD) staff

Lake Auburn is included on the most recent NPS Priority Watersheds list and list of lakes Most at Risk from New Development (MAR).

2.2 Summary of Watershed Survey

To support the development of Lake Auburn's Lake Watershed-based Protection Plan, CDM Smith and AWD/LWD staff completed a watershed survey in September 2022 to identify areas of concern that could be contributing phosphorus, sediment, and other contaminants to the lake. The watershed survey followed the Maine Department of Environmental Protection (MDEP) guidance described in *Volunteer Lake Watershed Surveys: How to Conduct a Nonpoint Source Phosphorus Survey* (MDEP, 2011). **Figure 2-1** shows the location of each identified area of concern, colored by the NPS site category, and **Figure 2-2** shows the distribution of categories across the study area. A detailed discussion of each site is contained in **Appendix B**. The majority of the water quality issues identified were on state or city/town roads (55 percent), with smaller percentage of identified water quality issues on private property. The 2022 watershed survey was limited to areas accessible by state, city, or town roads and private properties targeted by AWD/LWD staff. The survey did not enter private properties within the watersheds beyond those noted in **Appendix B**; additional water quality improvements may be realized through actions taken on private properties not surveyed in 2022.

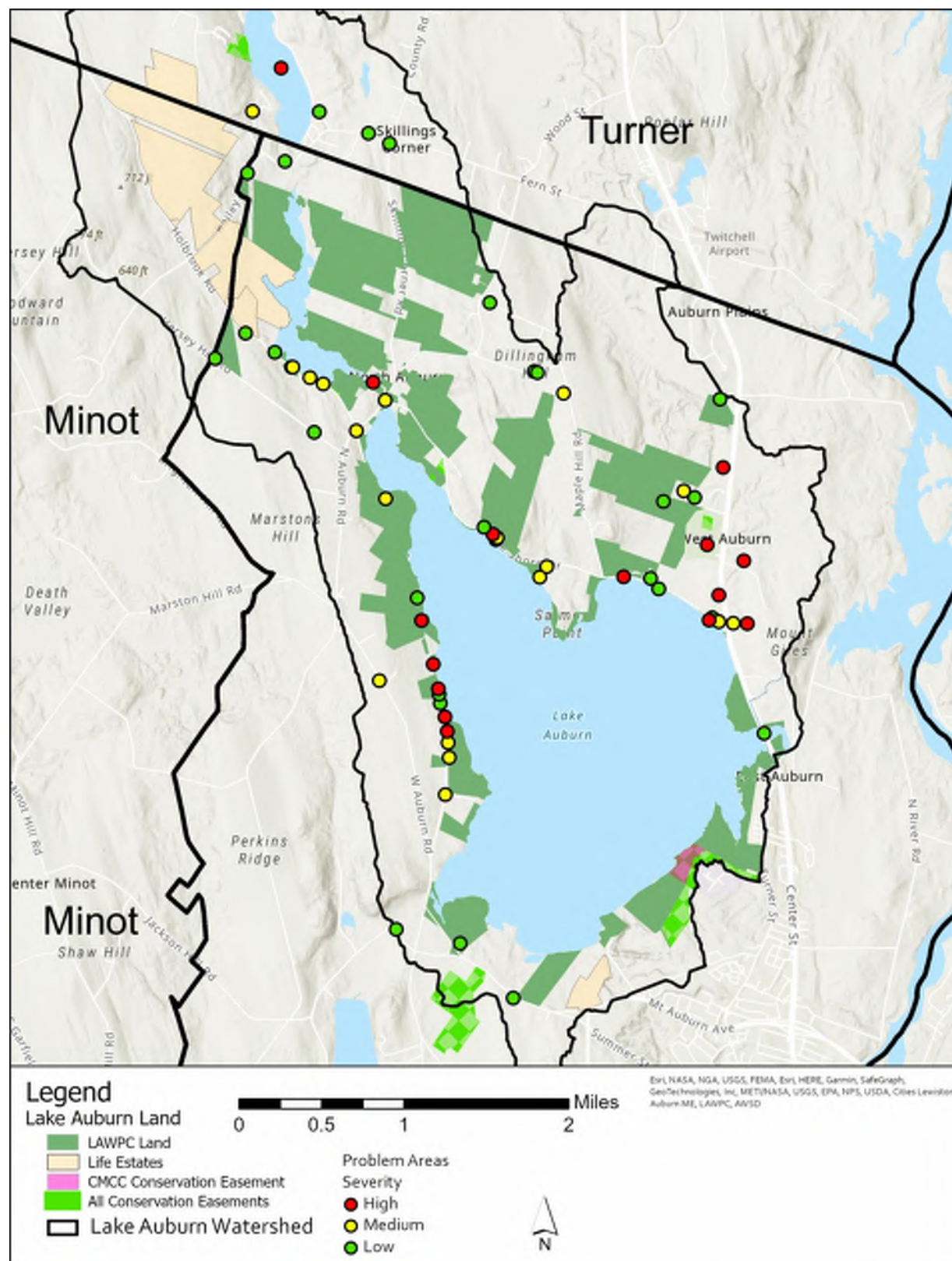


Figure 2-1
Problem Areas Identified in the 2022 Watershed Survey

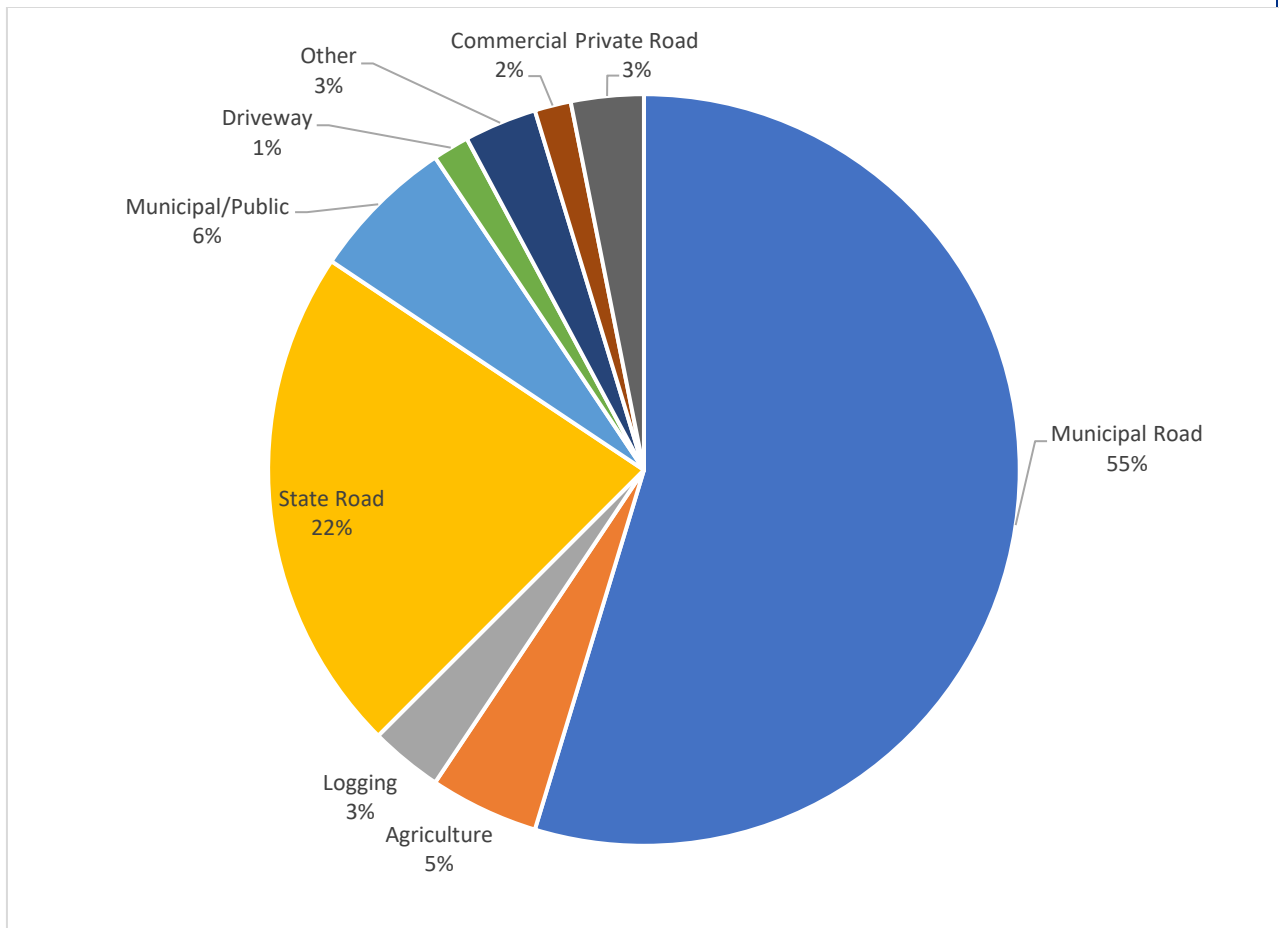


Figure 2-2
Distribution of NPS Categories of Sites with Water Quality Issues Observed in the 2022 Watershed Survey

The relative water quality impact of each NPS site was assessed during the watershed survey. The impacts were classified as:

- Low - either minimal erosion, not immediately proximate to Lake Auburn, a relatively small area, or low potential for nutrient pollution
- Moderate - minimal erosion but proximate to Lake Auburn, or greater erosion or potential nutrient sources but not proximate to Lake Auburn
- High - significant erosion, a large area of development or forestry, and/or immediately adjacent to Lake Auburn.

The relative water quality impact of each site observed during the 2022 watershed survey is shown in **Figure 2-3**. Details and photographs of water quality issues associated with each site can be found in **Appendix B**.

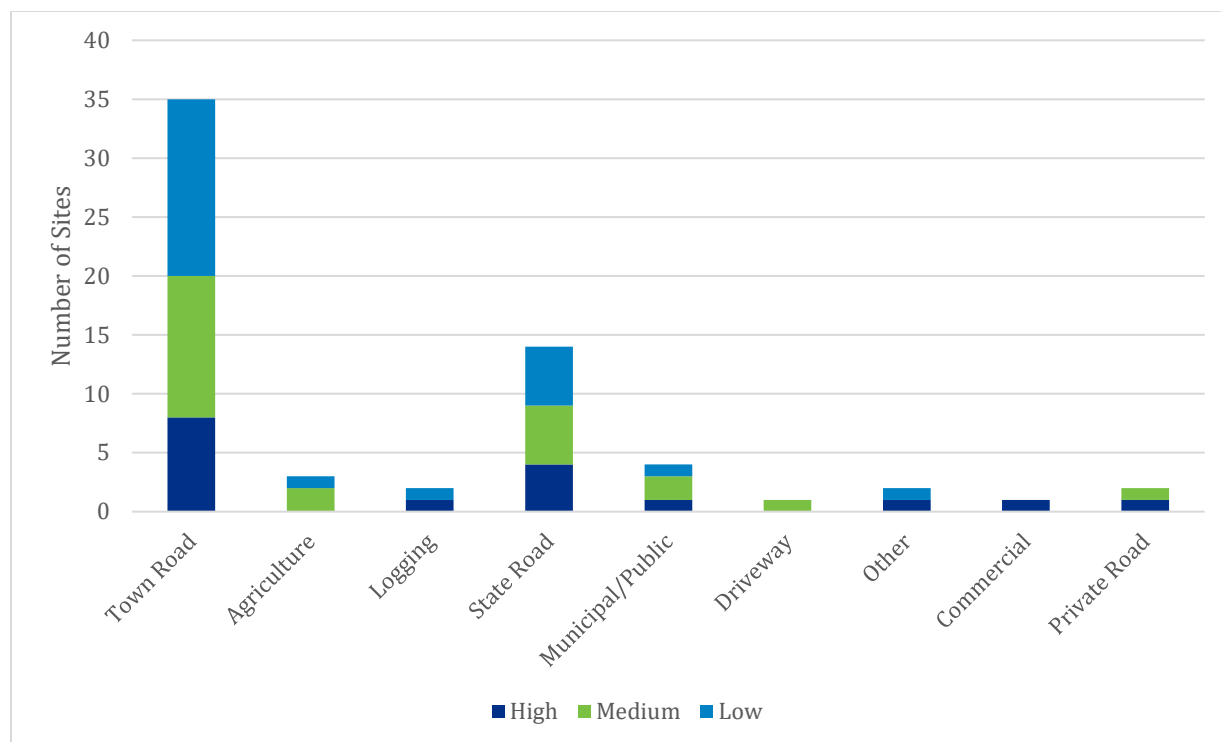


Figure 2-3
Land Use and Relative Water Quality Impact of Problem Areas in the 2022 Watershed Survey

2.3 Data Summary and Objectives

Water quality data are collected in Lake Auburn at the intake (temperature and turbidity) and at up to 11 sites within the lake and 15 in its watershed (**Figures 2-4** and **2-5**); Lake Auburn's bathymetry is also included in **Figure 2-5**. The water quality data collected within the lake were analyzed to understand key drivers of periodic degraded water quality with respect to nutrients, algae, and turbidity increases that may threaten AWD/LWD's filtration avoidance waiver.

This assessment represents a continuation and update of the analysis completed in CDM Smith's 2013 *Diagnostic Study of the Lake and its Watershed* with a focus on changes in trends and water quality indicators since the data were last evaluated and an assessment of any observed water quality improvements associated with BMPs implemented since the previous study (see **Section 1.3** for a summary of these actions).

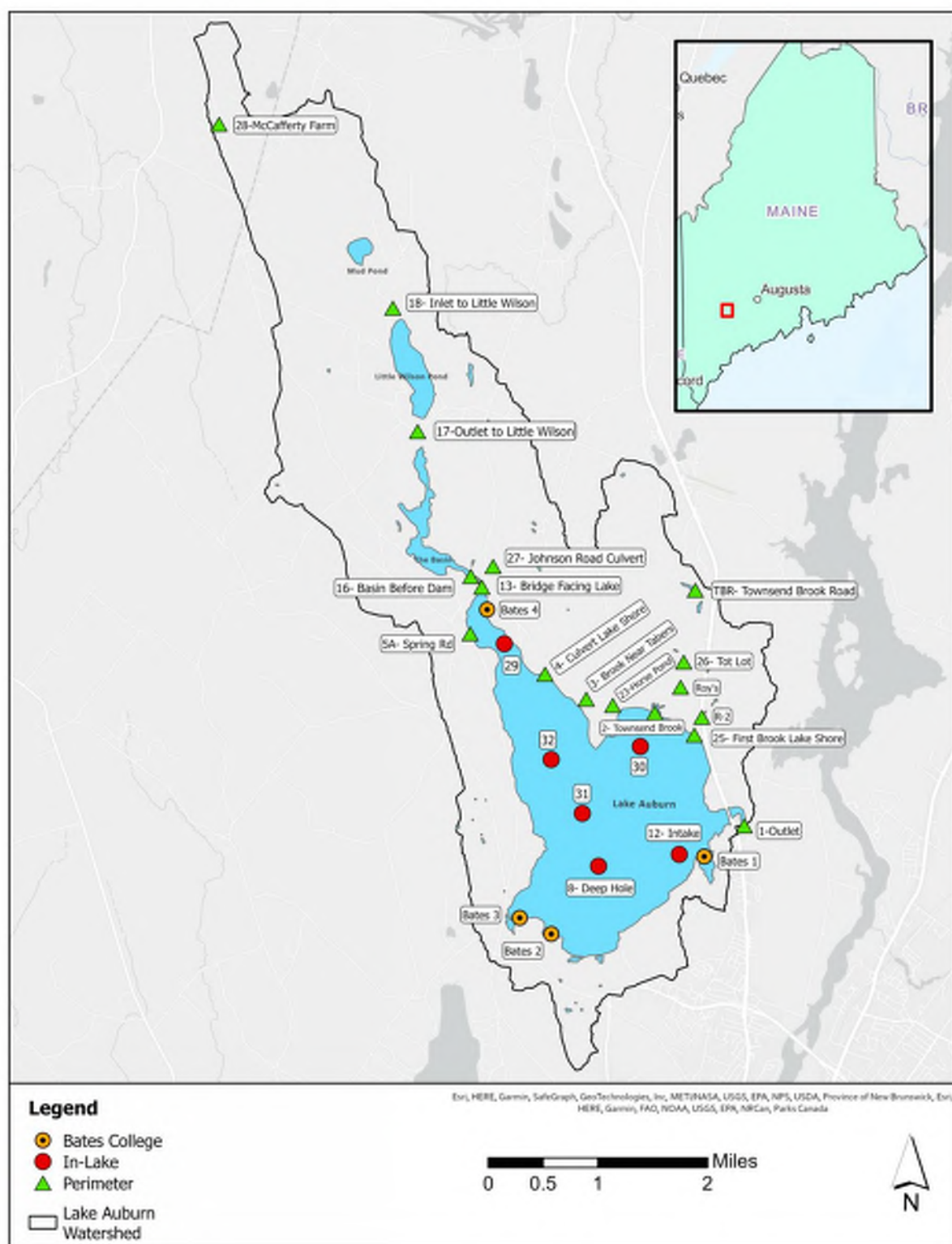


Figure 2-4
Lake Auburn Watershed Monitoring Locations

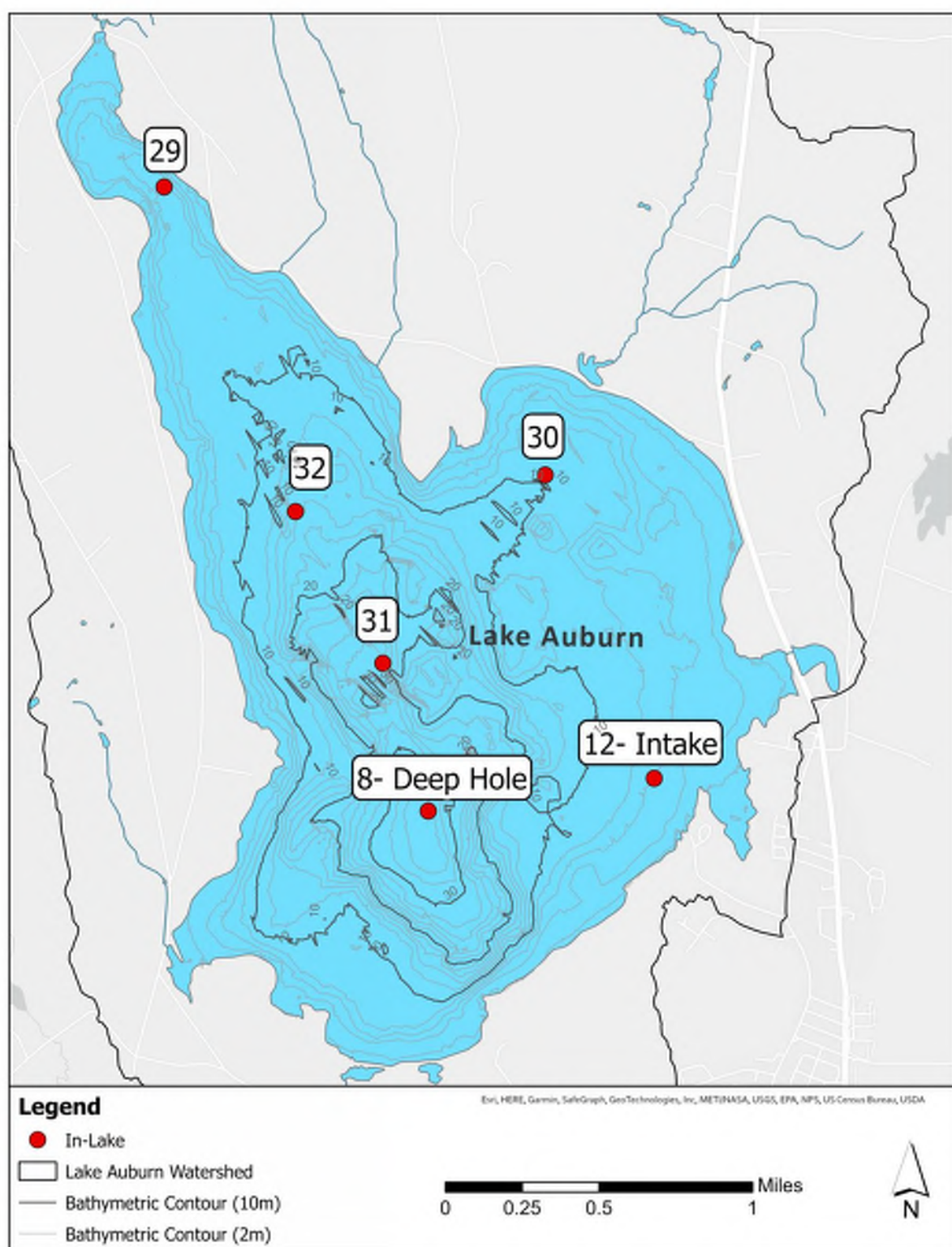


Figure 2-5
Lake Auburn In-lake Monitoring Locations

2.4 Precipitation

Rainfall generally correlates to the load of phosphorus delivered from watershed. Intense storms increase the load by creating high velocity in the tributaries that can cause bed scour; this sediment transported into the lake during intense storms is also a source of phosphorus.

Meteorological data were obtained from the National Center for Environmental Information (NCEI), part of the National Oceanic and Atmospheric Administration (NOAA). The Poland, ME gage (COOP 176856) was selected for use in this analysis because it is the closest station to Lake Auburn and was used for the 2013 analysis. The 1991-2020 U.S. annual Climate Normal for Lewiston, ME is 45.18 inches. This was compared to the annual precipitation totals between 2010 and 2021 (**Figure 2-6**) to understand inter-annual trends in precipitation. This indicates that 2010 through 2012, 2014, 2019, and 2020 were above average, 2017 and 2021 about average, and 2013 and 2015 below average.

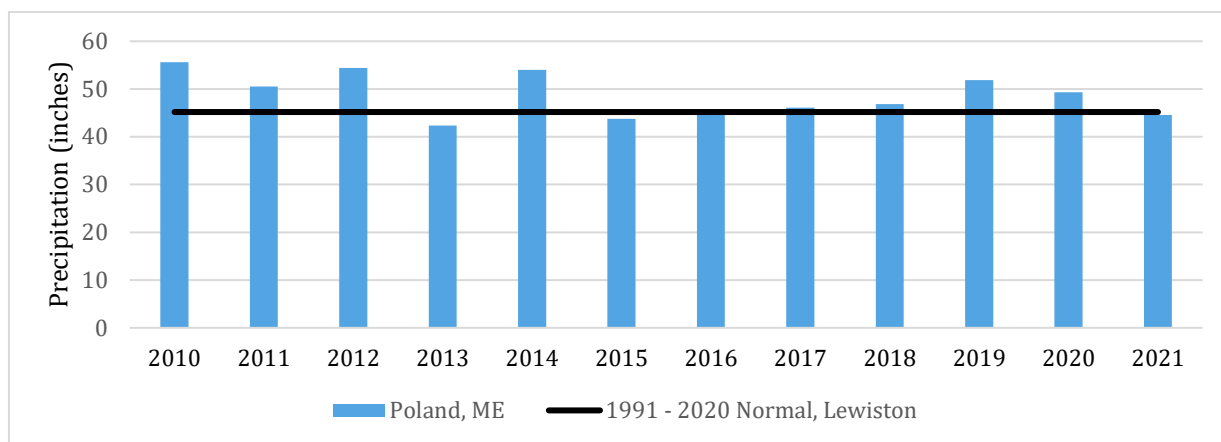


Figure 2-6
Annual Precipitation Totals Compared to the 2000-2021 Average Precipitation at the NWS COOP Station 176856 in Poland, ME and the U.S. 1991-2020 Climate Normal for Lewiston, ME.

The precipitation data were further analyzed to understand monthly trends and the frequency of large storms. **Figure 2-7** shows a cumulative precipitation plot by year compared against the monthly precipitation normal (Lewiston, ME). This plot shows the time periods where large storms occur and whether the cumulative precipitation in any given year was above or below normal. The intensity, duration, and frequency of major storms were evaluated against NOAA's Atlas 14 for Lewiston, ME (**Table 2-1**), which describes the annual probability of a given storm depth at each duration. Notable large storms include:

- June 2012, where 7.51 inches of precipitation fell across 7 days which included 4.48 inches in 24 hours, a 24-hour, 8-year event.
- A wet summer 2014, where three large storms occurred during the summer:
 - July 3-5: 3.01 inches with a maximum 24-hour precipitation of 1.9 inches

- July 28-29: 3.25 inches with a maximum 24-hour precipitation of 1.81 inches, a 1-year, 48-hour storm
- August 14: 4.08 inches, a 5-year, 24-hour storm
- September 2015, where 6.25 inches fell in 48 hours, with a maximum of 4.08 inches in 24 hours (a 22-year, 48-hour event and a 5-year, 24-hour event).
- October 2016, where 4.78 inches fell in 72 hours, with a maximum 24-hour precipitation of 3.75 inches (a 4-year, 24-hour and 72-hour event).
- A wet October 2017, with 7.38 inches between October 27 and October 31 (about a 10-year, 7-day event, with about a 2-year, 24-hour event on October 30).
- A wet July 2021, with a total of 11.42 inches within the month (about a 5-year, 30-day event). Within July 2021, there were three large events (July 1 – July 5, 4.59 inches; July 8 – July 10, 2.63 inches; and July 18 – July 22, 2.39 inches).
- A 2.63-inch storm on July 29, 2022, about a 1-year, 24-hour event, and a 2.83-inch storm on October 14, 2022, with 1.58 inches in 24 hours (about a 1-year, 48-hour event)

Table 2-1 Precipitation Intensity, Duration, and Frequency Statistics for Auburn, ME (NOAA Atlas 14)

By Duration for ARI (years):	1	2	5	10	25	50	100	200	500	1000
5-min:	0.291	0.354	0.457	0.542	0.659	0.747	0.84	0.948	1.11	1.24
10-min:	0.412	0.501	0.647	0.768	0.934	1.06	1.19	1.34	1.57	1.75
15-min:	0.485	0.589	0.76	0.903	1.1	1.25	1.4	1.58	1.84	2.06
30-min:	0.65	0.79	1.02	1.21	1.47	1.67	1.88	2.12	2.47	2.77
60-min:	0.815	0.991	1.28	1.52	1.85	2.1	2.36	2.66	3.1	3.47
2-hr:	1.09	1.31	1.67	1.97	2.38	2.69	3.02	3.4	3.95	4.42
3-hr:	1.28	1.54	1.95	2.29	2.76	3.11	3.48	3.92	4.56	5.09
6-hr:	1.67	1.99	2.51	2.94	3.54	3.99	4.46	5.02	5.83	6.51
12-hr:	2.11	2.51	3.18	3.74	4.5	5.07	5.67	6.38	7.41	8.27
24-hr:	2.54	3.04	3.87	4.55	5.5	6.2	6.95	7.82	9.11	10.2
2-day:	2.94	3.54	4.51	5.32	6.43	7.25	8.14	9.17	10.7	12
3-day:	3.23	3.87	4.91	5.78	6.97	7.86	8.81	9.92	11.6	12.9
4-day:	3.48	4.14	5.23	6.14	7.38	8.31	9.3	10.4	12.1	13.6
7-day:	4.12	4.84	6.02	7	8.34	9.35	10.4	11.6	13.3	14.8
10-day:	4.73	5.49	6.73	7.76	9.18	10.2	11.4	12.6	14.3	15.7
20-day:	6.63	7.48	8.87	10	11.6	12.8	14.1	15.3	17	18.4
30-day:	8.23	9.16	10.7	12	13.7	15.1	16.4	17.7	19.4	20.7
45-day:	10.2	11.3	13	14.4	16.4	17.9	19.4	20.9	22.6	23.9
60-day:	11.9	13.1	15	16.6	18.7	20.4	22.1	23.6	25.5	26.8

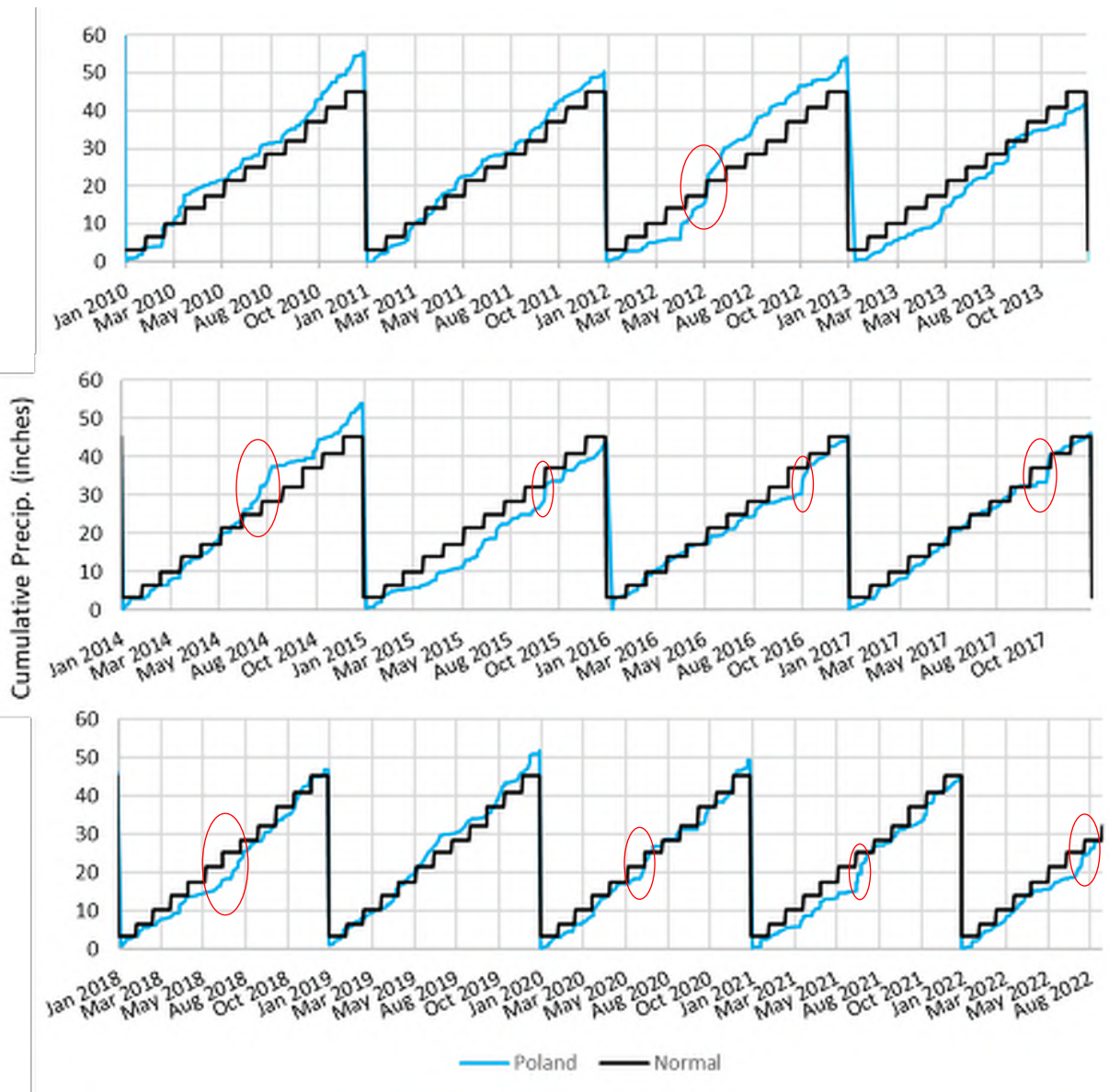


Figure 2-7
Cumulative Precipitation by Year of NWS COOP Station 176856 in Poland, ME and U.S 1991-2020 Climate Normal for Lewiston, ME.

Large storms are an important contributing factor to periods of poor water quality in Lake Auburn as they can deliver a substantial external phosphorus load to the lake in a short period of time. For instance, a significant contributor to the fish kill observed in 2012 was the exceptionally wet June of 2012, which both added additional phosphorus to the lake at the beginning of the summer clearwater period where phosphorus is low and added organic material to the lake that increased the hypolimnetic oxygen demand (CDM Smith and WRS, 2013). The late fall algal blooms in 2021 and 2022 may also have at least a partial external load source (noting that in 2022 internal loading likely also contributed to increased productivity, see **Section 2.4**).

2.3 Watershed Monitoring Data

Watershed monitoring data collected between 2005 and 2022 were evaluated to understand the external nutrient, sediment, and bacteria loads and their relationships to raw water quality.

Tributary monitoring is completed during wet and dry weather conditions at locations around the perimeter of Lake Auburn and its watershed (collectively called “perimeter” sampling).

2.3.1 Overview of Watershed Monitoring Data

The watershed monitoring data were evaluated using summary statistics presented in boxplots¹ showing the median and range for phosphorus (total and orthophosphate), turbidity, bacteria (*E. coli*), and conductivity at each location, 2005 through 2022 (**Figures 2-8 through 2-12**). These plots were used to evaluate the relative concentration at locations around the perimeter of Lake Auburn and at locations in the watershed, and to identify potential areas of concern for continued or additional field investigation or implementation of watershed BMPs. Additional plots for all monitored parameters are in **Appendix C**.

Phosphorus

Total phosphorus data indicate that concentrations at most stations are below 50 micrograms per liter ($\mu\text{g/L}$), and are often below 20 $\mu\text{g/L}$. Orthophosphate is generally low: non-detect (at a typical detection limit of 1 $\mu\text{g/L}$) to below 10 $\mu\text{g/L}$. Primary exceptions are found at:

- Site 25 (First Brook Lake Shore): a relatively small drainage area in the Blanchard Pond watershed that enters Lake Auburn near the intersection of Route 4 and Lake Shore Drive. Agricultural land use in the headwaters of this brook and sediment erosion are potential sources of phosphorus. Median total phosphorus concentrations range between 25 and 50 $\mu\text{g/L}$, with concentrations above 100 $\mu\text{g/L}$. There are two additional sites upstream: R-2, with median concentrations above 50 $\mu\text{g/L}$ and many measurements above 100 $\mu\text{g/L}$, and Blanchard’s Pond, with median concentrations above 100 $\mu\text{g/L}$ and frequent exceedances of 200 $\mu\text{g/L}$. This brook is often dry in July and August (Gundersen, 2020).
- Site 23 (Horse Pond): located on Lake Shore Drive east of Tabers in a small intermittent stream that rarely discharges to Lake Auburn (Gundersen, 2020). This site is characterized by high historical phosphorus concentrations (median between 25 and 50 $\mu\text{g/L}$, and outliers above 100 $\mu\text{g/L}$), especially 2010 and 2011, with high outliers occurring in subsequent years.
- Site 28 (McCafferty Farm): located in the northern portion of the Upper Watershed near a farm with swine, cattle, and firewood. This site has not been monitored since 2012 but recorded relatively high phosphorus concentrations (between 50 and 200 $\mu\text{g/L}$) when it was an active monitoring site.
- Roy’s: located in the Townsend Brook watershed on Pine Acres Golf Course. Previous sampling (especially in 2015) has found high concentrations, occasionally exceeding 100

¹ The boxplot represents the range of data observed in each year. The dark middle line represents the median, the box the 25th and 75th percentiles, and the height of the box the interquartile range. The lines (“whiskers”) represent the range of data within 1.5 times the interquartile range, and the points statistical outliers that fall above or below 1.5 times the interquartile range.

µg/L, but the concentrations were lower in subsequent years and the site has not been monitored since 2019.

- Site 5A (Spring Road): located on the northern end of Whitman Spring Road with relatively high total phosphorus concentrations (50 – 300 µg/L) in 2020. The stream upstream of the culvert at this location was armored with riprap up to North Auburn Road in 2019, with plunge pool and culvert repairs occurring in 2021. These changes are anticipated to mitigate phosphorus levels; these changes should be monitored as additional data are collected.

The two largest discharges to the lake – the upper watershed through the Basin (Sites 16 and 13) and Townsend Brook (Site 2) – are both characterized by relatively low total phosphorus concentrations. Average 2017 through 2022 wet and dry weather total phosphorus concentrations at Site 13 were 12.3 µg/L and 11.6 µg/L, respectively, and at Site 2 (Townsend Brook) were 22.0 and 18.8 µg/L, respectively. However, the data at both of these sites include occasional elevated phosphorus levels, suggesting the potential for elevated watershed loads from these areas and highlighting the importance of watershed controls in the Upper Watershed and Townsend Brook.

Turbidity

Turbidity is used as an indication of erosion within the watershed for this study; total suspended solids (TSS) is only occasionally monitored.

- Turbidity concentrations are relatively low (median below 2 Nephelometric Turbidity Units (NTU)) at most sites in the upper watershed (from north to south, 18, 17, 16, 13). A slight increase in turbidity occurs in recent years with outliers above 5 NTU, especially at the inlet to Little Wilson Pond.
- Higher turbidity concentrations occur at sites coincident with the high phosphorus locations, including Site 25 (First Brook Lake Shore), Site 23 (Horse Pond), Site 28 (McCafferty Farm), and Site 5A (Spring Road).
- Occasional high turbidity (outliers above 5 NTU, and occasionally above 10 NTU) have been recorded at Townsend Brook Sites 2 and 26. The median turbidity is lower at Site 2 (Townsend Brook outlet) than at the upstream Site 26 (Tot Lot/Townsend Brook), suggesting that a reduction in sediment transport from upstream to downstream, but the frequency of high outliers is slightly higher at the downstream Site 2.

Bacteria (*E. coli*)

Bacteria concentrations at all Lake Auburn perimeter sites occasionally exceed the MDEP single sample maximum concentration of 236 colony forming units per 100 milliliters (cfu/100 mL). Areas with more frequent exceedances of water quality criteria occur at both the inlet and outlet to Little Wilson Pond, First Brook Lake Shore (Site 25), Tot Lot (Site 26), and the Johnson Road Culvert (Site 27).

Conductivity

Increases in measured conductivity have been linked to water quality degradation due to increased urbanization (see, e.g., Baker et al., 2019; EPA, 2010). An upward trend in conductivity is apparent at all routinely monitored locations (excluding the infrequently sampled McCafferty Farm, Roy's, and areas on Spring Road). Coupled with the findings of the FB Associates (2021) report (see **Section 1.2**), these data suggest that the increased development in the watershed is having a noticeable impact on water quality.

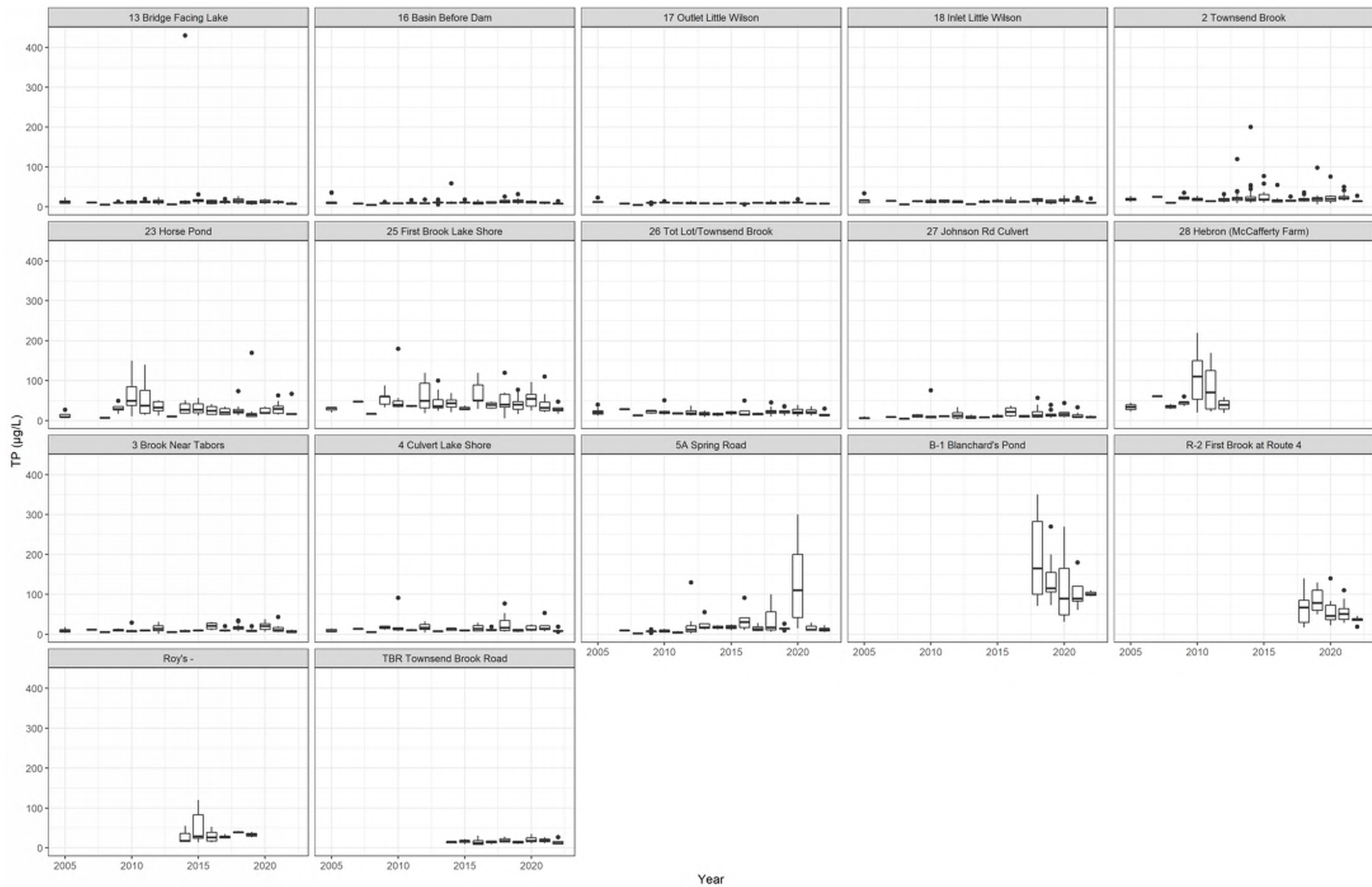


Figure 2-8
Tributary Total Phosphorus Monitoring Data

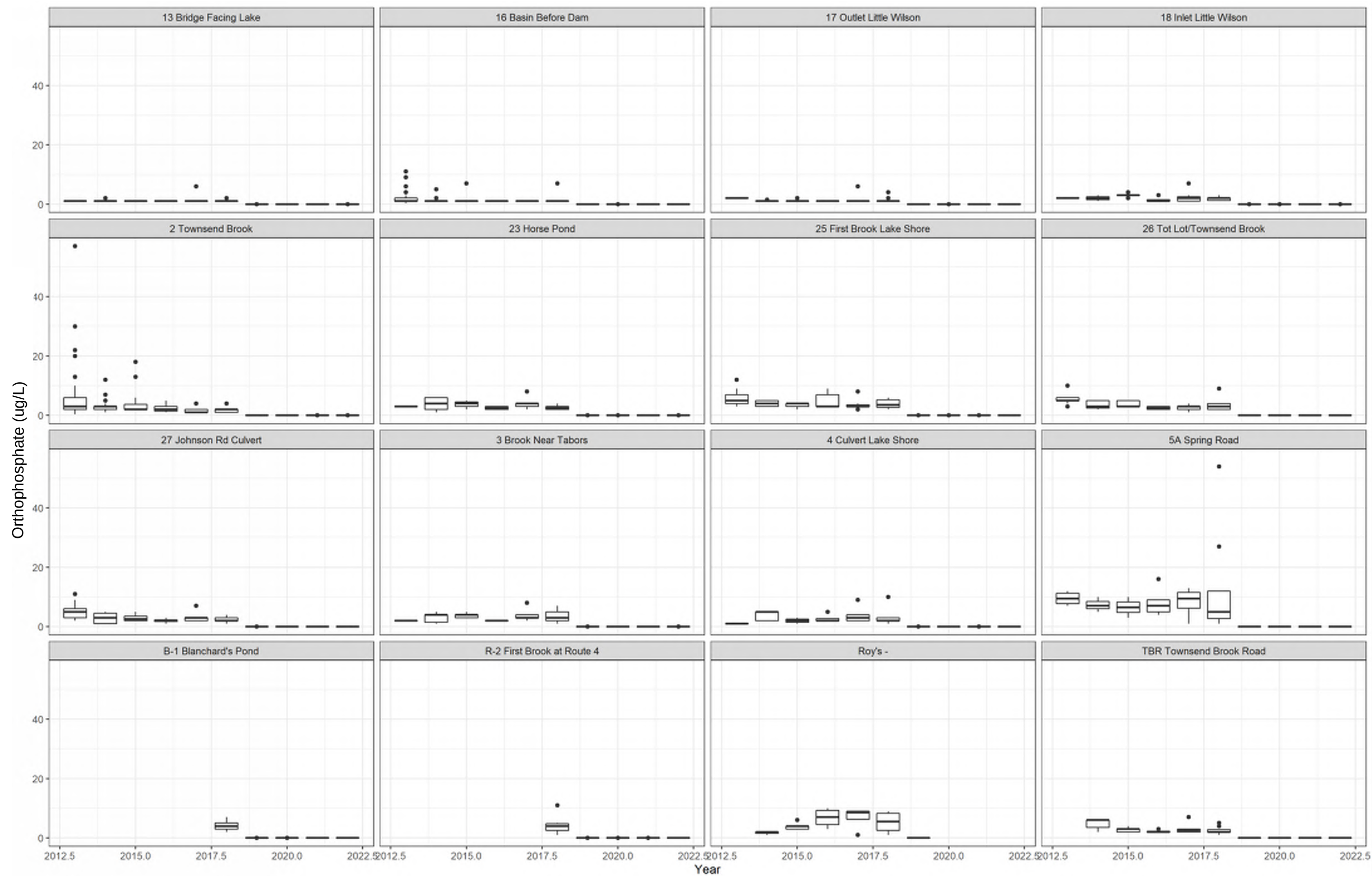


Figure 2-9
Tributary Orthophosphate Monitoring Data

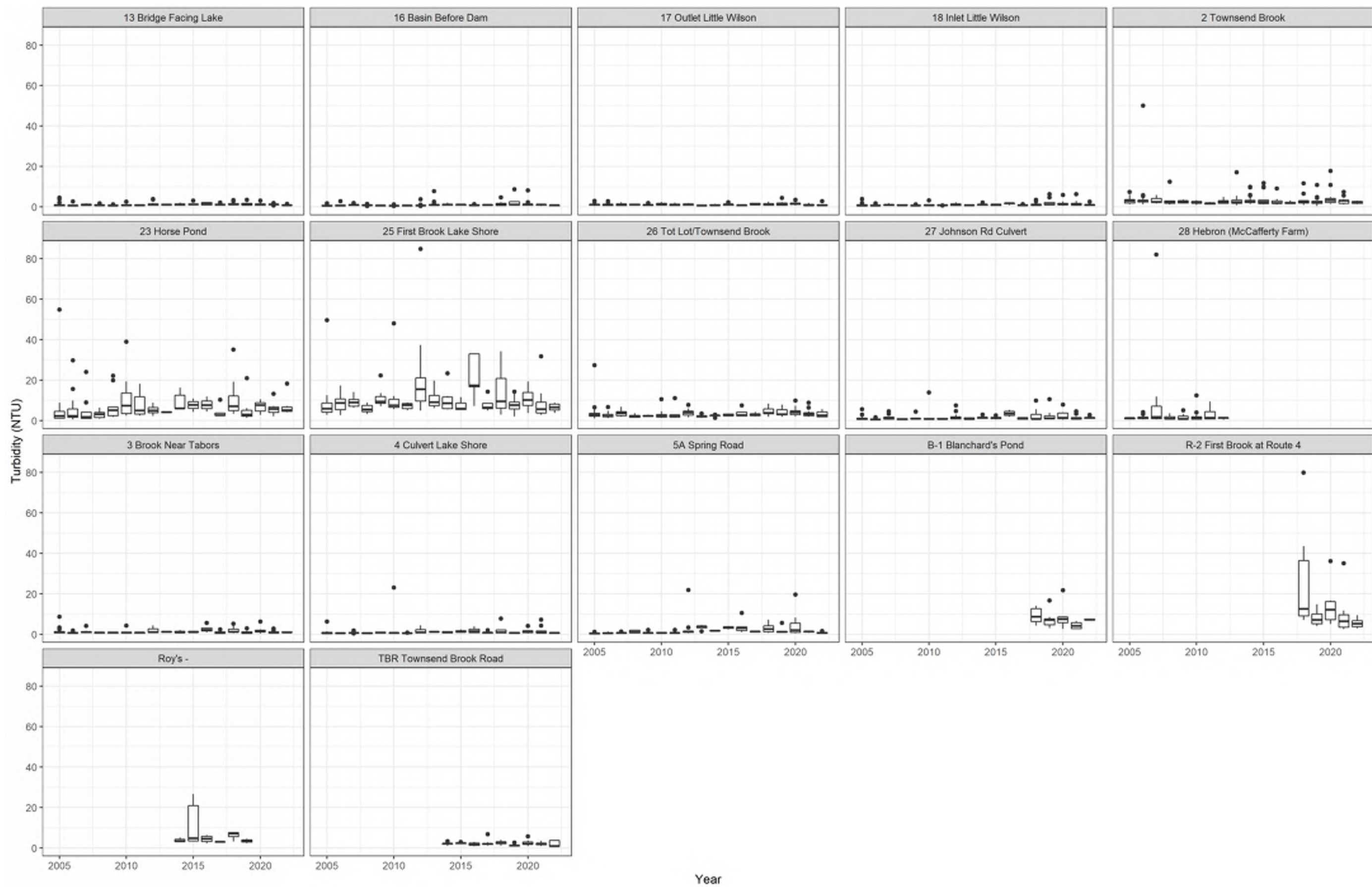


Figure 2-10
Tributary Turbidity Monitoring Data

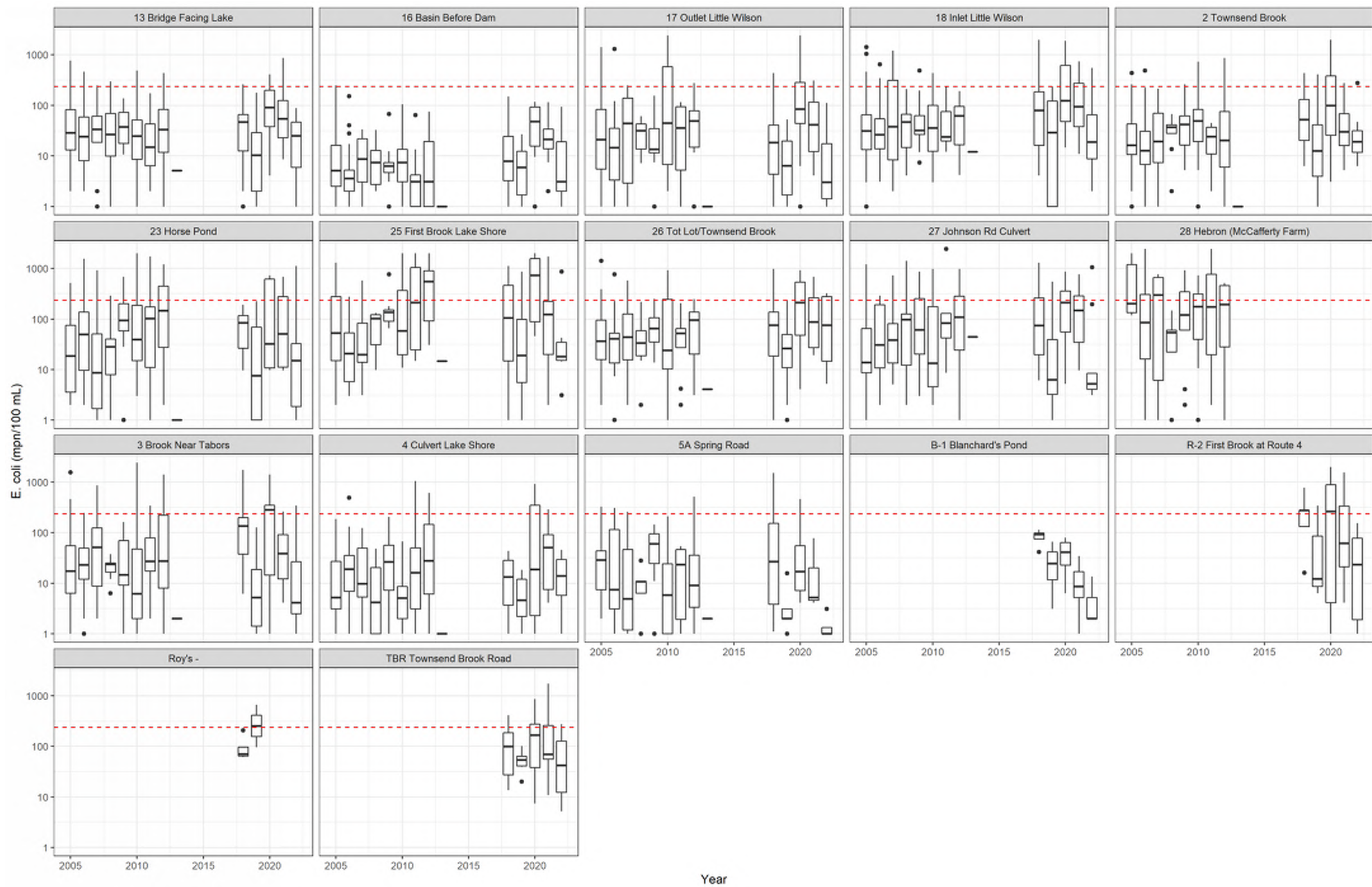


Figure 2-11
Tributary *E. coli* Monitoring Data

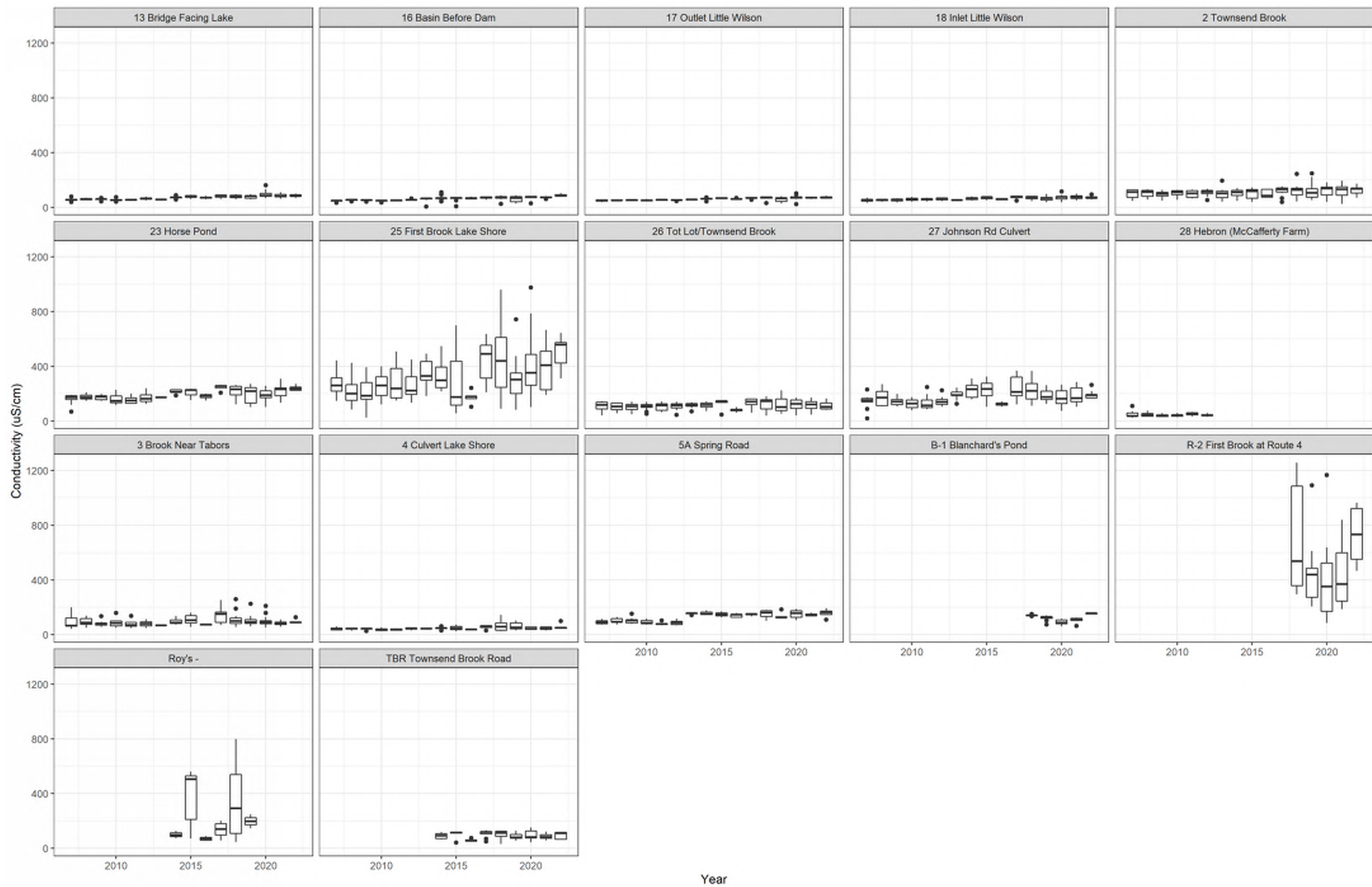


Figure 2-12
Tributary Conductivity Monitoring Data

2.3.2 Trend Analysis: Phosphorus

Two trend analyses were completed on the total phosphorus tributary data: a linear regression and a Seasonal Mann-Kendall statistical trend analysis and significance test.

A screening-level assessment was first completed using a linear regression of all tributary monitoring data. This assessment was completed for all data aggregated together and then separately for wet and dry weather conditions. Wet weather conditions were broadly defined as those with more than 0.1 inches of precipitation on the day of monitoring. **Figure 2-13** presents all tributary data with a linear regression and **Figure 2-14** presents all tributary data separated into wet and dry conditions with a linear regression. This assessment was conducted to provide a high-level, visual overview of the data, and indicates an apparent increasing trend in concentration at many sites, including Basin Stream, the Brook near Tabers, the Johnson Road Culvert, Spring Road, and Townsend Brook.

A limitation of the linear regression approach is that it presumes that the residuals of the monitoring data are normally distributed (not typically the case for environmental data), can be biased by statistical outliers, and does not account for the impact of seasonality on the statistics and trends. To better examine trends in the tributary sampling data, a statistical trend analysis was completed using a Seasonal Mann-Kendall test (Helsel et al., 2020). The Seasonal Mann-Kendall test is a non-parametric statistical test (e.g., the test does not infer a specific statistical distribution) that incorporates a specified time frame or “seasonal” time frame into the trend assessment and statistical significance test. For this study, the analysis was completed at a monthly time frame using data from the full period of record (2005 through 2022), where data from each month were compared against data from that same month. The trend is determined by the sum of the residuals between the previous data point and the current data point; if the sum of the residuals is positive then an increasing trend is indicated. The trend analysis was completed for three groupings: all data, dry weather, and wet weather conditions (**Table 2-2**). Because the Seasonal Mann-Kendall test statistic does not assume that the data are linearly correlated, there are slight differences from the slope of the linear regression and the results of the trend analysis.

This Seasonal Mann-Kendall test indicates several trends in the data:

- Most of the trends observed in the tributary data are not statistically significant, especially for the monitoring locations that discharge directly to Lake Auburn.
- When using all data without controlling for precipitation, the phosphorus concentrations from two largest inflows (Townsend Brook and the Upper Watershed, measured at Site 13) into Lake Auburn are steady.
- The phosphorus concentrations from several smaller direct discharging inflows exhibit an increasing trend. Site 5 (Spring Road) shows an increasing trend for all, wet, and dry weather data, with the all data and dry weather condition trends statistically significant. Site 3 (Brook near Tabers) exhibits an increasing trend in concentrations for all data (statistically significant at the 95 percent confidence level) but steady for dry weather and wet weather conditions (the linear regression suggests an increase in the wet weather concentrations).

- Statistically significant increasing phosphorus concentrations are evident in several upstream tributary monitoring locations (the Basin, Roy's, Johnson Road Culvert). This indicates that increases in phosphorus concentrations are occurring within the watershed even if this increase is not evident at the downstream monitoring locations that discharge directly to Lake Auburn (either due to settling of particulate phosphorus, nutrient uptake, or the timing of sampling).
- Blanchard's Pond (B-1) and the downstream site R-2 demonstrate a statistically significant decrease in phosphorus concentrations, suggesting some level of improvement in water quality at these sites. However, the phosphorus concentrations at these two sites and the downstream Site 25 remain among the highest observed in the tributary sampling, suggesting significant phosphorus sources within this small watershed.

Table 2-2 Seasonal Mann-Kendall Test for Perimeter Samples

Station ID	Name	All Data		Wet Weather Only		Dry Weather Only	
		Trend	Significance	Trend	Significance	Trend	Significance
Direct Discharge to Lake Auburn							
2	Townsend Brook	Steady	n/a	Steady	n/a	Decreasing	n/a
3	Brook near Tabers	Increasing	95%	Steady	n/a	Steady	n/a
4	Culvert Lake Shore	Steady	n/a	Steady	n/a	Steady	n/a
13	Bridge Facing Lake	Steady	n/a	Decreasing	n/a	Steady	n/a
23	Horse Pond	Increasing	n/a	Decreasing	n/a	Decreasing	n/a
25	First Brook Lake Shore	Steady	n/a	Decreasing	90%	Decreasing	n/a
5	Spring Road	Increasing	99%	Increasing	n/a	Increasing	98%
Upstream Tributaries							
18	Inlet Little Wilson	Steady	n/a	Increasing	n/a	Decreasing	n/a
17	Outlet Little Wilson	Steady	n/a	Steady	n/a	Decreasing	n/a
16	Basin Before Dam	Increasing	99%	Increasing	99%	Increasing	99%
Roy's	Roy's	Increasing	90%	Increasing	n/a	Decreasing	n/a
26	Tot Lot/Townsend Brook	Steady	n/a	Decreasing	n/a	Steady	n/a
27	Johnson Road Culvert	Increasing	99%	Decreasing	n/a	Increasing	n/a
28	McCafferty Farm	Decreasing	n/a	Insufficient Data	n/a	Decreasing	n/a
B-1	Blanchard's Pond	Decreasing	n/a	Decreasing	n/a	Increasing	n/a
R-2	First Brook at Route 4	Decreasing	99%	Decreasing	99%	Decreasing	n/a

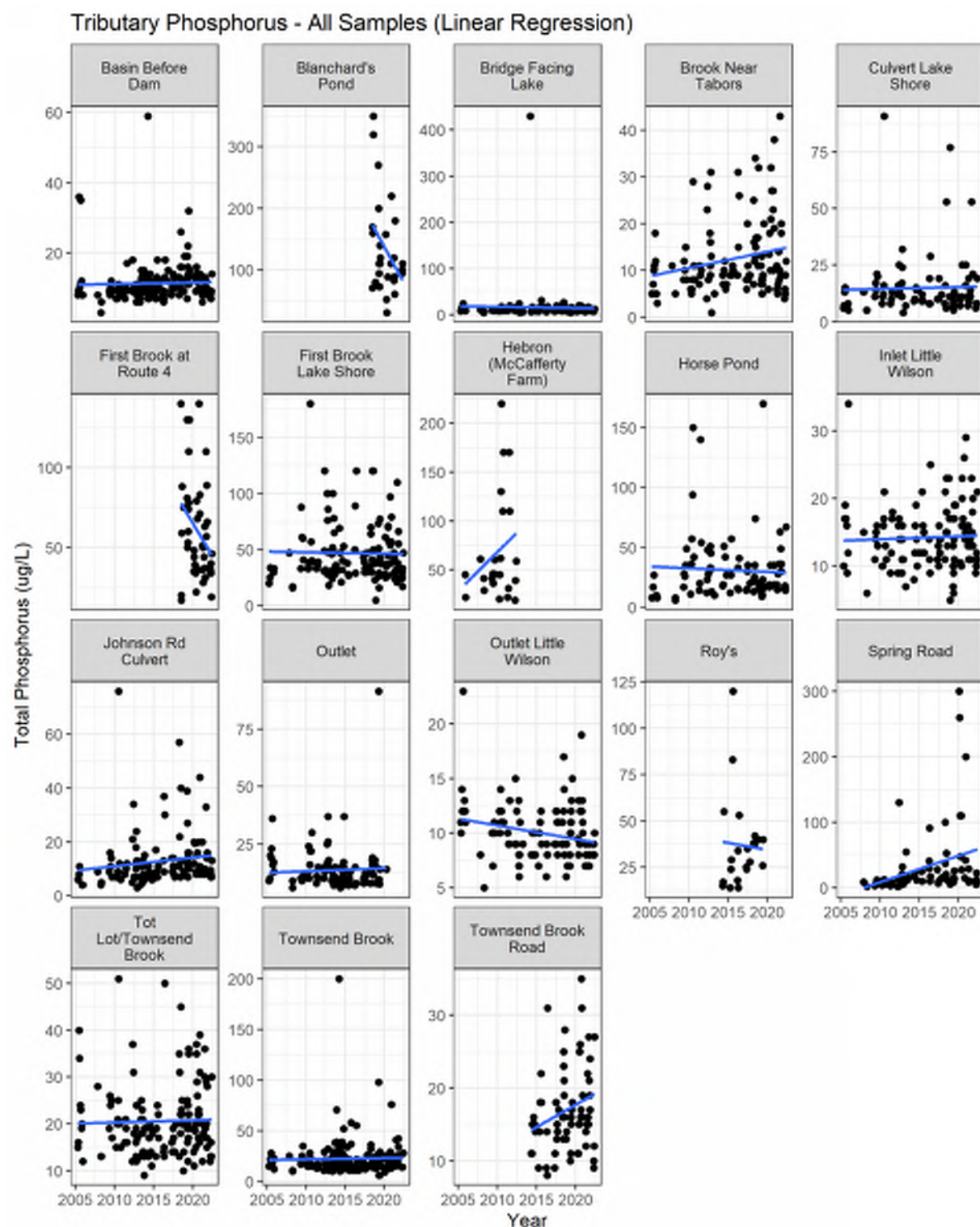


Figure 2-13
Tributary Monitoring Data (2005 through 2022), Linear Regression
Note: the y-axis ranges differ by plot



Figure 2-14
Tributary Monitoring Data – Wet and Dry (2005 through 2022), Linear Regression
Note: the y-axis ranges differ by plot

2.4 Lake Monitoring Data

The in-lake water quality data collected between 1952 and present were used to understand trends in physical lake structure, strength of stratification, water clarity, and nutrient and algae concentrations. Data used in this assessment and their roles in lake water quality are described below.

- **Intake Water Temperature** – This is the longest continuous record of data in Lake Auburn, stretching from 1952 to present. Eutrophication can be enhanced by warming water temperatures in the spring leading to earlier onset of stratification, warmer summers prolonging and strengthening stratification, and warmer winters reducing the duration of ice cover.
- **Strength of Stratification** – The strength of stratification was evaluated using the Schmidt stability index, a measure of the energy required to fully mix the water column. Increased water temperatures can result in earlier onset and stronger stratification, which can inhibit mixing between the epilimnion and hypolimnion and result in a longer duration of anoxic or low oxygen conditions in the hypolimnion that can cause release of phosphorus, iron, and manganese into the water column.
- **Raw Water Turbidity and Secchi Depth** – Raw water turbidity is measured in the intake and thus reflects turbidity at about 4 meters depth (the epilimnion during the stratified season). Secchi depths are recorded at the in-lake monitoring locations. Both parameters describe clarity in the water column, where increased turbidity and reduced Secchi depths can reflect microbiological (particularly algal) activity and inorganics that are resuspended due to wave action or inflows from tributaries. In Lake Auburn, turbidity readings above 1 NTU and Secchi depths shallower than 6 meters are used as indications of elevated turbidity.
- **Presence of Anoxia** – Anoxic conditions in the bottom waters can lead to greater release of sediment phosphorus, although the sediment phosphorus release rate will have been reduced by the alum treatment in 2019. The presence of anoxia is evaluated using the Anoxic Factor, a metric that integrates the area and duration of anoxic conditions.
- **In-lake Phosphorus and Chlorophyll *a* Concentration** – Phosphorus is the primary limiting nutrient in freshwater systems like Lake Auburn. Excessive levels of phosphorus can result in algal blooms that increase turbidity. In addition, comparing surface and deep phosphorus concentrations can give insight into the potential for and the magnitude of internal phosphorus flux from sediments.

2.4.1 Intake Water Temperature

The intake water temperature at Lake Auburn has been tracked since 1952, representing the longest-term dataset of water quality within Lake Auburn. The current Lake Auburn intake is relatively shallow, with the crown of the 48-inch pipe located about 4 meters below the normal high water surface elevation. The intake was relocated to its current location and depth in 1996. Prior to this date, the intake was located at a shallower depth. Because both the old and present intake draw water from the epilimnion, variation in temperature between the two depths pre-

and post-1996 is expected to be minimal because the epilimnion is typically vertically well-mixed. However, temperature data collected prior to 2001 may be less accurate due to an improvement in the quality of the data collection that occurred after this date.

The intake temperature was analyzed on an annual basis for the average intake temperature (**Figure 2-15**). The intake temperature data indicate that the annual average temperature observed has increased since the beginning of the record in 1952. The average intake temperature between 1952 and 1962 was 10.5°C, compared with the last 10 years (2011 through 2021) average of 12.2°C, a 16 percent increase. Higher temperatures are associated several issues related to the impacts of eutrophication, including:

- higher algal growth rates, increasing the likelihood of a harmful cyanobacteria algae bloom,
- earlier onset of the spring increase in temperature allowing for a longer algal growing period,
- lower dissolved oxygen saturation, reducing the oxygen carrying capacity of the water, and
- stronger stratification that lasts longer into the fall, expanding the time frame for sediment and hypolimnetic oxygen demand to decrease oxygen levels in the hypolimnion, which increases the potential for phosphorus release from sediment under anoxic conditions.

Additional analysis of the duration and extent of anoxic conditions and the strength and duration of stratified conditions is discussed in **Section 2.4.3**.

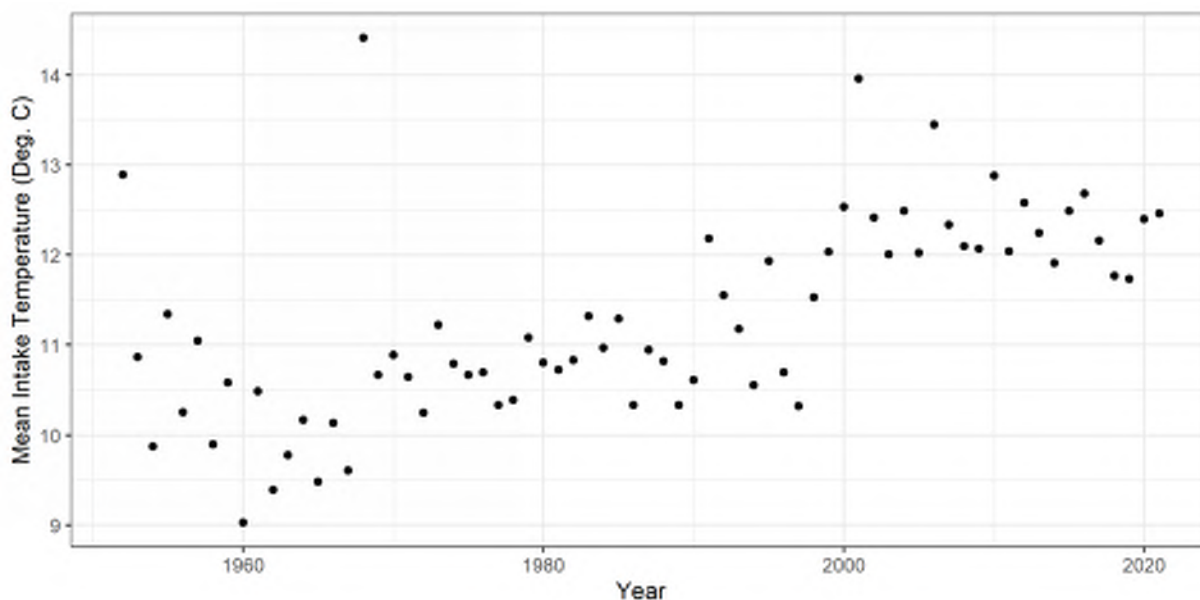


Figure 2-15
Mean Annual Intake Temperature, 1952 - 2021

Seasonal variations in temperature are also important relative to water quality dynamics in Lake Auburn. Monthly minimum, mean, and maximum intake temperature between 2010 and 2021 were compared against the long-term average temperature record. This assessment is shown in **Figure 2-16**, which shows the range of temperature in each year as a vertical bar, the mean temperature as a point, and the mean 1952-2021 temperature as the black line. Monthly variation in lake temperature may have an impact on algal productivity and the likelihood of algal blooms. As an example, the 2018 cyanobacteria bloom occurred in September, coincident with a warmer than typical August and September, and the 2021 fall bloom occurred during a warm September, October, and November. Additional discussion of the potential impact on seasonal temperature trends relative to algal productivity can be found in **Section 2.5**.

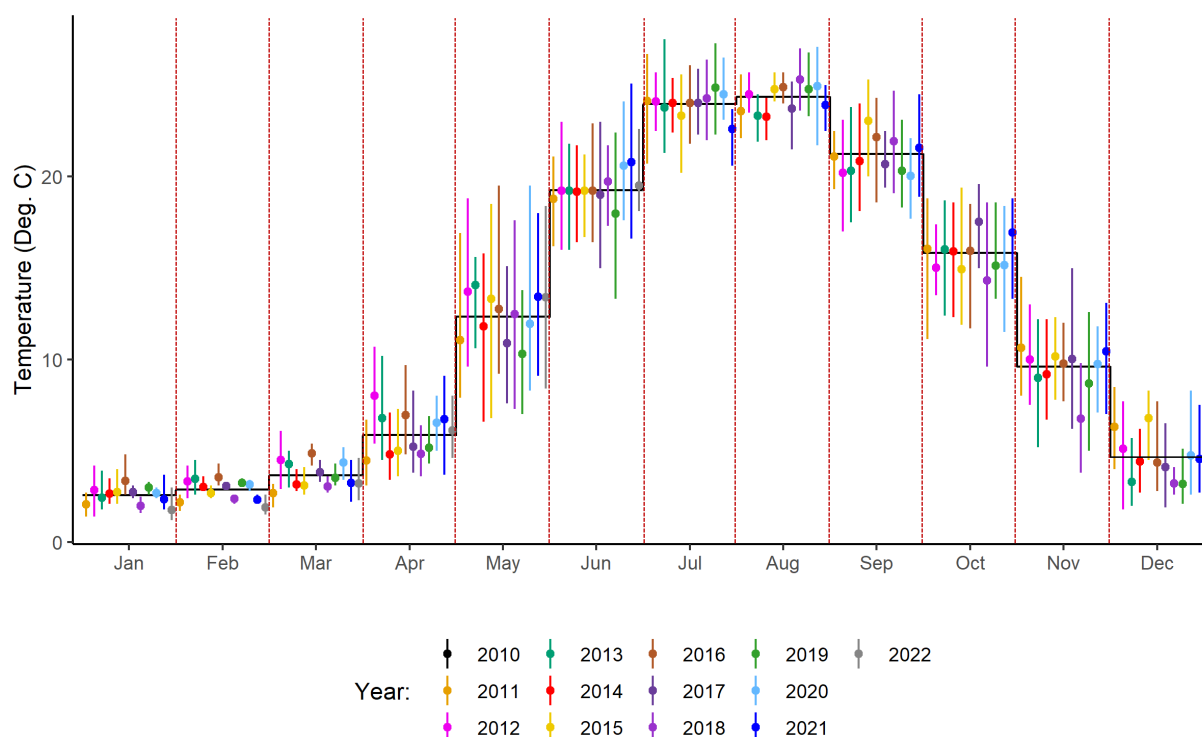


Figure 2-16
Monthly Trends in Intake Temperature, 2010-2021

2.4.2 Water Clarity: Secchi Depth and Turbidity

Trends in water clarity were evaluated using data on Secchi depth taken at the Deep Hole monitoring location since 1978 and turbidity measured at the intake since 2005. Reduced water clarity is indicative of algae and other microscopic organisms, suspended sediment (typically clays and silts) and dissolved organic compounds in the water column.

Previous studies in Lake Auburn (e.g., CDM Smith and WRS, 2013) have found turbidity and Secchi depth to be well correlated with water column chlorophyll *a* and algal concentrations. However, turbidity at the intake is also impacted by wind-driven sediment resuspension that causes short-duration periods of elevated turbidity. This condition occurs occasionally – about 5

to 10 times per year –and is driven by strong northwest winds. Additional monitoring is required to better understand the potential sources and the extent of non-algal turbidity; see **Section 5.5** for recommendations.

Turbidity

Daily average turbidity measurements at the Lake Auburn intake are shown as annual boxplots in **Figure 2-17** and with individual data points between 2010 and 2022 shown in **Figure 2-18**. Across all years monitored, the daily average turbidity is often below 0.5 NTU, and nearly always below 1 NTU. Primary exceptions to this trend are in 2011, 2012, and 2018 where significant algal blooms occurred during the summer months, and 2021 and 2022 where late fall algal blooms (and potentially sediment resuspension from inflows and wind) caused elevated turbidity. The algal blooms in 2011 and 2012 triggered the 2013-2014 diagnostic study. As planned in that study, a copper sulfate treatment was implemented in 2018 when the next algal bloom occurred, which was followed by an alum treatment in 2019 to reduce phosphorus in the water column and release of phosphorus from the sediments under anoxic conditions.

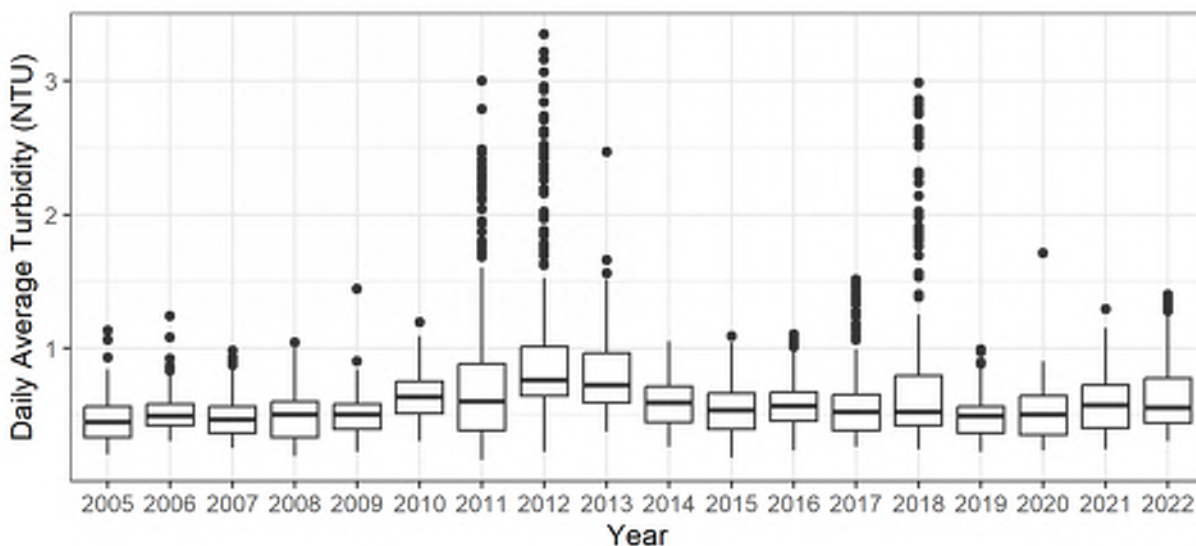


Figure 2-17
Annual Range of Daily Average Turbidity at the Lake Auburn Intake

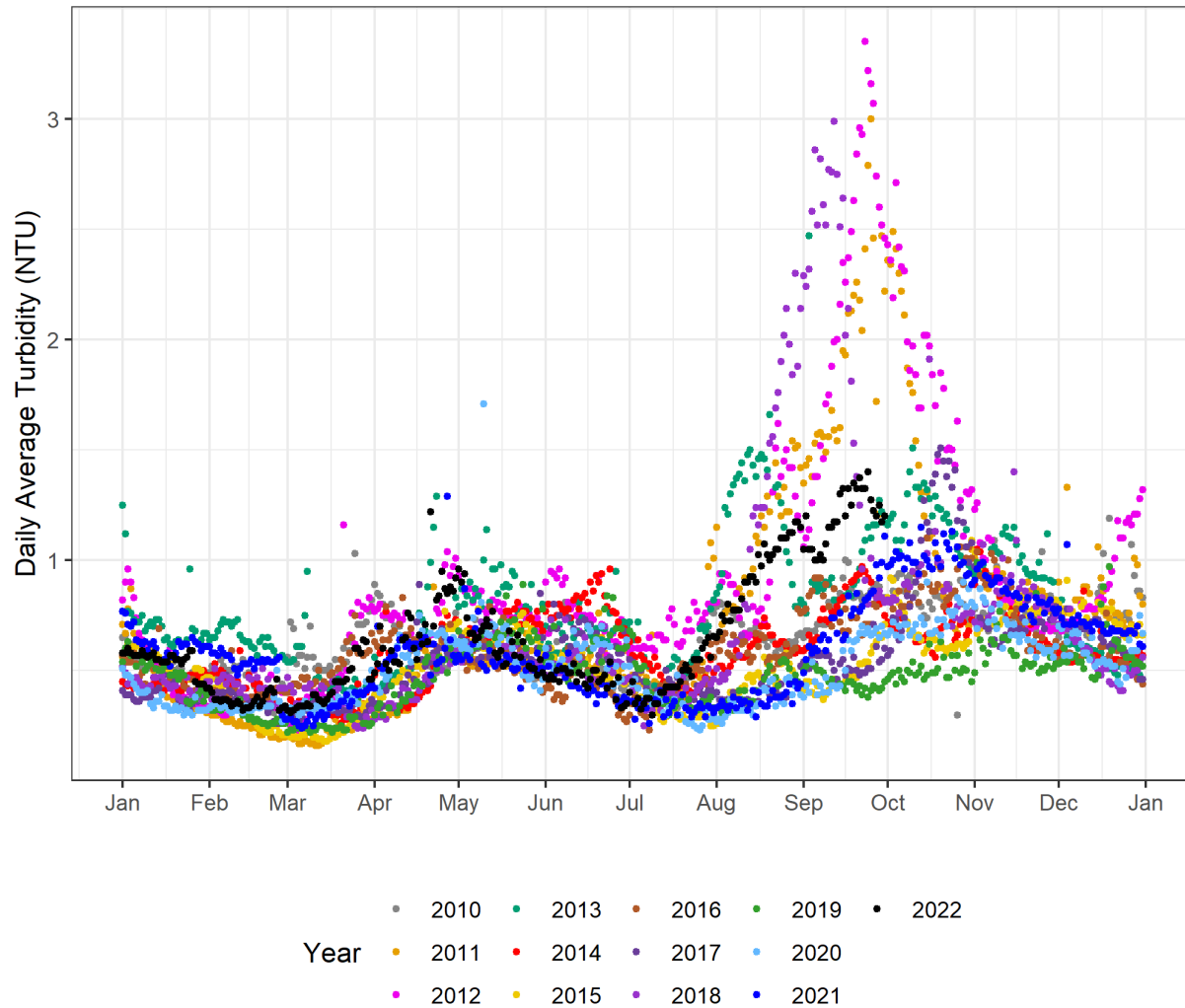
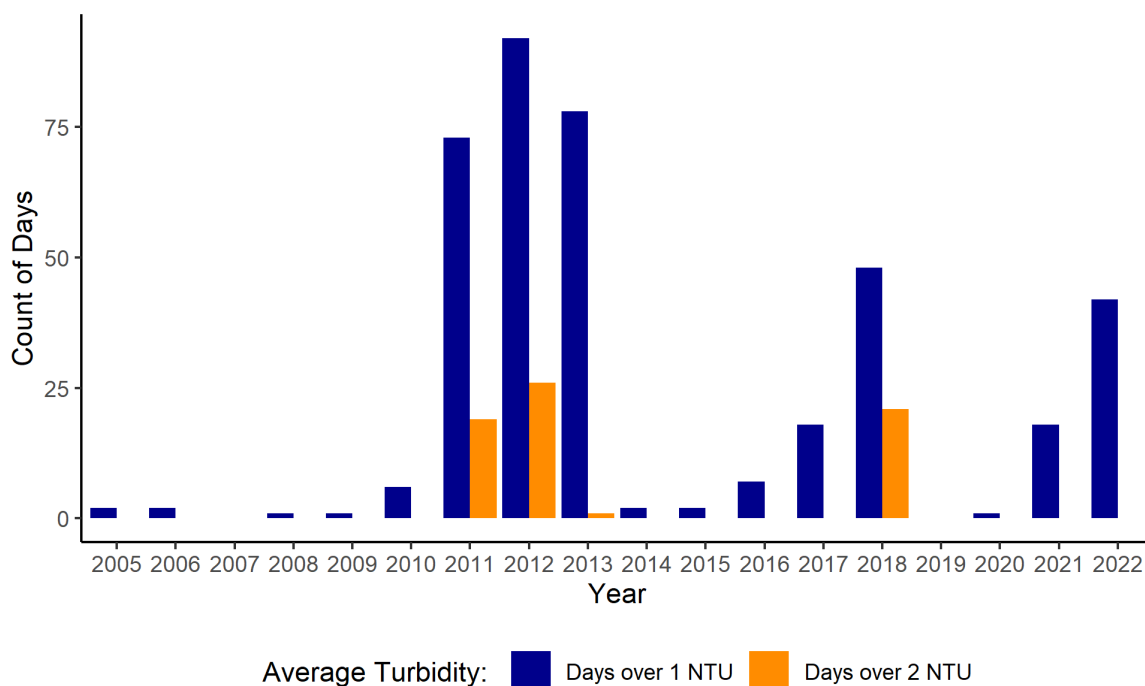


Figure 2-18
Daily Average Turbidity, 2010 – 2022

Note: 2022 record incomplete and contains records through September 30

Using the frequency of occurrence of turbidity above 1 NTU as an indicator of relatively poor water quality in any given year, **Figure 2-19** represents a count of the number of days where the daily average turbidity was greater than 1 and 2 NTU. These data indicate that in most years less than 2 days per year recorded a daily average turbidity over 1 NTU, and 2 NTU was almost never exceeded. Exceptions to this trend are 2011 through 2013, 2017, 2018, 2021, and 2022. These periods of extended elevated turbidity are principally associated with elevated algal productivity. Most of the periods of elevated turbidity occur in the late summer to early fall, with occasional exceedances in spring.

**Figure 2-19**

Days per Year Daily Average Turbidity Exceeds 1 NTU and 2 NTU, 2005 through 2022

Note: 2022 is a partial year (through September 30)

Secchi Depth

Secchi depth data at the Deep Hole were evaluated across the full period of record (1981-present), providing a temporally comprehensive dataset to understand whether recently observed trends in turbidity are a new phenomenon or have been observed in previous years based on the historical record. Secchi depth measurements were evaluated both on an annual and a monthly basis.

The entire Secchi disk record at the Deep Hole was first evaluated on an annual basis (see boxplot, **Figure 2-20**). This assessment indicates that the low Secchi disk measurements associated with the 2011 through 2013 period are unprecedented, with the lowest median and minimum Secchi disk measurements on record; these low Secchi depths correspond with the high intake turbidity in those years. In the other year with high turbidity (2018), the Secchi depth also shallow, with the fourth highest 75th percentile Secchi depth in the record. Low Secchi depths occur in the older part of the data record, with occasional periods of relatively low Secchi depth measurements observed most notably in 1993, 1994, and 1979 (albeit with limited data in that year). Finally, conditions following the alum treatment in 2019 are associated with relatively deep median Secchi depths, and the deepest Secchi depths on record, greater than 12 meters in 2021. However, these years are also characterized by significant variability within each year, suggesting that periods of relatively low Secchi depth occurred despite the record high Secchi depths.

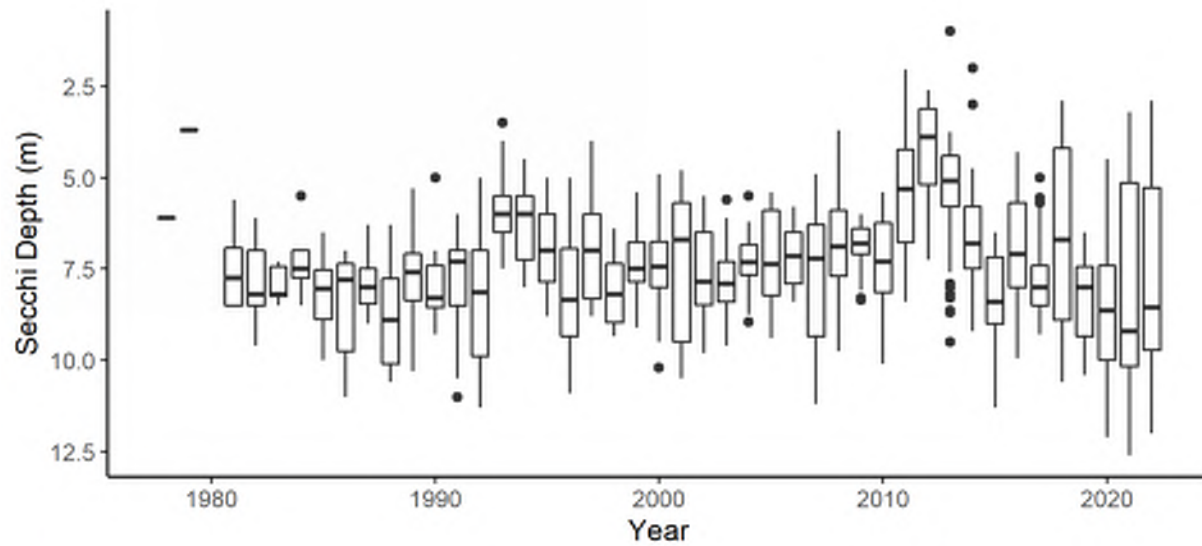
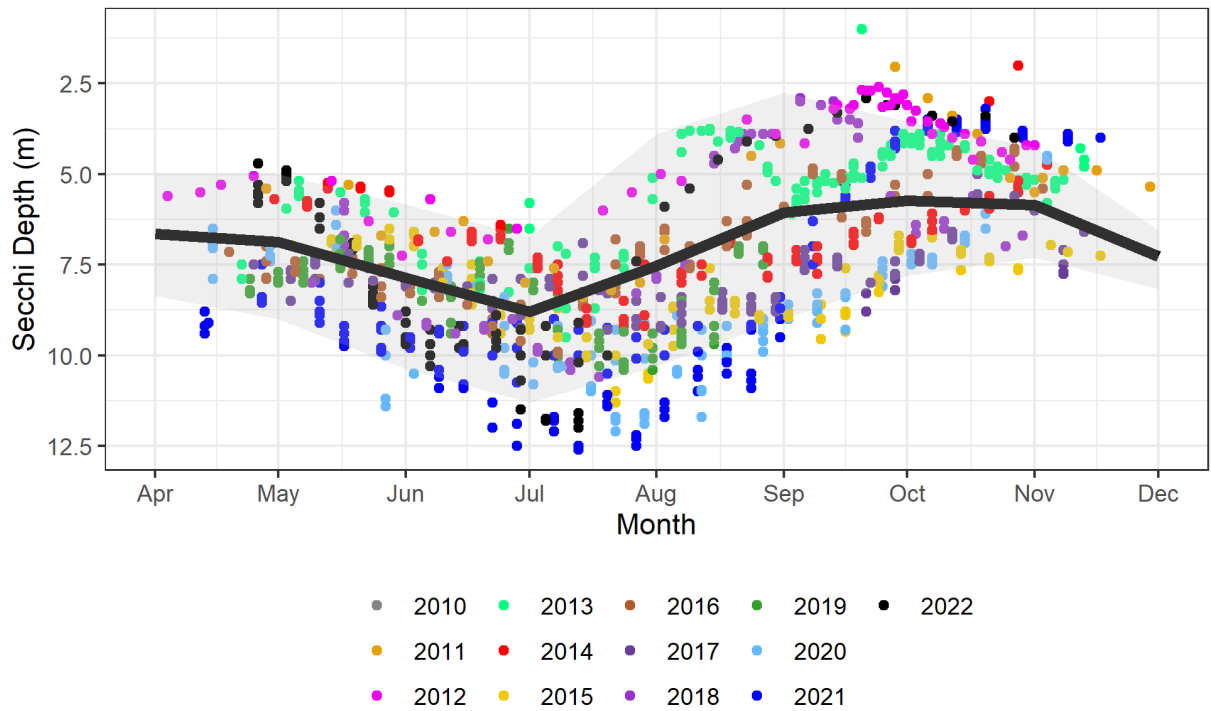


Figure 2-20
Long-term Secchi Depth Record at the Deep Hole

The Secchi depth measurements prior to the 1990s were relatively sparse and generally only taken in the “clear water” phase of early to mid-summer prior to the algal blooms that typically occur in mesotrophic and eutrophic water bodies as the epilimnion deepens with cooler nights in late summer/early fall; this also biases the range of observed Secchi depths shown on **Figure 2-20**, where the box-and-whisker plot may not show the full range of Secchi depths during each year due to the short period of data collection. Data collected after 1990 were collected more frequently and span the spring-summer-fall algal growing season.

Seasonal trends are also important for understanding overall water quality trends in Lake Auburn. Therefore, Secchi depth readings were evaluated on a monthly basis to understand intra-annual trends in water clarity. **Figure 2-21** presents all Secchi depth measurements collected at all sites between 2010 and 2022 compared against the mean, upper 95th, and lower 95th percentile measurements (1981 through 2022), and **Figure 2-22** presents monthly average Secchi depth measurements collected at all sites between 1981 and 2022; the infrequent Secchi depth readings in 1979 and 1980 were omitted from this plot.

**Figure 2-21****Secchi Depth Measurements, 2010 – 2022**

Black line indicates mean monthly Secchi depth; gray border indicates the range of the upper and lower 95th percentile Secchi depth

The seasonal trends shown in **Figures 2-21** and **2-22** indicate that the data collected since 1990 data show trends typical of high-quality northern temperate lakes, where spring and fall Secchi depths are shallower due to algal blooms and deepest in the summer when phosphorus and algal productivity are lowest. In addition, the periods of high algal productivity (2011, 2012, 2018) are characterized by the low Secchi depths in late summer and early fall, with many points falling beyond the upper 95th percentile line. Similarly, the deep Secchi depths post-alum in 2020, 2021, and 2022 fall well below the lower 95th percentile line.

The data collected since 2013, which added Secchi depth measurements at up to four additional locations around the lake (depending on the year) demonstrate that the patterns in Secchi depth are spatially consistent across the lake. The differences in Secchi depth in the graphs at stations 29 and 30 – especially in 2020, 2021, and 2022 – represent the Secchi disk on the lake bottom. This condition rarely occurred prior to the 2019 alum treatment, corroborating the significant observed improvement in summer clarity in the initial post-treatment years. However, the deep Secchi depths observed post-alum have been followed by a rapid decline in Secchi depth associated with late fall algal blooms. It is possible that the increased water clarity following the alum treatment has deepened the photic zone, enhancing algal productivity following the introduction of additional phosphorus to the lake (either through fall storms or internal release of phosphorus).

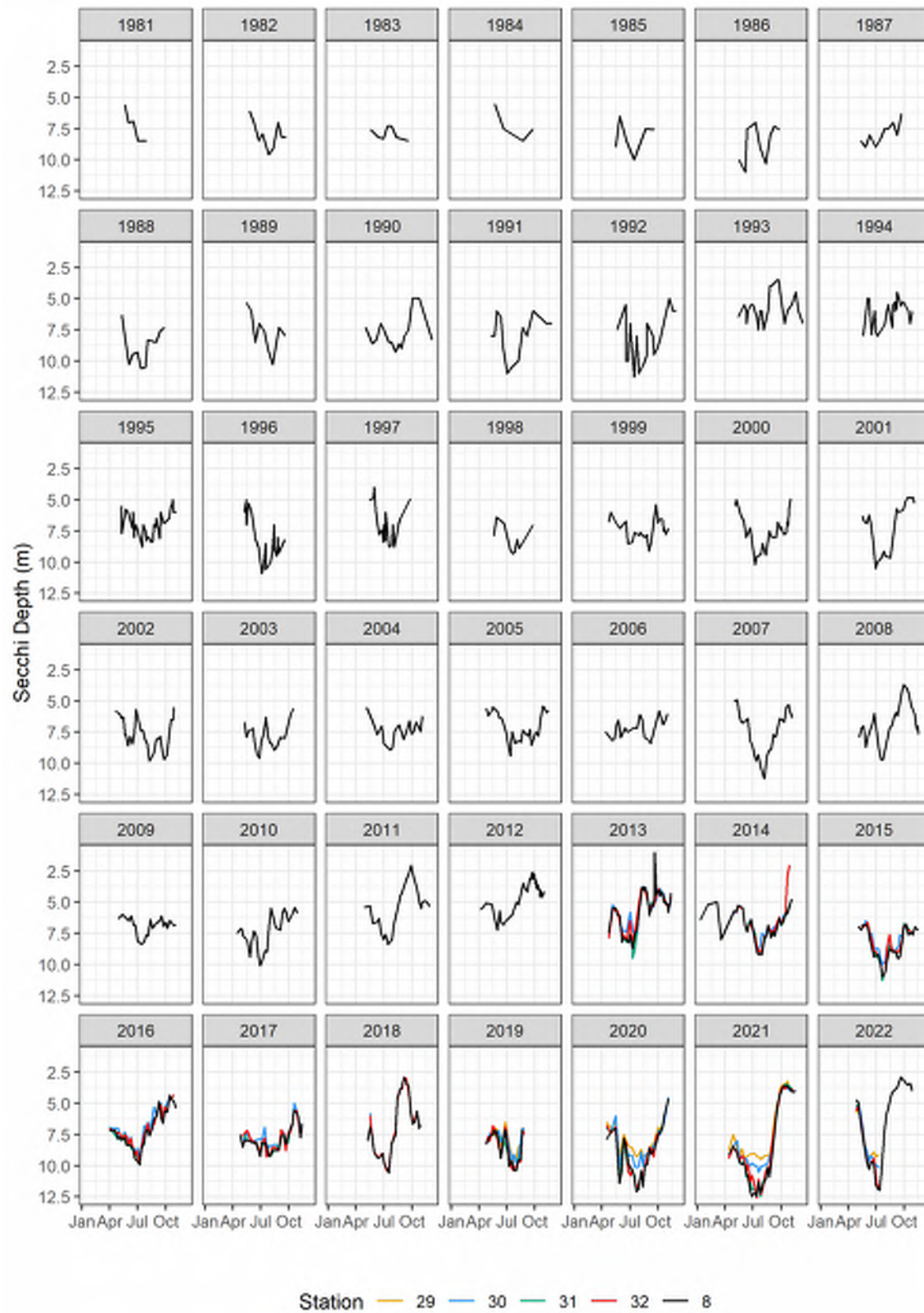


Figure 2-22
Secchi Depth by Year (1981 – 2022)

2.4.3 Profile Data Analysis: Temperature and Dissolved Oxygen

Water temperature and dissolved oxygen (DO) profile data can be used to evaluate the water quality impact of stratification. In a typical northern temperate lake, temperature stratification begins forming in the spring and strengthens into mid-summer as air temperature and solar radiation increase. Peak stratification is typically observed between late July and mid-August. Between mid-August to early September, the epilimnion (surface layer of the lake) begins to cool and deepen. This process continues throughout the fall until the lake reaches uniform temperature in early winter. A stratified reservoir can be divided into three distinct zones (**Figure 2-23**):

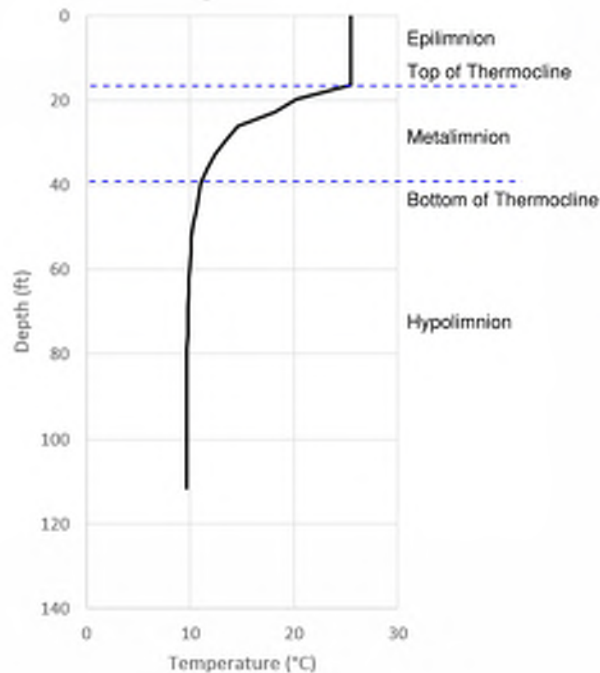


Figure 2-23
Typical Temperature Profile in a Stratified Reservoir

- **Epilimnion:** surface layer and is typically well-mixed due to wind- and solar radiation-induced mixing.
- **Metalimnion:** depth with the steepest temperature and density gradient, separating the epilimnion from the hypolimnion. The steep temperature gradient acts as a boundary isolating the deeper waters from the surface layer, which limits reaeration from the atmosphere and the cycling of nutrients up to the surface layers where photosynthesis occurs. The **thermocline** is the location of the maximum rate of temperature decrease with respect to depth.
- **Hypolimnion:** deep, poorly mixed layer below the metalimnion.

Dissolved oxygen concentrations can be strongly impacted by the density gradients that develop under stratified conditions. Reaeration only occurs at the air-water interface into the epilimnion; when strong stratification is in place very little oxygen transfer can occur between the epilimnion and the hypolimnion. If a significant oxygen demand is present in the hypolimnion then bottom water dissolved oxygen concentrations can be depleted, which can have significant impacts on source water quality.

Profiles of temperature and dissolved oxygen collected regularly describe the overall structure of the lake and can provide insights into overall raw water quality. Analysis of profile data in Lake Auburn was completed to determine trends on the presence of stratified conditions during the summer months, information on the relative strength of stratification and the overall resistance to mixing across the thermocline, and the amount of hypolimnetic dissolved oxygen present in each year.

Temperature

Temperature profile data were used to evaluate the duration and relative strength of stratification and identify trends in lake temperature over the period of record. Temperature data for each reservoir are displayed using two plotting techniques: vertical profiles and monitoring season isopleths. Vertical profiles for each reservoir monitoring station show depth along the y-axis (surface is 0 m) and temperature across the x-axis. All profiles for given monitoring date are shown in a separate panel, with the panels ordered by date. Vertical profile plots compare the thermal structure across the reservoir on a single day and between days.

The monitoring season isopleth plots are a color-contoured cross-section representation of the change in temperature for a single location across the monitoring period. In these plots, the sampling dates are shown across the x-axis, the depth (surface is 0 meters) across the y-axis, and the temperature is shown using the color mapping, with cold temperatures in purple and blue and warm temperatures in orange and red. The isothermal contours, indicated by different colors or shades of a color, are at 1°C intervals. An example isopleth plot (**Figure 2-24**) and vertical profile plot (**Figure 2-25**) are shown in this section for the 2021 monitoring season; all plots are contained in **Appendix D**.

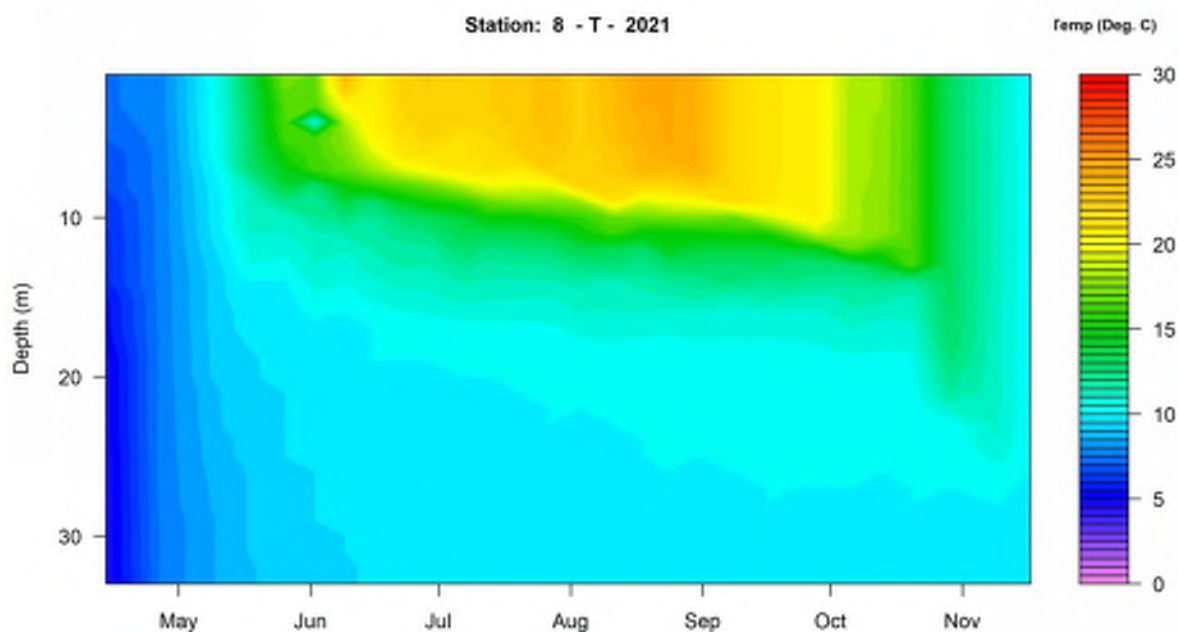


Figure 2-24
Temperature Isopleth Plot for 2021 at the Deep Hole

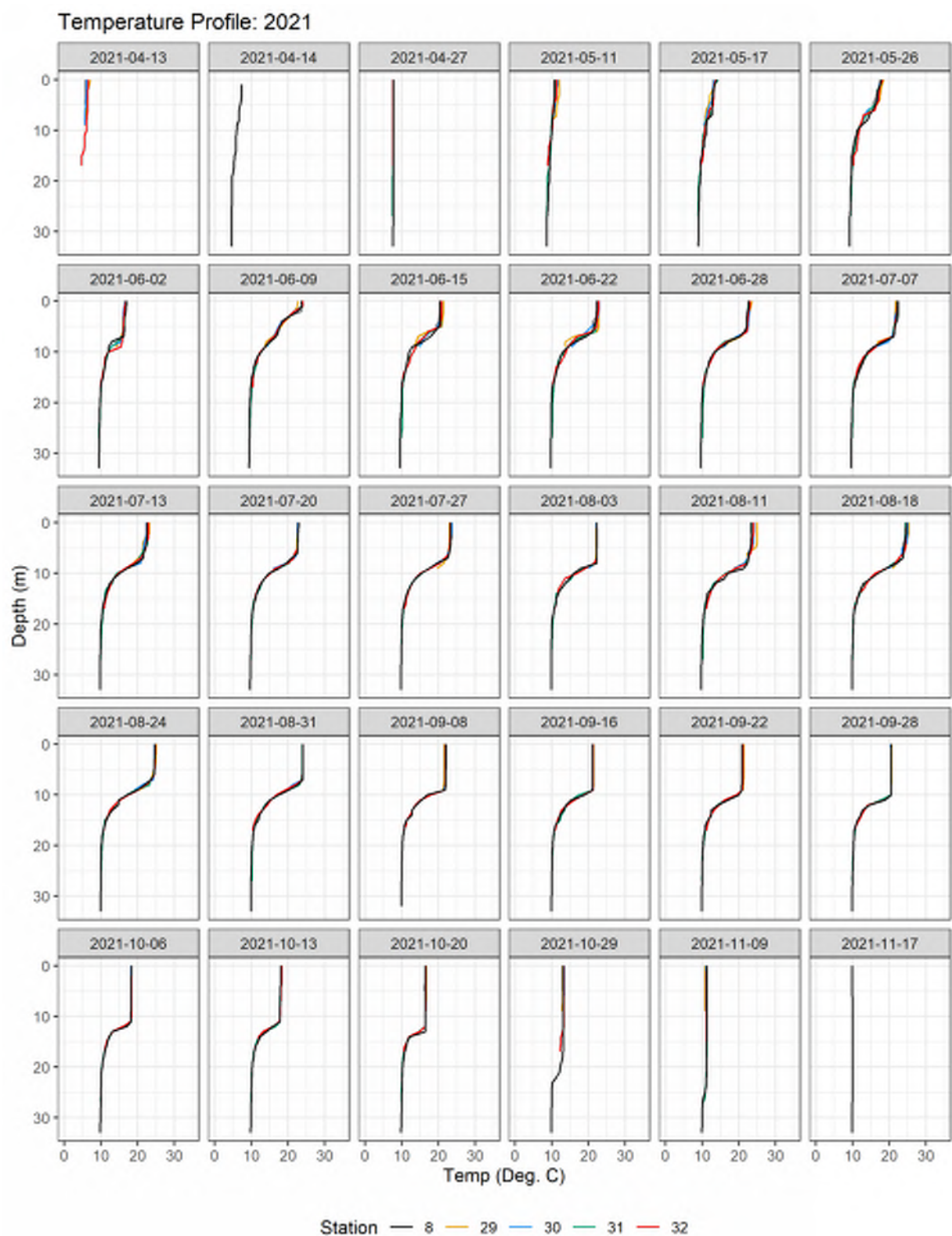


Figure 2-25
2021 Temperature Profiles at the Deep Hole

The discrete temperature profiles are typical for a northern temperate lake and show that the temperature structure across the lake is uniform, where little spatial variation in the thermocline depth and the duration of stratification. In general, after ice-out, weak stratification begins to be established by early May, with nearly all the April profiles showing a uniform temperature gradient and those in May showing the start of a warming of the surface layer. The stratification develops through spring and summer, with the thermocline deepening to below 10 meters by late fall. Through late fall, the thermocline deepens and begins to erode, with the lake generally mixed fully by early November.

The profile data were used to evaluate the relative strength of stratification for each year using the Schmidt stability index. This index represents the overall amount of energy required to mix the lake. The Schmidt stability index, S , is computed by summing the difference between the bottom water and upper water density per unit area. A large S implies that there is a large difference between the density of the top and bottom water and therefore a strongly stratified structure exists. Similarly, a small S implies that the density is close to uniform throughout the water column, implying weak stratification. The Schmidt stability index will be zero following fall turnover when the lake is fully and uniformly mixed across the entire water column (Stainsby et al., 2011; North et al., 2014; Idso, 1973).

The Schmidt stability index was computed using Lake Analyzer (Winslow et al., 2022) for each temperature profile collected from the Deep Hole site in Lake Auburn from 1981 to 2022 (except for years with less than 3 profile measurements). The maximum value of the index in each year was used to determine whether the overall strength of stratification is changing over time (Figure 2-26). Since 1982, the annual maximum Schmidt stability index exhibits an upward trend over the period of record, indicating that the overall strength of stratification has been steadily increasing.

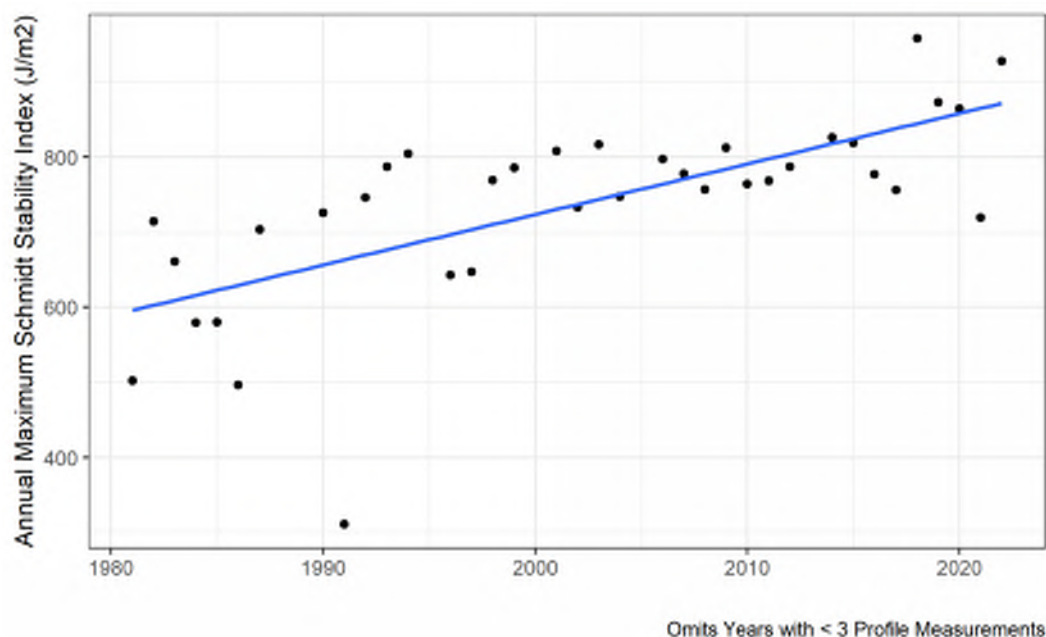


Figure 2-26
Annual Maximum Schmidt Stability Index at the Deep Hole, Lake Auburn (1982 – 2022)

The maximum Schmidt stability index represents only the day with the strongest density gradient, and therefore does not provide information about the duration of strongly stratified conditions. Peak stratification strength occurs in July and August when the upper waters are at their warmest. Therefore, we compared the monthly average Schmidt stability index for July, August, September, and October. A scatterplot with monthly linear regression lines is presented in **Figure 2-27**. Each of the monthly average Schmidt stability index computations show a general positive year over year increase, suggesting that the strength of stratification has increased significantly since the early 1980s. This result agrees with published Schmidt stability index trends from the Lake of Zurich in Switzerland between 1972 – 2010 (North et al., 2014) and Lake Simcoe near Toronto, Canada between 1980 and 2008 (Stainsby et al., 2011). Furthermore, this represents an update of the analysis completed by CDM Smith in the Phase 2 diagnostic study (CDM Smith and WRS, 2014). The year-over-year increase in the Schmidt stability index has continued since the end of the previous analysis in 2013.

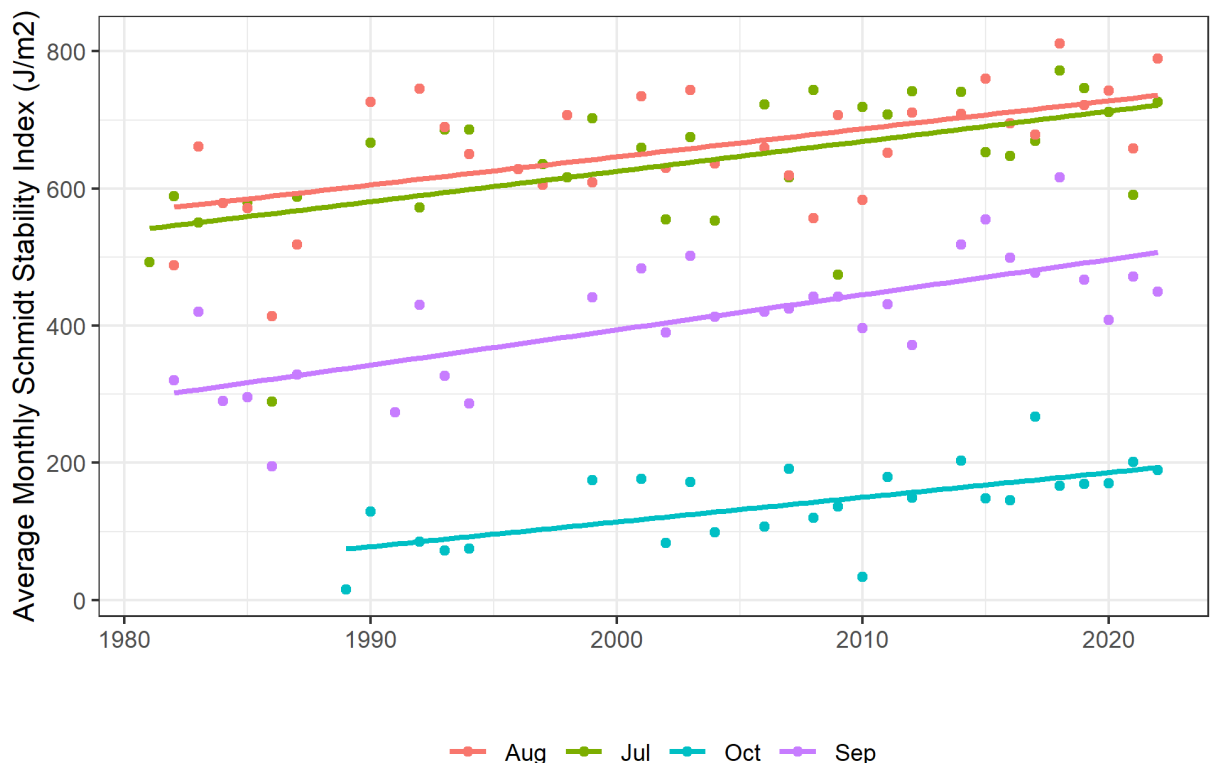


Figure 2-27
Trends in the Monthly Average Schmidt Stability Index at the Deep Hole, Lake Auburn

Dissolved Oxygen

Trends in dissolved oxygen were evaluated using dissolved oxygen profiles collected at the Deep Hole monitoring location between 1979 and present, and at additional locations starting in 2013. This assessment consisted of a quantitative and qualitative evaluation of dissolved oxygen trends with depth across years and an assessment of the spatial extent and relative severity of anoxia in

each year. Collectively, these data provide information on the trends in hypolimnetic dissolved oxygen, including insight into whether the conditions observed in 2011 and 2012 are indicative of a downward trend in water quality or were an anomalous occurrence and data on the potential for hypolimnetic phosphorus release (noting that the potential internal load is much lower following the 2019 alum treatment).

Evaluation of Dissolved Oxygen Trends

The dissolved oxygen data are displayed two ways, as was done for the temperature data: vertical profiles of dissolved oxygen concentrations and isopleths of monitoring season dissolved oxygen concentrations and dissolved oxygen saturation. Vertical profiles for each monitoring station within the lake show depth along the y-axis (surface is 0 meters) and dissolved oxygen across the x-axis. All profiles for given monitoring date are shown in a separate panel, with the panels ordered by date. Vertical profile plots compare the thermal structure across the reservoir on a single day and between days. The monitoring season isopleth plots are a color-contoured cross-section representation of the change in dissolved oxygen for a single location across the monitoring period. In this plot, the sampling dates are shown across the x-axis, the depth (surface is 0 meters) across the y-axis, and the dissolved oxygen concentrations are shown using the color mapping, with high concentrations in purple and blue and low concentrations in orange and red. An example isopleth plot (**Figure 2-28**) and profile plot (**Figure 2-29**) are shown in this section for the 2021 monitoring season; all plots are contained in **Appendix D**.

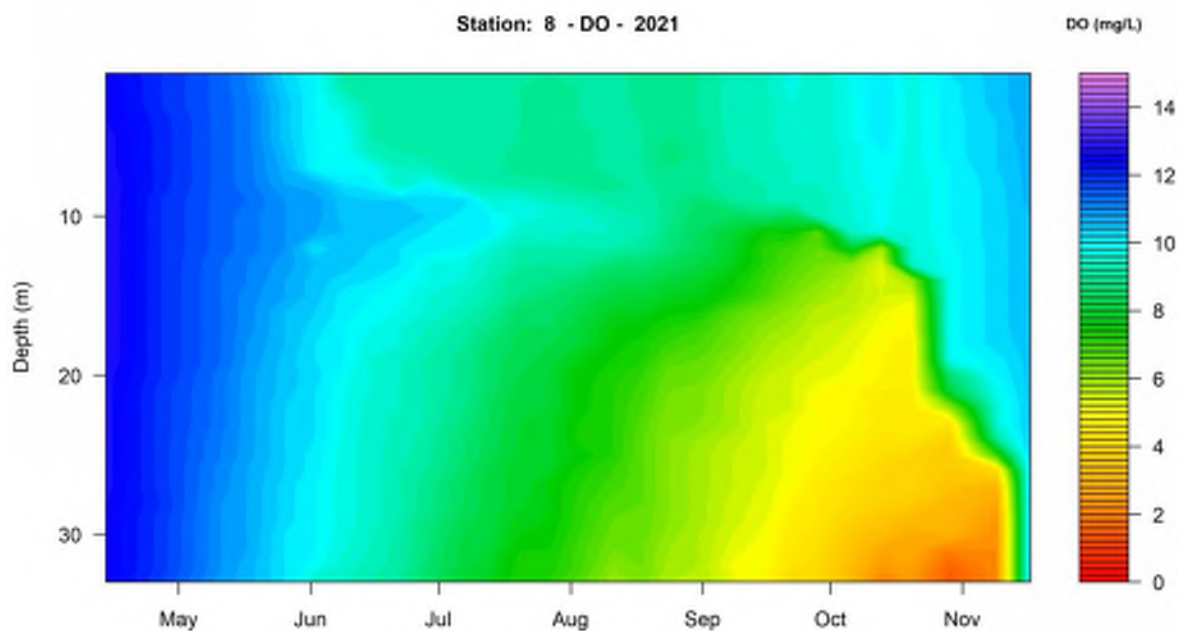


Figure 2-28
Dissolved Oxygen Isopleth Plot for the 2021 Monitoring Season

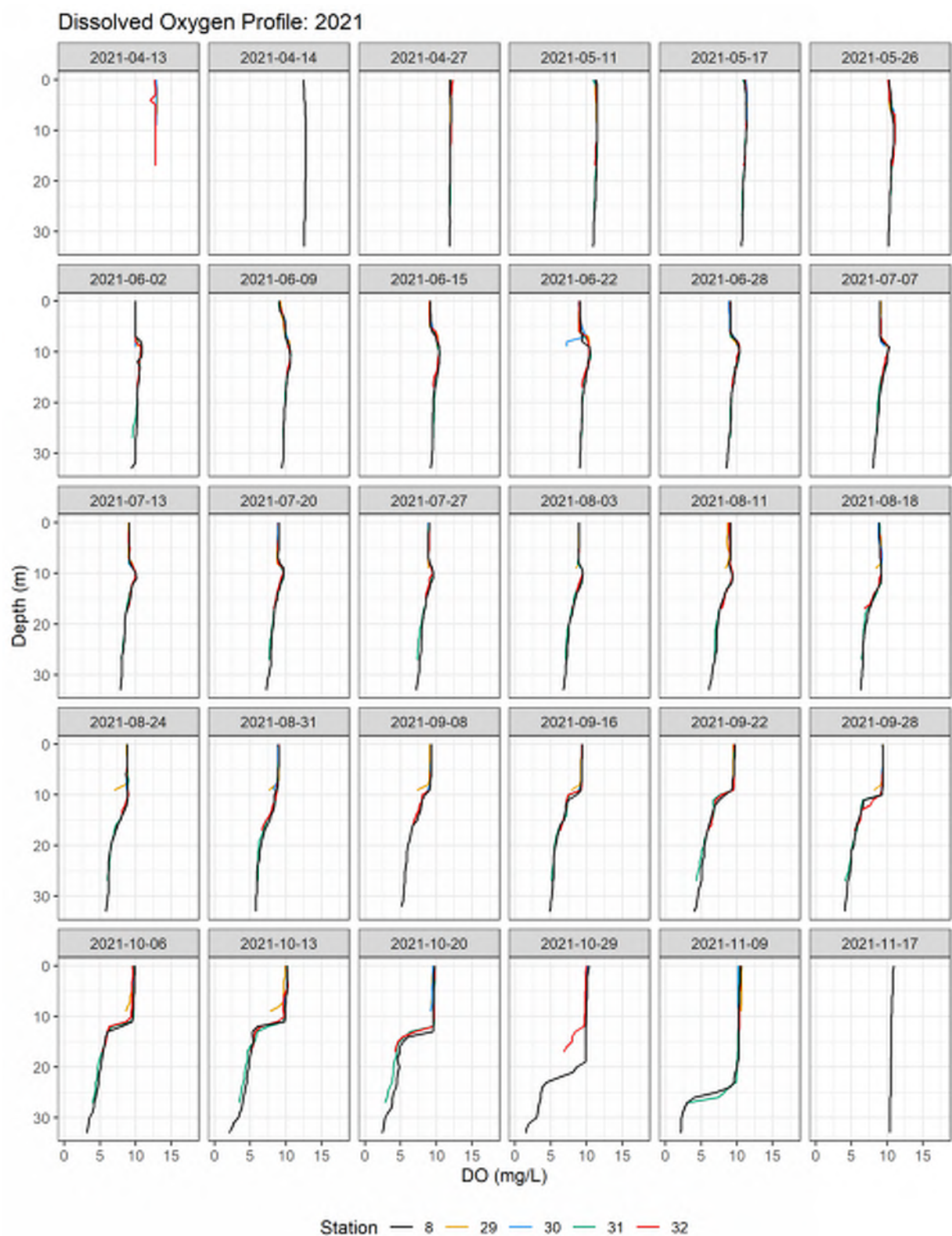


Figure 2-29
Temperature Isopleth Plot for the 2021 Monitoring Season

The dissolved oxygen profile data show a substantial oxygen demand in the hypolimnion, with low dissolved oxygen conditions occurring in the deep hole during most years and occasional periods of anoxic conditions (defined here as less than 1 mg/L). Under the right circumstances (for instance, the conditions observed in 2011 and 2012), anoxic conditions can persist across a large portion of the hypolimnion. In addition, the dissolved oxygen profiles show evidence of algal growth at the thermocline (generally occurring around 10 m depth in mid- to late summer), with an observed dissolved oxygen maxima (due to algal production). In some years, the dissolved oxygen maxima are followed by a minima at the hypolimnion. This could indicate that dead algae are decaying on the thermocline, organic material from watershed inputs are oxidizing, or zooplankton are accumulated at the metalimnion consuming oxygen (Wetzel, 2001).

Spatial Extent and Severity of Anoxic Conditions

Profile data at the Deep Hole monitoring location were evaluated across the period of record to evaluate spatial and temporal trends in anoxic conditions. The principal metric used for this assessment was the anoxic factor (Nürnberg, 1995), which is a factor that quantifies the spatial and temporal extent of anoxia in a stratified lake. The anoxic factor (AF) is normalized by the lake surface area to allow comparison to lakes of different sizes. The anoxic factor is calculated using the following equation:

$$AF = \left(\sum_{i=1}^n t_i a_i \right) / A_o$$

where t_i is the total number of days that anoxic conditions were observed, a_i is the surface area in contact with anoxic water in square meters, and A_o is the lake surface area in square meters. For this assessment, anoxia was defined to be dissolved oxygen concentrations less than 1 mg/L based on the definition by Nürnberg to account for the fact that there is likely to be some level of anoxic conditions at the sediment-water interface not captured by the profile data². In general, a healthy, oligotrophic lake will have an AF of less than 10 days per year. If the AF exceeds 20, lake health is in danger but can be recovered with appropriate management. AF over 100 indicates a hypereutrophic lake with widespread anoxia throughout the hypolimnion.

The AF was calculated for Lake Auburn for the full period of record (**Table 2-3** and **Figure 2-30**). In addition, **Table 2-3** indicates the shallowest depth that anoxia was observed in each year and the overall duration of anoxic conditions during each year. Years that are not noted did not have any observed anoxia. The spatial extent of anoxic conditions is shown graphically in the map in **Figure 2-31**.

This analysis indicates that anoxic conditions occasionally occur in the deep hole but do not occur outside of the deep hole in most years. The exceptions to this are the period between 2011 and 2013, where anoxic conditions were observed in the shallower areas of the lake (up to 10 meters in 2012 and 2013), which persisted from mid- to late-September through early November. The

² Note that CDM Smith's previous analysis (Phase 1 in 2013) used the more conservative threshold of 2 mg/L to define anoxic conditions based on guidance in Nürnberg (1995), which indicated that if the data were believed to be of questionable quality or if large portions of the hypolimnion had dissolved oxygen concentrations between 1 and 2 mg/L. At the time that the Phase 1 study was written, both 2011 and 2012 were characterized by extensive areas below 2 mg/L; data collected in the subsequent ten years are generally above 2 mg/L, even in the deep hole. Based on the new data the lower threshold of 1 mg/L was selected for this updated assessment.

severity and extent of anoxic conditions in 2012, when the fish kill occurred, was notable, with the highest anoxic factor on record – 13.2, exceeding Nürnberg’s 10-day threshold for a healthy, oligotrophic lake. The data collected since 2013, however, indicate little to no anoxia, with recorded dissolved oxygen concentrations below 1 mg/L occurring only in 2016 below 30 meters and in 2019 below 14 meters (albeit briefly), and 2022 (not indicated in these plots but reported by AWD/LWD staff).

Table 2-3 Statistics on the Spatial Extent and Severity of Anoxic Conditions

Year	Shallowest Depth of Anoxic Conditions (m)	Start of Anoxic Conditions	Last Recorded Anoxic Conditions	Anoxic Factor (Days)
1994 ¹	27 (8/10) 32 (10/27)	8/10/1994 10/20/1994	8/10/1994 10/27/1994	0.17
2002	30	10/10/2002	10/25/2002	0.36
2004	34	10/29/2004	10/29/2004	0.04
2011	17	9/28/2011	11/3/2011	2.95
2012	10	9/13/2012	11/1/2012	13.22
2013	10	9/13/2013	11/8/2013	4.02
2016	30	10/6/2016	10/27/2016	0.28
2019	14	10/24/2019	11/7/2019	0.58

Notes: 1. 1994 anoxia observed on 8/10, but recovered by the subsequent monitoring date on 8/25. Anoxia reoccurs on 10/20 and remains through the 10/27 monitoring date

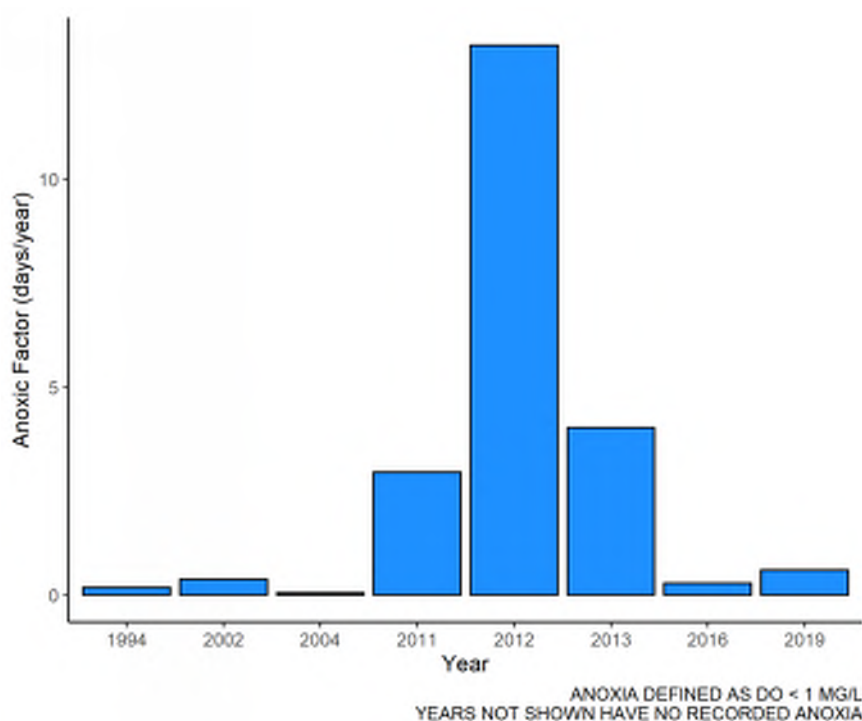


Figure 2-30
Anoxic Factor for Lake Auburn, 1980 through 2021

Note: Anoxic conditions were also reported in 2022, though this is not included as only a partial data record was available when the report analysis was completed

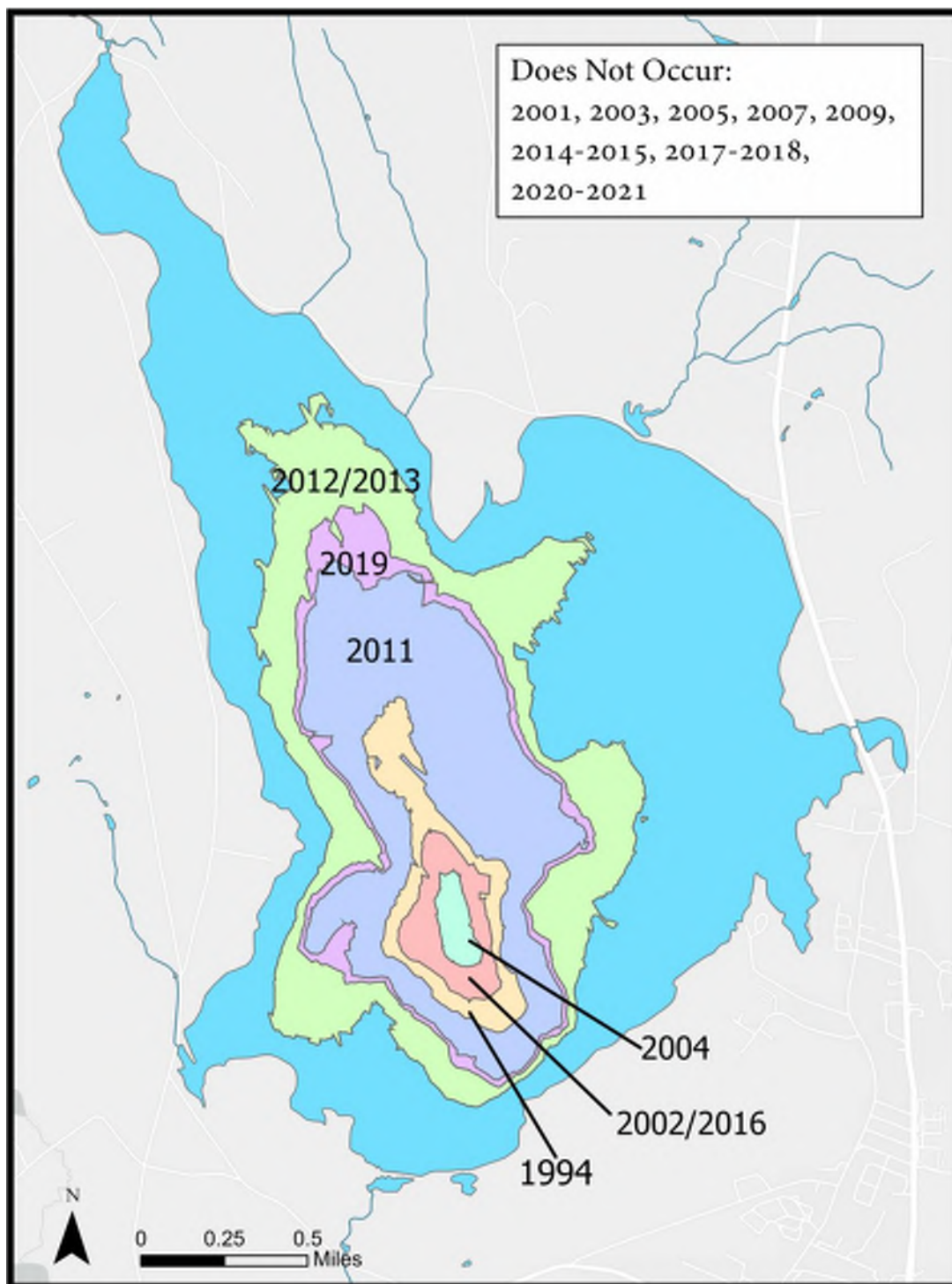


Figure 2-31
Maximum Spatial Extent of Anoxia (DO < 1 mg/L) in Each Year (1994 through 2021)
Note: Anoxic conditions were also reported in 2022, though this is not included as only a partial data record was available when the report analysis was completed

2.4.4 Phosphorus, Chlorophyll *a*, and Algae

Water quality data are collected from 11 locations within Lake Auburn by the Lake Auburn Water Quality Team and Bates College. Data on nutrients, chlorophyll *a*, and algal counts were evaluated to establish the current water quality condition of Lake Auburn and to evaluate potential water quality changes since the 2011/2012 algal bloom and fish kill, the 2018 algal bloom, the 2018 algaecide treatment, and the 2019 aluminum sulfate treatment.

Phosphorus

Total phosphorus was measured in surface and deep samples collected throughout Lake Auburn. Limited samples were collected for in-lake nutrient levels prior to 2011, with deep samples for phosphorus starting in 2014. There was also a significant increase in the frequency and number of locations in 2011 that has continued through present day.

In-lake total phosphorus data were evaluated in two ways:

- **Monthly average surface and deep phosphorus:** The average epilimnetic (core, collected at stations across the entire lake) and deep total phosphorus concentrations are presented in **Figure 2-32**.
- **Annual statistics of surface and deep phosphorus:** All phosphorus data collected in the epilimnion (core samples) and hypolimnion are presented in boxplot format in **Figure 2-33** for all sites. Both plots start in 2005 coincident with the start of most of the nutrient sampling data within Lake Auburn; occasional samples were collected in previous years.

The phosphorus monitoring data can be used to understand the potential for algal productivity in Lake Auburn. In general, values less than 10 µg/L are considered desirable as they are indicative of lakes with low algal productivity, while values above 25 µg/L are considered undesirable with high levels of algal productivity. Increases in hypolimnetic total phosphorus throughout the monitoring season are indicative of release of phosphorus from sediment while the lake is stratified.

- Prior to the alum treatment in 2019, hypolimnetic phosphorus increased significantly throughout the period of stratification. The largest increase in hypolimnetic phosphorus concentrations correspond to years when anoxia was present (**Table 2-3** and **Figure 2-30**): 2011, 2012, 2013, 2016, and possibly 2019 where hypolimnetic phosphorus levels were affected by the alum treatment. Most of these years also had large algal blooms, though some were also influenced by large external loads. Between 2013 and the 2019 alum treatment, several years had more modest increases in hypolimnetic phosphorus levels, which is notable as anoxic conditions (< 1 mg/L dissolved oxygen) were not measured suggesting that the phosphorus regeneration is likely still occurring at sediment-water interface. Even though the DO remained above 1 mg/L in these years, late summer DO is often below 4 mg/L and frequently below 2 mg/L, suggesting a significant hypolimnetic oxygen demand and further supporting the likelihood of anoxia at the sediment-water interface.
- Median and average epilimnetic phosphorus concentrations were elevated in 2010 through 2019, but have decreased following the alum treatment to below 10 µg/L. The lake-wide

mean epilimnetic phosphorus concentrations post-alum treatment represent some of the lowest concentrations on record, noting the data set prior to 2010 is relatively sparse.

- Following the 2019 alum treatment (2020 and 2021), the hypolimnetic phosphorus concentration is significantly and noticeably lower than in previous years, but the lack of anoxic conditions in the hypolimnion may have reduced the potential phosphorus flux.
- Both 2021 and the first portion of 2022 show a slight increase in both surface and deep phosphorus concentrations through the growing season suggesting that internal and external loads are slowly raising the lake's phosphorus levels following the 2019 alum treatment.
- While the overall epilimnetic total phosphorous concentrations have decreased since the alum treatment, occasional outliers have occurred in 2020, 2021, and 2022. The outliers were especially high in 2022, with two core measurements exceeding 40 µg/L (August 30 at sites 29 and 32).
- The partial 2022 data (through September) show an increasing trend in deep phosphorus levels. This corresponds with the first period of recorded anoxia since the 2019 alum treatment, and may suggest that an additional follow-up alum treatment may be required to further reduce the potential for internal phosphorus flux. This is consistent with the planning for the 2019 alum treatment, where about half the dose required to fully inactivate the sediment phosphorus was applied.

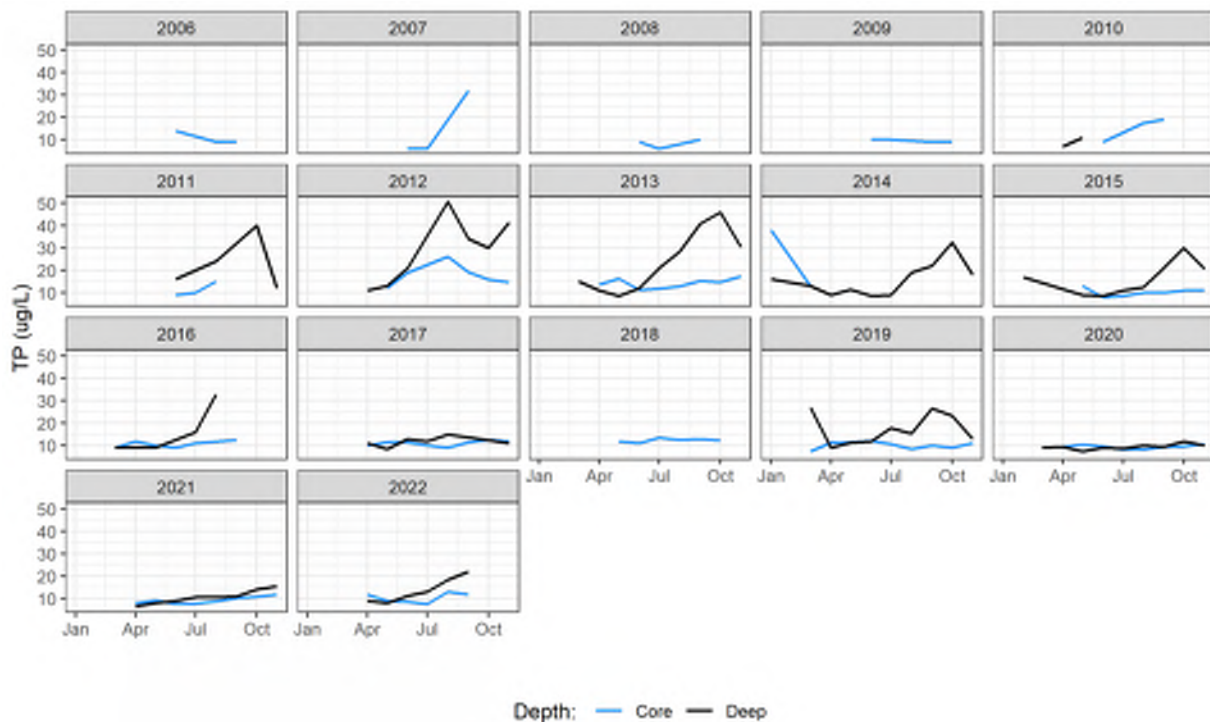


Figure 2-32
Deep Hole Monthly Average Total Phosphorus in the Surface (Core) and Deep (Deepest Sample on Each Sampling Day > 20 m)

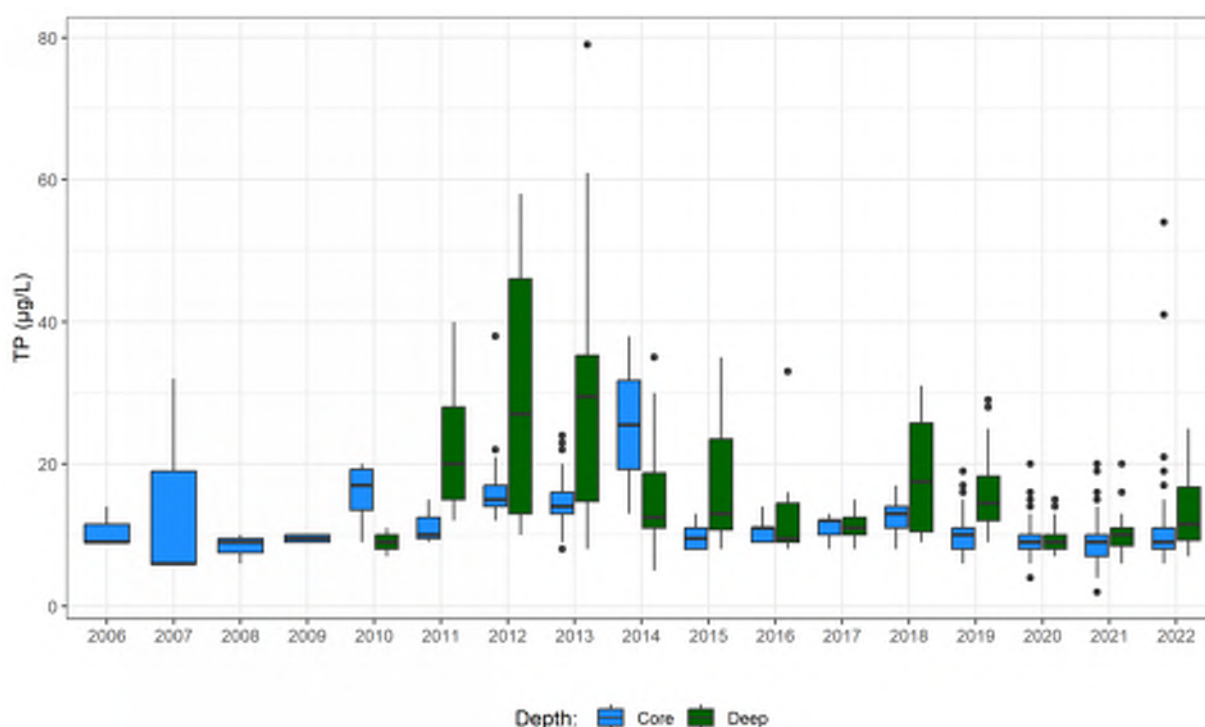


Figure 2-33
Range of Surface and Deep Total Phosphorus at All In-lake Monitoring Locations, 2005-2022

Chlorophyll *a* and Algae

Chlorophyll *a* and algal data were evaluated using two datasets:

- Lab samples of chlorophyll *a*:** Chlorophyll *a* is a measure of algal productivity, where this parameter represents the concentration of the primary photosynthetic pigment in algae and cyanobacteria. Chlorophyll *a* data were collected periodically in Lake Auburn prior to 2013, and routinely as epilimnetic core samples between 2013 and present day. The more detailed data permit an understanding of annualized trends in algal productivity and also provide insight into seasonal succession of algae within each year.
- Algal enumeration and identification:** AWD/LWD has completed algal enumeration and identification in its lab since 2013. The taxonomic analysis completed by AWD/LWD provides more insight into the annual and seasonal trends in algal dominance within Lake Auburn.

Chlorophyll *a*

Chlorophyll *a* data were evaluated based on the annual average (**Figure 2-34**), monthly average (**Figure 2-35**), and each individual measurement observed during each year (**Figure 2-36**) to examine trends in algal productivity across the dataset. Annual mean chlorophyll *a* concentrations have decreased since the 2011, 2012, and 2013 algal blooms, going from a 2012 through 2013 annual average of 9 µg/L to a 2019 through 2021 annual average concentration of 1.7 µg/L. Elevated chlorophyll *a* concentrations are evident in late summer 2018 corresponding

to the cyanobacteria (*Dolichospermum (Anabaena)*) bloom that was treated with copper sulfate in late 2018.

Following the 2019 alum treatment, chlorophyll *a* concentrations were comparatively low in 2020 and 2021 compared with conditions in previous years.

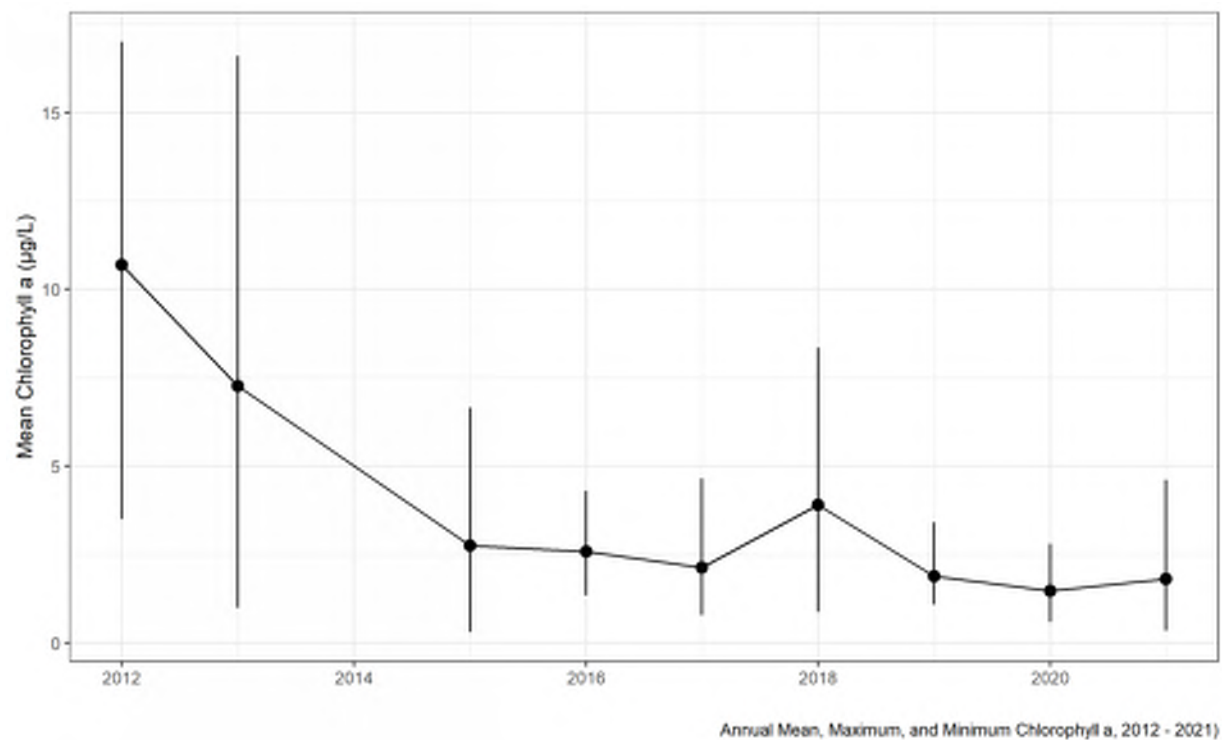


Figure 2-34
Annual Average, Minimum, and Maximum Chlorophyll *a*, Lake Auburn, 2012 – 2021
Note: Data collected prior to 2012 not included

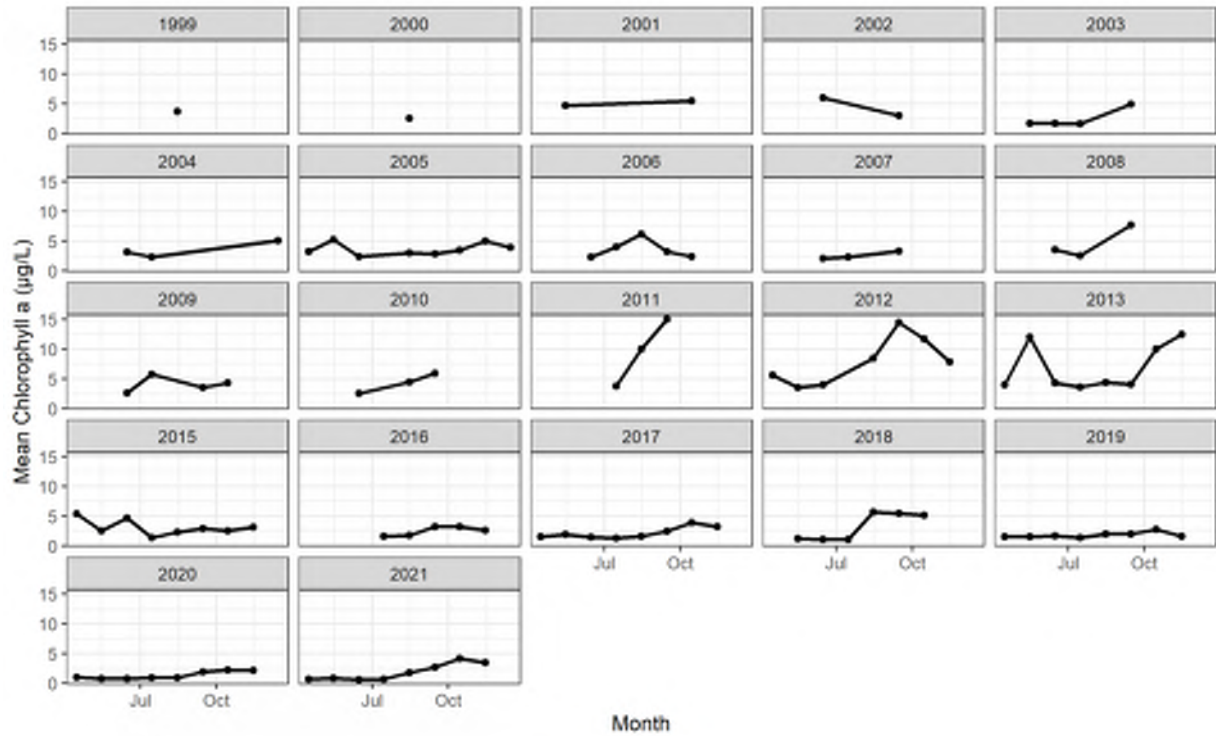


Figure 2-35
Monthly Mean Epilimnetic Core Chlorophyll *a* in Lake Auburn, 1999 through 2021

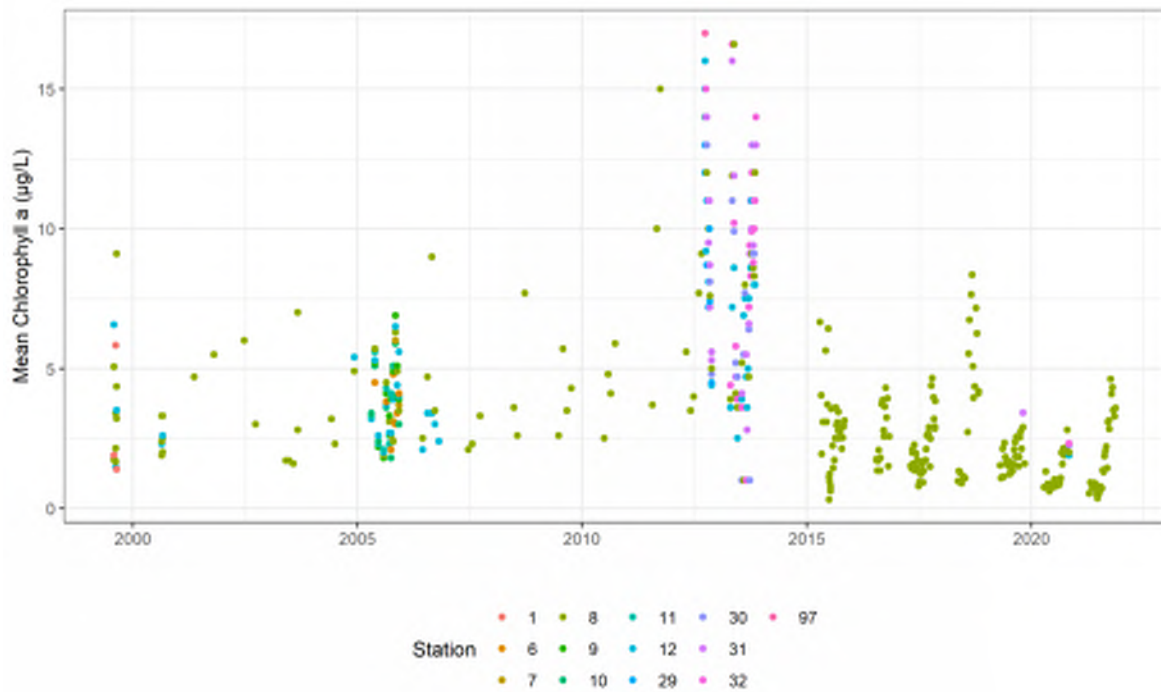


Figure 2-36
All Epilimnetic Core Chlorophyll *a* Data, 1999 through 2021

The chlorophyll *a* data collected by AWD/LWD show patterns typical of northern temperate lakes, where relatively higher algal productivity occurs in the spring and fall (both corresponding to the spring and fall destratification and subsequent mixing of deep nutrients into the photic zone) and a summer clearwater phase, where the stable stratified condition in summer results in low nutrient availability in the epilimnion.

Algal Enumeration

AWD/LWD has collected algal samples since 2013 for enumeration and identification at the Deep Hole (when no ice is present) and at the wet well (when ice is present). Considerable interannual variability exists within the succession of algal populations within a lake. Variables include the timing, duration, and strength of stratification, temperature, nutrient availability, and grazing by zooplankton. However, a generalized model of seasonal successional patterns can be inferred from the seasonality of dimictic temperature lakes (such as Lake Auburn). As an example, **Figure 2-37** presents a typical biomass seasonal succession across eight periods within each year. This seasonal succession depends on physical characteristics (spring and fall turnover and summer stratification), nutrient availability, and zooplankton grazing. While algal population dynamics are complex and difficult to generalize, this progression provides a framework for understanding trends in algal populations within Lake Auburn.

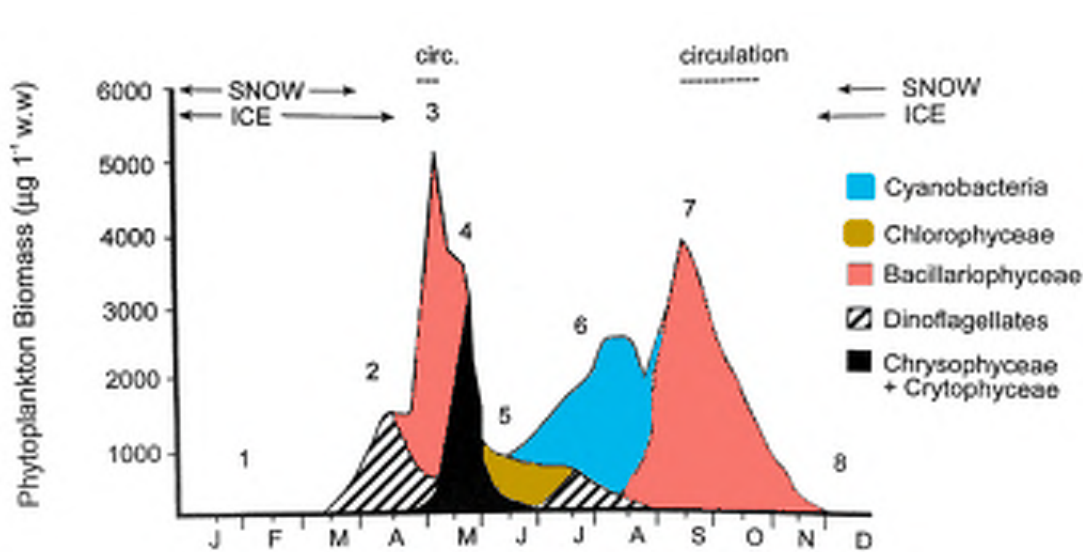


Figure 2-37
Typical Seasonal Succession of Major Phytoplankton Groups in a Moderate Productivity Temperate Lake
 Reproduced from Wetzel (2001) showing biomass data from Lake Erken, Sweden.

Numbers identify seasonal periods (Wetzel, 2001):

1. *Midwinter* with low temperatures, stable stratification, limited light, moderate nutrient availability, and low zooplankton grazing. Low phytoplankton biomass dominated by ultraplankton. Dominant algae are small and motile.
2. *Late winter* is characterized by similar conditions as in midwinter, but light availability increases. Dominant algae are dinoflagellates that are able to migrate vertically and small centric diatoms.
3. *Spring circulation* is the period of spring turnover as the ice melts, with increasing light and high nutrient availability. Typically, diatoms are dominant during the spring algal bloom.

4. *Initial summer stratification* is characterized by rapidly increasing temperatures within the epilimnion, increased light availability, and decreasing nutrient availability. This period coincides with a decrease in diatom biomass due to settling and phosphorus limitation and increasing zooplankton grazing rates. Small flagellate algae (e.g., golden-browns [*Chrysophyceae*] and *Cryptophyceae*) are dominant in this period.
5. *Summer clearwater phase* corresponds to high temperatures, high water column stability, high light availability, low nutrient availability, and high zooplankton grazing rates. This results in a period of relatively low biomass.
6. *Late summer* represents the period in late summer where the lake is still stratified, but the metalimnion is eroding and deepening, temperatures remain high, light availability is high but declining, and zooplankton grazing is decreasing. Algal dominance in this period depends on nutrient availability. Green algae are often abundant, but if silica is available in sufficient quantities, diatoms can dominate during this period. However, if the lake is both silica and nitrogen limited (or after these nutrients have been reduced to limiting levels), cyanobacteria can increase due to their nitrogen fixing ability, allowing this type of algae to out-compete other taxa.
7. *Fall circulation* occurs after fall turnover, and is often dominated by diatoms after nutrient-rich water from the hypolimnion is mixed throughout the water column.
8. *Late autumn decline* is characterized by low temperatures, declining light, and low nutrient availability, with a concomitant decline in biomass.

The Lake Auburn data show significant variability year-over-year, with considerable variation following the 2019 alum treatment. Algal cell count and biomass concentrations post-alum are shown in **Figures 2-38** through **2-41**, with plots of the remaining years in **Appendix E**. These data indicate that spring and fall are often dominated by diatoms, and that significant populations of golden-browns are evident in late spring/early summer. Occasional blooms of cyanobacteria occur in late summer and early fall; note that the 2018 algal bloom – although not currently in the algal identification dataset from AWD/LWD – was comprised of a cyanobacteria bloom (*Dolichospermum* (*Anabaena*)).

Changes from historical succession patterns appear evident following the 2019 alum treatment, although there is considerable interannual variation in the data so it is difficult to assign all of these changes to the alum treatment, and some are likely due to interannual variability. In late summer 2019 (following Phase 1 of the treatment), golden-browns (predominantly *Chrysosphaerella* and *Synura*) were dominant, and then almost no biomass was observed during and after the Phase 2 treatment in October. In 2020, a large diatom bloom (predominantly *Tabellaria*) occurred in late fall. However, this bloom did not appear to have a significant impact on turbidity or Secchi depth. Late summer/early fall 2021 and 2022 both consisted of an increased dominance of cyanobacteria (in both cases *Dolichospermum*) coupled with a decline in water clarity, noting that the chlorophyll *a* concentration and turbidity both remained much lower than the algal blooms in 2011, 2012, and 2018. Nonetheless, the increase in cyanobacteria abundance and the reduced water clarity is a potential water quality concern.

While elevated turbidity appears to be causally related to elevated chlorophyll *a* concentrations and high algal cell counts, this does not always appear to be the case. For instance, the algal cell counts and biomass in 2017 were relatively low compared to other years observed, but elevated turbidity and low Secchi depths were observed. A similar observation can be made for 2021, where there was an observed cyanobacteria bloom, but chlorophyll *a* concentrations were relatively low (relative to the 2011 and 2012 levels, approaching 5 µg/L) yet high turbidity and

low Secchi depths were observed in the late fall. Therefore, it is possible that additional sources of turbidity besides algae are present and are impacting the water clarity at the intake. Additional data collection on in situ turbidity and organic material could be collected to better answer these questions about the source of turbidity, especially in years where algal productivity appears to be relatively low (see **Section 5.5**).

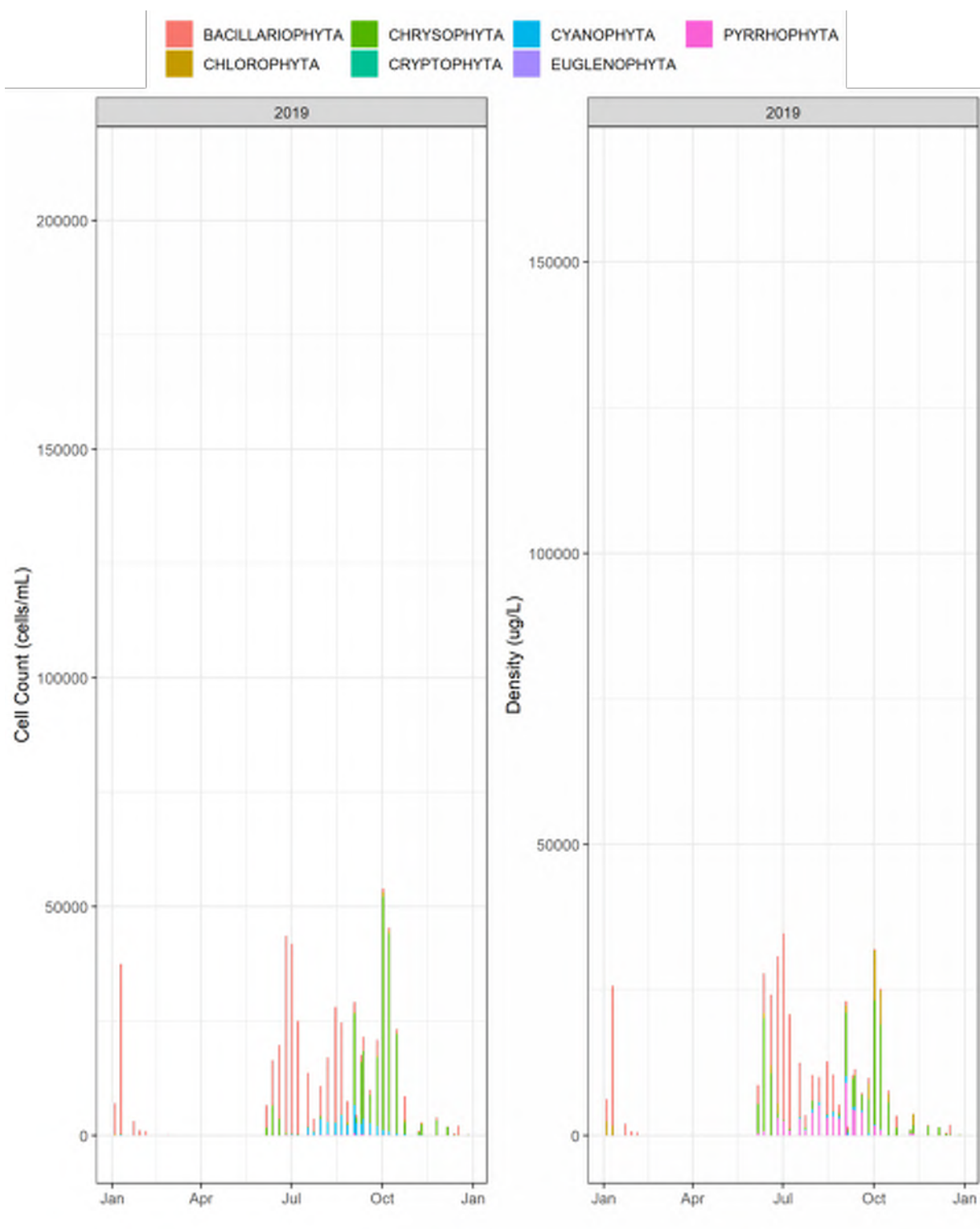


Figure 2-38
Algal Cell Count and Cell Density in 2019

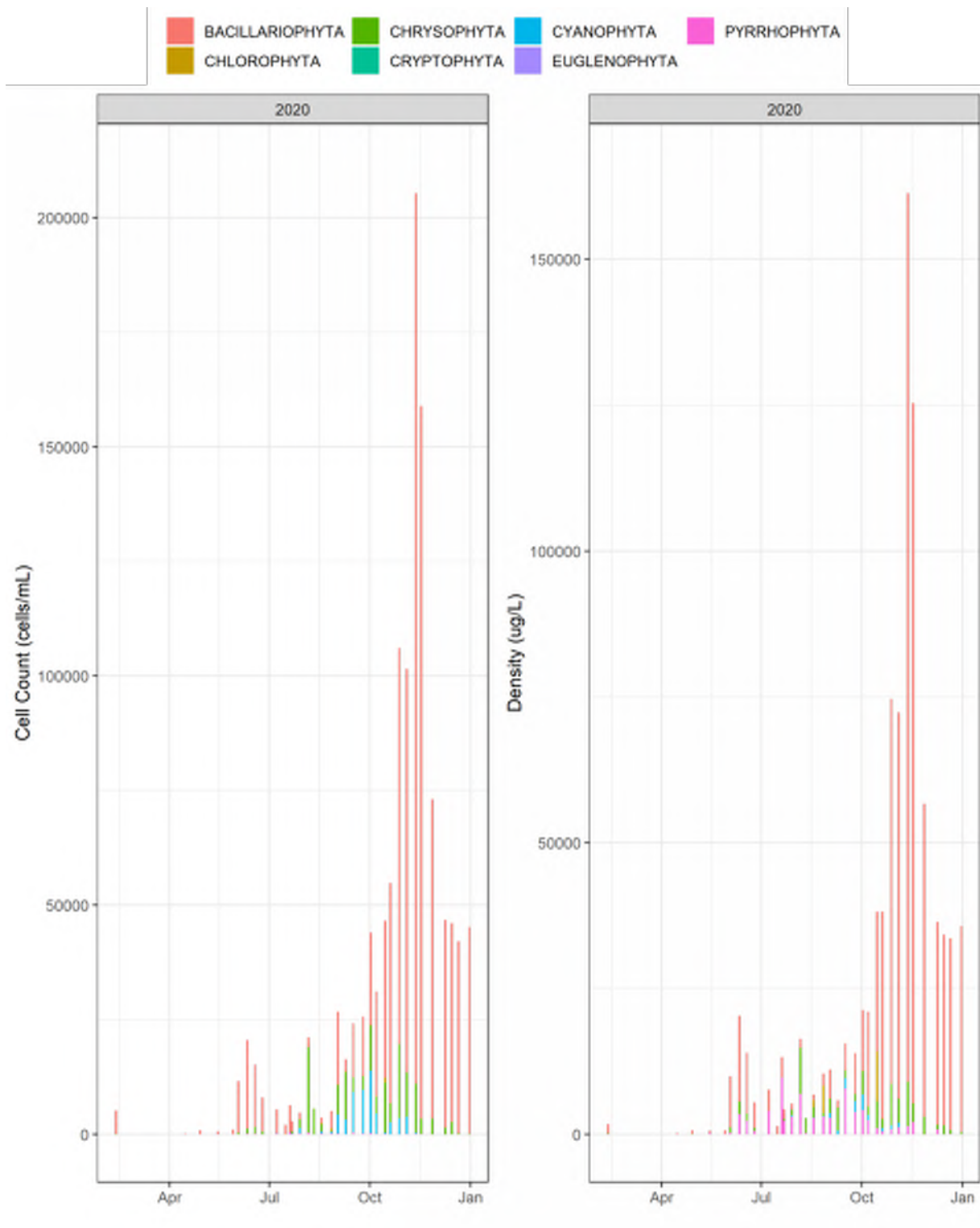


Figure 2-39
Algal Cell Count and Cell Density in 2020

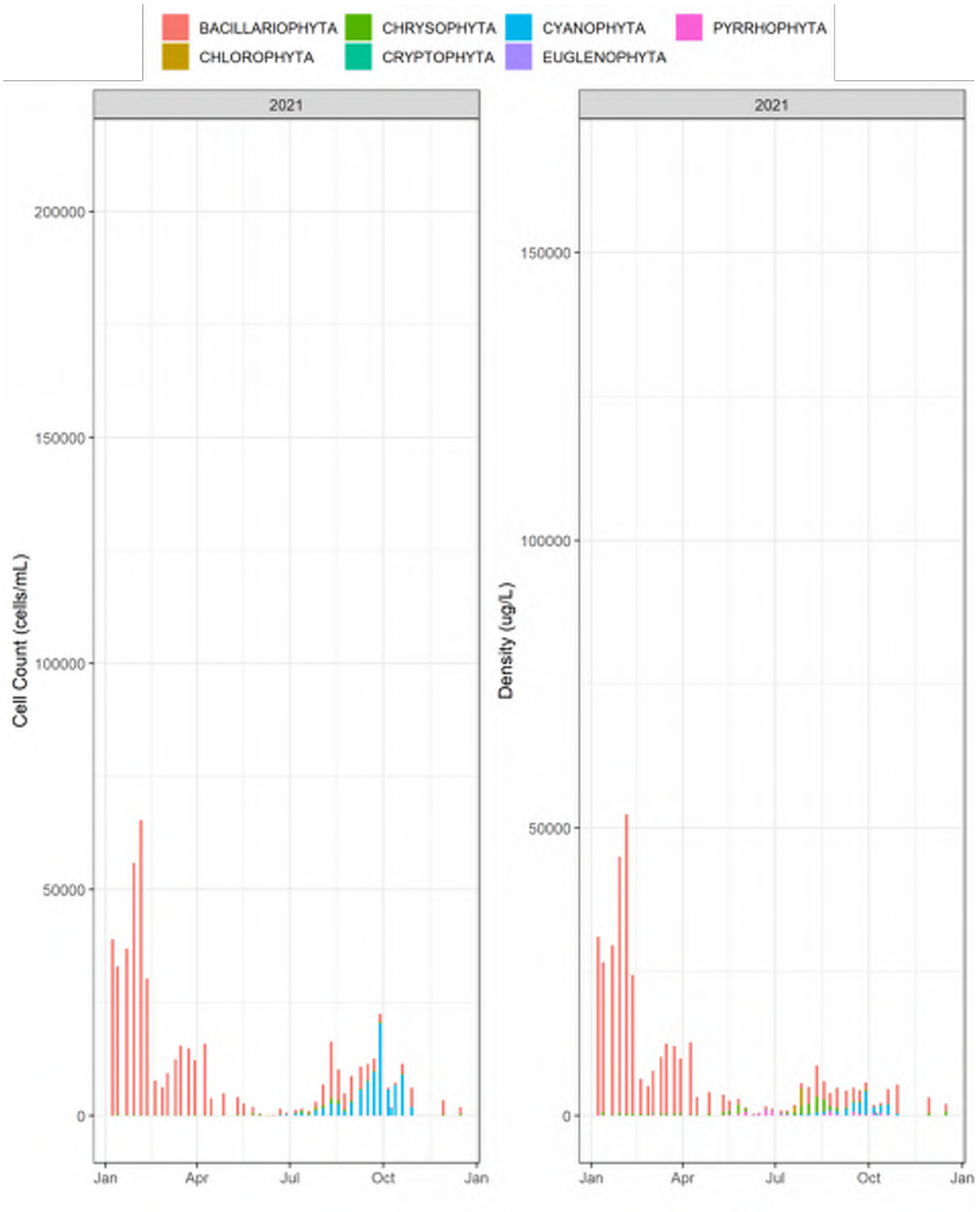


Figure 2-40
Algal Cell Count and Cell Density in 2021

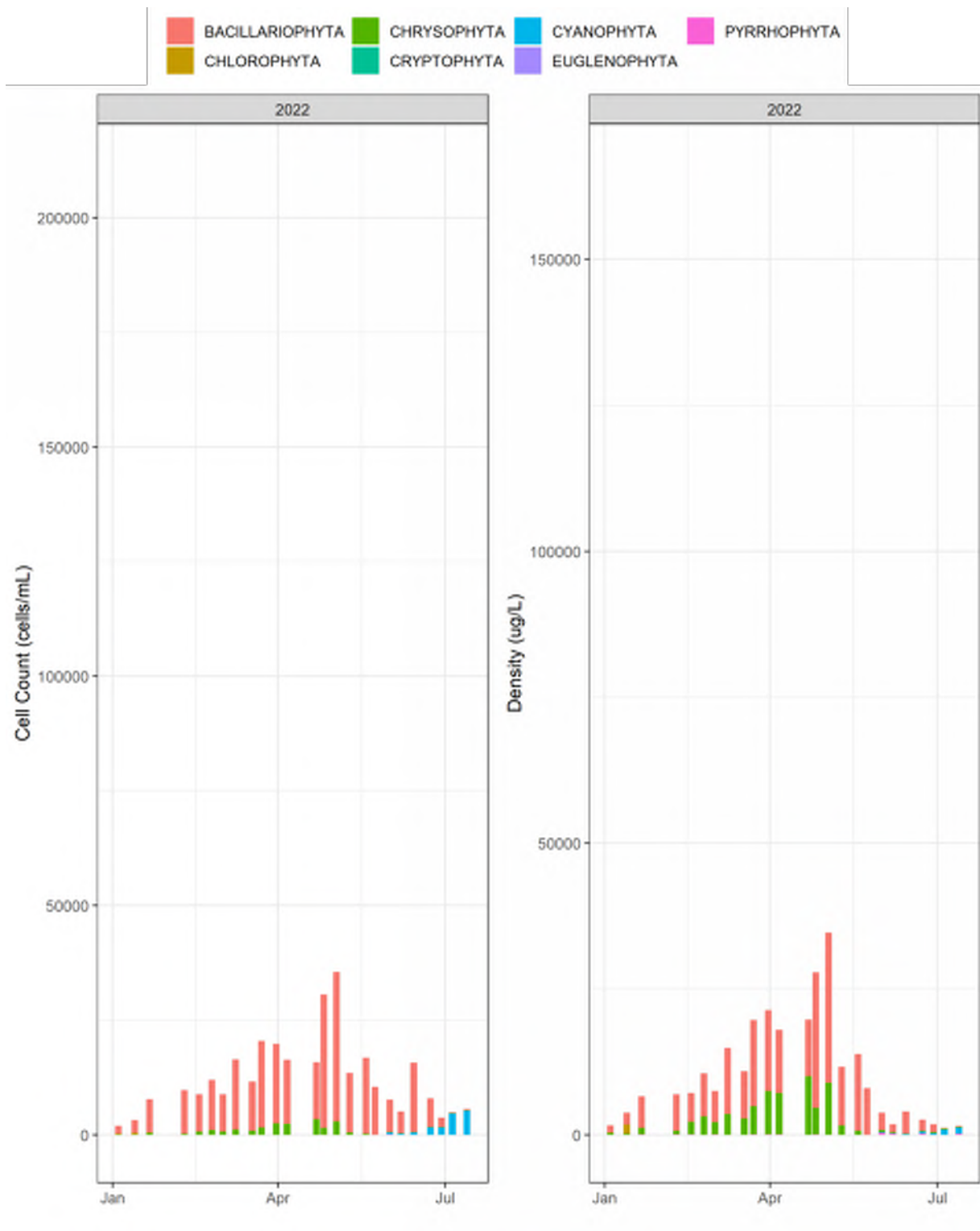


Figure 2-41
Algal Cell Count and Cell Density in 2022

Note: Both whole water and plankton tow samples were analyzed in 2022; this plot shows tow samples for comparability with prior years' sampling

2.4.5 Translating Lake Data to Trophic State

Water quality data collected within Lake Auburn were compared against Carlson's Trophic State Index (TSI; Carlson, 1977) and a general trophic classification of lakes based on Vollenweider (1979) (as cited in Wetzel, 2001).

Carlson's TSI is an empirical model that relates chlorophyll *a*, surface phosphorus, and Secchi depth measurements to an index between 0 and 100; 0 represents an oligotrophic lake and 100 a hypereutrophic lake using the following equations.

$$TSI(CHL) = 9.81 \ln(CHL) + 30.6$$

$$TSI(SD) = 60 - 14.41 \ln(SD)$$

$$TSI(TP) = 14.42 \ln(TP) + 4.15$$

While Carlson notes that shifts between trophic states “do not occur at sharply defined places,” Wetzel (2001) broadly interprets the TSI to indicate that values less than 30 are indicative of oligotrophic conditions, values between 50 and 70 of eutrophic conditions, and values above 70 indicative of hypertrophic conditions (**Table 2-4**).

Table 2-4 Trophic Status Index (Carlson, 1977)

TSI	Chlorophyll <i>a</i> (µg/L)	Surface Phosphorus (µg/L)	Secchi Depth (m)	Trophic State (Wetzel, 2001)
0	0.04	0.75	64	Oligotrophic
10	0.12	1.5	32	
20	0.34	3	16	
30	0.94	6	8	
40	2.6	12	4	Mesotrophic
50	6.4	24	2	Eutrophic
60	20	48	1	
70	56	96	0.5	
80	154	192	0.25	Hypereutrophic
90	427	384	0.12	
100	1,183	768	0.062	

Note: TSI reproduced from Table 1 in Carlson, 1977; trophic state is based on Wetzel (2001)

The TSI was calculated for the annual average chlorophyll *a*, total phosphorus, and Secchi depth measurements for Lake Auburn across the period of record, and are plotted by year in **Figure 2-42**. Considering the TSI for chlorophyll *a* and total phosphorus, Lake Auburn was best described as mesotrophic prior to and following the 2011/2012 algal blooms. The elevated chlorophyll *a* concentrations observed during the 2011 and 2012 algal blooms are suggestive of eutrophic conditions. Following the 2019 alum treatment, the three indices suggest oligotrophy, owing to the reduction in water column phosphorus concentrations and the relatively low chlorophyll *a* concentrations. The exception to this trend is in the Secchi depth TSI; the Secchi depth TSI indicates that Lake Auburn Secchi depth, on an annual basis, falls generally within the

oligotrophic classification, albeit with the TSI increasing during the 2011/2012 algal blooms. This can likely be attributed to the relatively deep Secchi depths in Lake Auburn observed over time and the historically short duration of algal blooms that cause turbidity increases.

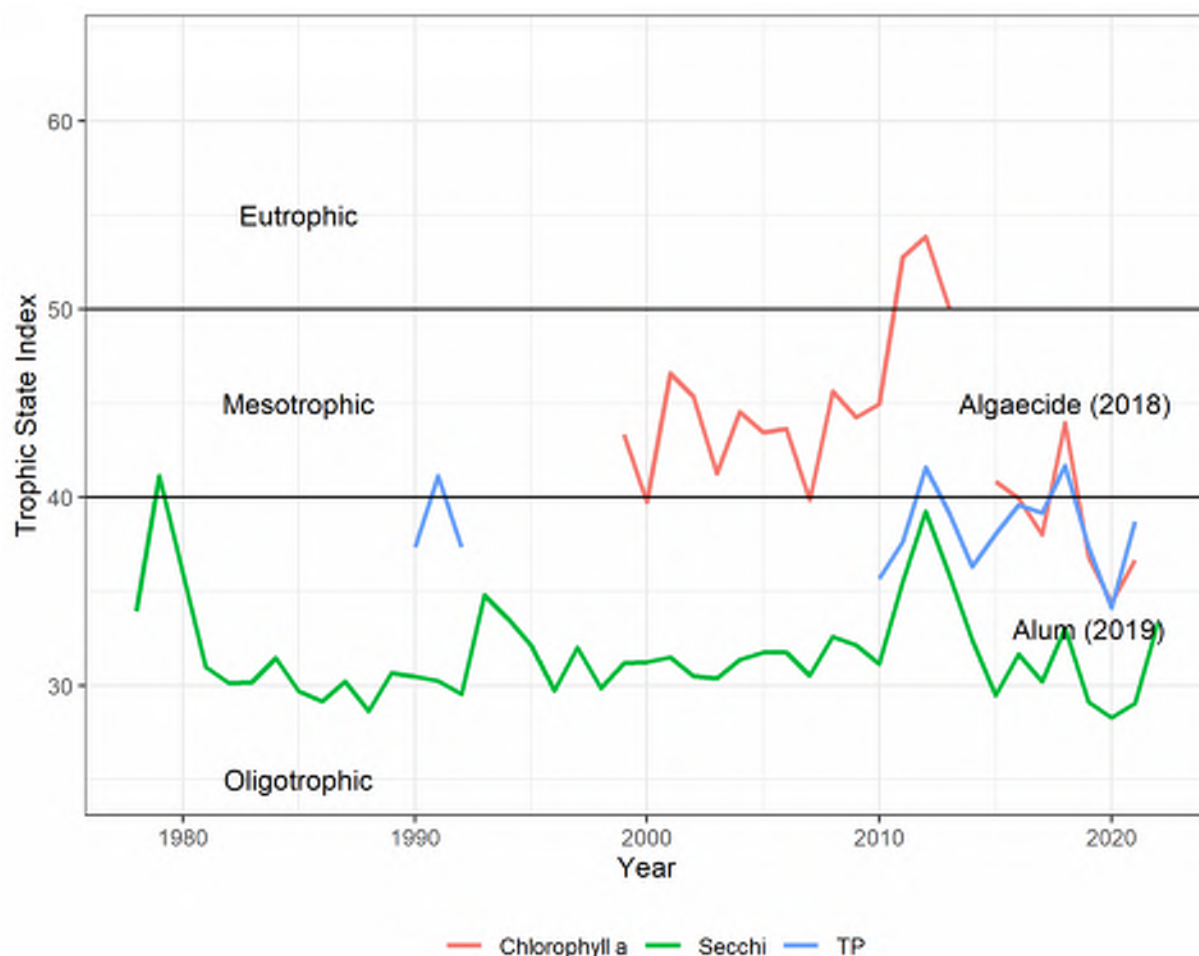


Figure 2-42
Annual Trophic State Index for Lake Auburn

The three trophic state indices deviate from each other, where the Secchi TSI is always much lower than the chlorophyll *a* and total phosphorus indices. This result is typical; Carlson (1991) indicates that the TSI frequently diverges for the three state variables. The relationship between the three indices can be used to infer the potential source of turbidity (algal or non-algal) and whether phosphorus-limited conditions dominate. This relationship is plotted for Lake Auburn for years where all three indices were calculated (**Figure 2-43**). The annotation on the plot is adapted from Carlson's (1991) interpretation of the relationship between the three trophic state indices. Values above the zero y-axis are suggestive of phosphorus limiting conditions, and values to the right of the zero x-axis suggest that the primary source of turbidity is derived from large particles.

The relationship of the three indices suggest that phosphorus limited conditions dominate (the main exception, 1999, is characterized by limited, but high, total phosphorus data and may not be representative), and that the primary source of turbidity is likely algal in nature (as opposed to DOM or clay). Note that this analysis is based on the annual average conditions and represent the central tendency on an annualized basis. This will therefore not necessarily capture the impact of short-duration turbidity increases from sediment inflows or resuspension nor the impact of short duration, but potentially impactful, cyanobacteria blooms on water column turbidity.

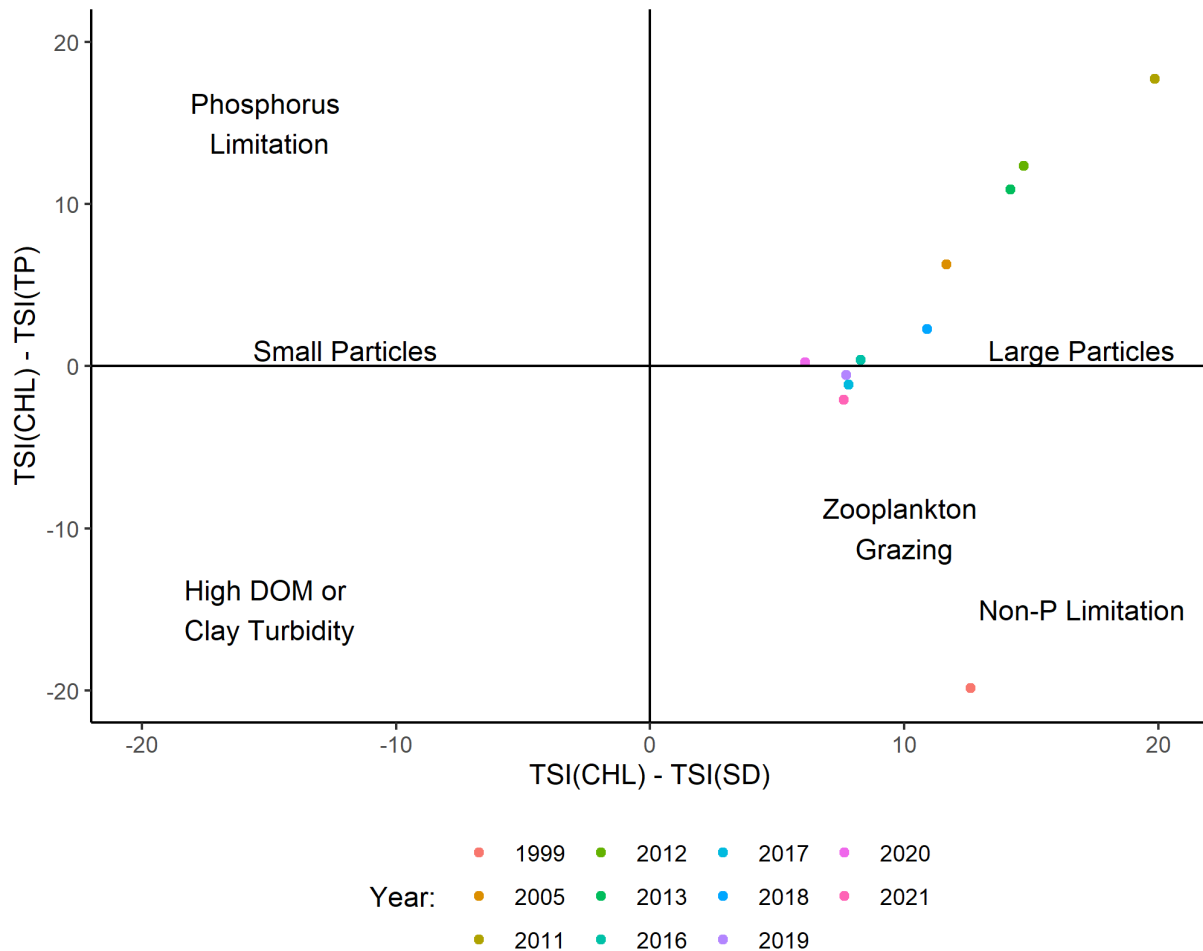


Figure 2-43
Potential Nutrient-limited and Non-nutrient-limited Causes for Deviation of TSI

2.5 Summary of Water Quality Issues and Trends

This section summarizes the water quality issues identified through the 2022 watershed survey, discussions with AWD/LWD staff, and a review of satellite imagery, and provides an integrated assessment of lake water quality to identify potential causes of high algal productivity and turbidity.

2.5.1 Summary of Watershed Water Quality Concerns

The Lake Auburn watershed is largely forested, with a substantial portion in the City of Auburn either owned by or controlled by LAWPC, including most of the immediate shoreline of Lake Auburn. This provides substantial watershed protection to preserve source water quality. Despite the protection afforded by the largely forested watershed, modest increases in development have occurred over the past 20 years, contributing to increases in phosphorus and sediment loads to Lake Auburn. Key findings from the watershed survey, discussions with AWD/LWD, a review of historical satellite imagery and land use trends, and watershed monitoring data are described below.

- Tributary phosphorus concentrations are generally low – often below 20 µg/L – with a few exceptions: First Brook (Site 25), Horse Pond (Site 23), McCafferty Farm, Roy’s, and Spring Road. An increasing trend in phosphorus concentrations is evident for many perimeter monitoring locations, and many exhibit an increase in variability with more high concentration outliers than have been observed in previous years.
- The watershed survey found the largest potential sources of erosion and phosphorus loading are from development within the watershed – both from stormwater drainage issues in the vicinity of roads and culverts and from private development with poor erosion controls.
 - Modifications to stormwater infrastructure at roads and culverts increases phosphorus loading potential. An example of this is Spring Road, where stormwater drainage from the uphill Auburn Road causes erosion on the steep slope, and the cross culvert drainage on Spring Road causes erosion towards the lake and Lake Shore Drive.
 - Private logging operations and construction sites were observed to have inadequate erosion controls, potentially contributing to additional watershed load.
- Development has increased within Minot and Turner, especially around Mud Pond and Little Wilson Pond. This has included the construction of new residential subdivisions on land that was formerly forest or agricultural land use.
- Commercial and agricultural land uses on Route 4 and Lake Shore Drive show a high potential risk for phosphorus loading to Lake Auburn. This is supported by the relatively high phosphorus concentrations observed in tributary samples collected in these areas.

These findings suggest that additional watershed BMPs to mitigate the increase in load from new development can improve source water protection and that additional development throughout the watershed represents a future risk to water quality. LAWPC should continue to strategically acquire property within the watershed to reduce the future development potential.

2.5.2 Summary of Lake Water Quality Trends and Drivers

The water quality data presented in this report indicate that Lake Auburn's water quality exhibits a substantial degree of interannual variability, with poor water quality conditions (marked by high phosphorus, high turbidity, and low Secchi depths) occurring with some regularity in the last ten years. To better explore the interannual variability and potential causes for differential water quality among the years, key drivers and water quality indicators were assessed for each year since 2001. These key drivers and water quality indicators by year, calculated or obtained from our analysis, are summarized in **Table 2-5** from 2001 to present day (noting that 2022 represents a partial year of data).

Several factors may contribute to high turbidity and algal blooms. Examples of key water quality drivers and indicators are described for each year since 2001 in **Table 2-6**. The drivers and indicators suggest strongly that increased precipitation and elevated lake temperature are related to the increased likelihood of elevated turbidity events where years with high lake temperatures and large storms are well-correlated to anoxia, algal blooms, and elevated turbidity.

Table 2-5 Assessment of Key Trends in Lake Auburn Water Quality

Factor	Description	Key Examples and Potential Links to Turbidity and Algae
Precipitation	More frequent large storms have been recorded in recent years, with several significant (> 5-year average recurrence interval) storms. These storms have the potential to deliver a significant watershed load of organic material and phosphorus to Lake Auburn; depending on the time of year, they both can cause an increased hypolimnetic oxygen demand and the potential for algal blooms. In addition, large storms can add sediment to the water column, potentially increasing non-algal turbidity within the water column.	2006: large storms in May and October, and elevated chlorophyll <i>a</i> in summer with low fall Secchi depth. 2012: exceptionally wet June followed by complete hypolimnetic anoxia and fish kill. 2014: wet summer and record low Secchi depth and high chlorophyll <i>a</i> concentrations. 2017: wet October, followed by elevated chlorophyll <i>a</i> and low Secchi depth. 2021: wet July and November, with cyanobacteria bloom in October corresponding to low Secchi/high turbidity.
Temperature	Statistically significant increasing trends in intake temperature and strength of stratification have been observed in Lake Auburn. This has the potential to increase the rate of algal growth and extend the period of stratified conditions that can cause a larger extent and longer duration of hypolimnetic anoxia.	2011 through 2013: above average temperatures, significant algal productivity and high turbidity in fall. 2017: below average through most of year, with low productivity and generally deep Secchi depths. Hot October with Secchi depth of 5 m. 2021: above average fall temperatures with fall algal bloom and low turbidity.
Increased development and watershed load	An analysis of land use changes over time (FB Associates, 2021, Section 1.2.1) shows modest changes, but an overall trend of increased development, especially in the upper watershed.	Insufficient data to draw firm conclusions, but increased variability and upward trend in tributary phosphorus and turbidity may be at least partially explained by increased development.

Our analysis of water quality data collected in Lake Auburn coupled with the drivers and water quality indicators described in **Table 2-6** indicate that:

- Poor water quality is well correlated with high temperatures, intense or large rain events, and relatively high phosphorus. Elevated water column phosphorus can be derived from internal loading (for instance in 2011 and 2012) or from watershed loading due to large storms (such as 2012, and the fall algal blooms in 2021). Continued monitoring of the internal load potential coupled with continuing to reduce watershed phosphorus sources can help mitigate the risk of future poor water quality conditions.
- The hypolimnion has a large oxygen demand, evident with low dissolved oxygen conditions (<5 mg/L) in most years throughout the hypolimnion, and occasional periods of anoxia (<1 mg/L) in many years. If the right combination of external inflows of organic material, temperature, and stratification are present, there is a potential for significant and severe anoxia to develop, such as the conditions that occurred in 2011 through 2013, and for a shorter duration in 2019 and 2022. The risk of these conditions occurring is likely to increase as climate change causes more frequent and intense storms, higher temperatures, and longer and stronger stratification during the summer and fall to inhibit mixing.
- Lake Auburn total phosphorus concentrations decreased following the 2019 alum treatment, but are still elevated relative to a clean, oligotrophic lake; algal blooms have occurred since the 2019 alum treatment causing periods of elevated turbidity. Additional phosphorus loads to Lake Auburn, either through additional development in the watershed or increases in existing sources will increase the risk of algal blooms in the future.
- The elevated 2022 deep phosphorus concentrations suggest a continued potential for internal load during anoxic conditions. A follow-up alum treatment may be required to achieve further reductions in internal load.
- An increase in lake temperature is evident at the intake relative to data collected from 1952 to present. The consistent year-over-year increase in temperature is concerning, as it can contribute to both increased rates of algal productivity and stronger and more persistent stratification. An assessment of the relative strength of stratification since 1982 corroborates the increase in temperature, with the Schmidt stability index increasing year-over-year, including since the last water quality assessment was completed in 2014.
- While most of the historical record has been characterized by deep Secchi depths with low variability across the year, the historical record has occasional periods of low Secchi depth (for instance the low Secchi depths in 1993, 1994, and 1995) and high variability (for instance, 1992 and 2007) suggesting water quality in a given year has readily responded to changes in external inputs. In recent years (post 2010), more variability is evident, with record-low Secchi depths recorded approaching 2 meters; this appears to be due to increased influence of internal phosphorus load and climate change factors.
- Water clarity has increased post-alum treatment, with the deepest Secchi depths nearing 13 meters – a record high Secchi depth in the period of record in Lake Auburn. However, the high Secchi depths have been counteracted by significant variability that appear to be

associated with late fall algal blooms and potentially sediment-driven turbidity, where the water clarity in October has declined significantly in 2020, 2021, and 2022.

The water quality data and analysis indicate that Lake Auburn continues to exhibit concerning water quality trends after the 2011/2012 algal bloom and fish kill, and that these trends have persisted even after the 2019 alum treatment. This has included periods of anoxia in the hypolimnion (e.g., 2016, 2019, and 2022) and increases in the frequency of algal blooms and episodes of high turbidity. The increased temperature and strength of stratification – a climate-change driven phenomenon – has increased the likelihood of adverse water quality events within Lake Auburn. Continued monitoring and reductions in watershed and in-lake sources of phosphorus coupled with a strong watershed protection program will be important to maintaining or improving water quality.

Table 2-6 Key Drivers and Water Quality Indicators in Lake Auburn, 2001 through 2022

Year	Intake Temperature	Rainfall/Extreme Precipitation Events	Anoxia Present?	Turbidity (days daily average above 1 NTU after 2005)	Secchi Depth (months where 1 or more readings < 6 meters)	Algae/Chlorophyll (Where Data Available)
2001	Spring cooler than average; August through December warm	32.5 inches; severe drought with very low rainfall from August through the end of the year; lake level dropped 4 ft	No	Generally below 0.5 NTU; max turbidity of 1.3 NTU in October	3 months: September through November	Limited data
2002	Summer cooler than average; August through December warm	44.3 inches; well below average. April, May, and June above average	Onset 10/10; mild to 30 m	Average close to 0.5 NTU. May and August higher.	4 months: April, May, June, and October	Limited data
2003	January, February, and July through November warmer than average	46.0 inches; below average, October wetter than average	No	Average close to 0.5 NTU; one reading above 1 NTU in May and another in November	October less than 6 meters	Limited data, but low concentrations (< 3 µg/L)
2004	Generally warmer than average, with cool June and July	41.6 inches; well below average	Onset 10/29, brief and limited to deep hole	Highest in April and October	May less than 6 meters	One measurement (5 µg/L), limited data
2005	Often warmer than average, but April through June, October, and December cooler than average	65.5 inches; far above average, very wet April/May (18 inches), October; 5+ inch storm in October	No	Average turbidity above 1 NTU in April and early May	5 months: April, May, June, October, and November	Slightly elevated chlorophyll <i>a</i> , but limited data
2006	Warmer than average except for August and September	62.5 inches; well above average; large inflow associated with Mother's Day storm (3.65 inches) and October storm (4.5 inches in 48 hours, with most falling in 24 hours)	No	Average 0.51 NTU (2 days when turbidity exceeded 1 NTU)	2 months: October and November	Elevated chlorophyll <i>a</i> in summer (> 5 µg/L average, with one measurement near 10 µg/L)
2007	Generally average	45.9 inches; below average, large inflow associated with Patriots Day Storm	No	Average 0.5 NTU, with maximum daily average 0.98 NTU. (0 days)	3 months: April, May, and October	Low chlorophyll <i>a</i> , no algal data

Year	Intake Temperature	Rainfall/Extreme Precipitation Events	Anoxia Present?	Turbidity (days daily average above 1 NTU after 2005)	Secchi Depth (months where 1 or more readings < 6 meters)	Algae/Chlorophyll (Where Data Available)
2008	Cooler than average. June, July, October, and November warm	63.9 inches; well above average, large inflow associated with Hurricane Kyle in late September	No	Average 0.50 NTU (1 day)	4 months: June, September through November	No data
2009	Mostly below average, but November and December warm	60.0 inches; above average, February, September, and November wet	No	Generally below 1 NTU. (1 day)	May less than 6 meters	No data
2010	Temperatures above average. Hot July. October and December cool	55.5 inches; Slightly above average	No	Most high turbidity occurs after November 1 st (6 days)	3 months; August through October. No data for November	No data
2011	Above average T start in June. Warm October, November, and December.	50.4 inches; slightly below average	Onset 9/28; severe but not anoxic at top of hypolimnion	Record instantaneous (4.4 NTU) in September. Average far above 1 for most of summer (73 days)	6 months; April-May; Aug-Nov; shallowest Secchi depth is 2.1 m	Elevated chlorophyll <i>a</i> (limited samples but > 15 µg/L), large <i>Gleotrichia</i> bloom in June and <i>Dolichospermum</i> bloom in August/September
2012	Significantly above average for most of year; average temperatures in September and October	53.5 inches; slightly above average, June 3 storm (6 inches) increased lake level by 1 foot; total June precipitation over 12 inches	Onset 9/13; severe, with anoxic conditions across complete bottom layer	Average turbidity above 1 NTU for most of summer. Highest instantaneous value 3.6 NTU in September (92 days)	7 months: all growing season but June; near record low depths, but slightly deeper than 2011	Elevated chlorophyll <i>a</i> (> 15 µg/L) with <i>Gleotrichia</i> bloom in June and July, <i>Dolichospermum</i> in August and September.
2013	Above average February through May, with May significantly above average. About average for remainder of year, with cool August	42.3 inches, which is below average for the year. Drier than average in January and October (< 1.3 inches compared to the normal of 3.28 inches in January and 4.9 inches in October)	Onset 9/13, severe, with anoxic conditions across complete bottom layer (but less severe than 2012 based on the AF)	Average turbidity 0.8 NTU (78 days)	6 months: all growing season but April and June. Minimum Secchi depth 3.8 m in August.	Significant cyanobacteria concentrations in summer, with golden-brown bloom in late September followed by diatoms. Elevated chlorophyll <i>a</i> (> 10 µg/L) in May and Oct/Nov.

Year	Intake Temperature	Rainfall/Extreme Precipitation Events	Anoxia Present?	Turbidity (days daily average above 1 NTU after 2005)	Secchi Depth (months where 1 or more readings < 6 meters)	Algae/Chlorophyll (Where Data Available)
2014	Cool overall, with April and August significantly below average.	54.0 inches; slightly above average; dry September (<1.3 inches). Summer 2014 was wetter than normal, with two large storms in July and one in August, including a 5-year, 24-hour storm.	No	Average turbidity 0.6 NTU (2 days)	5 months: February through April, and then October and November	Elevated chlorophyll <i>a</i> concentrations (nearing 5 µg/L in summer and late fall). Low algal cell counts and biomass, but golden-browns and diatoms dominant.
2015	January through August was about average, with warmer than usual temperatures in September, November, and December	43.7 inches; slightly below average overall, and significantly below average until September. Large storm in September, with 6.25 inches in 48 hours (22 year, 48-hour event)	No	Average turbidity 0.52 (2 days)	None, minimum 6.5 m	Low algal productivity.
2016	Warmer than average January through May; average June; warmer than average August through November	45.0 inches, about average. Dry September and October until a large 4.78-inch storm occurred 10/21	Onset 10/6, mild to 30 m	Average turbidity 0.59 (7 days)	4 months, August through November. Minimum is 4.3 m in October.	Low algal productivity. October period of low Secchi appears to be coincident with high diatom biomass.
2017	Average to below average for most of the year (January through September). Significantly above average October and above average November. Below average in December.	46.0 inches, about average overall; wet October (>8 inches), including 7.38 inches over 7 days in late October (10-year, 7-day event)	No	Average turbidity 0.55 NTU and maximum daily average 1.5 NTU (18 days)	October (5 m)	Elevated chlorophyll <i>a</i> in October (nearing 5 µg/L), but low algal cell counts and biomass.
2018	Below average January through May, but significantly above average June through September. Cool fall, with temperatures significantly below average Oct through December.	46.8 inches, slightly above average overall; dry May (< 1 inch), with occasional 2-3 inch storms in April and November	No	Average turbidity 0.72 NTU and maximum daily average 2.99 NTU. High turbidity associated with algae bloom. (48 days)	3 months (August through October), with a minimum of 2.9 m in September	Significant cyanobacteria bloom in September, leading to CuSO ₄ treatment mid-September. <i>Synura</i> bloom in late fall.

Year	Intake Temperature	Rainfall/Extreme Precipitation Events	Anoxia Present?	Turbidity (days daily average above 1 NTU after 2005)	Secchi Depth (months where 1 or more readings < 6 meters)	Algae/Chlorophyll (Where Data Available)
2019	Overall below average, with spring significantly below average (March through June). Significantly above average July/August.	51.9 inches; slightly above average; dry September (<1.3 inches). No significant storms.	Onset 10/24, brief in duration but anoxia present to 14 m depth	Average turbidity 0.48 NTU, maximum 0.99 NTU (0 days)	None, minimum 6.5 m	Low algal productivity. Significant population of golden-browns between Phase 1 and Phase 2 alum treatment. Almost no algae in late fall after alum.
2020	Generally above average except May, September, and October. Significantly above average June through August.	49.3 inches, slightly above normal; December 1 st storm (3 inches in 48 hours)	No	1 day, with average turbidity 0.51 NTU (0 days)	November (4.5 m)	Large diatom bloom in fall. Chlorophyll < 3 µg/L
2021	Temperatures variable. Cool January through March, but above average April through June. Cool July and August. Above average September through November (with October significantly above average). Slightly below average in December.	44.6 inches, about normal annually. Precipitation very low until August, with an exceptionally wet July (over 11 inches, including a 4.59-inch event on 7/1 – 7/5). October 31 st storm (3 inches)	No	Average turbidity 0.59 NTU. High turbidities occur in October (18 days)	3 months (September through November), with a minimum of 3.2 m in October	Cyanobacteria (<i>Dolichospermum</i>) in October corresponding to low Secchi. Chlorophyll nears 5 µg/L in fall bloom.
2022	Below average January through March, average through June. Significantly above average in summer.	About average as of September 2022 (32.99 inches compared to Jan – Sept average of 32.16 inches).	Yes in October (partial year of data available)	(42 days through 9/30/2022)	5 months (through 10/27/2022): April, May, August through October.	Cyanobacteria (<i>Dolichospermum</i>) in October corresponding to low Secchi. No chlorophyll data.

Section 3

Watershed Plan Goals and Objectives

The Lake Auburn Watershed-based Plan is intended to be a 10-year plan with the following goals:

- Identify watershed BMPs to reduce phosphorus and sediment loads to the lake and maintain Class GPA water quality standards
- Reduce the frequency of algal blooms and occurrence of cyanobacteria
- Continue to collect water quality data to measure the efficacy of the 2019 alum treatment and future planned watershed BMPs
- Enhance AWD/LWD's strong watershed protection program to prevent or reduce the impact of any new phosphorus sources

3.1 Phosphorus Load Reduction Requirements

The load reduction needed to meet the watershed plan goals and objectives was estimated using several estimates of the internal and external phosphorus load. Internal and external loads are subject to significant inter-annual variability and uncertainty. Therefore, several sources of existing load and permissible load were used to identify the recommended phosphorus load reductions.

- CDM Smith and WRS (2013) used the Lake Loading Response Model (LLRM; AECOM, 2009) to estimate the external and internal load and the reduction required to achieve a seasonal average TP concentration of 10 µg/L.
- Comprehensive Environmental Inc. (CEI) applied the Generalized Watershed Loading Function – Enhanced (GWLF-E) model with ArcView Generalized Watershed Loading Function (AVGWLF) to estimate nutrient loads between 2001 and 2012.
- FB Associates (2021) updated the CEI GWLF-E model to estimate baseline (2018) and future watershed loads (accounting for climate change and potential development scenarios). Internal loads were estimated by comparing the difference in phosphorus concentrations between the epilimnion and hypolimnion before and after the 2019 alum treatment. A 76 percent reduction in internal load was assumed as a result of the alum treatment.

The results of the CDM Smith LLRM model, the CEI baseline model runs, and the FB Associates baseline model runs are presented in **Table 3-1**. The three approaches (noting that FB Associates updated the CEI model) resulted in consistent estimates of the internal and external load and target load, with the modeled external load slightly higher than the inferred external load from the LLRM that formed the basis of CDM Smith's 2013 estimate. This assessment suggests that the alum treatment resulted in a significant reduction in total phosphorus load to Lake Auburn in years with significant anoxia, but that an additional reduction between 11 and 25 percent in

external phosphorus load is required to meet the target load. However, given the observed internal load in 2022 and the fact that the alum dose was planned to be 50 percent of the dose required for sediment inactivation (WRS, 2019), the 76 percent reduction in the internal load cited in the FB Associates study may be overstated, resulting in an additional required phosphorus reduction to meet the plan goals.

Table 3-1 Comparison of Load Estimates for Internal and External Load

Load	CDM Smith (2013; 2014)	CEI (2013)	FB Associates (2021)
Baseline External	1,029 kg/year ¹	1,162 kg/year ⁴	1,114 kg/year ⁶
Internal Load (before alum)	348 kg/year ²	414 kg/year ⁵	373 kg/year ⁷
Internal Load (after alum)	n/a	n/a	83 kg/year ⁸
Permissible Load	988 kg/year ³	n/a	900 kg/year
Reduction Required (not including alum)	28%	n/a	39%
Reduction Required After Alum	13% ⁹	n/a	19%

Notes: 1. Average LLRM result assuming an epilimnetic phosphorus concentration of 10.3 µg/L
 2. Calculated using the LLRM based on additional phosphorus load required to match 2013 epilimnetic phosphorus concentrations (CDM Smith and WRS, 2014)
 3. Calculated using the average LLRM result to achieve a target concentration of 10 µg/L
 4. Average of 2001 through 2012 external load and atmospheric deposition
 5. Calculated based on a comparison of epilimnetic and hypolimnetic phosphorus concentrations
 6. 2018 baseline condition
 7. Calculated by comparing the difference in phosphorus concentrations between the epilimnion and hypolimnion before and after the 2019 alum treatment
 8. Assumes a 76 percent reduction in internal phosphorus load after the alum treatment (as described in the FB Associates report). No citation is given for this reduction, and the increase in internal load observed in 2022 suggests that the effectiveness of the alum treatment may be waning
 9. Assumes that the post-alum internal load is equivalent to the assumptions in the FB Associates analysis

3.2 Actions to Meet Watershed Goals

The following actions are proposed to meet the water quality goals in Lake Auburn.

- Implement priority BMPs over the 10-year planning horizon to reduce external total phosphorus and sediment loads to Lake Auburn described in **Section 5** according to the schedule presented in **Section 4**
- Continue to monitor tributary and lake water quality conditions to evaluate progress against the target concentration and loading goals
- Work to prevent increases in external phosphorus loads to the extent possible through a strong watershed protection program and strategic land purchases within the watershed
- Continue strong outreach program to targeted commercial/agricultural landowners to work with them to reduce their phosphorus loads

- Continue the strong public education program to inform watershed residents about the sensitive nature of the Lake Auburn watershed
- Continue working with other municipalities in the watershed to strengthen watershed protection
- Maintain the NPDES permit for algaecide and aluminum sulfate in case conditions require additional treatment of the lake

Section 4

Proposed Management Measures

CDM Smith used the BMP recommendations in the previous watershed plan (CEI, 2013), LAWPC's NPS Site Tracker (**Appendix A**), and the findings of the 2022 watershed survey to develop and prioritize BMPs for implementation throughout the watershed. The structural and non-structural BMPs are separated into three categories based on observed tributary phosphorus concentrations, proximity to Lake Auburn, land ownership, and best professional judgement.

1. Recommended high priority BMPs – Developed to address a prioritized list of water quality issues noted during the 2022 watershed survey, in previous watershed surveys, and through consultation with AWD/LWD staff that will have a high impact on reducing phosphorus and sediment loads to Lake Auburn and its tributaries. This list includes both structural and non-structural BMPs. Planning-level costs have been developed for these BMPs where possible.
2. Additional structural BMPs to address water quality issues found during the 2022 watershed survey. These BMPs will reduce phosphorus and sediment loading, but are located farther from Lake Auburn, are associated with smaller areas, or were judged have a lower water quality impact to Lake Auburn. Planning-level costs have been developed for these BMPs where possible.
3. Additional non-structural BMPs to strengthen LAWPC's watershed protection.

In addition, **Appendix B** contains a full list of all pollution sources identified during the 2022 watershed survey, the land use category, the relative severity (low, medium, high – see **Section 2.1**), and potential management measures.

4.1 Recommended High-priority BMPs

This section contains a brief description of each high-priority BMP, summarized in **Table 4-1**. Where feasible, **Table 4-1** includes planning level costs. These costs include a 25 percent contingency and, where appropriate, labor cost, 15 percent for general conditions and 15 percent for contractor overhead and profit. In addition, the costs assume that no rock excavation is required, only nominal dewatering is needed, and no contaminated soils or hazardous materials are present. An overview of the location of each high-priority BMP is shown in **Figure 4-1** below.

Table 4-1 High Priority BMP Recommendations for Lake Auburn

Watershed and Site(s) Addressed	Structural or Non-structural	NPS Category	Principal Concern	Recommended Actions	Planning-level Cost
Upper Watershed: The Basin	Structural	Municipal/Public	Potential for erosion on emergency spillway	Armor emergency spillway with riprap. Complete additional recommendations from 2022 dam inspection report.	Spillway: \$190,000 ¹ No costs developed for remaining 2022 dam inspection findings
	Non-structural	Municipal/Public	Significant sediment accumulation behind the Basin dam	Conduct a bathymetric and sediment depth survey in the Basin to create a baseline for monitoring additional accumulation and plan for future dredging. Monitor sediment accumulation following initial survey.	6 acres: \$10,000 to \$15,000 Entire Basin: \$70,000 – \$80,000
	Non-structural	Municipal/Public	Milfoil	Harvest or control milfoil	\$300 to \$600 per acre for hand harvesting; \$20,000 to \$50,000 per acre for benthic barriers, and \$5,000/acre for suction harvesting
Spring Road	Structural	Town Road	Erosion in western ditch	Clear sediment in the ditch, add vegetation, and schedule regular inspection	\$7,000
	Structural	Town Road	Erosion downstream of culvert crossings and on culvert embankment inlet and outlets	Construct plunge pools downstream of culvert crossings, and armor the culvert inlet and outlets	\$21,000
	Structural	Town Road	Erosion on road surface	Regrade road, construct water bars	\$3,000

Watershed and Site(s) Addressed	Structural or Non-structural	NPS Category	Principal Concern	Recommended Actions	Planning-level Cost
Lake Shore Drive	Structural	State Road	Direct runoff from the inland side of Lake Shore Drive into Lake Auburn	Add a vegetated filter strip to eroded sections of Lake Shore Drive	\$19,000
	Structural	State Road	Unpaved parking areas on the southern side of Lake Shore Drive adjacent to Lake Auburn show signs of erosion	Resurface parking areas with asphalt or pavers to prevent erosion	\$198,000 - \$240,000 ²
	Structural	State Road	Lack of Guard Rail	Add a guard rail on south side of Lake Shore Drive	\$331,000
Townsend Brook: Blanchard Pond / First Brook	Structural	Residential	High phosphorus loading from Blanchard Pond	Install a riparian buffer around Blanchard Pond	\$12,000 - \$23,000 ³
	Structural	Residential / State Road	Erosion along First Brook	Route 4 erosion control and stream stabilization	\$73,000 - \$130,000 ³
Townsend Brook	Structural	Residential	High phosphorus loads from Townsend Brook into Lake Auburn	Install Biochar logs upstream of the outlet to Lake Auburn to reduce phosphorus concentrations	\$6,400 (2-year pilot) plus analytical chemistry costs
	Structural	Municipal/ Public		Construction of bioretention basin at 2656 Turner Road (Roy's)	\$730,000
	Non-Structural	Residential		Work with landowners on ongoing Townsend Brook drainage issues	No cost assigned
Upper Watershed and Townsend Brook Aluminum Feed System	Structural	Municipal/ Public	High phosphorus loads from wet-weather watershed flows	Pilot test aluminum compounds and doses to evaluate feasibility of an alum feed system	\$20,000 - \$25,000 per site (not including analytical chemistry)
				If pilot test indicates it is effective, install alum feed system at Townsend Brook, Basin Stream, or both	Each system: \$120,000 capital cost + \$47,000/year O&M ⁴
Route 4	Non-Structural	State Road	Runoff from Route 4 south of Hathaway Street entering Lake Auburn through catch basins / vortex separators	Add Route 4 vortex units into the water quality sampling program. Track sediment removal in the vortex units to assess efficiency	No cost assigned

Watershed and Site(s) Addressed	Structural or Non-structural	NPS Category	Principal Concern	Recommended Actions	Planning-level Cost
All Watersheds Land Acquisition	Non-Structural	Residential	Additional land watershed commission-owned land is needed for conservation purposes	Continue to strategically purchase land throughout the watershed when it comes up for sale	No cost assigned
All Watersheds Forestry	Non-Structural	Forestry	Sediment and phosphorus load from logging on LAWPC and private property	Maintain current moratorium on logging until water quality stabilizes. If logging restarts, follow enhanced BMPs (see Section 5.4 for recommendations)	No cost assigned
Lake Auburn	Structural	Municipal/ Public	Studies should be undertaken in Lake Auburn or at the WTP to maintain water quality and filtration avoidance waiver	Design and implement a water quality monitoring program to establish a suitable location for the intake extension	No cost assigned
	Structural	Municipal/ Public		Design and construct the intake extension	No cost assigned
	Non-Structural	Municipal/ Public		Maintain Algaecide and Alum Application Permit	No cost assigned

Notes: 1. Capital and O&M cost from CEI (2013) and escalated to 2022 dollars using the ENR Construction Cost Index (May 2013 = 9,516 – November 2022 = 13,175)
2. Higher cost is for concrete pavers. Lower cost is for asphalt.
3. Costs from Tighe & Bond (2021), escalated to 2022 dollars using the ENR Construction Cost Index (February 2021 = 11,698 – November 2022 = 13,175)
4. Capital and O&M cost from WRS (2019) and escalated to 2022 dollars using the ENR Construction Cost Index (January 2019 = 11,206 – November 2022 = 13,175)

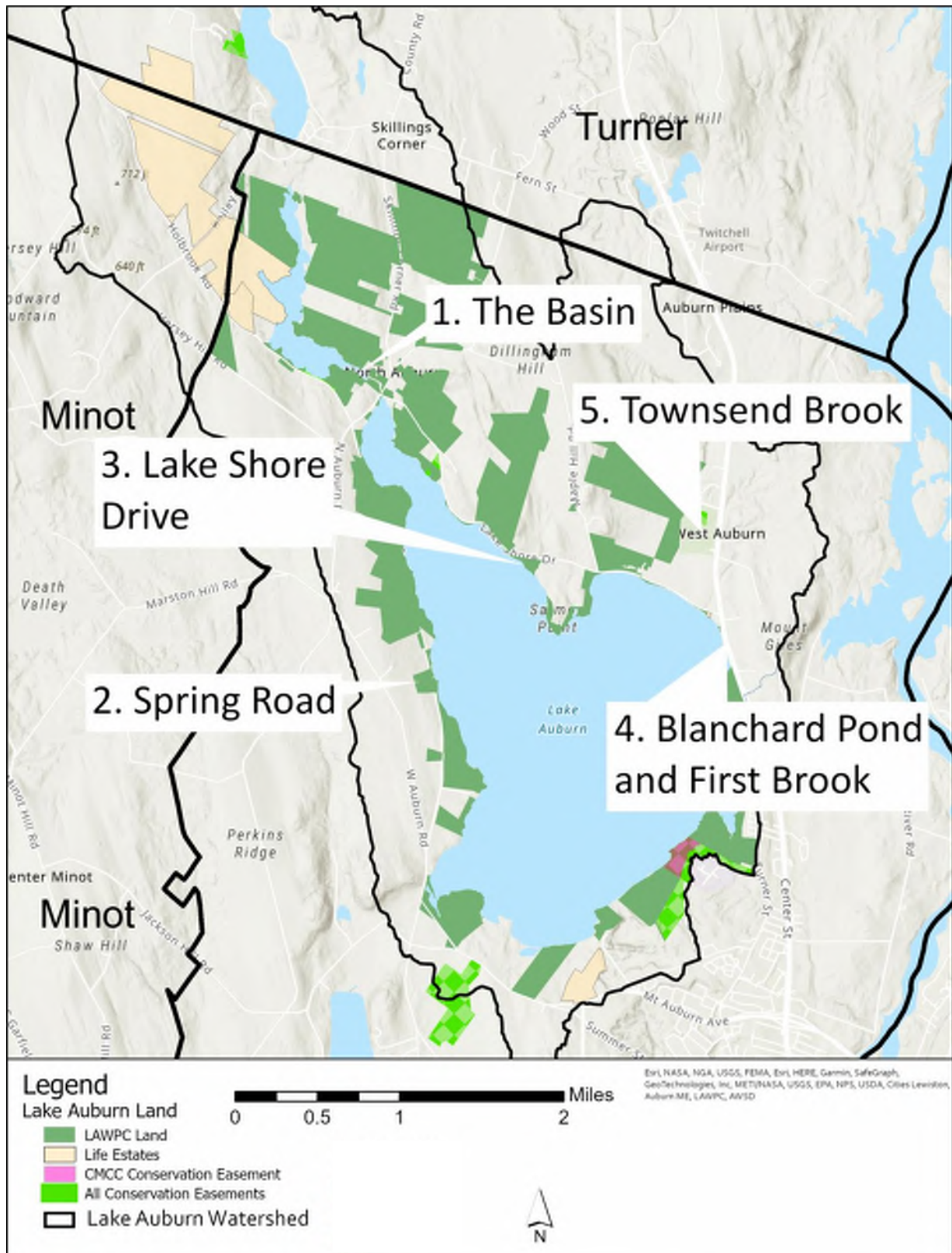


Figure 4-1
High Priority BMPs

4.1.1 Upper Watershed: The Basin

The Basin is located in the Upper Watershed and provides a buffer between Lake Auburn and the upper watershed. It receives runoff from the northern Lake Auburn watershed, including Mud Pond and Little Wilson Pond. This series of ponds reduces phosphorus and sediment loads through sedimentation in each pond as well as nutrient uptake in emergent vegetation. However, water quality data (**Section 2.3**) indicate an increase in phosphorus concentrations between Little Wilson Pond and the Basin indicating the potential for sediment release of phosphorus in the Basin itself. The Basin is controlled by the North Auburn Dam, which has accumulated a significant amount of sediment behind the dam. This sediment accumulation increases the likelihood of sediment resuspension and transport downstream during high flow events and reduces the sediment attenuation capacity of the Basin. Therefore, we recommend that a bathymetric and sediment depth survey be conducted behind the North Auburn Dam to collect data required to monitor accumulation and plan for future dredging of the Basin (see Potential Long-term Management discussion below).

In addition, we recommend armoring the emergency spillway to prevent erosion of the spillway during extreme events, and implementing the additional recommendations from the Maine Emergency Management Agency for retrofits to the North Auburn Dam.

The Basin, Basin Stream, and the northern lobe of Lake Auburn also have invasive milfoil present. Invasive species, such as milfoil, can grow rapidly in lakes and ponds. It can degrade habitat by out-competing native vegetation, and interferes with recreational uses of the water body. In addition, decaying milfoil can result in oxygen demand that can reduce dissolved oxygen within the water column. A submerged aquatic vegetation (SAV) survey should be completed to determine the extent and density of milfoil in these waterbodies. If necessary, LAWPC should consider removing milfoil with divers (either hand pulling or suction harvesting) or with benthic mats (e.g., in Basin Stream). Removed milfoil should be replaced with native vegetation.

Planning-level Costs

The planning-level cost for a bathymetric, sediment depth, and SAV survey for the 110-acre Basin is between \$70,000 and \$80,000, assuming a 10-day program.

Costs for the emergency spillway improvements were derived from CEI's Phase 2 study (CEI, 2013), which cited a cost of \$135,000 for armoring the emergency spillway and installing an in-stream stilling pool. This cost was escalated to 2022 dollars using the ENR Construction Cost Index (\$190,000). The additional recommendations from MEMA are not included in this cost estimate.

Hand harvesting of milfoil with divers can cost up to \$500 per acre (Wagner, 2004), with the cost dependent on the density of plants in the target area. Suction harvesting with divers can cost between \$5,000 and \$15,000 per acre (Wagner, 2004). Benthic mats can range from \$20,000 to \$50,000 per acre (inclusive of design, permitting, materials, and labor).

Potential Long-term Management

Sediment accumulation should be monitored regularly (at least every 5 years), and excess sediment should be dredged restore the full potential of the Basin to reduce nutrient loads to

Lake Auburn. Dredging can result in significant water quality improvements, where high-phosphorus sediment and milfoil can be removed. Dredging will also result in improved sediment trapping capacity upstream of the North Auburn Dam to better buffer nutrient and sediment loads from upstream and removal of the invasive milfoil at this location. However, dredging is an expensive solution and requires significant permitting effort.

The dredging costs are currently uncertain and will depend on the depth of sediment and the area selected to dredge. Hydraulic dredging costs are based on the volume of material dredged. Using a unit cost of \$20 per cubic yard (Wagner, 2004), a dredge depth of 1 to 3 feet of sediment, no contaminated sediment present, and a 30 percent contingency, dredging could cost between \$2.8 million to \$8.5 million across the entire 110-acre area of the Basin. However, this cost will need to be refined following the bathymetric and sediment survey. Furthermore, if hazardous materials are found in the sediment, the disposal cost may be higher, and disposal costs will depend on the distance from the site to the disposal site and the use of the material.

4.1.2 Spring Road

Whitman Spring Road (Spring Road) is a dirt road that is generally closed to traffic (exceptions include access to private camps adjacent to the road and snowmobile use on a portion of the road in the winter). This road is oriented perpendicular to a steep slope and intercepts runoff from the upslope areas. To drain the water across the road, Spring Road was constructed with cross-culverts where runoff flowing down the steep inland side of the road flows east into a ditch on the western side of the road, through the crossings, and then through channels leading to Lake Auburn. An example from the Maine Forestry BMP guidance document, similar to the Spring Road runoff conveyance system, is shown in **Figure 4-2**. The soils in this area of the watershed are highly erodible with a naturally high phosphorus content; reducing the erosion potential is an important BMP given the close proximity of this area to Lake Auburn and the steep slopes in this area. Spring Road BMP recommendations are shown on **Figure 4-3**.

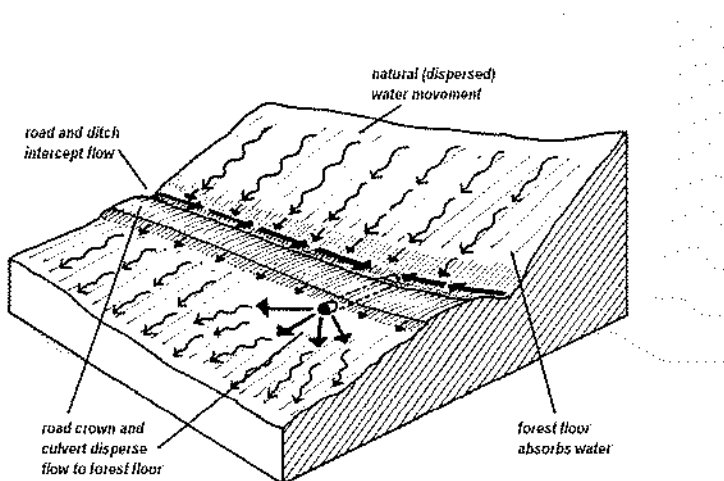


Figure 4-2
Maine Forestry BMP Guide Example – Similar to Spring Road Runoff Conveyance

LWD recently replaced most of the culvert crossings on Spring Road, armored the inlet and outlet embankments, and installed a plunge pool to capture sediment and reduce runoff velocities. However, four culverts (all historical stone culverts that generally drain existing natural streams) are not planned for replacement and show signs of erosion downstream. In addition, erosion is present on the ditch on the upland side of the road.

Recommendations for Spring Road are described below:

- Inspect ditches on the western (inland) side of Spring Road, clear sediment, and revegetate with a native seed mix to reduce runoff velocities and increase the infiltration capacity within the ditch. A schedule for regular ditch inspection and sediment removal following heavy rainfall should be maintained. Ditches should be revegetated as needed following sediment removal.
- Retrofit four culverts with plunge pools on the downstream side of the culverts and armor the upstream and downstream embankments. The four culvert retrofits are located at the old, historical granite block culverts and the following (approximate) coordinates:
 - -70.2705, 44.1561
 - -70.2691, 44.1523
 - -70.2684, 44.1501
 - -70.2676, 44.1477
- Regrade the road and add water bars to prevent roadway erosion at two steep locations. Spacing of the water bars is based on the slope of the roadway, and ranges from every 250 feet for a 2 percent grade to every 40 feet for a 25 percent grade (MDEP and PWD, 2006). The steep locations are 3 percent grade (spacing every 200 feet, 1 water bar required) and 6 percent grade (spacing every 120 feet, 3 water bars required). The two steep locations are located at the following (approximate) locations along Spring Road:
 - -70.2704, 44.1561
 - 44.1669, -70.2748

Planning-level Costs

Costs for ditch revegetation assumed a swale length of 1,400 feet (the length of the road), a width of approximately 3 feet, and unit costs per square foot of \$1.65 per square foot.

Costs for plunge pool development were derived from a unit cost per square foot of BMP of approximately \$65, adjusted to present day cost using the ENR Construction Cost Index. Plunge pool sizes were set at a minimum of fifty square feet each; this value is derived from Massachusetts design criteria as well as from general sizing of prior plunge pool installations on Spring Road. Costs for embankment armoring assumed a conservative 120 square foot embankment face, with a unit cost of approximately \$13 per square foot. Costs include labor.

Costs for water bar installation and road regrading were estimated from a unit cost per foot of water bar of \$15. The number of water bars was estimated based on the length and grade of the road in the two steep sections. Costs include labor, and were increased by 30 percent for planning level contingencies.

Maintenance Requirements

Maintenance requirements include:

- Initially conduct plunge pool inspections and cleaning annually. Inspections and cleaning should be tracked in AWD/LWD's Asset Management system. Long-term, plunge pool cleaning frequency should be evaluated based on sediment buildup rates recorded during inspections.
- Inspect ditches following heavy rainfall and remove sediment before permanent damage is done to vegetation or if infiltration times are longer than 12 hours. Bare spots should be reseeded as needed, and woody or other undesirable vegetation should be removed. Inspections should be tracked in AWD/LWD's Asset Management system.

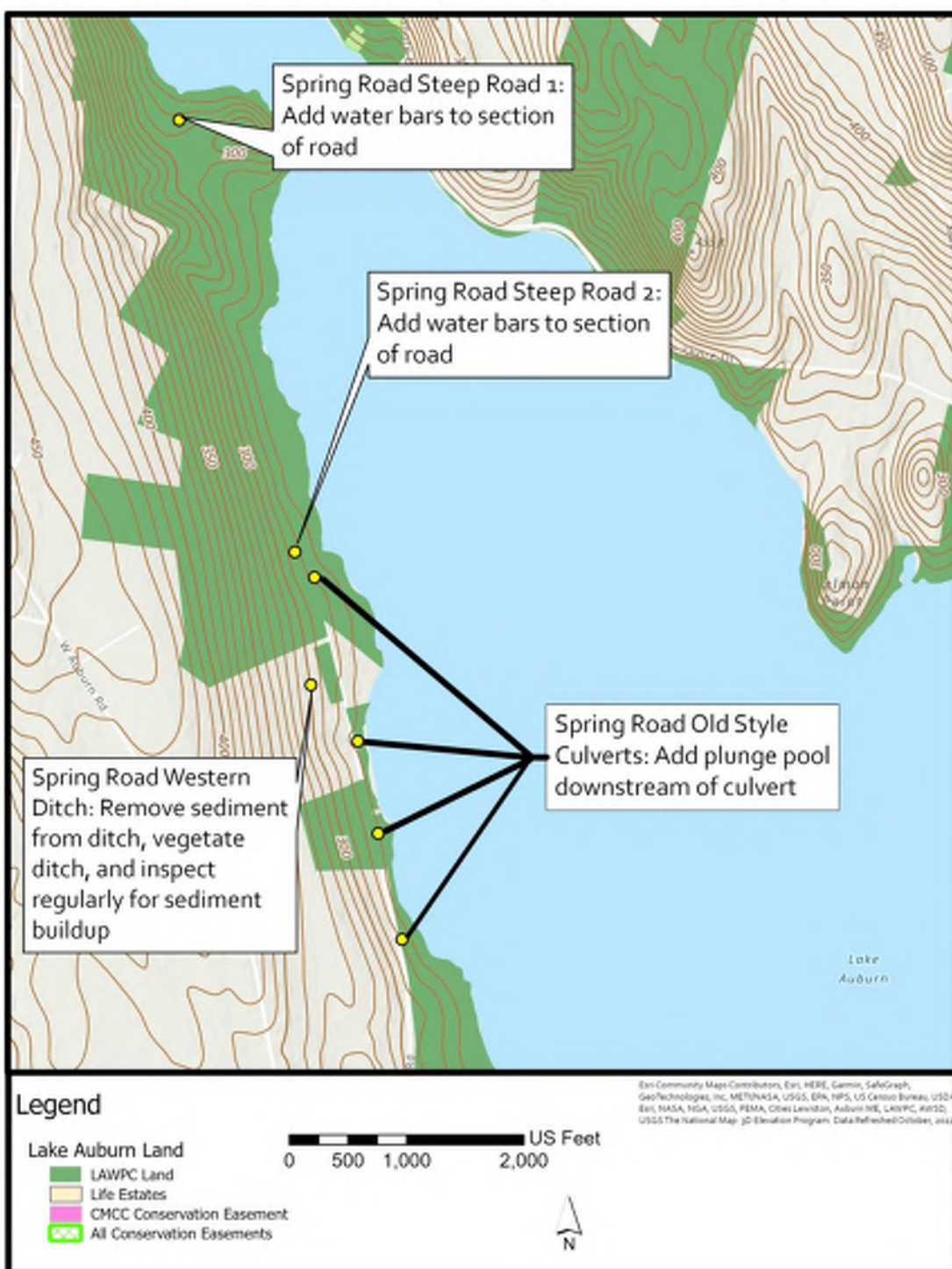


Figure 4-3
Spring Road BMPs

4.1.3 Lake Shore Drive South Direct Drainage

The lake side of Lake Shore Drive is characterized by a narrow, vegetated buffer between the lake and the road, which is broken or non-existent in places. The embankment to the lake characterized by steep slopes where runoff travels either by sheet flow or concentrated flow in shallow eroded channels directly into Lake Auburn. Additional erosion occurs from unpaved parking areas that slope toward Lake Auburn and allow recreational access to the lake shore. Additionally, the stretch of Lake Shore Drive adjacent to Lake Auburn does not have a guard rail on the lake side.

Vegetated filter strips should be constructed using a native seed mix on the bare patches of earth where runoff currently creates eroded channels leading to the lake. An example of a vegetated filter strip design from the Rhode Island Stormwater Design Manual (RIDEM, 2015) is shown in **Figure 4-4**. In addition, the unpaved parking areas should be regraded and resurfaced with asphalt or concrete pavers. Locations of proposed vegetated filter strips and parking areas are shown in **Figure 4-5**.

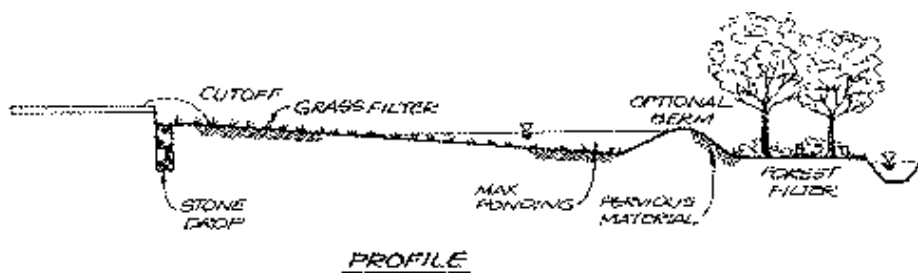


Figure 4-4
Vegetated Filter Strip Example

Additionally, guard rails can act as a source of spill prevention by preventing vehicles from driving off a roadway and into a waterway. To prevent such accidents, a guard rail should be built along the stretches of Lake Shore Drive and Route 4 that are adjacent to Lake Auburn.

Planning-level Costs

Vegetated filter strip costs were calculated assuming a total square footage of roughly 25,000 square feet, based on observations during the 2022 watershed survey and images on Google Earth. The cost of seed mix was estimated from New England Wetland Plants' logging seed mix, with an application rate of 20 pounds per acre and a cost of \$30 per pound. An additional labor rate of \$82 per hour, with two people working a full 8-hour day, was added to the total cost. Costs for erosion control were added, with a cost per foot of silt fence of \$10.

Guard rail costs were calculated using a per-foot rate of approximately \$48 per foot, assuming a total of 6,900 feet of guard rail will be necessary in locations where Lake Shore Drive is directly adjacent to Lake Auburn. Costs include labor.

The cost for resurfacing of the unpaved parking areas was calculated assuming an estimated 15,000 square feet of area to be resurfaced; this was found from survey data as well as that from

Google Earth. A cost per square foot of approximately \$149 for concrete pavers, and \$122 per square foot for asphalt pavement were utilized to estimate the total cost. Costs include labor.

Maintenance Requirements

Maintenance requirements for the vegetated filter strip include an inspection of the area for sediment buildup and signs of bare spots, erosion, and overall plant health twice a year for the first year, and yearly after the first year.

Potential Long-term Management

In the future, when Lake Shore Drive requires roadway reconstruction, LAWPC should work with Maine Department of Transportation (MaineDOT) to regrade the road to slope toward the northern side of Lake Shore Drive or add deep-sump hooded catch basins to intercept sediment prior to discharge into Lake Auburn. This would direct runoff either to the Townsend Brook wetland or to the swales on the inland side of the road, and in doing so provide additional treatment and infiltration before the runoff reaches Lake Auburn. While this would reduce the direct drainage to Lake Auburn, the large expense of this BMP, coupled with the fact that Lake Shore Drive was recently resurfaced, indicates that this should be considered in the distant future when the roadway is already scheduled for reconstruction.

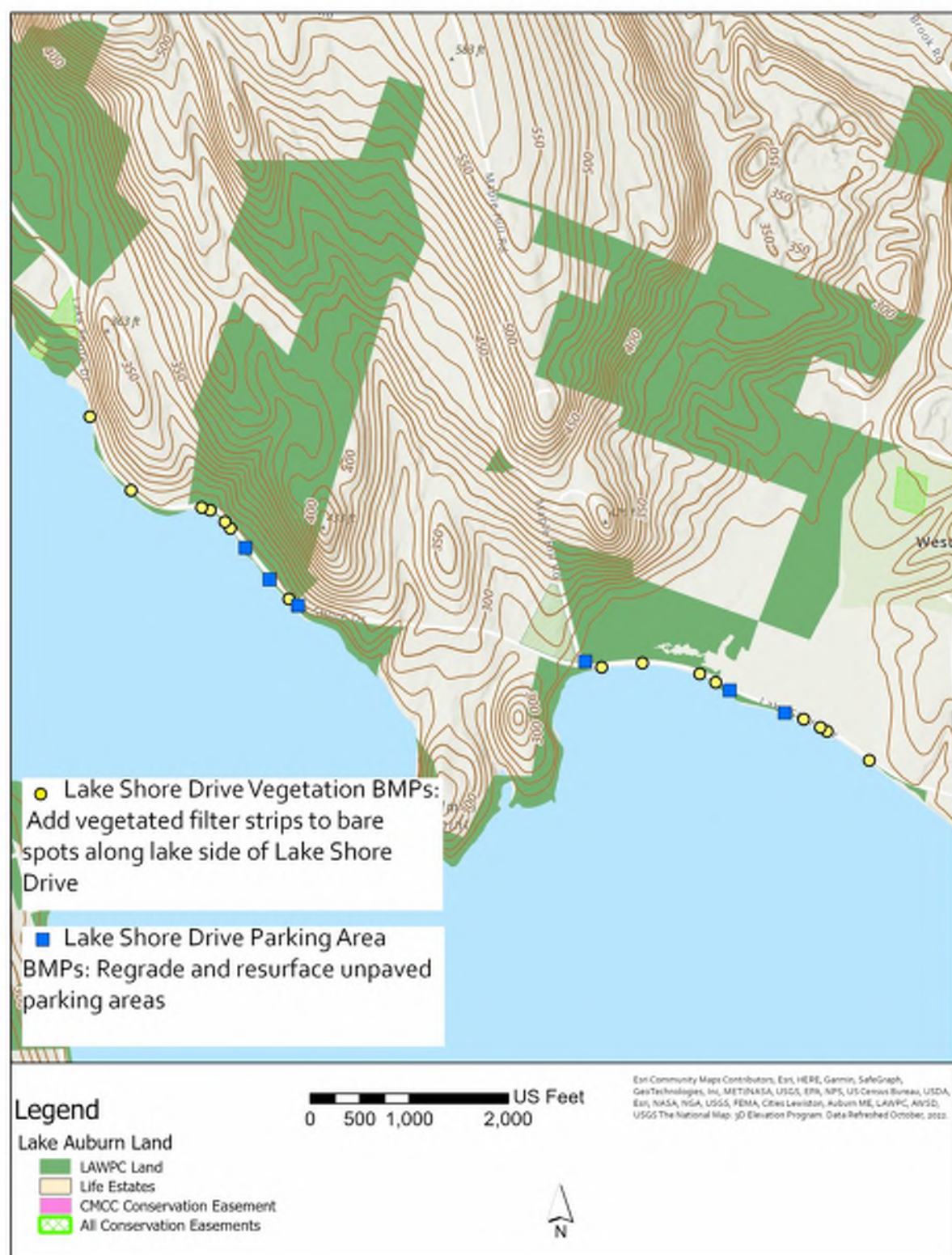


Figure 4-5
Lake Shore Drive BMPs

5.1.4 Blanchard Pond and First Brook

Recommendations from the Tighe & Bond (2021) study should be adopted, including:

- Installing a riparian buffer around Blanchard Pond
- Repairing, stabilizing, and improving drainage along the northbound shoulder of Route 4 near the Turner Road culvert, and stream restoration at 2481 Turner Road
- Continuing to collect water quality and streamflow data in Blanchard Pond and along First Brook

The riparian buffer location and areas for drainage improvements are shown in **Figure 4-6**.

Finally, if the biochar log pilot in Townsend Brook (see **Section 4.1.5**) is effective, LAWPC should consider implementing biochar logs within Blanchard Pond.

Planning-level Costs

Planning level costs for a riparian buffer, as well as for drainage improvements and stabilization work along First Brook, were developed in the Tighe & Bond (2021) study and escalated to November 2022 dollars using the ENR Construction Cost Index.

Maintenance Requirements

Maintenance requirements for the riparian buffer include inspections twice annually, and after large storms, to determine if any damage has occurred to the buffer system. Replanting or reseeding should occur in any locations where plants have died or washed away.

Potential Long-term Improvements

If elevated phosphorus concentrations persist following the implementation of recommended improvements, we recommend pond remediation, which could consist of an alum treatment to reduce sediment phosphorus release or dredging Blanchard Pond to restore the pond and to remove the additional accumulated phosphorus mass in the pond sediments.

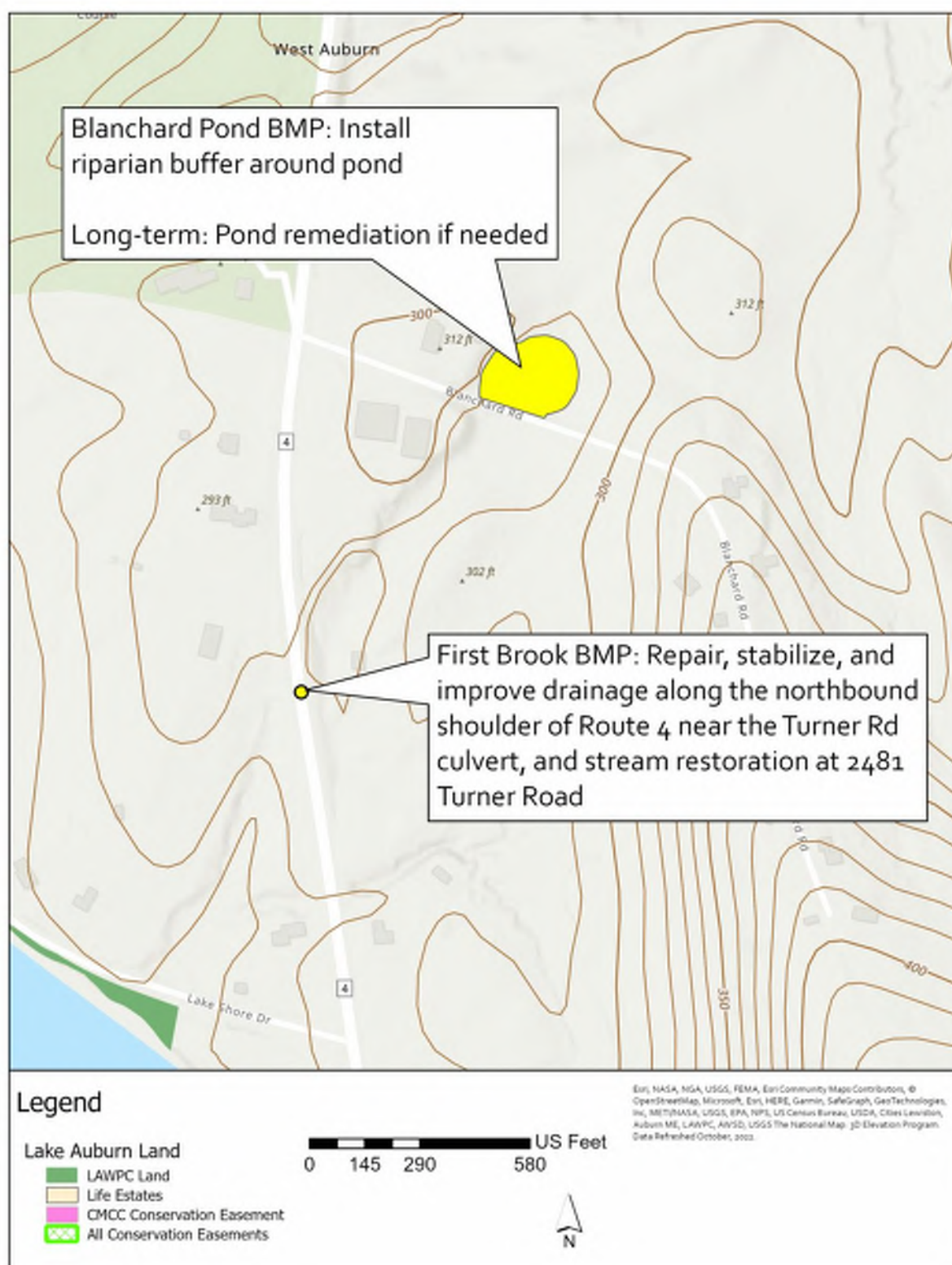


Figure 4-6
Blanchard Pond and First Brook BMPs

4.2.5 Townsend Brook

Water quality issues in Townsend Brook result from several sources upstream, including erosion from ATV and snowmobile use at the sand pits west of Tot Lot and Gammon's Nursery, upstream and commercial operations at Roy's and Gammon's Nursery. Several structural and non-structural improvements are recommended in the Townsend Brook watershed to reduce phosphorus and sediment loads.

Structural BMPs

Structural BMPs recommended for Townsend Brook are shown in **Figure 4-7**.

- Build a bioretention basin with a sediment forebay on the tributary to Townsend Brook that flows through Roy's disk golf downstream of Route 4. Tributary phosphorus monitoring has indicated that the sampling location downstream of this location (Roy's) has historically high total phosphorus concentrations relative to the downstream Townsend Brook monitoring location. The bioretention basin would help to infiltrate and treat water from this tributary before it reaches Townsend Brook. This would need to be located on private property and would require establishing an easement or other suitable arrangement with the property owner.
- Pilot biochar filter bags upstream of the Townsend Brook culvert under Lake Shore Drive to provide additional phosphorus removal within the wetland.
- Conduct a pilot study to determine if an alum feed system is feasible and effective at Townsend Brook; pilot study details are included in **Section 4.2.6**.

Planning-level Costs

Planning-level costs for the sediment forebay upstream of the bioretention basin were derived from a unit cost per square foot of BMP of approximately \$65, adjusted to present-day cost using the ENR Construction Cost Index. Sediment forebay sizing calculated to treat 10 percent of the water quality volume. Planning-level costs for the bioretention basin were calculated using a price per impervious acre treated of \$155,000 based on CDM Smith's experience with similar BMP installations.

Planning-level costs for biochar filter bags were calculated for a 2-year pilot using a cost of \$40 per unit, assuming 16 biochar bags will be purchased each year. A labor rate of \$82 per hour, for two people completing setup in four hours was added to the total cost. The filter bags should be installed 4 at a time, and changed every 3 months. This cost does not include analytical chemistry.

Costs for the alum feed pilot are included in **Section 4.1.6**.

Maintenance Requirements

Maintenance requirements for a bioretention basin include semi-annual inspections, as well as those following any major storm. Debris and sediment buildup should be removed from the forebay and basin as needed, and any bare areas or erosion rills should be replaced with new filter media, seeded, and mulched as needed. Mulch replacement and harvesting and pruning of excessive growth should both be done annually or as needed.

Maintenance requirements for biochar filter bags include regular inspections so that debris has not built up on the filter bags, and water quality testing downstream of the site to determine when the filter bags should be replaced. We expect that the filter bags will need to be changed every 3 months, and the cost assumes quarterly replacements for 2 years.

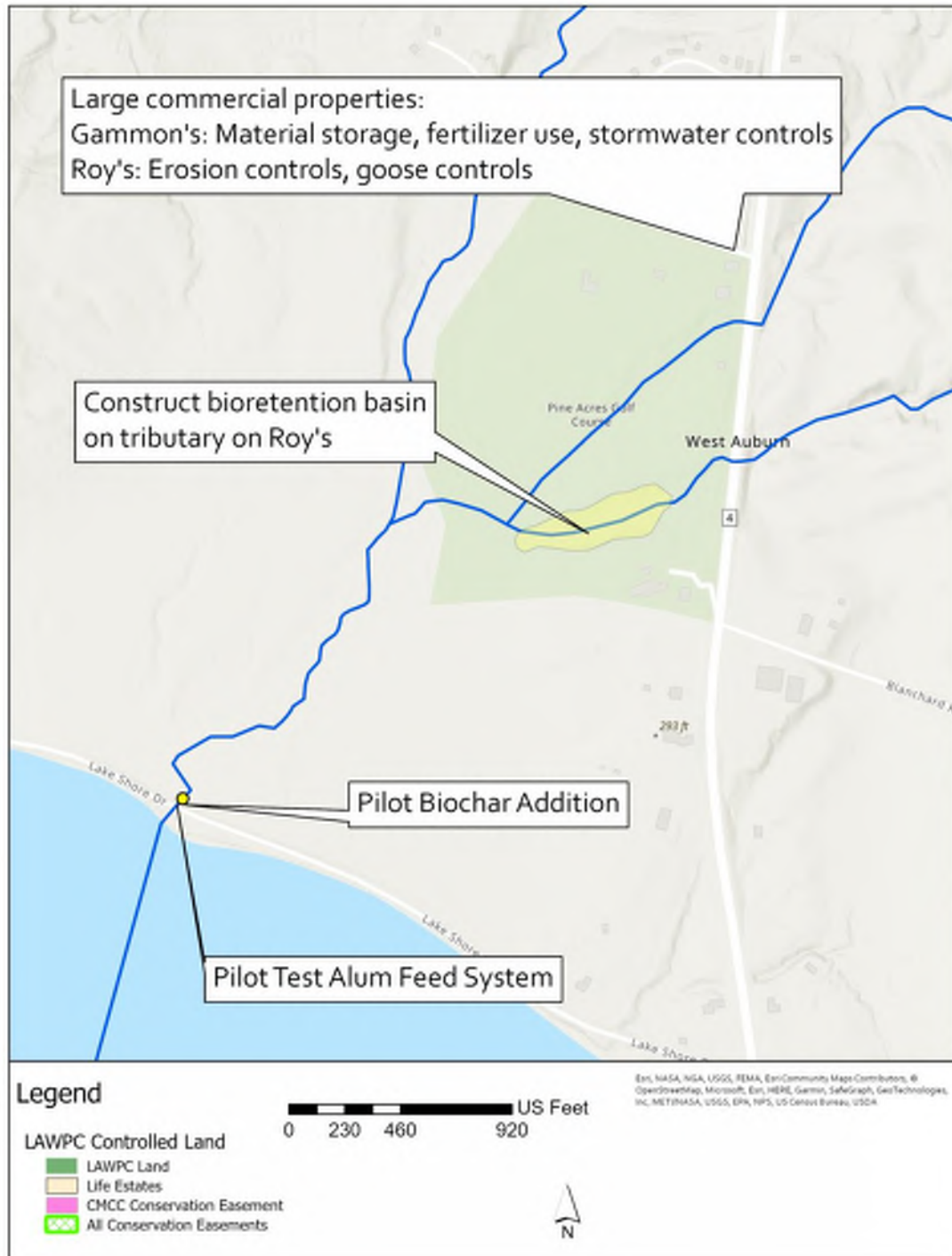


Figure 4-7
Townsend Brook BMPs

Non-structural BMPs

During the 2022 survey, several private properties were identified with conditions that may contribute to elevated nutrient loading to Townsend Brook.

- Gammon's Nursery had several uncovered stockpiles of mulch and soil. LAWPC should work with the landowners to check that stockpiles of mulch and soil are stored on a concrete pad and covered. In addition, LAWPC should work with the landowners to determine how fertilizer and stormwater is managed and identify ways to reduce potential discharges to Townsend Brook.
- Roy's, the Pine Acres disk golf course and driving range, contained a good buffer around Townsend Brook during the 2022 survey, but a significant population of Canada Geese were observed on the disk golf course. Additionally, the area adjacent to Townsend Brook showed evidence of excavation without adequate erosion controls. LAWPC should work with the landowner to improve erosion controls on this property.
- The sand pits located off Route 4 west of Tot Lot and Gammon's Nursery show evidence of ATV use that may contribute to erosion that reaches the brook. LAWPC should work with the Auburn Police Department and the Maine Warden Service to find ways to reduce ATV use at the sandpits. In addition, a gate and signage or other deterrent should be installed on the newly acquired LAWPC property on Townsend Brook (50 Townsend Brook Rd) to discourage ATV traffic from traveling through this property to the sand pits and Townsend Brook.

4.2.6 Pilot Testing for Aluminum Feed Systems for Tributary Inflow Treatment

Townsend Brook and Basin Stream represent most of the phosphorus load to Lake Auburn. As an interim measure, AWD/LWD should determine whether an aluminum feed system located at one or both streams would be effective at reducing external phosphorus loads during wet weather. Water Resource Services, Inc. (WRS) previously installed a chemical feed system at a pond in Wellesley, Massachusetts, that feeds 1 to 3 mg/L of polyaluminum chloride during wet weather that has been effective at reducing tributary phosphorus loading.

As a first step, AWD/LWD should conduct a feasibility study to determine if an aluminum feed system would be feasible and effective on inflows at Townsend Brook and/or Basin Stream by conducting a jar testing and water quality sampling for particulate and dissolved phosphorus components, dissolved organic carbon (DOC), total organic carbon (TOC), and TSS over the course of several storms that span a range of seasons and flow conditions. Jar testing should be completed using two compounds: (1) aluminum sulfate and sodium aluminate (2:1 ratio) and (2) polyaluminum chloride. The cost to develop a jar testing protocol to test flocculation and sedimentation, complete the jar testing, and prepare a technical memorandum documenting the results is estimated to be \$20,000 to \$25,000 per site, not including analytical chemistry (phosphorus, TSS, DOC, and TOC).

If the feasibility study indicates that a chemical feed system is feasible and results in a satisfactory concentration reduction, this system could be considered for implementation while additional watershed controls are implemented. WRS (2019) estimated that a chemical feed system with

polyaluminum chloride could be implemented for a capital cost of \$100,000 and an annual O&M cost of \$40,000 (2019 dollars), or \$120,000 capital and \$47,000 O&M (2022 dollars, ENR 13,175).

4.1.7 Route 4

Route 4 contains several direct stormwater outlets to Lake Auburn. Recently, vortex separators were installed along the northern stretch of Route 4 adjacent to the lake to remove sediment from stormwater before discharging into the lake. The Route 4 vortex separator units should be added into the water quality sampling program. Sediment removal should be tracked in AWD/LWD's Asset Management System to assess the vortex units' efficiency.

4.1.8 Land Acquisition

LAWPC has purchased land or established conservation easements in the Lake Auburn watershed, limiting development within the watershed and reducing future potential pollution from associated development activities. Additionally, purchased land within the watershed can be used to house structural BMPs where appropriate. LAWPC should continue to strategically purchase land within the watershed when it comes up for sale and should consider purchasing land outside of the City of Auburn to provide additional protection in the upper watershed.

4.1.9 Forestry

We recommend that LAWPC continue its current moratorium on logging on Commission-owned land within the watershed. As described in **Section 2**, recent years have been characterized by elevated turbidity, reduced Secchi depth, and an increased frequency of cyanobacteria blooms. Fall algal blooms in 2020 and 2021 were likely caused by external phosphorus load based on the lack of anoxic conditions in the hypolimnion and the low phosphorus concentrations at depth. Given the potential sensitivity of Lake Auburn to additional phosphorus loads from the watershed, the long-term benefits of silviculture in the watershed may be outweighed by short-term increases in stormwater runoff and erosion from recently logged sites within the watershed. Even a well-designed forestry program has inherent risks of increased erosion, and the highly erodible soils within the Lake Auburn watershed enhance this risk considerably.

Once the lake water quality stabilizes after the perturbations from the 2019 alum treatment and subsequent fall algal blooms and more data are collected on the potential sources of elevated turbidity within the lake, LAWPC could consider restarting its forestry program to meet specific watershed protection goals; additional BMPs are recommended to be adopted if the logging moratorium is lifted (see **Section 4.4**).

Forestry operations conducted on private property are subject to the state-wide restrictions and best management practices.

4.1.10 Lake Auburn

Several studies should be undertaken in Lake Auburn or at the WTP to maintain or improve water quality.

Intake Extension

The current intake is located at about 4 meters depth, and is impacted by algal blooms in the epilimnion, high temperatures, and sediment resuspension during certain wind conditions. AWD/LWD should:

- Design and implement a water quality monitoring program to determine if moving the intake would improve raw water quality for the water treatment plant. This should include adding the following analyses to the current in-lake monitoring program: turbidity profiles collected alongside the current profile data for temperature, conductivity and DO, and grab water samples at the surface, middle and bottom for total iron, and total manganese. Evaluate alternative intake locations and complete conceptual intake design.
- If desirable, design and construct the intake extension.

Maintain Algaecide and Alum Application Permit

AWD/LWD should continue to maintain a current Maine Pollutant Discharge Elimination System (MEPDES) permit to apply an algaecide should an algal bloom reoccur, and to be able to supplement the low-dose alum treatment if conditions require this in the future.

Follow-up Alum Treatment

The 2019 alum treatment was conducted following dosing guidance from Water Resource Services, Inc. (WRS, 2019). The dose selected for treatment was 2 mg/L, which is equivalent to 18 g/m² over the target treatment area. The primary goal of the 2019 treatment was to lower the in-lake phosphorus concentration to below 10 µg/L. WRS notes that a dose of 18 g/m² “would also represent up to 50 percent of the dose projected to be necessary to inactivate surficial sediment phosphorus and will reduce much of the internal load.” The water quality results in the year or two following the treatment appear to have achieved this goal, with water column phosphorus concentrations below 10 µg/L and a reduction in internal load. However, the anoxic conditions observed in 2022 have resulted in an increased internal phosphorus load (although not as large as was observed prior to the alum treatment).

If the monitoring program indicates that the internal load is increasing post-alum treatment in future years, a follow-up alum treatment should be considered within the next 10 years to further reduce the potential for internal phosphorus load. The strategy of repeated low-dose alum treatments is a common and accepted practice. WRS cites several examples, and notes that “[a]s sediment inactivation is an additive process, later treatment could augment this inactivation as warranted.”

A follow-up alum treatment should be preceded by additional sediment phosphorus and jar test testing to confirm the dose. Assuming that the follow-up treatment is at the same 2 mg/L dose, the cost will likely be between \$750,000 and \$1,000,000.

4.2 Additional Structural BMPs

The 2022 watershed survey identified other areas that contribute pollutants to Lake Auburn. These are either located in the upper watershed and thus have their impact mitigated by other waterbodies or represent a relatively lower potential load to the lake. Many of these can be

addressed as the opportunity arises, for instance when a culvert is already scheduled for replacement or a roadway is scheduled for resurfacing. Additional recommended structural BMPs are described briefly in **Table 4-2** and shown in **Figure 4-8**.

Table 4-2 Additional Structural BMPs

Structural or Non-structural	NPS Category	Site(s) Addressed	ID	Principal Concern	Recommended Actions	Planning-level Cost (2022 Dollars)
Structural	Town Road	Spring Road Snowplow Turnaround	SR1	Unpaved snowplow turnaround is eroding into the adjacent stream and ditch. Erosion is evident on culvert upstream and downstream embankments.	Pave turnaround, vegetate embankment surrounding paved area, and armor the culvert embankments.	\$12,000 - \$13,000 ¹
Structural	Town Road	Spring Road Southern Parking Area	SR2	The unpaved southern parking area shows signs of erosion.	Pave and level turnaround, and add vegetated filter strips adjacent to the paved parking area.	\$37,000 - \$44,000 ¹
Structural	Town Road	Spring Road North Parking Area	SR4	Evidence of significant erosion is observed from runoff flowing down the steep slope of N Auburn Road to Lake Auburn. The catch basin is not oriented in the correct direction.	Level and regrade the parking area. Realign the catch basin. Add a filter strip downstream to treat additional runoff.	\$32,000 - \$35,000 ¹
Structural	State Road	Lake Shore Drive Parking Area near Maple Hill Road	LS1	Erosion observed at small unpaved parking area.	If parking areas remain, resurface with concrete pavers or asphalt to reduce erosion.	\$32,000 - \$35,000 ¹
Structural	State Road	Steep Slopes on Inland Side of Lake Shore Drive	LS2	Erosion observed on the steep slope on the inland side of Lake Shore Drive	Hydroseed the north slope to add stabilization.	\$1,000

Structural or Non-structural	NPS Category	Site(s) Addressed	ID	Principal Concern	Recommended Actions	Planning-level Cost (2022 Dollars)
Structural	State Road	Ditch on South Side of Lake Shore Drive near Route 4	LS3	The ditch on the south side of Lake Shore Drive near Route 4 is not adequately vegetated, and erosion is occurring from the road and shoulder.	Vegetate the ditch.	\$2,000
Structural	Town Road	Hersey Hill and Holbrook Road Culverts	H1	UB-6 (Holbrook Road): moderate erosion on the outlet embankment	Armor culvert outlet embankment at UB-6.	\$2,000
			H2	UB-7 (Hersey Hill Road): Significant erosion where runoff flows off the road shoulder down the culvert inlet embankment	Armor culvert inlet embankment at UB-7.	\$2,000
			H3	UB-8 (Hersey Hill Road): Plunge pool is clogged	Clean plunge pool at UB-8.	\$400
Structural	Town Road	Holbrook Road Parking Areas	H4	Unpaved parking turnouts to access the pond which slope toward the pond show signs of erosion	Level and resurface the parking areas with pavers or asphalt.	\$28,000 - \$31,000 ¹
Structural	Town Road	Holbrook Road Drainage	H5	Drainage adjacent to the Basin shows signs of erosion along the shoulder and within the ditch on the south side of the road	Add vegetation to the ditch on the south side of the road to add additional stability and treatment.	\$15,000

Structural or Non-structural	NPS Category	Site(s) Addressed	ID	Principal Concern	Recommended Actions	Planning-level Cost (2022 Dollars)
Structural	Municipal / Public	Townsend Brook and Basin Stream Outlet	AL1/AL2	High phosphorus loads from tributary inflows	If pilot testing shows positive results, install chemical feed system at Townsend Brook and/or Basin Stream.	For each system: Capital cost: \$120,000 O&M cost: \$47,000/year ²
Structural	Municipal / Public	Blanchard Pond / First Brook	BP1	A dam at 2481 Turner Road, recorded in the 2021 Blanchard Pond study, was observed as a potential location for significant nutrient development along First Brook, where heavy rainstorms could flush loads downstream	Removal of impoundment on 2481 Turner Road.	\$5,600 - \$7,900 ³
Structural	Municipal / Public	Blanchard Pond / First Brook	BP2	High phosphorus loading from Blanchard Pond, as well as erosion along First Brook	Dredge Blanchard Pond.	\$67,600 - \$84,500 ³

Notes: 1. Higher cost is for concrete pavers. Lower cost is for asphalt pavement.
2. Based on cost estimates in WRS (2019) for a chemical feed system with polyaluminum chloride addition, which estimated a capital cost of \$100,000 and an annual O&M cost of \$40,000 (2019 dollars), or \$120,000 capital and \$47,000 O&M (2022 dollars, ENR 13,175).
3. Costs from Tighe & Bond (2021), escalated to 2022 dollars using the ENR Construction Cost Index (February 2021 = 11,698 – November 2022 = 13,175)

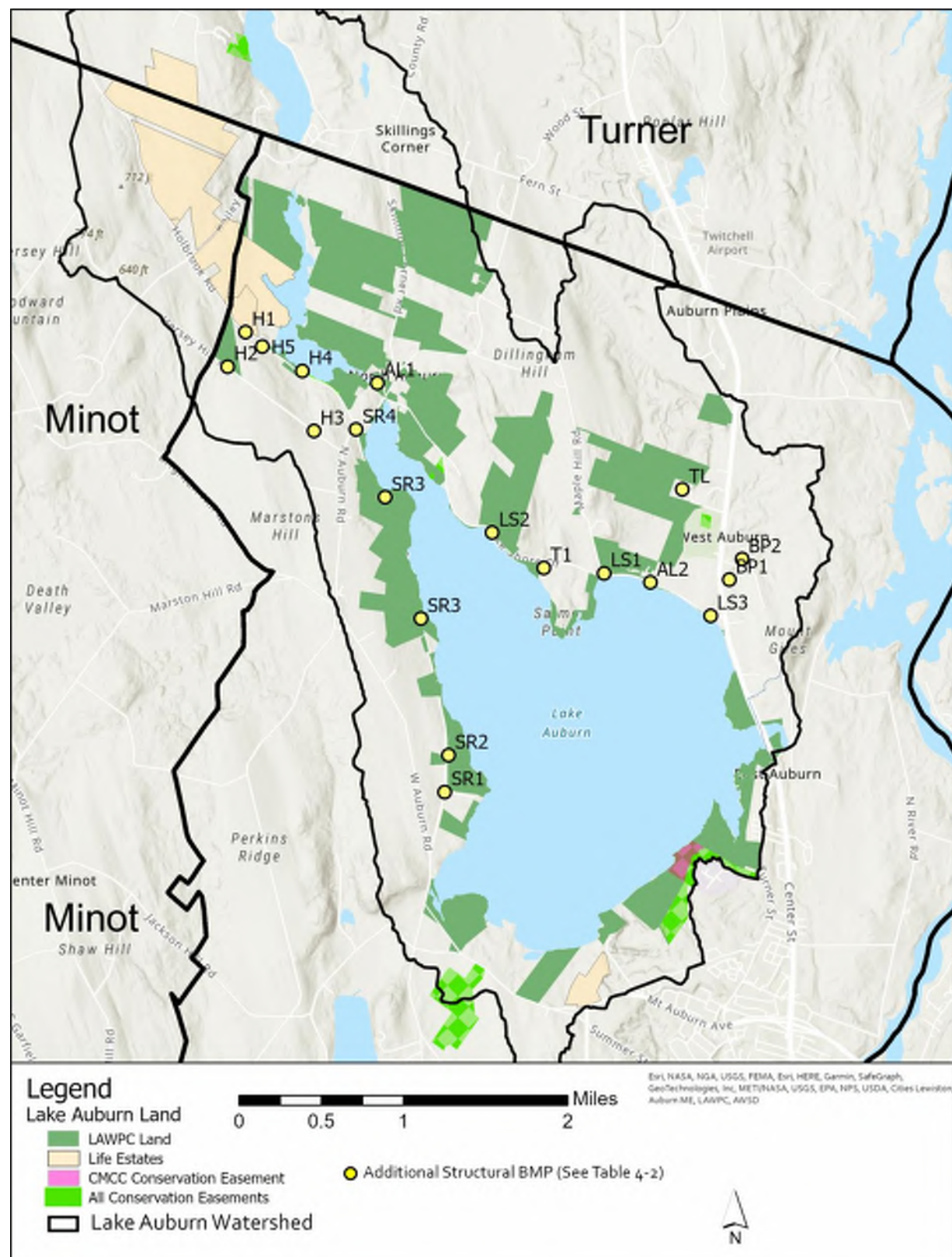


Figure 4-8
Additional Structural BMPs

4.3 Additional Non-structural BMPs

LAWPC should implement several additional non-structural BMPs to enhance watershed protection. These recommendations add to the existing non-structural BMPs currently implemented by LAWPC.

4.3.1 Ditch and Culvert Inspection

Ditches and culverts should be inspected annually for erosion and sediment buildup and the results recorded in AWD/LWD's asset management system. If erosion or sediment buildup are noted, stabilization or sediment removal should occur as soon as budget and staffing allow.

4.3.2 Increased Street Sweeping in Spring

The City of Auburn sweeps all streets in the spring according to a pre-set schedule. We recommend that the street sweeping frequency on roadways adjacent to Lake Auburn and its major tributaries be increased to at least two passes during the spring. Auburn should aim to sweep these roadways first once street sweeping resumes in the spring to remove the accumulated winter sand and debris. A second pass should be completed once the City-wide street sweeping is completed (typically June). LAWPC should work with the surrounding municipalities in the watershed and with MaineDOT to implement a similar sweeping schedule on roads outside of the City's jurisdiction.

4.3.3 Septic System Inspections

Septic systems, regardless of whether they are failing or not, can contribute pollutants such as phosphorus, nitrogen, bacteria, viruses, and emerging contaminants to a water bodies. Failing septic systems carry the largest risk of contamination, where direct discharge of contaminants can occur. Septic systems within the Lake Auburn watershed should be inspected to check that all systems are working as designed and none are failing, as a collaboration among LAWPC and Auburn and Turner's health departments. This inspection should first target septic systems in close proximity to a waterbody and older systems installed or upgraded prior to 2000.

4.3.4 Amend Ordinance to Prohibit Certain Land Uses Within the Lake Auburn Watershed Overlay District

Most of the land within the Lake Auburn watershed is zoned "Agriculture and Resources Protection" followed by "Rural Residential" and "Low Density Country Residential" with very little "Neighborhood Business," "General Business" and "Suburban Residential." The Zoning Ordinance identifies the type of land uses that are permitted within each of these zones and outlines a few that are not allowed within an environmental overlay district or over any known aquifer (e.g., cemeteries, municipal sanitary landfills). LAWPC should consider prohibiting some other uses based on their potential to contaminate the drinking water supply.

A section should be added to the Lake Auburn Watershed Overlay District portion of the Zoning Ordinance specifying prohibited land uses within the overlay district, with the following uses prohibited:

- Car washing facilities– Untreated wash water can contain petroleum residues and detergents

- Auto, boat, or other vehicle service and/or repair operations – potential for petroleum and solvent releases
- Bulk chemical outdoor chemical storage (e.g., herbicides, pesticides or fertilizers) – potential for release of large quantities of chemicals
- Cemeteries
- Hospitals and elderly care facilities – septage likely to contain large quantities of pharmaceuticals which can enter the water supply. Although not regulated yet, this can have impacts on future treatment requirements as regulations change.
- Automobile fuel stations– potential for release of petroleum and solvents
- Research, experimental, testing laboratories – specifically those that have the potential for chemical releases into septic systems
- Dry cleaners – potential for perchloroethylene (PCE) release
- Fire-fighting training facilities – these facilities represent a potential for Per- and Polyfluorinated Substances (PFAS) generation
- Uncovered or uncontained manure storage
- Uncovered or uncontained storage of fertilizers
- Facilities that generate, treat, store, or dispose of hazardous waste
- Junk and salvage operations
- Any new land uses that result in the rendering impervious of more than 15 percent, or more than 20 percent of land with artificial recharge, or 2,500 square feet of any lot, whichever is greater.

4.3.5 Construction Site and Logging Erosion Controls

LAWPC should continue to work with Auburn, Turner, Minot, and Buckfield to ensure that all site erosion requirements are properly implemented prior to construction or logging operations on land located within the Lake Auburn watershed. This could consist of landowner education, technical and/or financial assistance for implementation of adequate erosion controls, and more frequent watershed surveys to identify properties under construction or with logging operations that may not have adequate erosion controls in place.

4.4 Forestry BMPs

Sustainable forestry and active forest management are recognized as valuable tools for enhancing watershed protection and maintaining a healthy forest that is resistant to storms, fire, and invasive species (e.g., DCR, 2018). However, forestry can also adversely impact source water quality by increasing the likelihood of erosion of soils on logging sites, the potential for channelized flow on skid trails and other disturbed areas, accumulation of slash and debris that

can release nutrients after harvesting, and increased streamflow due to reduced canopy cover and evapotranspiration (EPA, 2015).

4.4.1 Current Regulations for Timber Harvesting Activities

The City of Auburn historically regulated timber harvesting in the Lake Auburn watershed in its Shoreland Overlay District Ordinance. The Timber Harvesting Standards in this ordinance were effective within 250 feet of the lake and tributary streams within the City of Auburn, and were more stringent than the statewide standards (listed in the Maine Forest Service Rules, Chapter 21). The remaining watershed municipalities (Minot, Turner, Buckfield, and Hebron) each had their own Shoreland Zoning Ordinance in accordance with Maine's Mandatory Shoreland Zoning Act.

A state-wide regulation was passed in 2013 to standardize timber harvesting requirements, and required communities outside of the Land Use Planning Commission jurisdiction (covering unorganized and deorganized areas of the state) to develop and adopt timber harvesting standards at least as stringent as those in Chapter 21. The 2013 regulation required each municipality to select one of three options:

- Repeal existing timber harvesting provisions from the shoreland zoning ordinance and adopt the statewide standards. If this option is selected, the Maine Bureau of Forestry administers and enforces the statewide standards.
- Adopt timber harvesting standards identical to the statewide standards. If this option is selected, the municipality has the option of administering and enforcing the rules itself, allowing the Bureau of Forestry to provide administration and enforcement, or sharing the responsibility for administration and enforcement with the Bureau of Forestry.
- Retain the current timber harvesting standards as long as these standards are at least as stringent as the statewide standards. However, in this case, the municipality takes on the responsibility for administration and enforcement unless it requests assistance from the Bureau of Forestry and that request is approved, and the Bureau of Forestry will not administer or enforce any ordinance that is more stringent or significantly different than the statewide standards.

The City of Auburn repealed the Timber Harvesting Standards in the Shoreland Overlay District Ordinance in 2019, replacing these requirements with the state-wide standards in Chapter 21. The other municipalities (Minot, Turner, Buckfield, and Hebron) have also adopted the state-wide standards.

4.4.2 LAWPC Timber Harvesting Activities

LAWPC has historically conducted timber harvesting operations on its watershed property following a Forestry Management Plan developed by a licensed forester (Southern Maine Forestry Services, Inc., 2013); forestry operations are not currently (Fall 2022) active, and LAWPC imposed a moratorium on logging on Commission-owned property on April 13, 2022. As stated in LAWPC's Forestry Management Plan, the primary objective of its timber harvesting operations is watershed protection through uneven aged management focused on the production of softwood species. Secondary goals are improved forest growth and productivity, aesthetics,

improved wildlife habitat, maintaining open space, and limited recreational potential. The plan notes that such a conservative forest management plan may result in lower wood production and income. Harvesting operations are generally completed in the winter months, although occasional harvesting occurs during dry periods with no significant precipitation. The Forestry Management Plan does not include specific BMPs for operations on watershed land beyond the State of Maine requirements³. However, LAWPC adopted standard operating procedures for forestry on Commission-owned property on January 13, 2021, which generally reference the Statewide Standards for Timber Harvesting in Shoreline Areas (Chapter 21).

Given the significant potential water quality impact on source water quality and the variable water quality observed since the 2018 algal bloom and 2019 alum treatment, we concur with the recommendations in the FB Associates report that logging operations pose a potential risk to the water supply (“In summary, timber harvesting is not a strategy for water supply protection that reduces contamination risk, but rather constitutes an additional and perhaps unnecessary risk to the water supply”). We recommend that LAWPC continue its moratorium on logging in the watershed until the causes of elevated turbidity are better understood and the water quality reaches several years of stable conditions with no significant algal blooms, Secchi depths greater than 6 m, and turbidity below 1 NTU. Exceptions could be made for emergency situations or to manage invasive pests within the watershed.

If logging operations restart on Commission property, we encourage LAWPC to adopt additional measures to guide its silvicultural operations:

1. LAWPC should formalize its goals for managing forested areas within the Lake Auburn watershed in a Natural Resources Management Plan. Timber harvesting should occur only to maintain a healthy forest or for water quality improvement in accordance with its Forestry Management Plan and BMPs. Potential revenue from timber harvesting operations should not factor into planning for future operations.
2. BMPs used during and after harvesting operations should be enhanced to exceed Maine state requirements where possible. Buffer areas and filter strips should be as wide as possible to reduce the potential impact on streams and wetlands, and should extend to intermittent streams as well as perennial streams. Slash left on the forest floor should be minimized to reduce nutrient loads, and bare areas should be reseeded as needed to reduce the erosion potential.
3. Water quality monitoring should be conducted before, during, and after timber harvesting operations to assess the efficacy of BMPs and to evaluate the potential water quality impacts on Lake Auburn.

³ Note that previously harvesting within the City of Auburn were covered by Chapter 60, Article XII, Division 5, Section 60-1003 of the Auburn Code of Ordinances. This ordinance was repealed in 2019 and the state-wide timber harvesting standards were adopted (Chapter 21). The state-wide timber harvesting standards are generally less stringent than the prior City ordinance.

4.4.3 Forest Management Goals

Each timber harvesting operation undertaken on LAWPC-owned land should be completed with a forest health or water quality improvement goal. LAWPC should develop a formal set of management goals for watershed land to judge whether the potential risks of harvesting are mitigated by the potential watershed benefits. This plan could be included in the Natural Resource Management Plan recommended in the FB Associates study or could be a standalone document.

Developing forestry management goals specific to LAWPC's land assets would allow the watershed protection or water quality improvement benefits of each individual timber harvest plan to be measured against the established goals. We recommend that revenue generation from timber harvesting operations be considered a secondary benefit and not factor into decisions about when and where to harvest timber within the watershed. In addition, strong consideration should be given to the 'no action' alternative, where the potential water quality impacts of a timber harvesting operation may outweigh the ecological and forest health benefits a timber harvest.

4.4.4 Enhanced BMPs

The State of Maine's timber harvest BMP requirements are designed to be protective of water quality. However, given the sensitive nature of water quality in Lake Auburn and the strict regulations associated with AWD/LWD's filtration avoidance waiver, we recommend implementing enhanced BMPs where practicable to provide the best water supply protection possible during and after harvesting operations. Our recommendations for enhanced BMPs are described in **Table 4-3** and are compared to the existing state-required water quality protections and the requirements in the previously effective City of Auburn Shoreland Overlay District Ordinance.

Note that this is not a complete listing of state and local requirements for timber harvesting operations, but instead represents a subset of BMPs for which enhancements over state requirements would improve source water protection. All timber harvesting operations have a risk of adverse water quality, especially in the first several years after the harvest is completed. These recommended enhanced BMPs will reduce, but not eliminate, the potential short-term water quality impacts of timber harvesting operations.

Table 4-3 Recommended Enhanced Forestry BMPs

Best Management Practice	Maine Requirement or Guidance ¹	Previous Auburn Shoreline Overlay District Ordinance	Recommended Enhanced BMP
Harvest timeframe	No restrictions	Conducted at such a time that minimal soil disturbance results.	Conduct operations in winter months only when ground is frozen
Temporary stream crossings (skid or forwarder trails)	Temporary crossings on skid or forwarder trails permissible if greater than 300 acres but less than 25 mi ² , and can include portable bridges, temporary culverts, logs/pole fords, or brush, and may not be required in winter months. For streams with a drainage area less than 300 acres, shoreline integrity must be maintained. For streams with a drainage area > 25 mi ² a bridge or culvert is required.	No restrictions beyond state requirements.	Avoid stream crossings where possible. If not possible, use a temporary bridge for any crossing of an intermittent or perennial stream or wetland.
Roads (skid/forwarder and truck)	Skid trails and yards must be designed and constructed to prevent sediment and concentrated runoff from entering a waterbody. Upon termination of their use, skid trails and yards must be stabilized. (Ch 21 §9) Guidance in the Maine BMP for Forestry (MFS, 2017), including planning skid/forwarder trails in advance during harvest planning, preventing water from entering or leaving landing, keep trails out of stream channels and banks.	No restrictions beyond state requirements.	Minimize skidding/forwarding distances to prevent erosion on road surface. Limit steep grades. After logging operations are completed, stabilize skid/forwarder trails with seeding, mulching, and/or water bars to prevent erosion. Do not place skid trails in stream channels or banks. Truck roads should be limited to the extent feasible.
Filter strips	Width between 25 to 165 ft based on slope table in Chapter 21, Section 12. Increase by 20 ft for each 10% increment in slope above 10%.	Increase the minimum filter strip width to 75 ft, and increase by 20 ft for each 10% increment in slope above 10%.	Increase the minimum filter strip width to 75 ft, and increase by 20 ft for each 10% increment in slope above 10%. Cut no more than 50% of the basal area within the filter strip.

Best Management Practice	Maine Requirement or Guidance ¹	Previous Auburn Shoreline Overlay District Ordinance	Recommended Enhanced BMP
Landings	See Shade and Tree Retention Standards.	See Shade and Tree Retention Standards.	In addition to the recommendations for Shade and Tree Retention Standards, minimize the area cleared for landing areas and locate at least 100 ft from streams and as far as practical from Lake Auburn, with a minimum distance of 250 feet. Check that adequate erosion controls are in place during operations. If located on moderately or poorly drained soils, landing areas should be constructed with geotextiles and/or gravel to support logging equipment and minimize erosion. Following harvest operations, the landing should be revegetated.
Slash	Do not leave slash or debris below the normal high water line of any water body. No accumulation of slash should be left within 50 feet of Great Ponds, rivers, non-forested wetlands greater than 10 acres. Slash used to protect soil from disturbance or to stabilize exposed soil may be left in place provided no part extends more than 4 feet above ground. Between 50 and 250 feet, all slash larger than 3 inches in diameter should be disposed of in a manner that it lies on the ground and no part thereof extends more than 4 feet above ground.	Slash should be placed at least 50 feet from public roads, property lines, and the normal high water mark of any pond, river or stream. At distances greater than 50 feet, all slash should be disposed of in a manner that it lies on the ground and no part thereof extends more than 4 feet above ground.	Follow previous ordinance but add restrictions to cover intermittent streams and wetlands. Slash should be placed at least 250 feet from Lake Auburn. Slash not required for site stabilization should be removed from site to reduce nutrient export to Lake Auburn.
Shade and Tree Retention Standards	Three options: (1) harvest no more than 40 percent of the total volume on each acre in any 10-year period; (2) retain at least an average basal area 60 ft ² /ac; (3) outcome based. For options (1) and (2): Maintain a well-distributed stand of trees which is windfirm and other vegetation, including existing ground cover. No cleared openings within 75 feet of the normal high water line; no single cleared opening greater than 14,000 ft ² , and where openings exceed 10,000 ft ² they must be at least 100 feet apart.	Adopted Option 1 in Ch 21. In addition, harvesting activities shall not create openings greater than 7,500 ft ² . No clear cut openings within 100 ft of the normal high water line of a great pond classified GPA or a river flowing to a great pond classified GPA, and within 75 feet of other water bodies, tributary streams, or the upland edge of a wetland.	Follow previous ordinance. Extend the clear cut opening restriction to 250 feet from Lake Auburn.

Timber harvesting completed on private lands within the watershed should be encouraged to use BMPs that surpass the state requirements. In addition, private operations should be encouraged to consult with the Maine Forest Service for technical advice prior to commencing harvest operations. LAWPC should be aware of private timber harvesting operations within the watershed, and should consult with the Maine Forest Service if any suspected violations are occurring during the harvest. Finally, the City of Auburn should consider establishing a Shoreland Zoning Ordinance that would allow timber harvesting BMP requirements that are more stringent than the current state-wide standards in effect for properties within the Lake Auburn watershed.

4.4.5 Monitoring

Water quality monitoring should be conducted prior to and after timber harvesting operations both above and below each lot to evaluate any potential water quality impacts from timber harvesting operations. Monitoring should consist of at least 3 wet weather events upstream and downstream and should be analyzed for turbidity, TSS, total phosphorus, and orthophosphate.

In addition, if runoff or snowmelt occurs during a timber harvest operation, water quality samples should be collected upstream and downstream of the operation, and the lake shore should be surveyed to determine if erosion is visibly impacting Lake Auburn.

4.5 Enhancements to the Water Quality Monitoring Program

We recommend that several additions and enhancements be made to the existing water quality monitoring program to better understand trends in turbidity, algal dynamics, and the potential for internal phosphorus release.

- Add a turbidity sensor to the existing YSI EXO sonde, and collect a turbidity profile at each lake station. This will collect detailed data on the location of high turbidity areas within the lake and provide additional data on the potential for sediment resuspension from the lake bottom or sediment plumes from tributary sources.
- Continue to monitor phosphorus profiles at the Deep Hole sampling location. These should be completed at least monthly during the stratified season, and can be used to estimate internal loading rates.
- Monitor periods of increased non-algal turbidity by documenting the start and stop dates and evaluating the horizontal and vertical extent of the elevated turbidity (with a turbidity sensor).

Section 5

Schedule and Milestones to Guide Plan Implementation

5.1 Implementation Schedule

A schedule was developed to guide the implementation of structural and non-structural BMPs (**Section 4**) over the 10-year plan duration. High-priority BMPs (**Section 4.1**) are recommended for implementation in the first six years of the program, and additional BMPs (**Section 4.2**) are recommended for implementation starting in 2026. Non-structural BMPs (**Section 4.3**) are intended to be implemented as soon as possible, and the forestry BMPs (**Section 4.4**) once timber harvesting resumes on LAWPC land.

Planning-level cost estimates are provided for each structural BMP in **Section 4**. Additional funding may be obtained from EPA Section 319 grants through MDEP, the State Revolving Fund, and the Maine Drinking Water Program's Source Water Protection Grant Program.

The implementation schedule, parties potentially responsible for implementation, and potential funding sources is shown in **Table 5-1**.

5.2 Milestones to Guide Project Implementation

The Lake Auburn Lake Watershed-based Plan will be implemented by LAWPC, with support from AWD and LWD. In addition, MDOT, the City of Auburn, Turner, Minot, and Buckfield may implement projects within areas of their jurisdiction, including private landowners. Finally, LAWPC will continue to work with Bates College to collect additional water quality data within the lake, including from a buoy located at the Deep Hole monitoring location, along with other university partners.

Milestones for the implementation of this plan will be evaluated against the proposed BMPs in **Section 4** and the target lake concentration described in **Section 3** and are described below.

- Implementation of recommended high-priority BMPs in the first 6 years of this plan
- Implementation of additional BMPs as feasible through the 10-year plan
- Observed reduction in tributary and in-lake phosphorus concentrations based on monitoring data at in-lake and tributary monitoring locations
- Observed reduction in algal blooms and turbidity at the raw water intake, particularly occurrence of days of turbidity above 1 NTU
- Continued engagement with landowners in the watershed to provide guidance on strategies to reduce phosphorus loads to Lake Auburn

5.3 Water Quality Results Monitoring

LAWPC will continue its water quality monitoring program. This program consists of samples collected from the lake, the intake, and tributaries in the watershed. Samples are generally collected weekly or biweekly, with less frequent samples collected in winter months.

- In-lake samples are collected and analyzed for nutrients, profiles (DO, temperature, conductivity, pH, chlorophyll *a*, phycocyanin), lab chlorophyll *a*, algal enumeration, bacteria, and Secchi depth
- Intake samples are analyzed for temperature, turbidity, and bacteria
- Tributary (perimeter) samples are analyzed for nutrients, field parameters, turbidity, bacteria, and flow.

Table 5-1 Implementation Schedule

BMP	Action	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	Implemented By	Potential Funding
The Basin	Bathymetric, Sediment Depth, and SAV Survey												1	A, B, C
	Armor Emergency Spillway												1	A, B, C
	Sediment Build-Up Monitoring												1	A
	Milfoil Harvesting												1	A, B, C
Spring Road Plunge Pool Retrofits	Design and Construction												1	A, B, C
	Monitoring / Maintenance												1	A, B, C
Spring Road Regrading, Waterbars, Ditch Inspection, Sediment Removal, and Vegetation	Initial Ditch Inspection / Feasibility Survey												1	A, B, C
	Sediment Removal												1	A, B, C
	Construction												1	A, B, C
	Monitoring / Maintenance												1	A, B, C
Lake Shore Drive Vegetated Filter Strips	Survey												1, 2	A, B, C
	Design and Permitting												1, 2	A, B, C
	Construction												1, 2	A, B, C
	Monitoring / Maintenance												1, 2	A, B, C
Lake Shore Drive Parking Areas	Survey												1, 2	A, B, C
	Design and Permitting												1, 2	A, B, C
	Construction												1, 2	A, B, C

BMP	Action	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	Implemented By	Potential Funding
Lake Shore Drive Guard Rail	Construction												2	A, B, C, F
Blanchard Pond Riparian Buffer	Discussion with Landowner												3	E
	Technical Assistance and Installation												1,3	A, B, E
Route 4 Drainage Improvements near Turner Rd Culvert, and stream restoration at 2481 Turner Road	Design												1, 2	A, B, C
	Permitting												1, 2	A, B, C
	Construction												1, 2	A, B, C
	Monitoring / Maintenance												1, 2	A, B, C
Townsend Brook Bioretention Basin	Pursue Partnership/Easement												3	A, B, C, D
	Permitting												1	A, B, C, D
	Feasibility Survey												1	A, B, C, D
	Soil Tests												1	A, B, C, D
	Design												1	A, B, C, D
	Construction												1	A, B, C, D
	Monitoring / Maintenance												1, 3	A, B, C, D
Townsend Brook Biochar filter bag pilot	Installation												1	A, B, C
	Testing/ Assessment												1	A, B, C
	If effective, consider at other locations (e.g., Blanchard Pond, Basin Stream)													
Route 4 Vortex Separator Sampling	Sampling Program												1	A, B, C

BMP	Action	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	Implemented By	Potential Funding
Alum Feed Systems for Tributary Inflow Treatment	Pilot Tests												1	A, B, C, D
	Permitting												1	A, B, C, D
	Construction on Townsend Brook (if selected)												1	A, B, C, D
	Construction on Basin Stream (if selected)												1	A, B, C, D
Land Acquisition	Continue to acquire properties in watershed												1	A, G
Lake Auburn Intake Extension	Data Collection												1	A, B, C, D
	Design, Permitting and Construction												1	A, B, C, D
Non-structural BMPs	Implement recommendations in Section 5.3												1, 5	A, B, C, E, F
Additional BMPs													1, 2, 3, 4, 5	A, B, C, D, E, F

Implementation Partners:

1. LAWPC, AWD, or LWD
2. Maine DOT
3. Private Landowner
4. Auburn Public Works
5. Other Municipalities

Potential Funding:

- A. LAWPC, Auburn DPW, AWD, or LWD (Cities)
- B. EPA 319 Grant
- C. Maine Drinking Water Program Source Water Protection Grant
- D. State Revolving Fund
- E. Voluntary Adoption by Landowners
- F. Other municipal (Minot, Turner, Buckfield) or state funding
- G. Drinking Water Program Land Acquisition Loans

Legend

	Priority BMPs
	Conditional on prior studies
	Additional BMPs

Section 6

References

AECOM (2009). Lake Loading Response Model. LLRM Lake Loading Response Model Users Guide and Quality Assurance Project Plan. AECOM, Willington, CT.

Baker, M.E., Schley, M.L., and Sexton, J.O. (2019). Impacts of Expanding Impervious Surface on Specific Conductance in Urbanizing Streams. *Water Resources Research*: 55:8 (6482-6498). Doi: 10.1029/2019WR025014

Carlson, R.E. (1977). A Trophic State Index for Lakes. *Limnology and Oceanography*: 2:22 (361-369). Doi: 10.4319/lo.1977.22.2.0361.

Carlson, R.E. (1991). Expanding the Trophic State Concept to Identify Non-Nutrient Limited Lakes and Reservoirs. *Enhancing the States' Lake Management Programs*. 59-71.

CDM Smith and WRS (2013). Diagnostic Study of Lake Auburn and its Watershed: Phase 1. Prepared for LAWPC.

CDM Smith and WRS (2014). Diagnostic Study of Lake Auburn and its Watershed: Phase 2. Prepared for LAWPC.

CDM Smith (2022). Watershed Delineation Rezoning Review – Gravel Pit Parcel. Prepared for the Lake Auburn Watershed Protection Commission.

Comprehensive Environmental, Inc. (CEI) (2010). Lake Auburn Watershed Management Plan. Prepared for LAWPC.

Department of Conservation and Recreation (DCR) (2018). Division of Water Supply Protection: 2017 Land Management Plan.

Dudley (2014). *Water Budget for Lake Auburn, Maine, May 1, 2000 through April 30, 2003*. Scientific Investigations Report 2004-5106. United States Geological Survey, Augusta, ME.

Environmental Protection Agency (EPA) (2010). Urbanization – Water and Sediment Quality. Causal Analysis/Diagnostic Decision Information System (CADDIS), Volume 2: Sources, Stressors, and Responses. <https://www.epa.gov/caddis-vol2>.

EPA (2015). National Management Measures to Control Nonpoint Source Pollution from Forestry. Chapter 2: Water Quality and Forestry Activities. EPA 841-B-05-001.

FB Associates, Horsley Witten Group, and the University of Maine (2021). A Regulatory, Environmental, and Economic Analysis of Water Supply Protection in Auburn, Maine. Prepared for the City of Auburn.

- Gunderson, L. (2020). The Origins and Dynamics of Phosphorus in Maine's Lake Auburn Watershed. An Honors Thesis Presented to the Faculty of the Environmental Studies Program, Bates College.
- Idso, S.B. (1973). On the Concept of Lake Stability. *Limnology and Oceanography*, 18:681-683.
- Maine Department of Environmental Protection (MDEP) and Portland Water District (PWD) (2006). Waterbars. *Conservation Practices for Homeowners*.
<https://www.pwd.org/sites/default/files/waterbar.pdf>
- Maine Department of Environmental Protection (MDEP) (2011). *Volunteer Lake Watershed Surveys: How to Conduct a Nonpoint Source Phosphorus Survey*.
- Minnesota Aquatic Invasive Species Research Center (MAISRC) (no date). Eurasian Watermilfoil Control Options. [Eurasian watermilfoil control options | Minnesota Aquatic Invasive Species Research Center \(MAISRC\) \(umn.edu\)](https://www.maisrc.org/eurasian-watermilfoil-control-options)
- MaineGIS (2021). Maine E911 Addresses Feature.
<https://maine.hub.arcgis.com/datasets/maine::maine-e911-addresses-feature/about>
- National Oceanic and Atmospheric Administration (NOAA) (2019). Precipitation-Frequency Atlas of the United States. Volume 10 Version 3.0: Northeastern States. Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, Vermont.
- North, R.P., North, R.L., Livingstone, D.M., Köster, O., and Köster, R. (2014). Long-term changes in hypoxia and soluble reactive phosphorus in the hypolimnion of a large temperate lake: consequences of a climate regime shift. *Global Change Biology*, 20:811-823.
- Nürnberg, G. (1995). Quantifying Anoxia in Lakes. *Limnology and Oceanography*, 40(6): 1100-1111.
- Helsel, D.R., Hirsch, R.M., Ryberg, K.R., Archfield, S.A., and Gilroy, E.J. (2020). *Statistical Methods in Water Resources*. Chapter 3 of Section A, Statistical Analysis, Book 4, Hydrologic Analysis and Interpretation. USGS Techniques and Methods 4-A3.
- Robertson, W.D., S.L. Schiff, and C.J. Ptacek. (1998). Review of Phosphate Mobility and Persistence in 10 Septic System Plumes. *Ground Water* 33 (1998):1000-10. Robertson, W.D., D. R. Van Stempvoort, D.R., and S.L. Schiff. (2019). Review of phosphorus attenuation in groundwater plumes from 24 septic systems. *Science of the Total Environment*. 692: 640-652. Doi: 10.1016/j.scitotenv.2019.07.198.
- Rhode Island Department of Environmental Management (RIDEM) (2015). Rhode Island Stormwater Design and Installation Standards Manual.
- Southern Maine Forestry Services, Inc. (2013). Timber Cruise Report and Forest Management Plan. Prepared for the Lake Auburn Watershed Protection Commission.

Stainsby, E.A., J.G. Winter, H. Jarjanazi, A.M. Paterson, D.O. Evans, and J.D. Young (2011). Changes in the Thermal Stability of Lake Simcoe from 1980 to 2008. *Journal of Great Lakes Research*, 37:63-71.

Tighe and Bond (2021). Blanchard Pond Watershed Study: Evaluation of Blanchard Pond & Downstream System and associated Sub-watersheds for Removal of Phosphorus. Prepared for the Lake Auburn Watershed Protection Commission.

Wagner, K. (2004). The Practical Guide to Lake Management in Massachusetts. Prepared for the Commonwealth of Massachusetts Executive Office of Environmental Affairs, Department of Conservation and Recreation and Department of Environmental Protection.

Water Resource Services, Inc. (WRS) (2019). Alternatives Analysis for Controlling Algae and Reducing Turbidity in Lake Auburn. Prepared for the Auburn Water District.

Wetzel, R.G. (2001). *Limnology: Lake and River Ecosystems*. 3rd Ed. Academic Press, San Diego, CA.

Winslow, L, Read, J., Woolway, R., Brentrup, J., Leach, T., Zwart, J., Albers, S., and Collingue, D. (2019) Package rLakeAnalyzer. Version 1.11.4.1.

Appendix A

LAWPC NPS Tracker

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Lake Auburn Watershed Management Plan (CEI, 2010)			
Summary			
Top Pollutant Sources:	Addressed Y/N	Completed Y/N	Notes
Direct stormwater discharges	Y		In June 2020, 2 vortex units were installed in 2 catch basins along Route 4 that drain to the lake; 3 more units are planned to be installed in other catch basins that drain to the lake in 2020. The units collect and filter out debris and pollutants. Maintenance of units will be twice a year.
Shoreline erosion	N		
In-lake sources of phosphorus	Y		Alum treatment in 2019
Septic systems	N		
Future development- residential and agricultural	Y		LAWPC land purchases prevent development; City of Auburn imposes restrictions on development through the Phosphorus Control Ordinance, Lake Auburn Watershed Overlay District, and the Shoreland Overlay District zoning regulations.
Wildlife	Y		Contract with USDA Wildlife Services for a gull management program and beaver removal.
Recommendations:			
Add Low Impact Development Standards to City Code		N	
Amend zoning ordinances to strengthen subsurface wastewater disposal requirements		Y	The vertical separation to groundwater or restrictive layer was increased from 24" to 36".
Update phosphorus control ordinance		N	Recommendation was to change the Future Area to be Developed (D value) from 1,180 acs to 1,524 acs, and the Per-acre Phosphorus Allocation (P value) from 0.047 lbs/ac/year to 0.036 lbs/ac/year.

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Amend ordinance to prohibit certain land uses within the lake auburn watershed overlay district		N	Recommendation was to prohibit the following uses in the Lake Auburn Watershed Overlay District: car washes, vehicle service repair, bulk outdoor chemical storage, hospitals and care facilities, auto fuel stations, laboratories, and dry cleaners.
Work with city and town DPWs to address drainage issues in watershed		Y	Coordination with Turner DPW to replace culverts as part of a 319 grant in 2016/2017; communication with Minot DPW for culvert replacement in 2020; ongoing communication with Auburn DPW, and MDOT, about drainage projects.
Set aside funds for maintenance of watershed lands		Y	Source Protection line item in LAWPC budget
Address direct stormwater discharges on Route 4 and within other areas of the watershed		Y	See note for Top Pollutant Sources: Direct stormwater discharges
Supplement erosion control strategies along Lake Shore Drive and other locations along the lake		Y	Recommendation recognizes previous stabilization work done along Lake Shore Drive. No further work has been done on that road, but erosion control projects have been completed on the Whitman Spring Road such as armored trenches, culvert replacements, and plunge pools.
Increase vegetated buffers around the lake-replace Route 4 paved turnaround with vegetation		Y 2021-2022	MDOT plans to remove the Route 4 paved turnaround and replace it with vegetation in 2021-2022. MDOT has coordinated with AWD on the timing and construction plans for this project. The project also includes traffic changes to the Route 4 boat launch.
Public education		Y	Recommendations completed: enhance website, develop and distribute educational materials, school education program. Recommendation not completed: agricultural education program.

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Continue key parcel acquisition and conservation efforts of environmentally sensitive land areas		Y	
Develop trail networks on LAWPC properties		N	Recommendation includes Southern Link Trail
Continue with invasive species controls		Y	Courtesy Boat Inspection funding through MDEP
Continue gull management		Y	
Continue monitoring program (lake and watershed)		Y	

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Diagnostic Study of Lake Auburn and its Watershed: Phase 1 (CDM Smith & WRS, 2013)			
Summary			
Study Recommendations:	Town	Completed Y/N	Notes
Implement a revised monitoring program to track water quality in 2013 and better understand drivers behind the degraded water quality.		Y	Extensive monitoring was added to the existing monitoring program-multiple in-lake sites and watershed sites are tested on a weekly and bi-weekly basis throughout the open water season. Several water quality parameters are collected during sampling.
Begin planning for an algaecide application for use as a contingency plan if turbidity levels rise in 2013 or beyond while implementing measures to reverse the degradation of the lake water quality.		Y	Algaecide permit was secured in 2013 for a 5-year term, and renewed in 2018 prior to the application on 9/11/2018. Erosion control projects and culvert replacements have been done to improve water quality in the lake. An alum treatment was done in 2019 to improve water quality as well.
Field Review (Fall 2012) Summary Recommendations:			
Spring Road	Auburn	Partial	North end BMPs installed- armored swales, plunge pools. Work remains to be done from middle to south end of road. Plunge pool repairs, culvert replacements, and ditching planned for Fall 2020.
Lake Shore Drive	Auburn	N	1. Remove sediment and stabilize steep banks in drainage next to Tabers that outfalls to lake. 2. At culvert outfall that runs under Lake Shore Drive, install sediment forebay to capture sediments and remove excess material, and stabilize banks at outfall. This drainage is being investigated as part of the Blanchard Pond study.
Skillings Corner Road	Turner	N	Culvert near intersection with Fern Street and Wilson Hill Road- remove sediment accumulation and stabilize bank. Evaluate size and effectiveness of culvert to minimize overtopping of road.

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Bailey Road	Minot & Auburn	N	Culvert on northern end of road- stabilization along banks, armor the channel, remove sediment accumulation. Culvert on southern end of road- stabilize or armor the area, plunge pool at the outfall.
Holbrook Road area	Minot & Auburn	Partial	Minot DPW replaced a culvert on Simeon Rd in 2020 that is included as a problem site in this report. LAWPC removed a failed culvert and placed riprap to stabilize stream bed and banks on the old Lunn Road in 2019. Need to stabilize downstream of the Lunn Road drainage. Holbrook Rd- stabilize steep banks, ditching, culvert maintenance.
Robinson Road	Turner	N	Roadside stabilization, riprap to slow water velocity
Little Wilson Pond Road	Turner	Partial	Culverts replaced under 319 grant (2016/2017).
Beaver Road	Auburn	N	Armor or stabilize banks at culvert to prevent roadside erosion from going into stream channel. Armor channel on steep sections.
Johnson Road/Dillingham Road	Auburn	N	Signs of livestock pasture and tributary within enclosure; install fencing to prevent livestock from accessing tributary
Route 4	Auburn	Partial	Culvert near Callahan and Roy's- stabilize roadside slope, remove accumulated sediment. Culvert to Roy's field- divert high nutrient runoff from entering outfalls. Culvert for First Brook- remove sediment and stabilize banks, replace pipe. Drainage work is planned for this site in 2021. Culvert near church- repair side slopes of drainage channel and armor outfall. The catch basin for this culvert is scheduled for a vortex unit in 2020. The next catch basin to the south has a vortex unit. The next two catch basins and culverts to the south- armor upstream slope, BMPs to provide stormwater treatment before the lake. Stabilize roadside and re-direct runoff.

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Hersey Hill Road	Auburn	N	Culvert near powerline- remove sediment and stabilize/armor area. Replace failed filter fabric.
East Hebron Road	Turner	N	Armor roadside along channel.
Route 4 Sand Pit	Auburn	N	Dirt road to Gendron's pit- improve buffering between pond and road
Townsend Brook	Auburn	Partial	Remove stone ATV bridge blocking flow; Gammon's detention pond repaired to manage flow with reinforced outlet; purchased the property on Townsend Brook Road in 2019 that previously had livestock that was an issue.
Stream draining to Tabers	Auburn	N	Stabilize hillside and armor bends in stream; reduce runoff from farms
Stream along Johnson Road	Auburn	N	Armor steep section and stabilize area

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Diagnostic Study of Lake Auburn and its Watershed: Phase 2 Draft (CEI, May 2013)

	Monitor sediment deltas & accumulation at other areas around Lake Auburn	Staff time	Staff time	AWD/LWD	Every 3 Years
	Continue and expand tributary flow monitoring	\$30,000	Staff time	AWD/LWD	On-going
★	Continue Lake/tributary water quality sampling	Staff time	\$75,000	AWD/LWD	On-going
★	Develop Forestry Activity and BMP Monitoring S.O.P.	\$2,500	Staff time	AWD/LWD	2013-2014
★	Water Watershed Activities				
★	Work with the City and Town DPWs to address BMP issues and establish and BMP monitoring & maintenance plan	Staff time	Staff time	AWD/LWD/City & Town DPWs	2013-2014
★	Set Aside Funds for Maintenance of Watershed Lands	None	\$10,000	AWD/LWD/City & Town DPWs	2013 - 2013
★	Continue Key Parcel Land Acquisition and Conservation Efforts of Environmentally Sensitive Land Areas	Staff time	\$250,000	AWD/LWD/City Councils	On-going

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	Develop Forestry Activity and BMP Monitoring S.O.P.	\$2,500	Staff time	AWD/LWD	2013-2014
	Other Watershed Activities				
	Work with the City and Town DPWs to address BMP issues and establish and BMP monitoring & maintenance plan	Staff time	Staff time	AWD/LWD/City & Town DPWs	2013-2014
	Set Aside Funds for Maintenance of Watershed Lands	None	\$10,000	AWD/LWD/City & Town DPWs	2013 - 2023
	Continue Key Parcel Land Acquisition and Conservation Efforts of Environmentally Sensitive Land Areas	Staff time	\$250,000	AWD/LWD/City Councils	On-going
	Develop Trail Networks on LAWPC Properties	\$400,000	Staff time	AWD/LWD/ATRC	2013 - 2023
	Install Lined Swales and Treatment BMP with Accidental Spill Containment at Crossing #20B	\$194,800	\$900	AWD/LWD/MEDEP/ Auburn DPW	2015-2018
	Install Shoreline Stabilization and Infiltration BMP Along Lakeshore Drive between Crossings 20 - 20B	\$241,600	\$800	AWD/LWD/MEDEP/ Auburn DPW	2018 -2023
	Install Swales and Treatment BMP with Accidental Spill Containment near intersection of Lakeshore Drive & Maple Hill Rd. Install Shoreline Stabilization	\$268,300	\$1,000	AWD/LWD/MEDEP/ Auburn DPW	2018 -2023
					
					
	Over Watershed				
	Stabilize Streambank and Install Treatment BMP near Crossing #4 prior to discharge into Ice house Wetland	\$129,400	\$600	AWD/LWD/MEDEP/ Auburn DPW	2018 -2023
	Install Treatment BMPs and Vegetated Filters along W. Auburn Rd & Summer Street	\$118,700	\$700	AWD/LWD/MEDEP/ Local Farms	2018 -2023
	Install Leaching Catch Basins and Sediment Capturing BMPs along Gracelawn Rd near Sandpit Entrance	\$84,700	\$600	AWD/LWD/MEDEP/ Auburn DPW	2018 -2023
	Work with Local Farmers to Install Nutrient Removal BMPs and Vegetated Filters	\$72,700	\$600	AWD/LWD/MEDEP/	2018 -2023

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between Crossings 20 - 20B			Auburn DPW	
Install Swales and Treatment BMP with Accidental Spill Containment near intersection of Lakeshore Drive & Maple Hill Rd. Install Shoreline Stabilization	\$268,300	\$1,000	AWD/LWD/MEDEP/ Auburn DPW	2018 -2023
Lower Watershed				
Stabilize Streambank and Install Treatment BMP near Crossing #4 prior to discharge into Ice house Wetland	\$129,400	\$600	AWD/LWD/MEDEP/ Auburn DPW	2018 -2023
Install Treatment BMPs and Vegetated Filters along W. Auburn Rd & Summer Street	\$118,700	\$700	AWD/LWD/MEDEP/ Local Farms	2018 -2023
Install Leaching Catch Basins and Sediment Capturing BMPs along Gracelawn Rd near Sandpit Entrance	\$84,700	\$600	AWD/LWD/MEDEP/ Auburn DPW	2018 -2023
Work with Local Farmers to Install Nutrient Removal BMPs and Vegetated Filters along Summer Street	\$72,700	\$600	AWD/LWD/MEDEP/ Local Farms	2018 -2023
Upper Watershed				
Install Lined Swales and Treatment BMP with Accidental Spill Containment along			AWD/LWD/MEDEP/	

Route 4/Turner Road Area		
	direct untreated stormwater runoff into lake	Rt 4 Causeway Curbing & Drainage Diversion to Treatment / Accidental Spill BMP at Crossing #53
	potential high-load land uses - animal pasture, golf course, greenhouse nursery, multiple driveway crossings	Drainage Repairs, Diversions & Roadside Erosion Repairs - Rt 4 Causeway
	erosion from steep slopes leading down to the gravel Spring Road	Install Armored Swales and Sediment Stilling Basin at Crossing #11

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		Accidental Spill BMP at Crossing #53 
	potential high-load land uses - animal pasture, golf course, greenhouse nursery, multiple driveway crossings	Drainage Repairs, Diversions & Roadside Erosion Repairs - Rt 4 Causeway 
		
	erosion from steep slopes leading down to the gravel Spring Road	Install Armored Swales and Sediment Stilling Basin at Crossing #11 
	multiple gravel roadway crossings and groundwater	Re-grade Gravel Road and Install Roadside Swales with plunge pools
		Install Swales and Treatment BMP with Accidental Spill Containment near intersection of Lakeshore Drive & Maple Hill Rd. Install Shoreline Stabilization
	erosion along banks of unnamed tributary discharging into Ice House Wetland and along roadway shoulders of Auburn Road and Shore Road	Stabilize Streambank and Install Treatment BMP near Crossing #4 prior to discharge into Ice house Wetland
	potential high-load land uses - farmland, gravel pit wetlands	Install Treatment BMPs and Vegetated Filters along W. Auburn Rd & Summer Street
Lower Watershed Area	large sandpit	Install Leaching Catch Basins and Sediment Capturing BMPs along

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		Shoreline Stabilization
Lower Watershed Area	erosion along banks of unnamed tributary discharging into Ice House Wetland and along roadway shoulders of Auburn Road and Shore Road	Stabilize Streambank and Install Treatment BMP near Crossing #4 prior to discharge into Ice house Wetland
	potential high-load land uses - farmland, gravel pit wetlands	Install Treatment BMPs and Vegetated Filters along W. Auburn Rd & Summer Street
	large sandpit	Install Leaching Catch Basins and Sediment Capturing BMPs along Gracelawn Rd near Sandpit Entrance
		Work with Local Farmers to Install Nutrient Removal BMPs and

Structural BMP Legend

 To be completed 2013 - 2015

 To be completed 2015 - 2018

 To be completed 2018 - 2023

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Townsend Brook Phosphorus Contributions from Groundwater (Summit Environmental Consultants, 2014)		
Summary		
Study Recommendations:	Completed Y/N	Notes
Water quality samples should be collected for analysis of total phosphorus and orthophosphorus at several points along Townsend Brook during the growing season to evaluate whether phosphorus concentrations during base flow conditions vary with seasonal cycles in plant growth and nutrient uptake.	Partial	Samples are collected in the tributaries to Townsend Brook throughout the growing season and analyzed for total phosphorus and orthophosphorus
Phosphorus data collected in this study, and phosphorus data collected in any follow-up study, should be used to validate or refine input parameters used to model phosphorus cycling in Lake Auburn.		
Repairs to the outfall of Gammon's detention pond and the erosion control measures between the outfall and Townsend Brook should be evaluated.	Partial	Looked at during 2018 field work; functioning infrastructure

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Diagnostic Study of Lake Auburn and its Watershed: Phase 2 (CDM Smith & WRS, 2014)		
Summary		
Study Recommendations:	Completed Y/N	Notes
Continued monitoring of the watershed and lake water quality	Y	Monitoring of the lake and watershed water quality is ongoing
Gloeotrichia monitoring	Y	Ongoing
Monitor sediment accumulation in The Basin and upstream ponds at the beginning and end of each sampling season.	N	
Maintain a log of boards and use of sluice gate	Y	Ongoing
Watershed management activities	Y	Ongoing
In-lake management activities	Y	Copper sulfate treatment 09/2018 and alum treatment in 2020
Maintain ability to apply algicide	Y	Permit was renewed in 2018, permit term is 5 years
If algicide treatment is required, immediately review that current year's water quality data and climatic events to determine a likely cause(s), and unless the cause is highly unusual, initiate design and permitting to implement either a diffused oxygen distributor system or alum application by July of the following year.	Y	After the copper sulfate treatment in September 2018, a plan was made to do an alum treatment in July 2020.
Long-term Alternatives:		
Dredging	N	
Hypolimnetic aeration or oxygenation	N	
Phosphorus inactivation	Y	Alum treatment 2020
Algicides	Y	Copper sulfate treatment 2019

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The Origins and Dynamics of Phosphorus in Maine's Lake Auburn Watershed (Lars Gundersen, Thesis, Bates College, 2020)	
Summary	
Study Recommendations:	Notes
Ground-truth the loading hotspots identified by the Soil and Water Assessment Tool (SWAT). Visit areas in the watershed which the model has identified as high-load to look for signs of runoff and/or erosion-induced loading. Draft and implement intervention strategies as needed.	
Do not ignore smaller inlets just because they contribute a small percentage of the total load. Even the smallest inlets can yield kilograms of P per year. Small interventions in some of these streams could reduce a substantial portion of the stream's load, and help contribute to an overall reduction in watershed load.	Small inlets are included in routine watershed sampling efforts.
Continue to increase watershed sampling. This could involve increasing the frequency of sampling, adding new sampling locations in areas upstream from outlets, and conducting in-lake sampling in the Basin, Little Wilson Pond, and Mud Pond. Focus particular attention on the Basin, Little Wilson Pond, and Mud Pond; this part of the watershed contributes about 80% of the total load according to the AWD/LWD data analysis.	This will be dependent upon staff capacity.
Conduct sampling in a way which improves stream load estimation capacity. Always collecting both discharge and P concentration data, and conducting additional sampling, would dramatically improve future stream load estimates. Consider sampling both on a regular schedule (e.g., every two weeks for the entire ice-free season) as well as during extreme precipitation events.	
Considering limiting residential development and regulating agricultural land in the watershed. Residential development is currently the main driver of land-use change in the watershed and cultivated crops contribute some of the highest per-hectare loads. Though it is unclear what proportion of land-use change-driven loading is caused by residential development and agriculture, these are two of the key causes of eutrophication in Lake Auburn. Consider monitoring residential developments and cultivated crop areas during heavy rainfall to look for signs of runoff and/or erosion-induced loading, strengthening buffer zone regulations, and limiting further residential development in the most sensitive areas.	This is done through the regulations included in the Lake Auburn Watershed Overlay District, Shoreland Overlay District, and the Phosphorus Control zoning ordinances.

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Prioritize buying and conserving undeveloped, high-load parcels of land. Most of the undeveloped land which contributes a large P load is in places with steep slopes or near roads with poor drainage. Both the load and the amount of undeveloped, high-load land is predicted to increase with climate change. When the LAWPC considers purchasing land, undeveloped, high-load areas should be prioritized. However, buying land is not a standalone solution. Loading can still be very high without interventions to address steep slopes, halt logging operations, reforest disrupted land, and improve drainage along roadways. There are currently large swaths of Water District land which are predicted to contribute large P loads. Loading in these areas should be addressed.	This is an ongoing watershed management strategy for LAWPC
Investigate potentially high loading around Mud Pond. The AWD/LWD data analysis found that at least half of the Basin load originates in and around Mud Pond and the SWAT analysis also shows the area around Mud Pond as a loading hotspot. Consider conducting sampling in and around Mud Pond to confirm this prediction, then explore mitigation measures.	
Investigate P loading originating in the Townsend Brook sub-watershed. Phosphorus concentrations in Townsend Brook are spatially variable. Concentrations at the outlet are low, but upstream concentrations are frequently high, particularly around Roys. Ground-truth potential loading hotspots based on both the AWD/LWD data and SWAT analyses, and draft mitigation measures.	See related 2014 study- Townsend Brook Phosphorus from Groundwater
Consider P load mitigation strategies for First Brook. Phosphorus concentrations in First Brook are the highest in the watershed, despite the overall load being small. Thankfully, discharge (and thus, load) at First Brook is low. Nonetheless, the brook contributes by far the largest load relative to discharge, mostly because the sub-watershed has so much developed and agricultural land.	Currently part of the Blanchard Pond Study

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Pursue mitigation strategies for any AWD/LWD sampling location with P concentrations over 20 ug/L. Four of the 13 long-term sampling locations have long-term mean P concentrations over 20 ug/L, and all 13 sites have at least one recorded value over 20 ug/L, with eight of the 13 sites having maximum concentration values over 100 ug/L. Sites with the highest mean P concentrations should be prioritized for interventions. Potential loading hotspots within sub-watersheds can be identified using the SWAT maps.	
Develop management options under the assumption that addressing P loading will also address N loading. Based on the SWAT analysis, locations with high N loading generally mirror high P load areas. Thus, interventions to address P loading will also address N loading, should the lake be N and P co-limited.	

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Tasks to Do
<u>Lake Auburn Watershed Management Plan (2010)</u>
Address shoreline erosion
Inspect septic systems
Add Low Impact Development Standards to City Code
Update phosphorus control ordinance
Amend ordinance to prohibit certain land uses within the lake auburn watershed overlay district
Develop trail networks on LAWPC properties
Supplement erosion control strategies along Lake Shore Drive
Develop agricultural education program
<u>Diagnostic Study of Lake Auburn and its Watershed: Phase 1 (2013)</u>
Spring Road: Work remains to be done from middle to south end of road. Plunge pool repairs, culvert replacements, and ditching planned for Fall 2020.
Lake Shore Drive: Remove sediment and stabilize steep banks in drainage next to Tabers that outfalls to lake.
At culvert outfall that runs under Route 4 and Lake Shore Drive, install sediment forebay to capture sediments and remove excess material, and stabilize banks at outfall. This drainage is being investigated as part of the Blanchard Pond study.
Skillings Corner Road: Culvert near intersection with Fern Street and Wilson Hill Road- remove sediment accumulation and stabilize bank. Evaluate size and effectiveness of culvert to minimize overtopping of road.
Bailey Road: Culvert on northern end of road- stabilization along banks, armor the channel, remove sediment accumulation. Culvert on southern end of road- stabilize or armor the area, plunge pool at the outfall.
Holbrook Road: Stabilize steep banks, ditching, culvert maintenance. Need to stabilize downstream of the Lunn Road drainage.
Robinson Road: Roadside stabilization, riprap to slow water velocity
Beaver Road: Armor or stabilize banks at culvert to prevent roadside erosion from going into stream channel. Armor channel on steep sections.
Johnson Road/Dillingham Road: Signs of livestock pasture and tributary within enclosure; install fencing to prevent livestock from accessing tributary
Route 4: Culvert near Callahan and Roy's- stabilize roadside slope, remove accumulated sediment. Culvert to Roy's field- divert high nutrient runoff from entering outfalls. Culvert for First Brook- remove sediment and stabilize banks, replace pipe. Drainage work is planned for this site in 2021. Culvert near church- repair side slopes of drainage channel and armor outfall. The catch basin for this culvert is scheduled for a vortex unit in 2020. The next catch basin to the south has a vortex unit. The next two catch basins and culverts to the south- armor upstream slope, BMPs to provide stormwater treatment before the lake. Stabilize roadside and re-direct runoff.
Hersey Hill Road: Culvert near powerline- remove sediment and stabilize/armor area. Replace failed filter fabric.

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East Hebron Road: Armor roadside along channel.
Route 4 Sand Pit: Dirt road to Gendron's pit- improve buffering between pond and road
Townsend Brook: Remove stone ATV bridge blocking flow.
Stream draining to Tabers: Stabilize hillside and armor bends in stream; reduce runoff from farms
Stream along Johnson Road: Armor steep section and stabilize area
<u>Diagnostic Study of Lake Auburn and its Watershed: Phase 2 Draft (May 2013)</u>
Establish Steep Slope Ordinance
Develop gravel road education program
Complete bathymetry mapping of The Basin and monitor accumulated sediments for long term dredge plan
Lake Shore Drive: Townsend Brook BMPs- wetland and culvert retrofits/filter media along road; install shoreline stabilization and infiltration BMPs along road; install swales and treatment BMP with accidental spill containment near intersection of Lake Shore Drive and Maple Hill Road
Route 4: causeway curbing and drainage diversion to treatment/accidental spill BMP at crossing; drainage repairs, diversions, and roadside erosion repairs to the causeway
Lower Watershed: stabilize streambank and install treatment BMP near crossing next to Ice House wetland
West Auburn Road: install treatment BMPs and vegetated filters along road
Summer Street: work with farmers to install nutrient removal BMPs and vegetated filters
Summer Street Ext: install treatment BMPs and vegetated filters along road
Gracelawn Road: install leaching catch basins and sediment capturing BMPs along road and sand pit entrance
Holbrook Road: install lined swales and treatment BMP with accidental spill containment along the road near The Basin access gate; stabilize stream channels and install armored roadside swales at crossings
Little Wilson Pond Road: install shoreline stabilization and sediment BMPs along the road
<u>Diagnostic Study of Lake Auburn and its Watershed: Phase 2 (2014)</u>
Monitor sediment accumulation in The Basin and upstream ponds at the beginning and end of each sampling season.
<u>The Origins and Dynamics of Phosphorus in Maine's Lake Auburn Watershed (2020)</u>
Ground-truth the loading hotspots identified by the Soil and Water Assessment Tool (SWAT). Visit areas in the watershed which the model has identified as high-load to look for signs of runoff and/or erosion-induced loading. Draft and implement intervention strategies as needed.

DRAFT

Continue to increase watershed sampling. This could involve increasing the frequency of sampling, adding new sampling locations in areas upstream from outlets, and conducting in-lake sampling in the Basin, Little Wilson Pond, and Mud Pond. Focus particular attention on the Basin, Little Wilson Pond, and Mud Pond; this part of the watershed contributes about 80% of the total load according to the AWD/LWD data analysis.

Conduct sampling in a way which improves stream load estimation capacity. Always collecting both discharge and P concentration data, and conducting additional sampling, would dramatically improve future stream load estimates. Consider sampling both on a regular schedule (e.g., every two weeks for the entire ice-free season) as well as during extreme precipitation events.

Investigate potentially high loading around Mud Pond. The AWD/LWD data analysis found that at least half of the Basin load originates in and around Mud Pond and the SWAT analysis also shows the area around Mud Pond as a loading hotspot. Consider conducting sampling in and around Mud Pond to confirm this prediction, then explore mitigation measures.

Pursue mitigation strategies for any AWD/LWD sampling location with P concentrations over 20 ug/L. Four of the 13 long-term sampling locations have long-term mean P concentrations over 20 ug/L, and all 13 sites have at least one recorded value over 20 ug/L, with eight of the 13 sites having maximum concentration values over 100 ug/L. Sites with the highest mean P concentrations should be prioritized for interventions. Potential loading hotspots within sub-watersheds can be identified using the SWAT maps.

Appendix B

Watershed Survey

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Appendix B

Watershed Survey

CDM Smith and City of Auburn staff completed a two-day survey of the Lake Auburn watershed on September 8 and 9, 2022. The goals of the watershed survey were to:

- Review problem areas identified in the previous watershed survey (CEI, 2013)
- Review BMPs installed since the previous watershed survey
- Identify additional areas within the watershed that may contribute to nonpoint source loads to Lake Auburn

The watershed survey area is organized into six subwatersheds. The findings of the watershed survey and the subsequent recommendations are organized by subwatershed. The watershed and sub-watershed boundaries are shown in **Figure B-1**.

A summary table of all sites visited during the survey with coordinates, and the severity of the non-point source threat is contained in **Table B-1** at the end of this document.

B-1 Lake Shore Drive

The Lake Shore Drive subwatershed consists of the area immediately adjacent to Lake Shore Drive between Townsend Brook and the upper watershed. Based on the previous watershed survey and observations during the 2022 watershed survey, principal sources of nonpoint source pollution in this area are:

- Direct drainage along Lake Shore Drive with little to no buffer between stormwater runoff and the lake
- Erosion around culverts and along tributaries to the lake, especially on the tributary adjacent to Tabers
- Agricultural land use in the upper portion of the watershed

The watershed survey identified 10 current areas of potential nonpoint source pollution (**Figure B-2**).

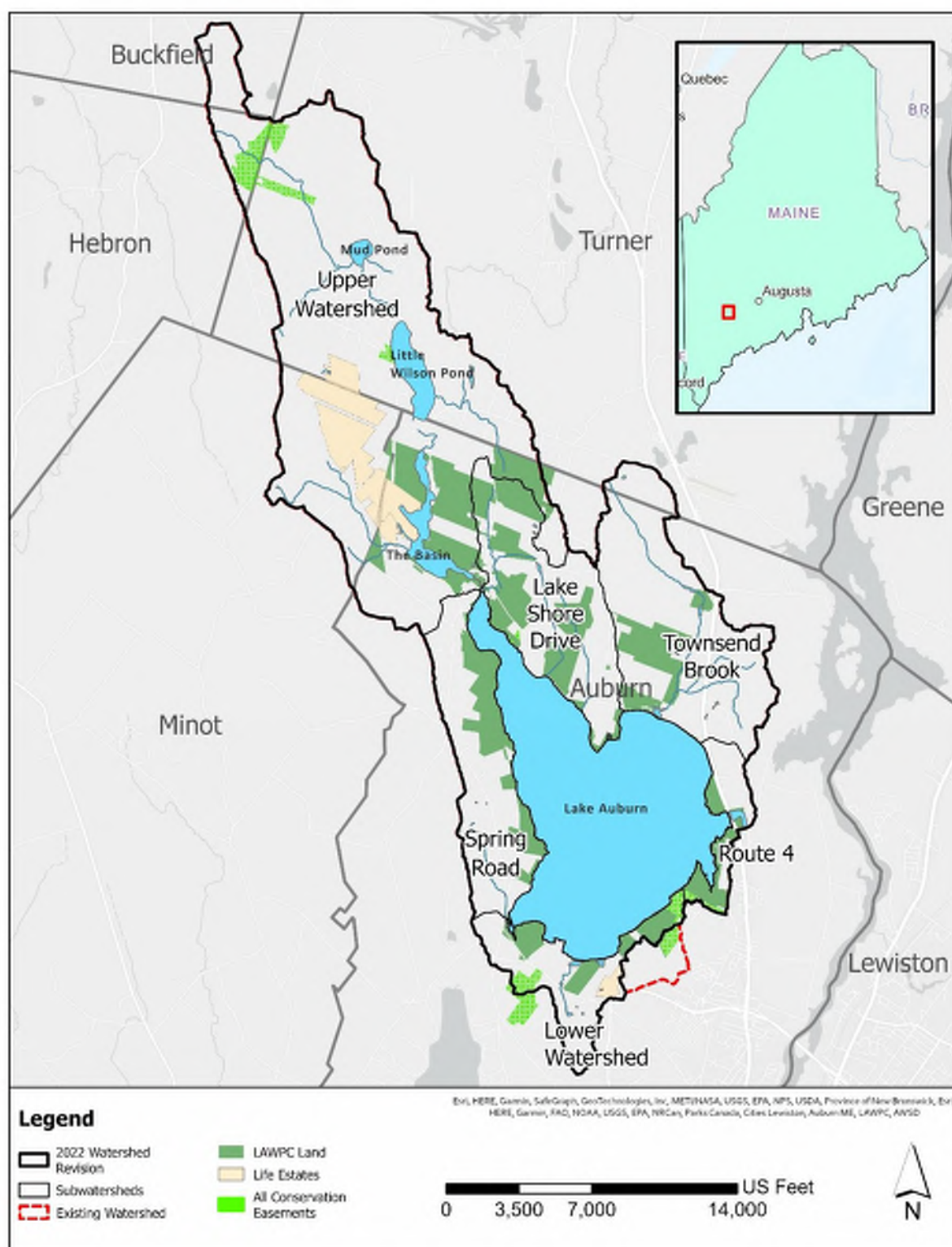


Figure B-1
Subwatershed Boundaries

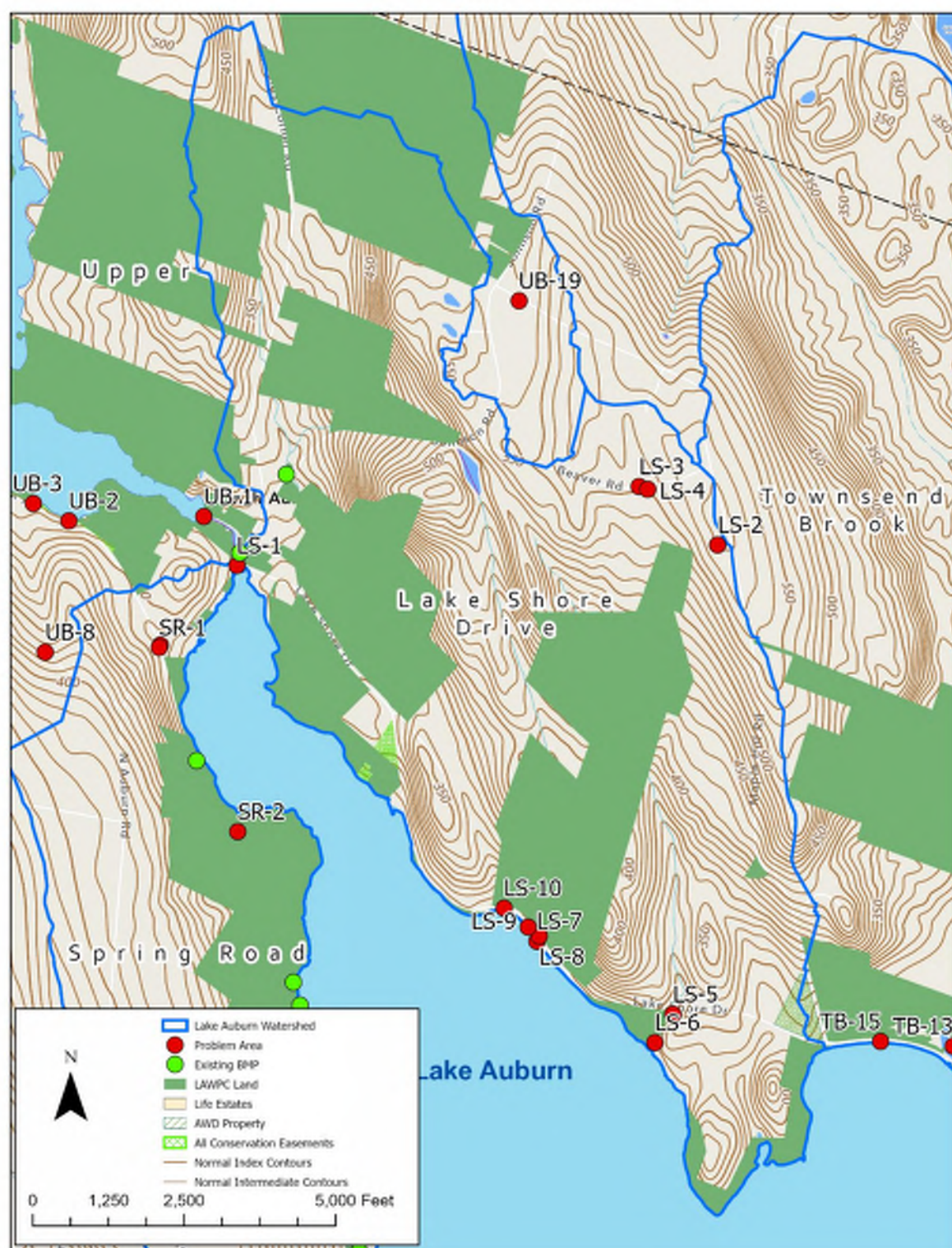


Figure B-2
Lake Shore Drive Pollution Sources

LS-1: The Basin Outlet/Lake Auburn Inlet

The inlet to Lake Auburn from the upper watershed is located at the junction of Lake Shore Drive and N. Auburn Road in Auburn. This location has historically had significant accumulations of milfoil, and this condition was observed during the 2022 watershed survey (**Figure B-3**).

AWD/LWD staff reported that milfoil was removed from the Basin (upstream of this location) in 2010, and that milfoil accumulation is limited to the Lake Auburn inlet. Milfoil has been restricted to the northern cove of the lake, and has not been observed outside of this location. However, the accumulation of milfoil has caused the boat ramp at the northern end of the lake (at Lake Shore Drive) to be closed to use. AWD/LWD should consider removing milfoil and replacing it with native vegetation.



Figure B-3
Milfoil Accumulation at the Lake Auburn Inlet

LS-2: Horse Farm on Maple Hill Road

A horse farm located at 464 Maple Hill Road in Auburn has occasionally been observed to have manure piled on farm property. LAWPC should work with the property owners to institute a manure management plan to ensure that manure is properly managed and does not contribute to stormwater pollution.

LS-3 and LS-4: Drainage on Beaver Road, Auburn

A culvert crossing in the vicinity of 50 Beaver Road in Auburn was recently replaced by AWD (**Figure B-4**). The 2022 watershed survey observed evidence of erosion in the ditch and across the culvert inlet and outlet embankments; the embankments are not hardened. Water appears to be flowing down both sides of the crowned road, causing significant erosion around the inlet and outlet in addition to erosion in the upstream ditch running parallel to the road. Evidence of a

sediment delta in the downstream stream and sediment accumulation within the culvert are apparent. In addition, the culvert inlet is not in contact with the bottom of the upstream ditch. At this location, the ditch should be revegetated and the culvert embankments armored or vegetated to prevent future erosion.



Figure B-4

Erosion at the Beaver St Culvert Crossing

Clockwise from top left: mild erosion on road embankment upstream of culvert, erosion of around culvert outlet and downstream, evidence of sediment in culvert outlet, culvert inlet

LS-5, LS-6: Brook Near Tabers

The brook that drains to Lake Auburn near Tabers crosses Lake Shore Drive immediately to the west of the Tabers parking lot (see map, **Figure B-5**). During the 2022 survey, sediment accumulation was observed in the pool located immediately downstream of the culvert outlet (LS-5, **Figure B-6**), with little sediment present at the time of the survey downstream. However, significant erosion was observed along the brook downstream of the culvert crossing at Lake Shore Drive and down the steep slope from Tabers (LS-6, **Figure B-7**). This consists of both undercutting of the bank and erosion of the steep bank into the stream from Tabers. No evidence of a sediment delta was present at the lake.

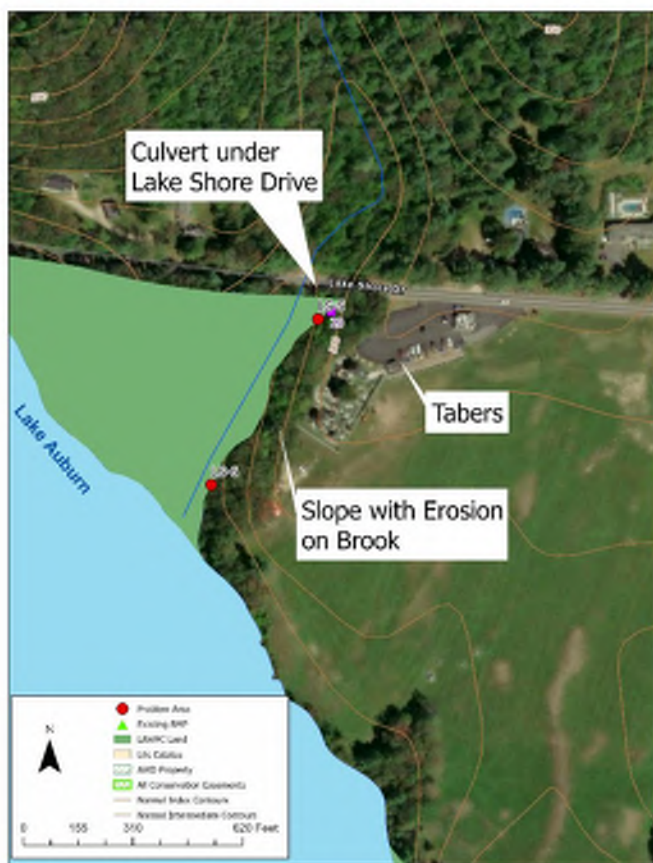


Figure B-5
Overview Map: Brook Near Tabers



Figure B-6
Sediment in the Pool Underneath the Culvert Crossing at Lake Shore Drive

While the previous watershed survey indicated concerns about the impact of Tabers driving range, discussions with AWD/LWD staff indicate that no fertilizer is used on the driving range, and that a vegetated buffer is maintained between the mowed driving range surface and the lake.

Actions to explore at this location are further investigations into upstream sedimentation sources and restoration of the stream banks with natural materials between Lake Shore Drive and the lake to reduce erosion.



Figure B-7

Erosion in the Vicinity of the Brook near Tabers at Lake Shore Drive, Auburn

Top: Erosion along the steep bank from Tabers; Bottom: Undercut stream downstream of Lake Shore Drive culvert

LS-7 – LS-10: Lake Shore Drive Direct Drainage (North)

Lake Shore Drive is located directly adjacent to Lake Auburn in several locations along the northern lake shore, with little stormwater infrastructure in place to prevent erosion and direct discharge into the lake. There are several concerns in the northern section of Lake Shore Drive (between Tabers and N. Auburn Road). Additional concerns are located in the area adjacent to Townsend Brook (see **Section B-2**).

A portion of the buffer between the road and the lake in this area has vegetated buffer that prevents runoff from the road from immediately discharging into the lake, while other portions of the road do not. Erosion was observed where there is not buffer resulting in direct discharge into the lake from the adjacent roadway (**Figure B-8**). Areas without a substantial vegetated buffer should be modified with a vegetated filter strip to prevent direct discharge of runoff into the lake.



Figure B-8
Vegetated Buffer on Lake Shore Drive (L) and Erosion (R)
Note erosion in foreground leading to the lake

Drainage on the inland side of Lake Shore Drive is conveyed by a ditch to several culverts. There are occasional areas of erosion from the steep slope inland from Lake Shore Drive into the ditch, with additional erosion evident within the ditch (**Figure B-9**). Armoring or stabilization (for instance, by hydroseeding) of steep slopes adjacent to Lake Shore Drive, and maintenance of ditches would reduce the potential for erosion and pollutant transport into the lake from Lake Shore Drive.



Figure B-9

Erosion on Inland Side of Lake Shore Drive (North)

Left: Erosion on steep slope; right: erosion in ditch on inland side of Lake Shore Drive

Erosion is also noted at a culvert crossing on Lake Shore Drive at the western edge of the LAWPC property (LS-10, **Figure B-10**), which drains a small, steep stream in addition to local road drainage. There is erosion noted upstream of the culvert, although no sediment deltas are evident in the lake on the downstream side. This culvert is in poor condition and is rotting away, when culvert replacement occurs additional BMPs could be added to intercept sediment that may discharge from the steep tributary stream. In addition, as with the site noted above, the steep slopes upgradient from the road should be armored or stabilized to reduce erosion.



Figure B-10
Erosion on Steep Stream (L) and Culvert in Poor Condition (R)

B-2 Townsend Brook

The Townsend Brook subwatershed consists of Townsend Brook, First Brook, and additional direct drainage from Lake Shore Drive south of Tabers. Water quality issues found in the Townsend Brook watershed include:

- ATV and snowmobile use causing erosion
- Agricultural use causing eutrophication in ponds and high nutrient concentrations in streams in the lower part of the watershed
- Poor housekeeping in commercial operations along Route 4 that discharge directly to Townsend Brook
- Direct drainage from Lake Shore Drive into Lake Auburn
- Parking areas along Lake Auburn's shoreline causing erosion

The watershed survey identified 15 potential nonpoint source pollution sources (**Figure B-11**).

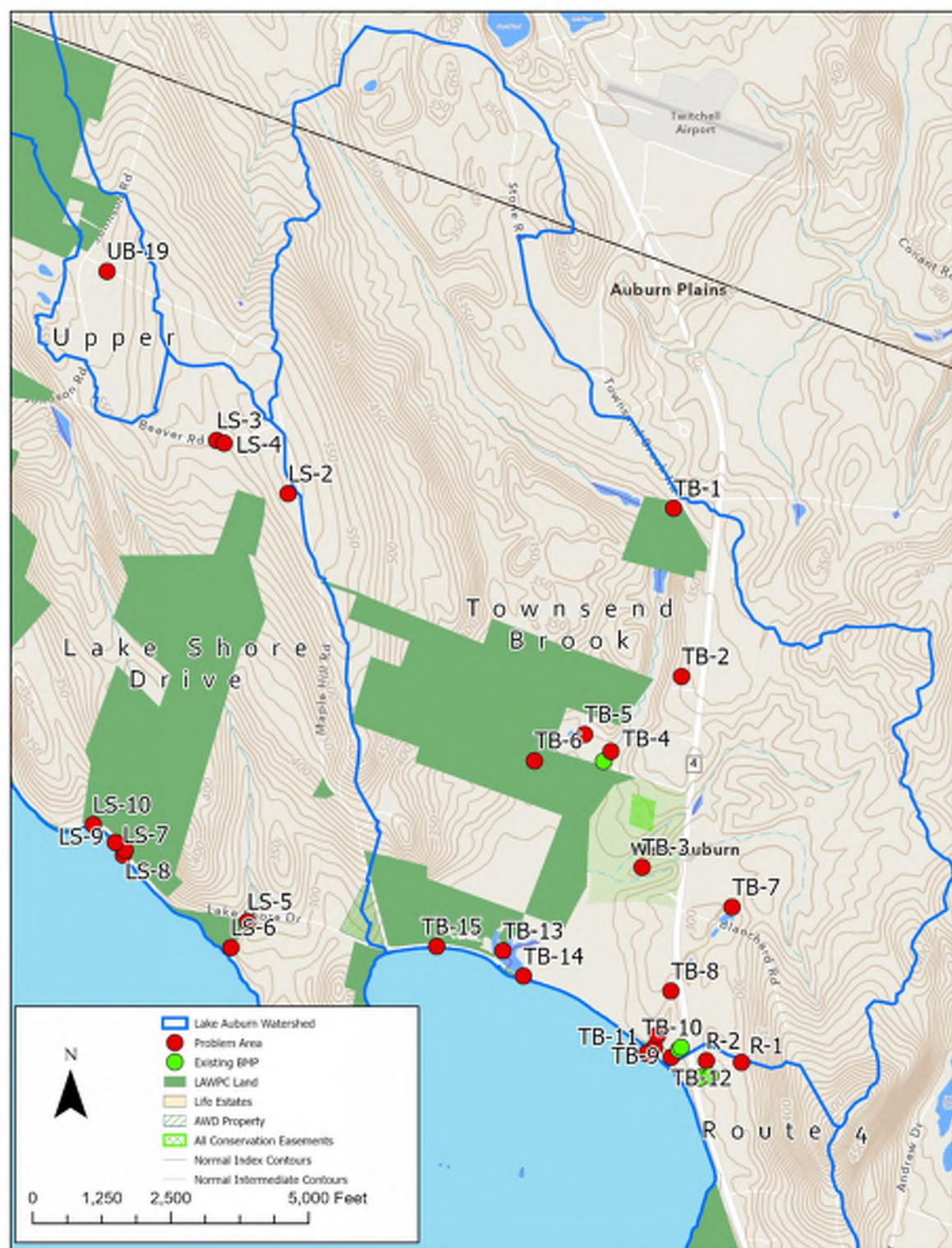


Figure B-11
Townsend Brook Pollution Sources

TB-1: LAWPC Property, North Townsend Brook, Auburn

This location was previously noted as an active livestock pasture with livestock access to the brook in the 2013 watershed-based plan. LAWPC has subsequently purchased this property and demolished the structures to enhance watershed protection, significantly reducing the nonpoint source pollution risk at this location. However, the 2022 watershed survey found evidence of ATV and snowmobile use and erosion on the old dirt roads within this property. In addition, erosion on old skid trails/ATV trails contribute additional sediment load to Townsend Brook (**Figure B-12**). A gate or other deterrent should be added to this property to discourage ATV and snowmobile use and access to the sand pits.



Figure B-12
Erosion on Existing Skid/ATV Trails (L) and Evidence of Snowmobile Use on Bridge (R)

TB-2 and TB-3: Commercial Properties (Gammon's and Roy's)

Two commercial properties along Route 4 that drain to Townsend Brook have evidence of poor housekeeping that may contribute additional nutrient and sediment load to Townsend Brook.

Gammon's Nursery had uncovered stockpiles of mulch and soil; these should be covered and placed on a concrete pad to reduce the likelihood of erosion and nutrient transport into Townsend Brook. Furthermore, a poorly constructed detention pond that was identified during the previous watershed survey. This location was not visited during the 2022 field survey, but discussions with AWD/LWD staff indicated that this pond has been repaired and is now properly functioning.

Roy's (consisting of Pine Acres disk golf course and the driving range) generally has a good buffer around Townsend Brook and tributaries running through the disk golf course. During the 2022

survey a significant population of Canada geese were observed on the disk golf course; efforts should be made to discourage the goose population from congregating on the golf course. In addition, the area immediately adjacent to Townend Brook exhibited significant disturbance without adequate erosion controls (**Figure B-13**). LAWPC should work with the landowner to institute erosion controls around work being done in the vicinity of the brook.



Figure B-13
Soil Disturbance Without Erosion Controls at Pine Acres Disk Golf

TB-4 and TB-5: Tot Lot

The culvert crossing at the Tot Lot property was recently replaced, and is well-armored at the inlet and outlet to reduce erosion potential. However, there remains evidence of erosion upstream and downstream of the replaced culvert (**Figure B-14**). Additional work to stabilize the bank or reduce the velocity in the stream would reduce erosion in this area.



Figure B-14
Erosion in the Stream Near Tot Lot Culvert (L) and Recently Replaced Tot Lot Culvert ®

The Tot Lot property also contains an old fish hatchery, with the pond remaining. Visual inspection of the pond during the 2022 survey (**Figure B-15**) found high levels of algae, suggesting excess nutrients in the pond. The outlet structure of this pond drains to Townsend Brook. Additional investigations are warranted to determine if this pond is a significant source of excessive nutrient loading to the lake.



Figure B-15
Old Fish Hatchery Pond
TB-6: Sand Pit

The sand pit located behind the Tot Lot shows evidence of ATV usage and erosion. LAWPC and the landowner could work with Auburn Police and the Warden Service to discourage ATV usage. In addition, revegetating this property would help reduce potential erosion sources into Townsend Brook.

TB-7 through TB-11: First Brook and Blanchard's Pond

First Brook flows from Blanchard's Pond (TB-7) to its confluence with Lake Auburn on the southern side of Lake Shore Drive (TB-11) and has several areas of concern. While this is a comparatively small watershed compared with the much larger Townsend Brook and Basin watersheds, AWD/LWD monitoring data (see **Section 2**) indicate that this tributary has among the highest nutrient concentrations in the watershed.

Blanchard's Pond, at the headwaters of First Brook, is located on a private farm, and appears to have excessive nutrient loading (**Figure B-16**). This pond is located downstream from tilled fields and livestock. AWD/LWD monitoring data indicate elevated nutrient concentrations at this location. The potential nutrient load from this pond is likely mitigated by a downstream wetland (**Figure B-17**), but still likely contributes nutrient load to Lake Auburn. This is supported by monitoring data that indicate an overall reduction in nutrient concentrations between the upstream extent to the outlet at the lake. A riparian buffer should be restored around Blanchard's pond. If elevated nutrient concentrations persist, pond remediation (alum or dredging) should be considered.



Figure B-16
Blanchard's Pond



Figure B-17
Wetland Downstream of Blanchard's Pond

First Brook downstream of Blanchard's Pond exhibits evidence of erosion and sediment transport. Examples include the culverts at Rt 4 (TB-8) and Lake Shore Drive (TB-9 and TB-10) (**Figure B-18**). Additional armoring of the stream, ditches on Lake Shore Drive, and culverts would help reduce this erosion and subsequent sediment transport to the lake.



Figure B-18

Examples of Erosion on First Brook

Clockwise from top left: sediment downstream of Route 4 culvert; severe erosion at Lake Shore Drive culvert; eroding ditch on south side of Lake Shore Drive; sediment downstream of Lake Shore Drive culvert

The erosion at the Lake Auburn shore is especially severe, with a significant sediment delta that has accumulated in the lake (**Figure B-19**). This was also noted in the 2012 watershed survey. Work to armor the stream upstream of Lake Shore Drive and a plunge pool or similar to reduce stormwater velocity downstream prior to discharge into the lake could reduce sediment transport and erosion at this location.



Figure B-19
Sediment Delta and Erosion at the First Brook Discharge

TB-12 – TB-14: Lake Shore Drive Direct Drainage (South)

As with the northern portion of Lake Shore Drive, the southern portion of Lake Shore Drive is characterized by direct drainage to the lake, with little to no stormwater infrastructure to reduce pollutant loading to Lake Auburn. This portion of Lake Shore Drive is from Tabers to Route 4.

Lake Shore Drive has occasional gravel pull outs for parking (see example, **Figure B-20**). These are typically sloped towards the lake and show evidence of erosion. The potential erosion source could be reduced either prohibiting parking on the shoreline of the lake or by constructing paved, level surfaces (using permeable pavement to reduce runoff). Note that these pull-out parking areas also exist in places on the northern portion of Lake Shore Drive.



Figure B-20
Lake Shore Drive Parking (L) and Erosion Near Parking Ar®(R)

Erosion along the lake side of Lake Shore Drive is also a potential pollution source. As with the northern portion (LS-7 – LS-10), the shoreline of Lake Shore Drive is characterized by a narrow buffer between the lake and the road. While much of the road does have a thin vegetated filter strip, occasionally this buffer is not present (e.g., **Figure B-21**), causing significant erosion from the road into the lake (**Figure B-22**).



Figure B-21
Shoreline of Lake Shore Drive Showing Vegetated Filter Strip with Gap Causing Erosion to Reach the Lake



Figure B-22
Erosion from Lake Shore Drive

MaineDOT recently updated drainage near the intersection of Lake Shore Drive and Route 4, including armoring/vegetating ditches. However, the ditch on the lake side of Lake Shore Drive in this area (TB-12) is not adequately vegetated, and erosion is occurring from the road onto the shoulder, and then into the lake (**Figure B-23**).



Figure B-23
Erosion on the Lake Side of Lake Shore Drive at the Route 4 Intersection

TB-15: Townsend Brook

Townsend Brook ends at a large pond/wetland on the north side of Lake Shore Drive, and then passes through a culvert before discharging to Lake Auburn. The pond appears productive, with significant emergent vegetation and turbid water (**Figure B-24**); AWD/LWD staff reported that algal blooms are not typically observed. The pond occasionally overtops Lake Shore Drive (once every few years), although more frequent overtopping occurs at a low spot on Lake Shore Drive to the west of Townsend Brook. Occasional beaver activity occurs that causes the culvert to become clogged. AWD/LWD has installed a grate to discourage beaver activity, and works with USDA if necessary to address beaver activity.



Figure B-24
Townsend Brook Outlet at Pond (North of Lake Shore Drive)

Downstream of the culvert, no sediment deltas or other indications of significant sediment transport or erosion were observed. However, moderate emergent vegetation and periphyton accumulation occurs on rocks located in the outlet channel prior to discharge into Lake Auburn. This accumulation of periphyton does not appear to continue into the lake (**Figure B-25**). The culvert is in adequate condition with no evidence of erosion near neither the inlet or outlet.



Figure B-25
Townsend Brook Downstream of Lake Shore Drive Culvert

B-3 Whitman Spring Road

Whitman Spring Road is a former road that is now closed to most vehicle traffic and is used as a walking trail. Vehicle access is maintained for several private landowners, and a portion of the road is an active snowmobile trail. It is a dirt road with ditching on either side and frequently spaced culverts. The area to the west between Whitman Spring Road and N. Auburn Road is steep with highly erodible soils (generally silty clay). AWD is in the process of replacing failing culverts along Whitman Spring Road, with culverts on the northern portion replaced in early 2022, and culverts on the southern side remaining to be replaced. Water quality issues found on Whitman Spring Road include:

- Erosion in the parking area at the northern and southern ends of the closed area of Whitman Spring Road and in the snowplow turnaround
- Significant erosion in the ditches and culverts along Whitman Spring Road; LWD has been replacing culverts, and the replacement culverts have been armored with plunge pools installed.
- Moderate road erosion on steep sections of the road

The watershed survey identified 14 areas of potential nonpoint source pollution (**Figure B-26**).

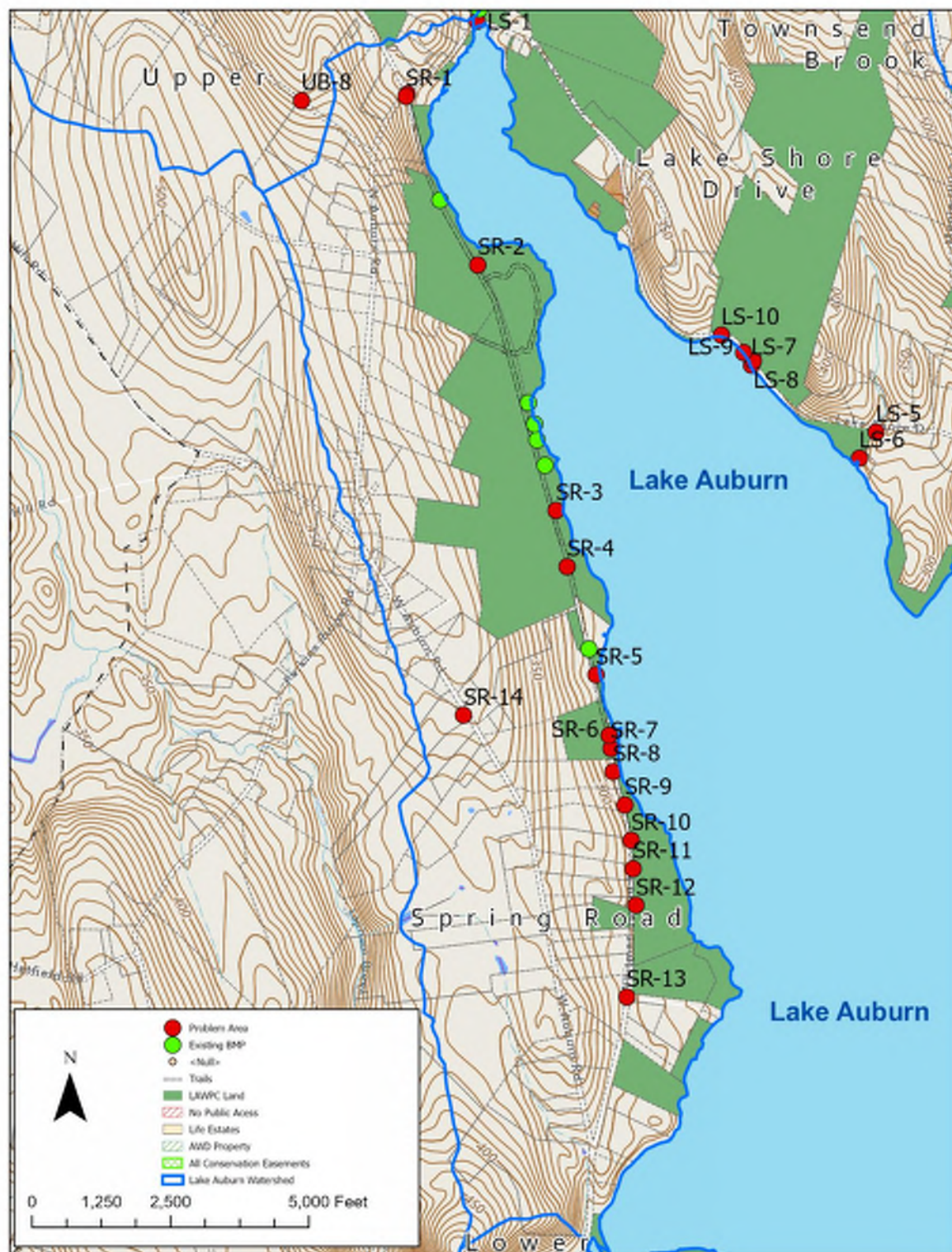


Figure B-26
Spring Road Pollution Sources

SR-1: North Parking Area

The parking area located at the northern terminus of the closed section of Whitman Spring Road on N. Auburn Road (at the intersection of Whitman Spring Road) has evidence of significant erosion from stormwater flowing down the steep slope of N. Auburn Road towards Lake Auburn (**Figure B-27**). A catch basin was installed at this location to divert flow into a culvert that then flows into Lake Auburn. The catch basin inlet is not oriented correctly to the direction of flow (it is pointing towards N. Auburn Road and not in the direction of the slope), and the significant erosion in the dirt parking area indicates that most flow currently bypasses the catch basin, flows down Whitman Spring Road, and into the stream to Lake Auburn. The culvert that the catch basin discharges to is newly installed with a significant, armored plunge pool that reduces sediment transport from the parking area to Lake Auburn (noting that most of the flow is currently bypassing this culvert).

Improvements at this location could include leveling and paving the parking area (either with asphalt or pavers), regrading the parking area such that the catch basin works properly, ensuring that the catch basin inlet is properly aligned to the main direction of flow, and potentially adding a filter strip to further treat runoff from N. Auburn Road.



Figure B-27
Eroding Parking Area and Catch Basin at Northern Whitman Spring Road Parking Area

SR-2 and SR-4: Erosion on Whitman Spring Road

Two locations on Whitman Spring Road exhibit evidence of erosion on the road surface. These locations are both on steep sections of the road where water runs directly down the road, causing rills to develop and sediment to be transported from the road, across the culvert inlet and outlet embankments, and into Lake Auburn (examples in **Figure B-28**). At SR-4, the runoff from the road is bypassing the ditch/culvert, and is eroding the culvert outlet embankment (**Figure B-29**).

This portion of the road should be regraded, and either crowned properly to prevent runoff from concentrating on the road surface or waterbars added to divert water from the road surface to the ditch on the side of the road.



Figure B-28
Erosion on Surface of Whitman Spring Road



Figure B-29
Slope at SR-4 and Erosion on Culvert Outlet Embankment

SR-3: New Culvert with Inlet/Outlet Embankment or Downstream Erosion

The typical condition of many of the culverts along Whitman Spring Road have significant erosion of either or both of the inlet and outlet embankments into the ditch or downstream channel, resulting in sediment to be eroded from the road into Lake Auburn. While several culverts at the northern end of Whitman Spring Road were recently replaced, they show evidence of significant erosion downstream; this erosion likely predates the culvert replacement and plunge pool installation, but should be monitored for future erosion. .

The culvert at SR-3 shows evidence of erosion in the channel downstream (left side, **Figure B-30**) of the culvert crossing (newly installed double barrel). The channel upstream of the culvert crossing (right side, **Figure B-30**) is well-armored with no evidence of erosion. In addition, the embankment on the outlet side at this culvert is significantly eroded (**Figure B-31**).

The outlet embankment should be armored with a plunge pool to reduce this source of erosion and the downstream channel stabilized (if necessary after armoring and adding a plunge pool).



Figure B-30
New Culvert at location SR-3 with Evidence of Significant Downstream Erosion (L) but Well Armored Upstream (R)



Figure B-31
Culvert at SR-3 with Significant Embankment Erosion

SR-6 through SR-11: Culvert Crossings on Whitman Spring Road

In general, the existing culvert crossings on Whitman Spring Road are characterized by erosion on the upstream ditches, evidence of sedimentation within the culvert, and erosion on the inlet and outlet embankments (see examples, **Figure B-32**).

Remaining planned culvert replacements and existing culverts not scheduled for replacement should include armored inlet/outlet embankment structures and plunge pools. Additional bioretention BMPs should be considered downstream of major culverts to further reduce nutrient load to Lake Auburn.



Figure B-32
Examples of Typical Erosion Patterns in Culverts on Whitman Spring Road
Clockwise from top left: silty clay sediment accumulation upstream; partially collapsed culvert with sediment accumulation downstream; significant outlet erosion; undercut bank downstream of culvert

SR-12: South Parking Area

The southern parking area at Whitman Spring Road was previously paved, but the paving is mostly failed and the surface is mostly dirt. This parking area is sloped away from the road and is eroding (**Figure B-33**). This area could be leveled and repaved to reduce erosion potential.



Figure B-33
South Parking Area

SR-13: Snowplow Turnaround

The City of Auburn maintains a snowplow turnaround on Whitman Spring Road (**Figure B-34**). This turnaround is unpaved and is eroding into the adjacent stream and ditch, which passes through a culvert and discharges to Lake Auburn. Additional erosion is occurring upstream and downstream of the culvert. Upstream, runoff from the turnaround discharges down a steep slope into the stream, and the unarmored inlet embankment is eroding into the stream, causing significant sediment buildup upstream of the culvert. On the downstream side, there is no ditch on the road, causing erosion from the road into the stream in addition to erosion over the outlet embankment. The culvert has a plunge pool to control sediment transport.

The snowplow turnaround could be paved, with the culvert armored upstream and downstream. The embankment between the snowplow turnaround and the stream should be armored or stabilized to prevent erosion.



Figure B-34
Erosion from Snowplow Turnaround (L) and Erosion at Culvert Outlet (R)

SR-14: Horse Farm

A recently developed horse farm on West Auburn Road has been observed to have poor manure management in the past. The owners have been responsive to guidance from AWD/LWD staff regarding proper manure management. However, this may be an area of concern in the future and should be monitored.

B-4: Upper Watershed

The Upper Watershed is the largest watershed by area within the Lake Auburn watershed. This watershed is largely undeveloped in Auburn, Turner, Minot, and Buckfield. However, residential development has been increasing in recent years (see **Section 1** for more details), and development pressure is a concern.

This watershed includes a series of ponds – Mud Pond, Little Wilson Pond, and the Basin – that collectively provide a significant buffer that may remove sediment and nutrients from watershed sources prior to discharge into the northern end of Lake Auburn. However, nonpoint source pollution into this watershed is still a concern with respect to loading to Lake Auburn, especially given the large size of the watershed.

The watershed survey identified 17 nonpoint source water quality concerns in the Upper Watershed (**Figure B-35**). Principal concerns include:

- Sedimentation in the Basin, especially in the southern portion near the dam

- Erosion adjacent to roadways and ditches and at or near culverts
- Construction and logging, especially in Minot and Turner
- Agricultural uses

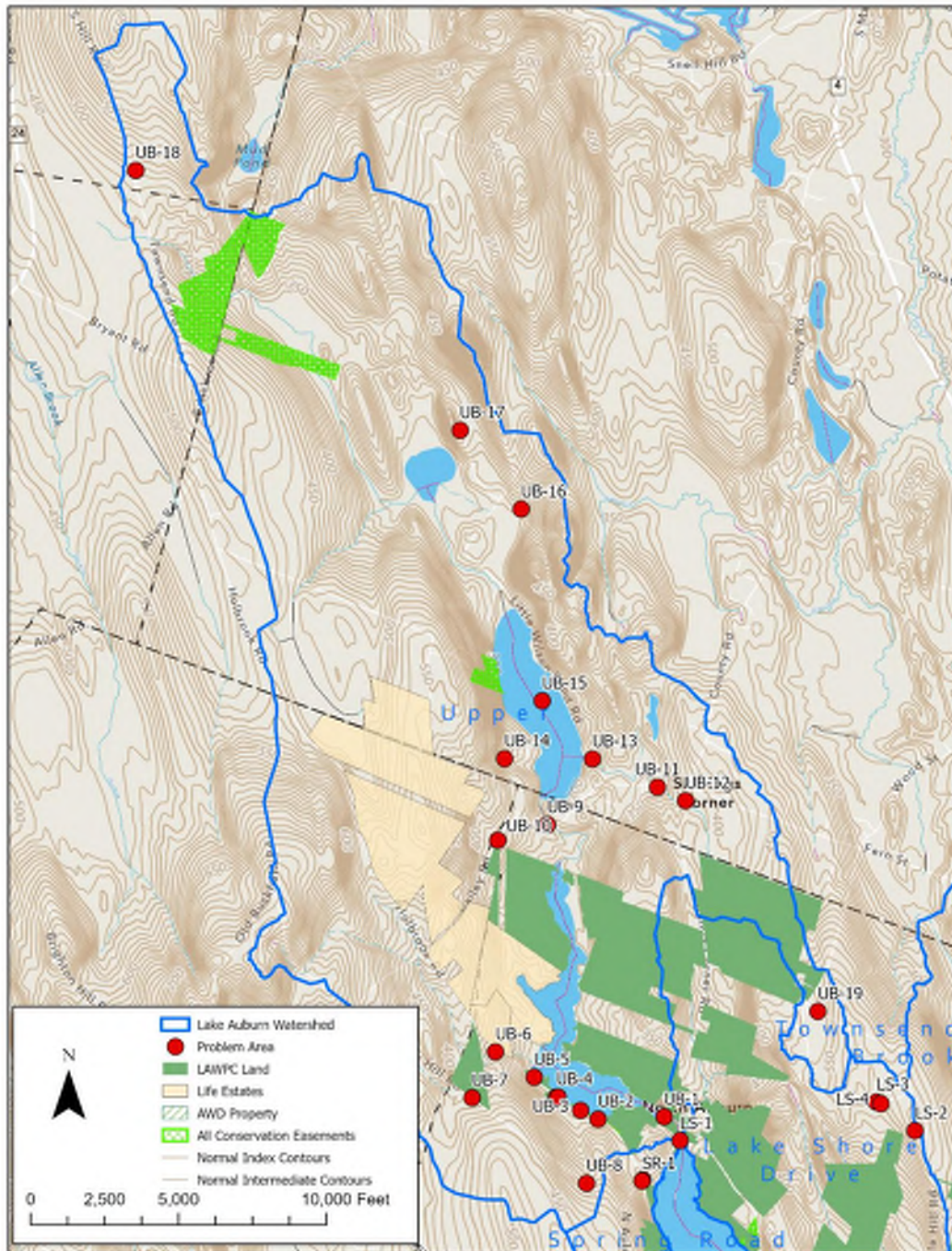


Figure B-35
Upper Watershed Pollution Sources

UB-1: The Basin

The Basin is the final pond prior to discharge into Lake Auburn. The dam appears to have significant sediment accumulation, where the top of the spillway is very close to the top of the sediment at the downstream end (**Figure B-36**). The top of the sediment was about 1 to 2 feet below the top of the spillway.



Figure B-36
Sediment Accumulation at the Basin Dam

While the pond appears to have a moderate amount of emergent vegetation including milfoil, algal blooms have not been observed in the pond (**Figure B-37**).



Figure B-37
The Basin

The extent of sediment deposition within the lower portion of the Basin should be evaluated, and if necessary, dredging should be considered to restore the sediment retention capacity of the Basin. Milfoil should be removed and potentially replaced with native vegetation. In addition, this location could be a potential area for an alum feed system.

UB-2 through UB-4: Parking and The Basin Boat/Fishing Access

There are several turnouts on Holbrook Road adjacent to the Basin for parking and access to the Basin. These are unpaved, slope towards the pond, and show evidence of erosion (**Figure B-38**). If these remain as parking areas for visitors to the Basin, these should be leveled and hardened (either paved or with pavers) to prevent future erosion.



Figure B-38
Erosion at Gravel Parking Areas on Holbrook Road near the Basin

Adjacent to each parking area are access points to the Basin. These show evidence of erosion, with one location (UB-4) eroded to expose geotextile fabric (**Figure B-39**). This location should be restored to prevent future erosion.



Figure B-39
Erosion at The Basin Access Point Near UB-4

UB-5: Holbrook Road Drainage

Drainage along Holbrook Road adjacent to the Basin shows evidence of erosion, both along the shoulder and within the ditch on the south side of the road. There is generally not a ditch on the north side of Holbrook Road near the Basin. The ditch should be revegetated or armored where needed.

UB-6 through UB-8: Erosion Near Culverts (The Basin – South)

Several culvert crossings in the Basin tributary area proximate to the Basin exhibit minor to moderate erosion on the inlet/outlet embankments (see overview map, **Figure B-40**). Culverts at UB-6 and UB-7 drain from Hersey Hill Road (UB-7) through Lund Road (where culvert was replaced with riprap), and past Holbrook Road (UB-6) to the Basin. The upstream culvert on Hersey Hill Road shows evidence of significant erosion with erosion off the road shoulder and down the embankment (**Figure B-41**). However, downstream of this location, AWD/LWD has removed a culvert that was located at Lund Road and replaced it with riprap (**Figure B-42**); this structure appears to be reducing the sediment load from upstream to the Basin based on sediment accumulation between the riprap. Moderate erosion is present on the outlet

embankment of the double-barrel RCP culvert across Holbrook Road (**Figure B-43**), but no sediment is present within the culvert itself or downstream. Eroded embankments should be armored or revegetated.

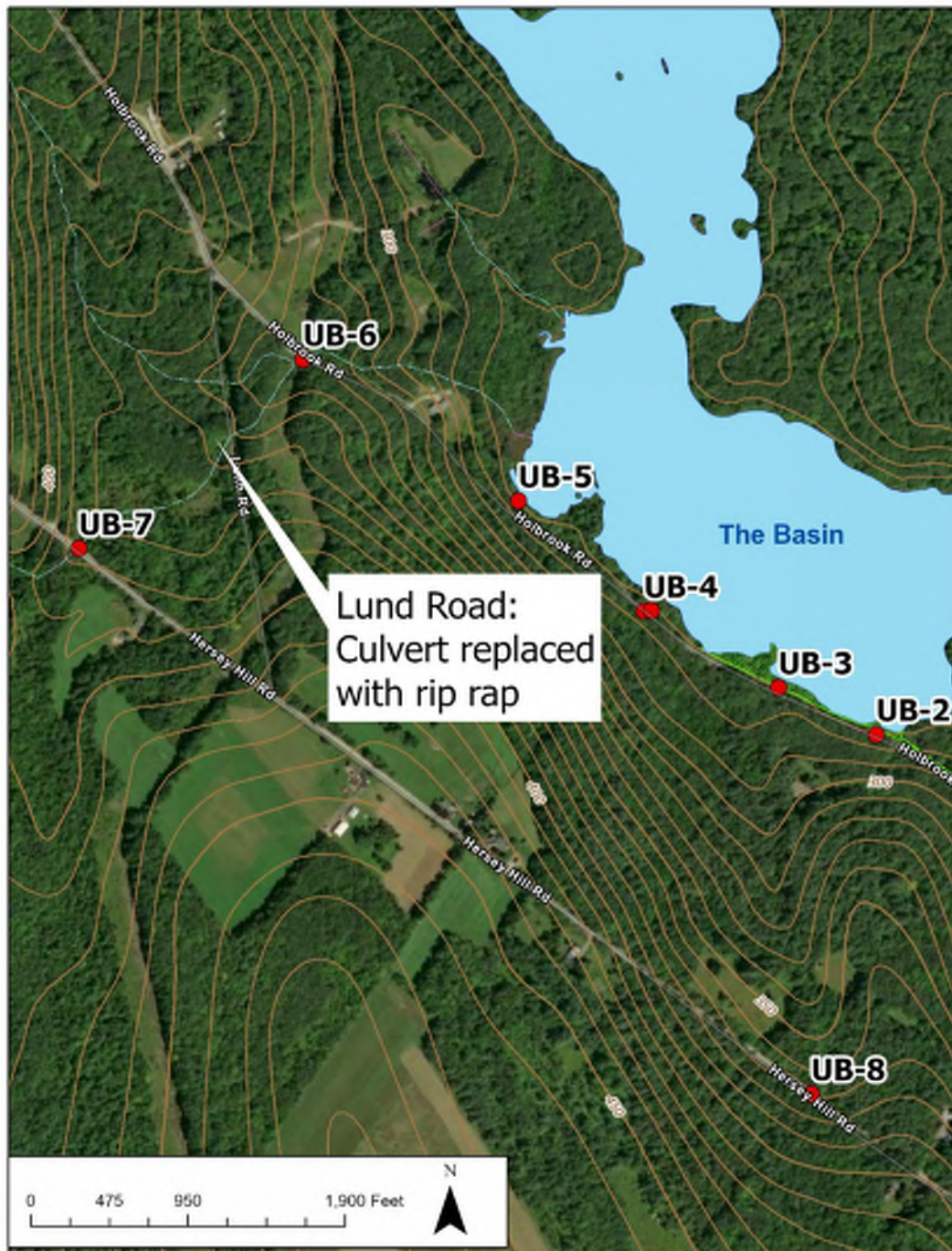


Figure B-40
Overview Map: UB-6 through UB-8



Figure B-41

Hersey Hill Road Culvert

Clockwise from top left: erosion on embankment; erosion on roadway shoulder at the culvert; erosion on culvert embankment; sedimentation in culvert exit



Figure B-42
Lunn Rd Culvert Replaced with Riprap



Figure B-43

Holbrook Road Culvert

Clockwise from top left: minor erosion on outlet embankment; no evidence of sediment transport within culvert; no evidence of sediment accumulation downstream

The culvert at UB-8 is located on Hersey Hill Rd, and exhibits evidence of moderate erosion on the upstream side of the culvert. A plunge pool exists on the downstream end, but it is clogged with sediment and debris. The ditch at this location should be revegetated, and the plunge pool cleaned.



Figure B-44
Plunge Pool at Hersey Hill Rd (UB-8)

UB-9: Little Wilson Pond Outlet

The outlet to Wilson Pond is located on a steep hill on Wilson Hill Road and has several water quality concerns related to erosion of the adjacent roadway and embankment near the culvert. While the entry and exit to the culvert are fairly well armored (**Figure B-45**), the lack of stormwater conveyance along the steep Wilson Hill Road (on both sides of the hill) causes road runoff to erode the embankment to either side of the culvert entry and exit (**Figure B-46**). This causes significant erosion that transports sediment from the roadway and adjacent shoulder into

the Basin downstream. A curb could be added to Wilson Hill Road to direct runoff to the low point at the culvert crossing, and the armoring at the inlet and outlet embankments augmented to prevent erosion.



Figure B-45
Armored Inlet (L) and Outlet (R) of the Culvert at the Little Wilson Pond Outlet



Figure B-46

Little Wilson Pond Exit

Clockwise from top left: Roadside at culvert entry looking west, ditch at culvert exit looking west, embankment at culvert exit, ditch/embankment at the culvert entry looking east

UB-10 through UB-12: Erosion Near Culverts (The Basin North)

As with the culverts located on the southern side of the Basin, culverts located on the northern side also exhibit erosion, commonly along the inlet or outlet embankments and in the adjacent ditches.

The culvert at UB-10 is located on Bailey Road, draining into the Basin from the steep area upslope. This culvert has moderate erosion along the outlet embankment, with steep slopes from the road into the stream at the culvert exit. At this location, road runoff is washing into the exit of the culvert and eroding the embankment (**Figure B-47**). In addition, the downstream shoreline is severely undercut. Given the steep slopes in this area, the culvert outlet embankment should be armored and a plunge pool or check dam installed to reduce downstream velocities.



Figure B-47
Erosion at Outlet Embankment on Bailey Road Culvert

The culvert at UB-11 is located on Wilson Hill Road (downstream of the Skilling Corner Road culvert). At this location there is significant erosion and sediment accumulation in the stream upstream of the culvert entrance, and erosion into the culvert entry (**Figure B-48**). Stream restoration could be considered downstream of this culvert. The culvert at this location was recently replaced, and no evidence of sediment accumulation is present at the exit, and the outlet is well armored with a plunge pool (**Figure B-49**).



Figure B-48
Erosion Upstream and Along the Roadside on the Wilson Hill Road Culvert (Turner)



Figure B-49
Exit of Wilson Hill Road Culvert

The Skillings Corner Road culvert (near the intersection with Wilson Hill Road) is an older corrugated metal culvert, and is beginning to fail. There is slight undercutting of the downstream stream, but evidence of erosion is minimal at this location. This culvert should be replaced, and the inlet/outlet embankments armored.

UB-13: Little Wilson Pond Road Culvert

The culvert on the south side of Little Wilson Pond was recently replaced by Turner under a 319 grant. The culvert is in good condition, with adequate armoring on the inlet and outlet. However, evidence of significant erosion is present upstream, with silt and clay accumulation. The area immediately upstream of the culvert appears to have been logged relatively recently, which may contribute to the erosion potential. Additional investigation should be completed in this area to identify potential sources of erosion and stabilize upstream sources (**Figure B-50**).



Figure B-50
Replacement Culvert at Little Wilson Pond Road with Significant Sediment Accumulation

UB-14: Robinson Road

Robinson Road is characterized by steep slopes with significant erosion (**Figure B-51**) along the upslope area to the west and at the culvert crossing to Little Wilson Pond. This area should be stabilized to prevent erosion, and the culvert armored to prevent erosion. In addition, a construction site at the end of Robinson Road is underway without adequate erosion controls. Adequate erosion controls should be implemented at this site.



Figure B-51
Robinson Road Erosion

UB-15: Little Wilson Pond

Little Wilson Pond is characterized by relatively dense development along the shoreline. An active lake association that works to improve water quality within the pond, and no significant water quality concerns have been noted by AWD/LWD staff. However, the relatively dense development near the pond, without sewer service, will contribute nutrient load to Little Wilson Pond, and development (lawns, docks, etc.) is located directly adjacent to the pond (**Figure B-52**). Septic systems in this area should be inspected, and additional education of landowners should occur to encourage best practices such as maintaining a riparian buffer, limiting use of fertilizer, and minimizing directly connected impervious area.



Figure B-52
Limited Riparian Buffer around Little Wilson Pond

UB-16: Construction near Mud Pond

An active construction site is located on a private road near Mud Pond off Little Wilson Pond Road. This construction involved clearcutting a portion of forest and appears to not have adequate erosion controls. Additional erosion controls are recommended for construction in the watershed.

UB-17: Boutin Road

Boutin Road is a dirt road adjacent to Mud Pond. There is severe erosion of the road surface and the steep slopes adjacent to the road (**Figure B-53**). Furthermore, this area was recently developed, and additional attention to erosion controls and nutrient reduction into Mud Pond should be considered.



Figure B-53
Erosion on Boutin Road and Adjacent Steep Slopes

UB-18: Agriculture in Upper Watershed

This area of the watershed has historically supported relatively intensive agricultural operations, including a timber operation and a pig farm. Education of farmers in this area should be continued to reduce downstream watershed impacts.

UB-19: Dillingham Hill Road

A culvert crossing at Dillingham Hill Road has an old electric fence across the stream that was noted in the previous watershed survey (**Figure B-54**). The fence is not currently in use (it is

falling down in places), so it is unlikely that livestock are currently using this area of the stream. However, LAWPC should monitor this location and work with the landowner ensure that livestock are not returned to this area and that livestock access to the stream is prevented.



Figure B-54
Old Livestock Fence at Stream Crossing

B-5: Lower Watershed

The lower watershed of Lake Auburn shoreline consists mostly of LAWPC-owned land with no public access allowed and is a relatively small portion of the watershed. Three water quality concerns were identified in the lower watershed area consisting of a failing culvert, agriculture, and recent logging on LAWPC property (**Figure B-55**). There were additional historical water quality concerns identified in the previous survey associated with agricultural operations and the

sand and gravel pit and old landfill. The 2022 watershed survey found that these concerns have been addressed:

- The agricultural areas highlighted in the prior watershed survey are either no longer active or are now associated with a conservation easement.

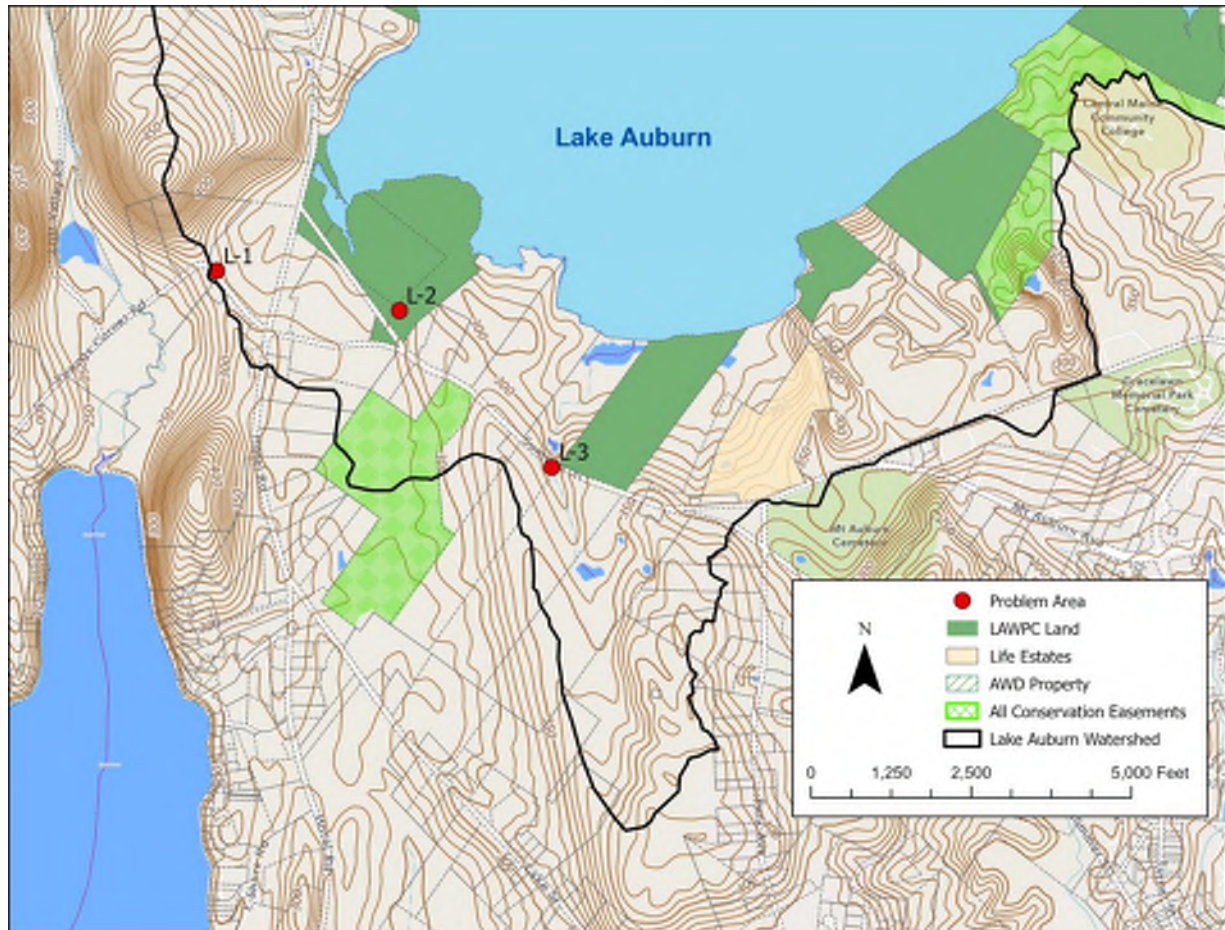


Figure B-55
Lower Watershed

L-1: Horses/Agriculture

One active farm was observed during the 2022 watershed survey on Youngs Corner Road. This farm has horses (**Figure B-56**). AWD/LWD staff indicated that this farm has had sound manure management practices in the past. Continued education and monitoring of this property should occur, especially given this farm's close proximity to Lake Auburn.



Figure B-56
Farm on Youngs Corner Road

L-2: Recent Timber Operations on LAWPC Property

The 2022 watershed survey included a visit to a LAWPC property on Summer Street that was logged in winter 2020. The conditions at the site were generally good, with no evidence of erosion towards the lake. The staging area is fairly large and clear cut, with a mixture of chipped wood and slash providing erosion control (**Figure B-57**); additional skid trails were cut radially outward from the staging area (**Figure B-58**).



Figure B-57
Staging Area



Figure B-58
Timber Operation on LAWPC Land in Winter 2020 showing Skid Trail Leaving Staging Area

L-3: Culvert on Summer St

A culvert crossing on Summer St adjacent to Lake Auburn is beginning to fail, with the corrugated metal culvert corroding on the bottom at the exit. The outlet is well-armored, with no evidence of erosion. This culvert should be considered for replacement, and if possible, a plunge pool added to reduce sediment transport given the close proximity of this culvert to Lake Auburn. (**Figure B-59**).



Figure B-59
Summer Street Culvert

B-6: Route 4

The Route 4 drainage area extends from Central Maine Community College to just south of the Lake Shore Drive and Route 4 intersection on the eastern shore of the lake (**Figure B-60**). This is a relatively small watershed area with the land adjacent to the lake almost entirely comprised of LAWPC protected land with no public access, including the water treatment plant. Problems identified include:

- Direct drainage and lack of guard rails on the Route 4 causeway
- Logging and construction at the northern end of the Route 4 drainage

In addition, BMPs have been constructed in this watershed since the 2013 watershed survey. An armored drainage swale was added on the eastern side of Route 4 south of Hathaway Street that drains to a vortex unit. Vortex units have been added to catch basins on Route 4 to provide pre-treatment of roadway runoff prior to discharge into the lake. These vortex units are cleaned by AWD twice annually. In addition, MaineDOT is currently converting a paved turnaround adjacent to Lake Auburn to into a vegetated area,



Figure B-60
Route 4 Pollution Sources

R-1: Route 4 Direct Drainage

The area of Route 4 located adjacent to Lake Auburn, especially the area across the causeway at the Lake Auburn outlet, is directly connected to the lake. In addition, the guard rail across the causeway appears to have been removed during the Route 4 construction.

During the 2022 watershed survey, a car crashed into the lake at the causeway, causing a spill of oil and gas that required cleanup, highlighting potential additional water quality concerns beyond the sediments that can be removed through vortex separators. Additional BMPs, beyond the vortex units, should be evaluated for feasibility in this stretch, and a guardrail added back to the causeway to prevent vehicles from crashing into the lake.

R-2: Construction

A residence on Hathaway Street recently constructed a driveway without adequate erosion controls (**Figure B-61**). Given the proximity to the lake, LAWPC should work with the landowner to implement erosion controls and reduce the potential for additional erosion once the development is complete. However, the drainage from this location discharges to the newly constructed armored swale on Route 4 and then to a vortex unit, so the water quality impact of this location is mitigated by these downstream controls.



Figure B-61
Construction on Hathaway Road

R-3: Logging

A private logging operation at the end of Hathaway St was completed with generally poor erosion controls (**Figure B-62**) prior to the property being offered for sale. LAWPC should work with the current and future landowners to implement improved erosion controls on this property.



Figure B-62
Logging Operation on Hathaway Street

Table B-1: Summary of Watershed Survey and BMP Recommendations

ID	Watershed	Description	Recommendations	Severity	High-Priority BMP	Coordinates
LS-1	Lake Shore Drive	Milfoil in the Basin outlet and Lake Auburn inlet, including the northern cove of the lake	Remove and/or treat milfoil, replace with native vegetation	Medium	No	-70.274935, 44.175439
LS-2	Lake Shore Drive	Horse farm that has occasionally been observed to have poor manure management	Work with property owners to institute a manure management plan to ensure that manure is properly managed	Medium	No	-70.253179, 44.176104
LS-3	Lake Shore Drive	Erosion in ditch and culvert embankments	Armor/revegetate ditch and culvert embankments	Low	No	-70.256731, 44.177995
LS-4	Lake Shore Drive	Erosion in ditch and culvert embankments.	Armor/revegetate ditch and culvert embankments.	Low	No	-70.256346, 44.177902
LS-5	Lake Shore Drive	Evidence of sedimentation and sediment accumulation in plunge pool downstream of culvert crossing Lake Shore Drive	Further investigations of sediment sources upstream of Lake Shore Drive and installation of an armored plunge pool	Medium	No	-70.2552, 44.160866
LS-6	Lake Shore Drive	Significant channel erosion in the brook on the steep bank from Tabers. Erosion appears to be stable based on review of photos from previous watershed survey.	Stream restoration and/or armoring	Medium	No	-70.256028, 44.159945
LS-7	Lake Shore Drive	Erosion from untreated/unfiltered runoff from Lake Shore Drive directly into Lake Auburn	Install vegetated filter strip	High	Yes	-70.261369, 44.16324
LS-8	Lake Shore Drive	Erosion on the steep slope on Lake Shore Drive and in ditch on the upland side of Lake Shore Drive	Hydroseed steep slope	Medium	No	-70.261259, 44.163399
LS-9	Lake Shore Drive	Erosion from untreated/unfiltered runoff from Lake Shore Drive directly into Lake Auburn	Install vegetated filter strip	High	Yes	-70.261748, 44.163691
LS-10	Lake Shore Drive	Broken culvert, with slight erosion on the upstream side of the culvert	Replace the culvert, and add armoring to the culvert embankments	Low	No	-70.262851, 44.164312
L-1	Lower Watershed	Horse farm	Landowner education	Low	No	-70.273538, 44.12898
L-2	Lower Watershed	LAWPC logging in 2020	Maintain current moratorium on logging. If logging on LAWPC land, follow enhanced BMPs in report.	Low	Yes	-70.265715, 44.127765
L-3	Lower Watershed	Culvert on Summer Street is corroding	Replace culvert and consider a plunge pool to reduce sediment transport to Lake Auburn	Low	No	-70.25914, 44.12299

Table B-1: Summary of Watershed Survey and BMP Recommendations

ID	Watershed	Description	Recommendations	Severity	High-Priority BMP	Coordinates
R-1	Route 4	Route 4 Causeway guard rail was removed during construction; vortex separators have been installed, but no data are available on the effectiveness	Reinstall guard rail following construction (planned). Conduct influent and effluent sampling of vortex units	High	Yes	-70.230692, 44.155862
R-2	Route 4	A residence on Hathaway Street recently constructed a driveway without adequate erosion controls	Landowner education	Medium	No	-70.232429, 44.155916
R-3	Route 4	A private logging operation at the end of Hathaway St was completed with generally poor erosion controls prior to the property being offered for sale	Landowner education	Low	No	-70.228643, 44.146245
SR-1	Spring Road	Erosion on north parking area for Whitman Spring Road	Level/pave parking area, regrade parking area so catchbasin is effective, filter strip for runoff from N. Auburn Road	Medium	No	-70.278442, 44.172776
SR-2	Spring Road	Signs of erosion are observed on the steep sections of Spring Road	Add a water bar in these areas to direct runoff off the road	Medium	Yes	-70.27489, 44.166796
SR-3	Spring Road	Erosion in stream downstream of culvert. Culvert was recently replaced by LWD	Stream restoration and/or armoring	Low	No	-70.271021, 44.158091
SR-4	Spring Road	Erosion downstream of culvert crossings and on culvert embankment inlet and outlets	Construct plunge pools downstream of culvert crossings, and armor the culvert outlet	High	Yes	-70.270469, 44.156102
SR-5	Spring Road	Erosion downstream of culvert crossings and on culvert embankment inlet and outlets	Construct plunge pools downstream of culvert crossings	High	Yes	-70.269057, 44.152268
SR-6	Spring Road	Erosion downstream of culvert crossings and on culvert embankment inlet and outlets	Construct plunge pools downstream of culvert crossings, and armor the culvert outlet	High	Yes	-70.268399, 44.150124
SR-7	Spring Road	Crushed/broken culvert	Replace culvert (completed 2022)	Low	No	-70.26831, 44.14965
SR-8	Spring Road	Culvert broken. Evidence of erosion in ditch upstream of culvert and embankment.	Revegetate/armor ditch. Construct plunge pool downstream of culvert crossing, replace culvert, and armor inlet and exit.	Low	No	-70.268198, 44.148834
SR-9	Spring Road	Erosion downstream of culvert crossings and on culvert embankment inlet and outlets	Construct plunge pools downstream of culvert crossings	High	Yes	-70.26762, 44.147655
SR-10	Spring Road	Erosion on upstream ditches and culvert inlet/outlet embankments	Replace culvert, armor inlet/outlet (Completed 2022)	High	No	-70.267304, 44.146393

Table B-1: Summary of Watershed Survey and BMP Recommendations

ID	Watershed	Description	Recommendations	Severity	High-Priority BMP	Coordinates
SR-11	Spring Road	Erosion in ditch with significant sediment accumulation in pool. Flow not draining through culvert because culvert inlet is raised up above bottom of ditch.	Clean and armor upstream ditch. Reseat or regrade culvert entry to permit water to flow through culvert during low flow events and prevent standing water.	Medium	No	-70.267212, 44.14539
SR-12	Spring Road	Southern parking area for Spring Road. Erosion on edge.	Pave and level turnaround, and add vegetated filter strips adjacent to the paved parking area	Medium	No	-70.267067, 44.14409
SR-13	Spring Road	Unpaved snowplow turnaround is eroding into the adjacent stream and ditch. Erosion is evident on culvert upstream and downstream embankments.	Pave turnaround, vegetate embankment surrounding paved area, and armor the culvert embankments	Medium	No	-70.267527, 44.140842
SR-14	Spring Road	New horse farm with historically poor manure management. No issues observed during 2022 survey.	Continue working with landowners to improve manure management.	Medium	No	-70.275593, 44.150828
TB-1	Townsend Brook	Evidence of ATV and snowmobile use.	Add a gate or other deterrent to discourage ATV and snowmobile use.	Low	No	-70.234045, 44.175587
TB-2	Townsend Brook	Gammon's Nursery is a potential source of nutrient pollution from uncovered stockpiles of landscaping material and fertilizer use.	Outreach to landowner to improve storage of landscaping material and discuss fertilizer use and storage and stormwater management.	High	Yes	-70.233655, 44.169592
TB-3	Townsend Brook	Roy's shows evidence of erosion near Townsend Brook. In addition, geese were observed to be congregating on the property.	Work with the landowner to improve housekeeping around Townsend Brook. Construct a bioretention basin on the tributary to Townsend Brook.	High	Yes	-70.235625, 44.162804
TB-4	Townsend Brook	Erosion upstream of replacement culvert on Townsend Brook	Armor/vegetate stream	Low	No	-70.237154, 44.166931
TB-5	Townsend Brook	The former fish hatchery near the Tot Lot shows signs of high levels of algae.	Monitor conditions within and downstream of the fish hatchery pond to evaluate whether this is a substantial source of phosphorus to Townsend Brook.	Medium	No	-70.238478, 44.167529
TB-6	Townsend Brook	Sand pits with evidence of ATV usage	Work with Auburn Police and the Warden Service to discourage ATV usage. Consider purchasing this property and revegetating this property if it is offered for sale.	Low	Yes	-70.240957, 44.166598
TB-7	Townsend Brook	High phosphorus loading from Blanchard Pond with no riparian buffer	Install a riparian buffer around Blanchard Pond. Consider pond remediation (dredging or alum) if nutrient loads do not decrease.	High	Yes	-70.23115, 44.161389

Table B-1: Summary of Watershed Survey and BMP Recommendations

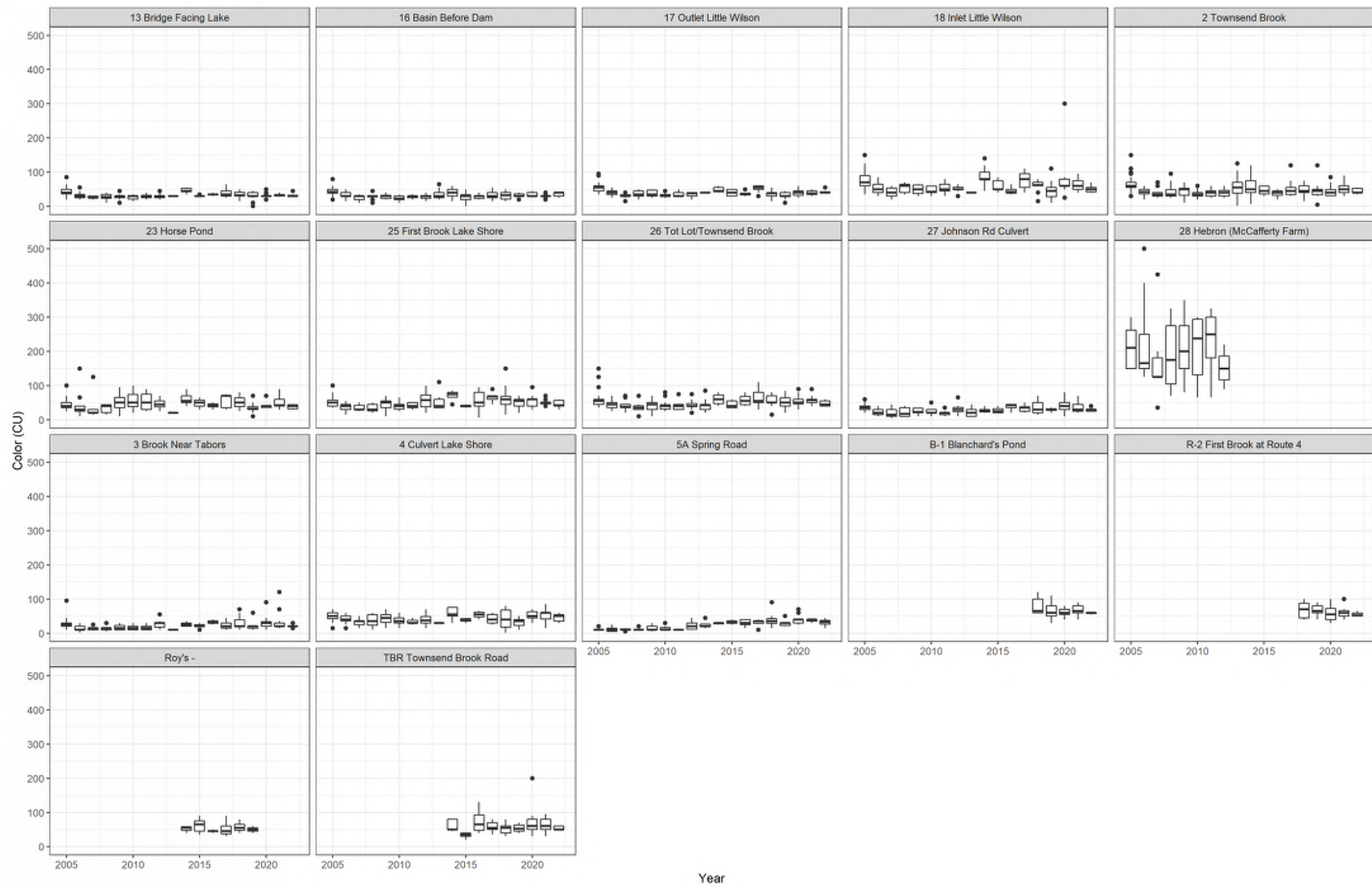
ID	Watershed	Description	Recommendations	Severity	High-Priority BMP	Coordinates
TB-8	Townsend Brook	Evidence of sedimentation at culvert crossing of First Brook at Route 4	Replace undersized culvert	High	Yes	-70.234183, 44.15839
TB-10	Townsend Brook	Failing culvert with significant sediment accumulation in ditch. Upstream ditch has grass with evidence of slight erosion.	Replace culvert. Revegetate or armor ditch.	Low	No	-70.235004, 44.156384
TB-11	Townsend Brook	Significant erosion and sediment accumulation in outlet of First Brook	Reduce upstream sources of sediment	High	Yes	-70.235375, 44.156184
TB-12	Townsend Brook	Roadside erosion into ditch from Lake Shore Drive	Armor/vegetate ditch	Medium	No	-70.234163, 44.156038
TB-13	Townsend Brook	Direct runoff from the inland side of Lake Shore Drive into Lake Auburn	Add a vegetated filter strip to eroded sections of Lake Shore Drive	Low	Yes	-70.245812, 44.159978
TB-14	Townsend Brook	Unpaved parking areas on the southern side of Lake Shore Drive adjacent to Lake Auburn show signs of erosion	Add pavers to parking areas to prevent erosion	Low	Yes	-70.241506, 44.158923
TB-15	Townsend Brook	Townsend Brook Outlet occasionally has beaver activity	Continue to work with USDA to discourage beaver activity	High	No	-70.242522, 44.159829
UB-1	Upper Watershed	The basin dam: sediment accumulation behind dam, aquatic vegetation present.	Pilot alum feed system; conduct survey to better understand sediment build-up within the basin; dredge the basin	High	Yes	-70.276419, 44.177027
UB-2	Upper Watershed	Unpaved parking area with erosion potential	Pave and regrade parking area	Medium	No	-70.282524, 44.176883
UB-3	Upper Watershed	Unpaved turnout with erosion potential	Pave turnout	Medium	No	-70.284142, 44.177442
UB-4	Upper Watershed	Erosion on parking area and access to the Basin	Pave parking area; regrade and vegetate/stabilize access point to the Basin	Medium	No	-70.286367, 44.178349
UB-5	Upper Watershed	Erosion on shoulder and ditch on Holbrook Road	Revegetate ditch	Low	No	-70.288448, 44.179657
UB-6	Upper Watershed	Erosion on culvert inlet embankment	Armor embankment	Low	No	-70.292013, 44.181336

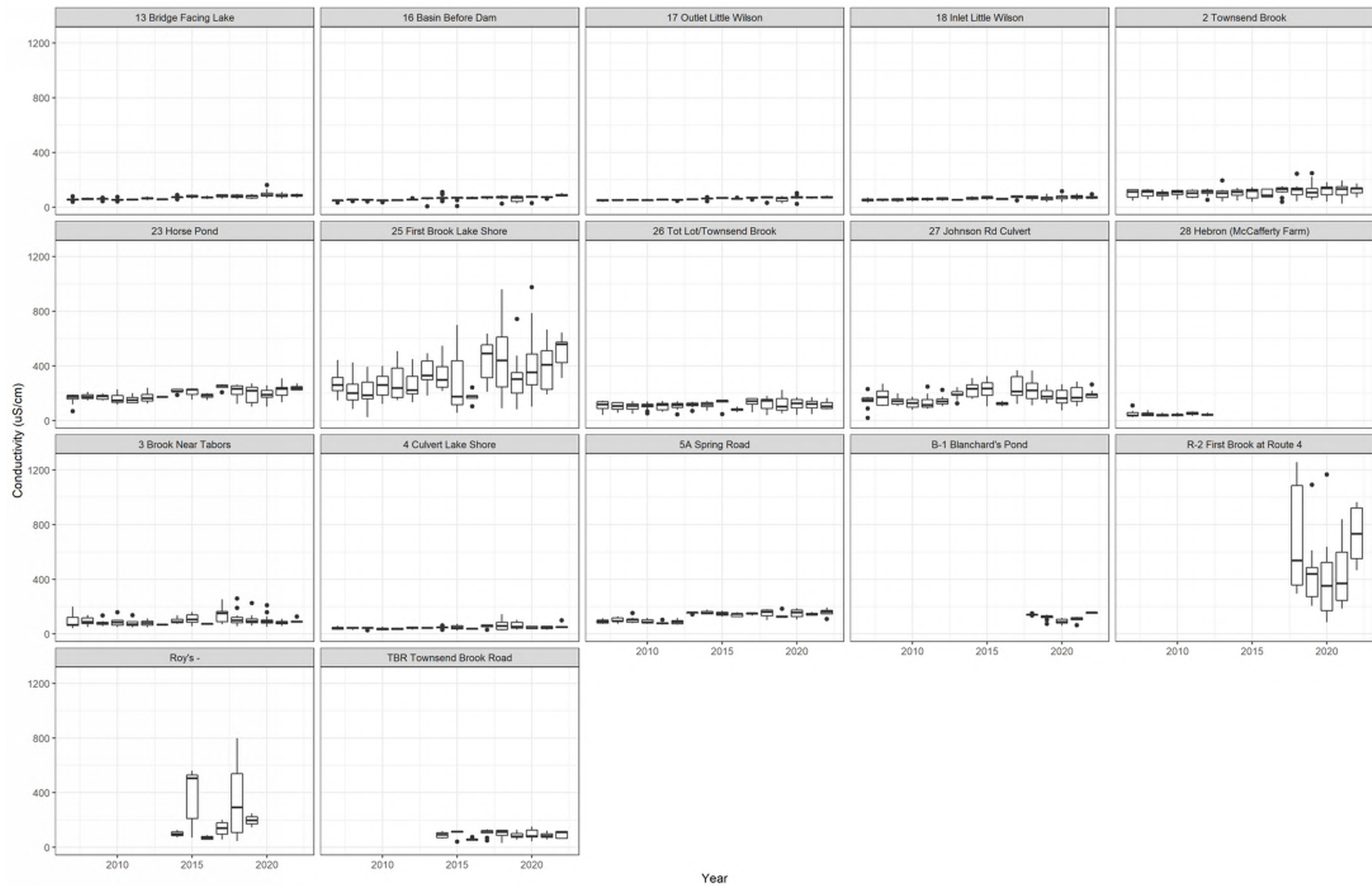
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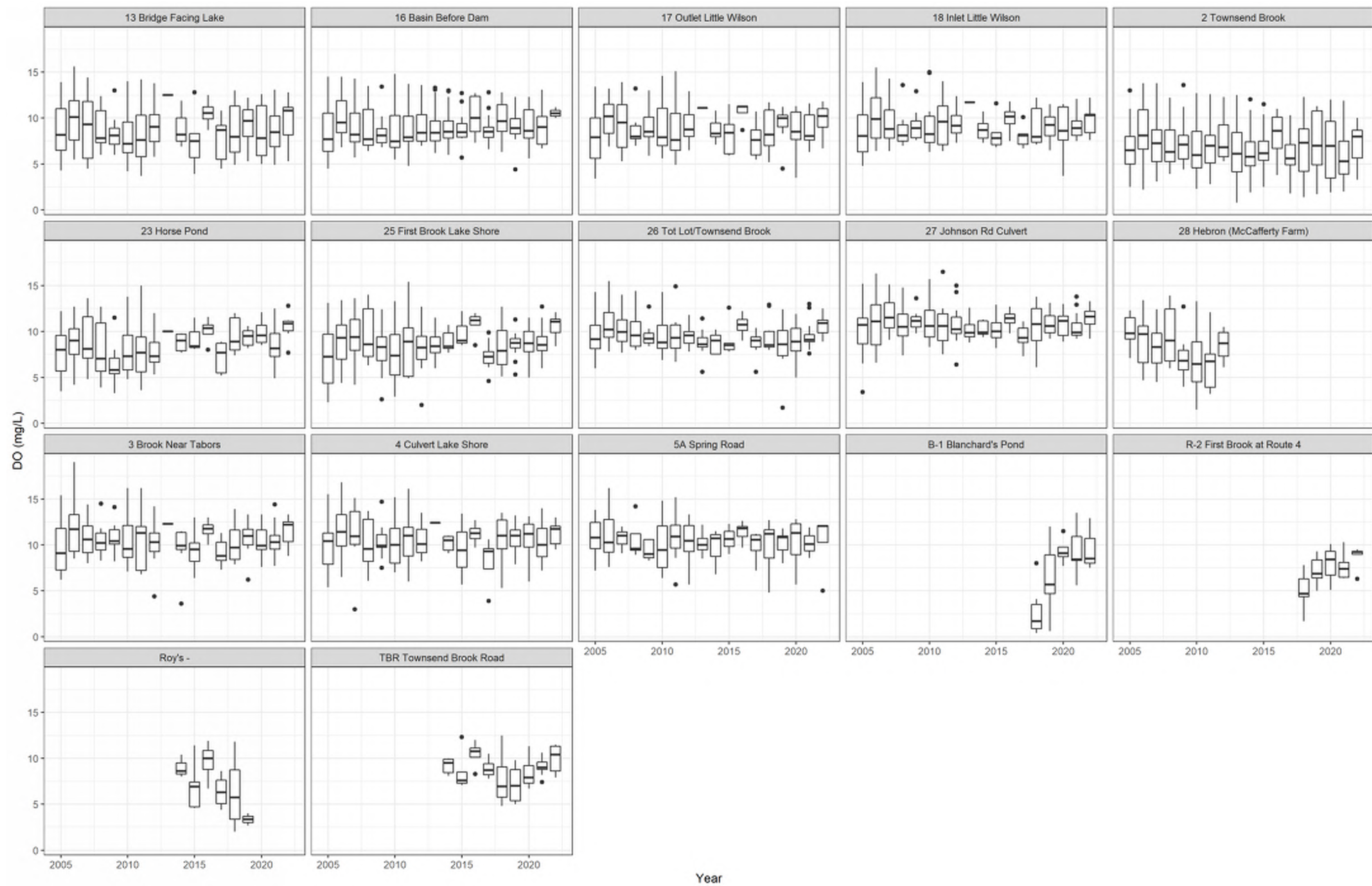
ID	Watershed	Description	Recommendations	Severity	High-Priority BMP	Coordinates
UB-7	Upper Watershed	Erosion on culvert inlet embankment, fine sediment accumulation downstream of culvert	Armor embankment	Low	No	-70.295723, 44.179093
UB-8	Upper Watershed	Slight erosion on ditch near culvert	Revegetate ditch and clean plunge pool	Low	No	-70.283598, 44.172621
UB-9	Upper Watershed	Steep slope to culvert results in erosion from road across culvert embankment and from roadway shoulder. Occasional beaver activity noted (not during 2022 survey)	Revegetate ditch, armor culvert embankments, work with USDA as needed to manage beaver population	Low	No	-70.28722, 44.196423
UB-10	Upper Watershed	Moderate to extreme erosion along Bailey Road outlet embankment	Armor culvert outlet embankment, add a plunge pool downstream, and armor the channel downstream	Low	No	-70.291795, 44.195398
UB-11	Upper Watershed	Wilson Hill Road culvert clogged; Erosion in stream and sediment accumulation on upstream side	Stream restoration, install a ditch where not present, armor embankment	Low	No	-70.277022, 44.198914
UB-12	Upper Watershed	Failing culvert with slight undercutting in channel downstream	Replace culvert, armor inlet/outlet	Low	No	-70.274441, 44.198014
UB-13	Upper Watershed	Little Wilson Pond Road culvert: recently replaced under 319 grant, but erosion is present upstream, with silt and clay accumulation present	Investigate the source of the sediment upstream; install plunge pool downstream of the culvert	Low	No	-70.283041, 44.200783
UB-14	Upper Watershed	Robinson Road: Steep slopes with significant erosion on upslope area, with a construction site at the end of the road underway without adequate erosion control	Stabilize slopes via hydroseeding. Armor the culvert outlet embankment to prevent erosion. Install adequate erosion controls at the construction site	Medium	No	-70.291178, 44.200805
UB-15	Upper Watershed	Dense lakeside development with little riparian buffer. Neighborhood served by septic systems.	Landowner education, septic system inspection program	High	Yes	-70.287699, 44.204632
UB-16	Upper Watershed	Driveway near Mud Pond: Construction	Regrade road and improve drainage from driveway.	Medium	No	-70.289638, 44.217353
UB-17	Upper Watershed	Severe erosion on road and from the steep slope near the road	Install a ditch adjacent to the road; regrade and crown the road	Medium	No	-70.295304, 44.222609
UB-18	Upper Watershed	Farm with swine, cattle, and logging	Continue to work with landowner to implement best practices for manure management and erosion controls	Medium	No	-70.325346, 44.239848
UB-19	Upper Watershed	Livestock Access to Waterbody	Limit livestock access to waterbody; discuss with landowners	Low	No	-70.262168, 44.184023

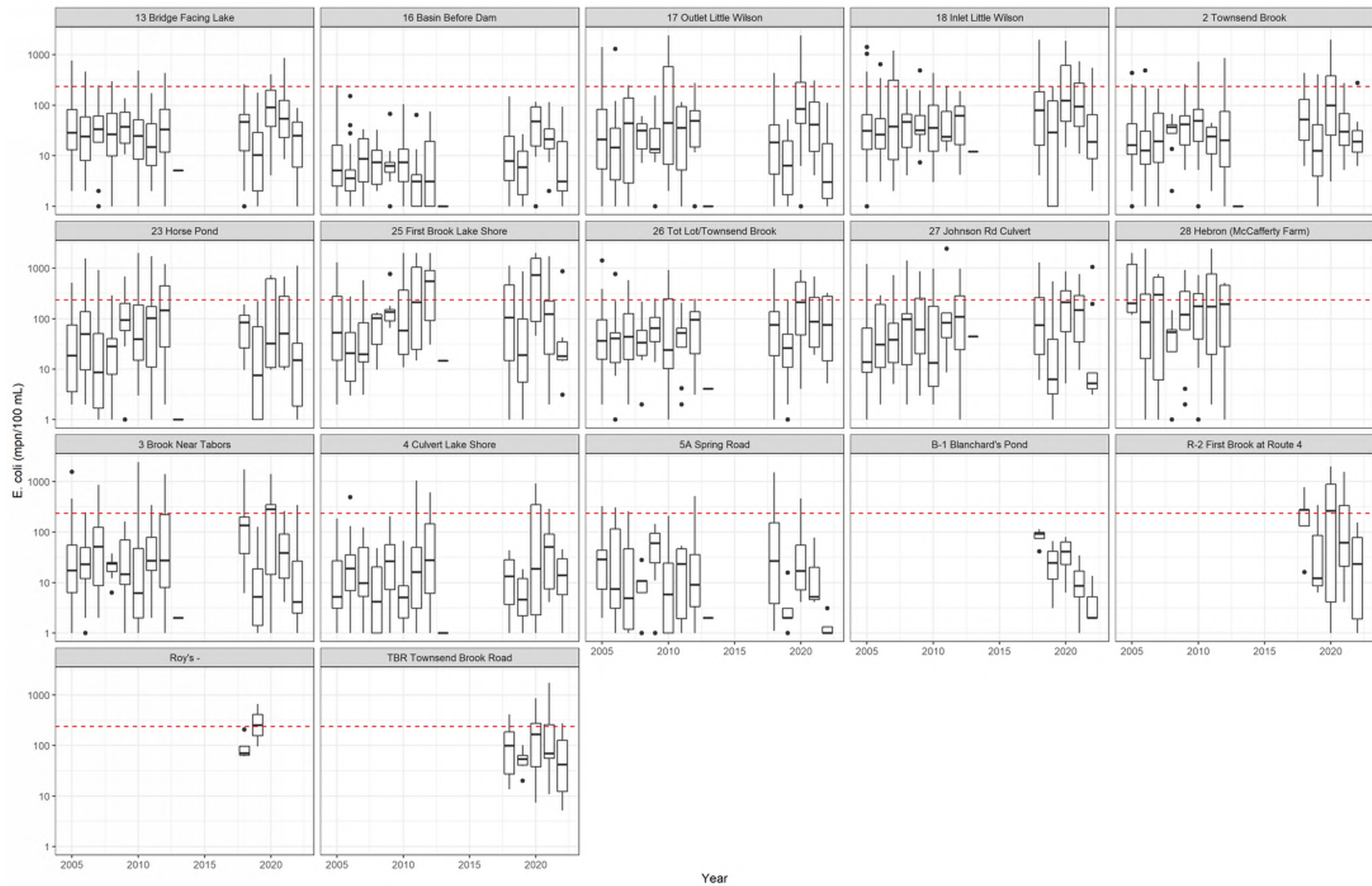
Appendix C

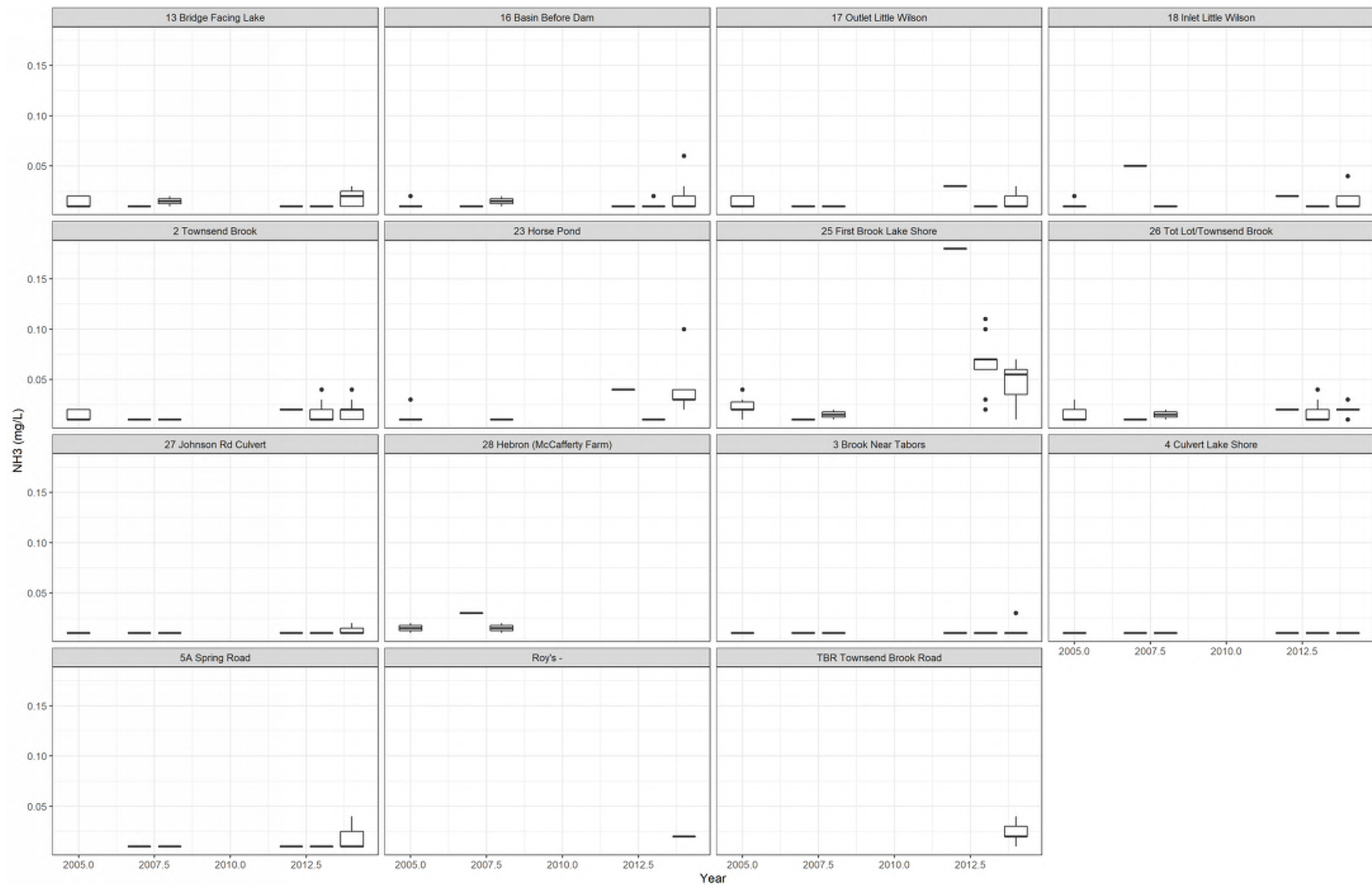
Perimeter Water Quality Plots

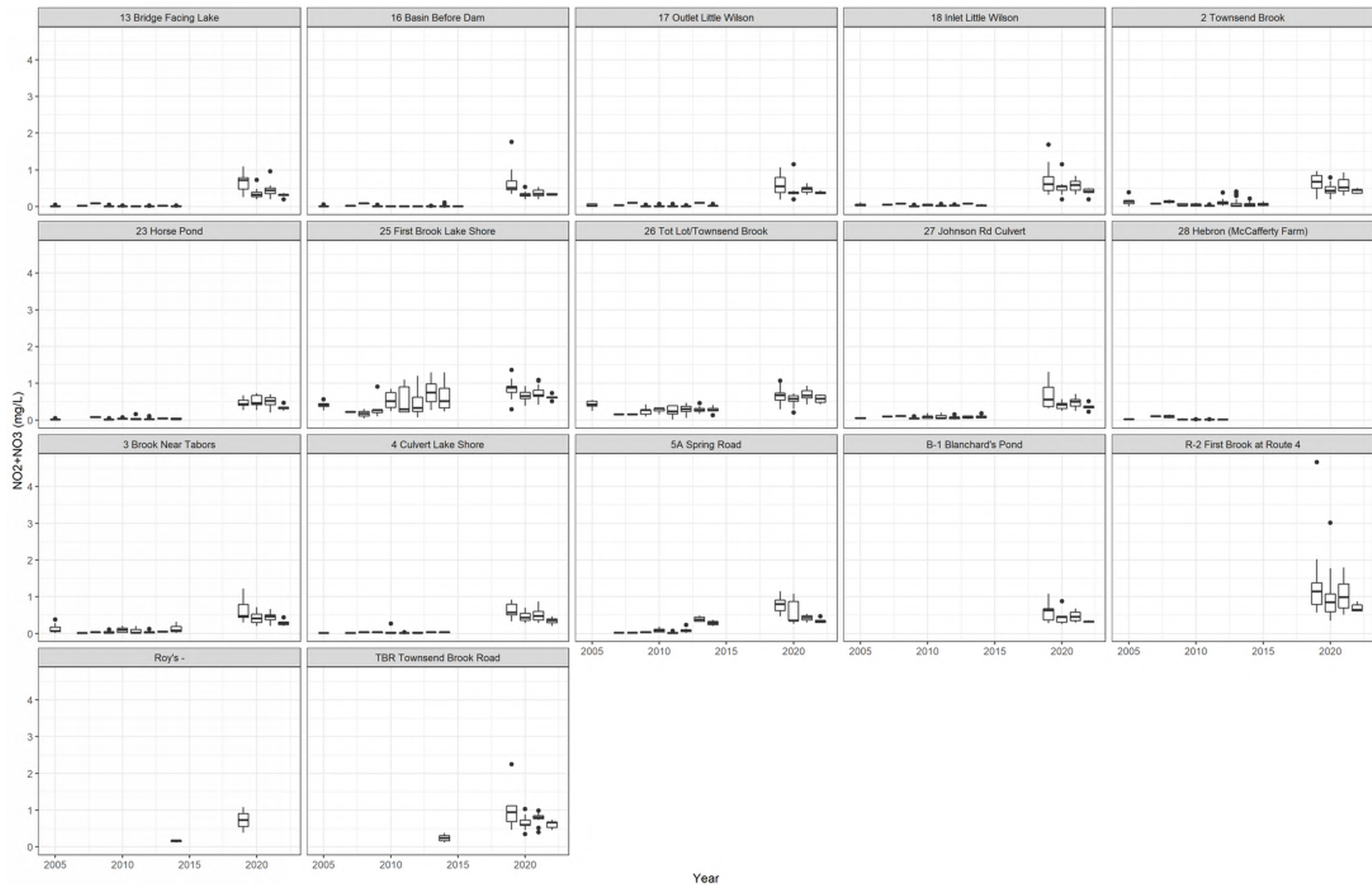


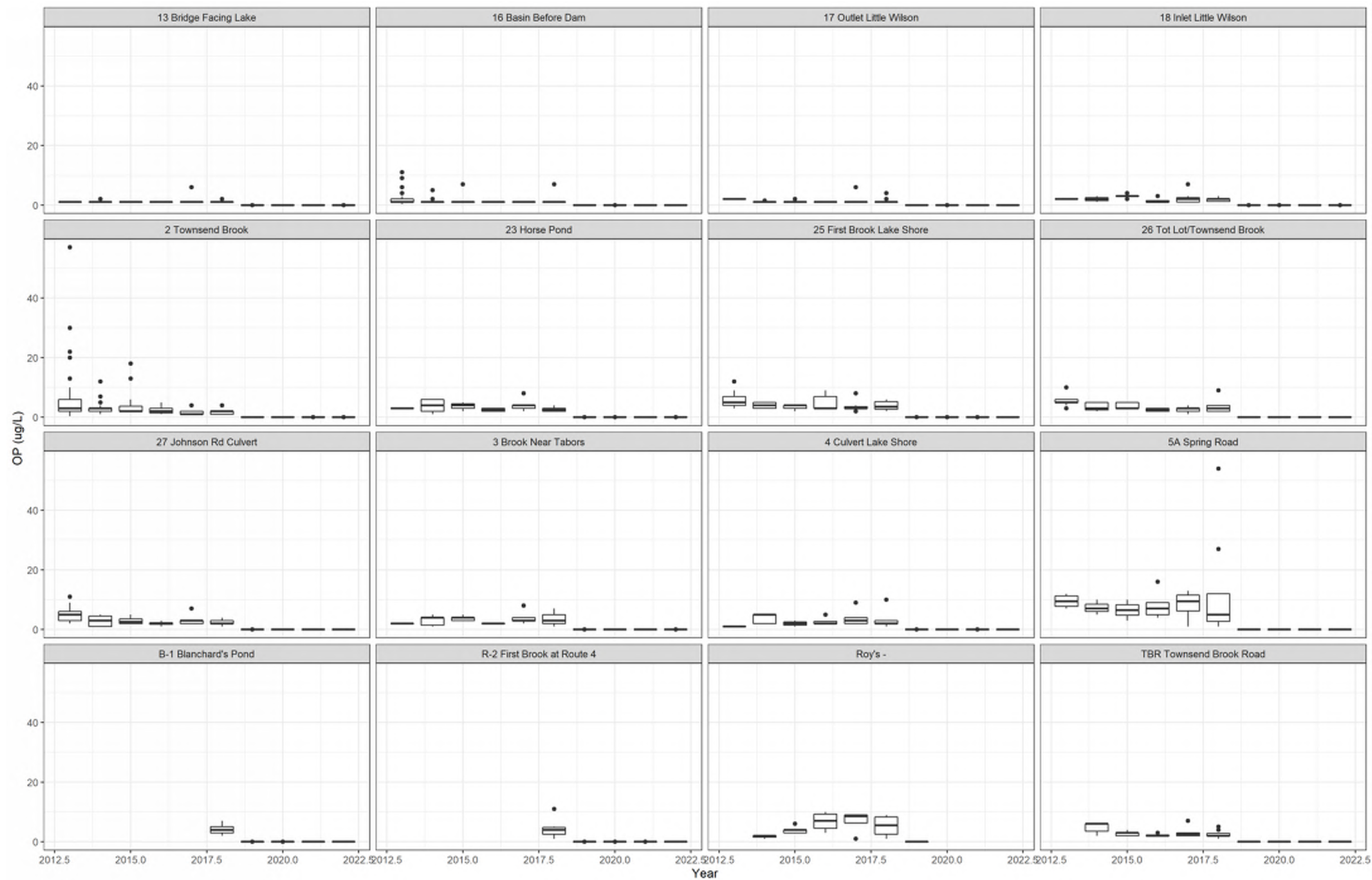


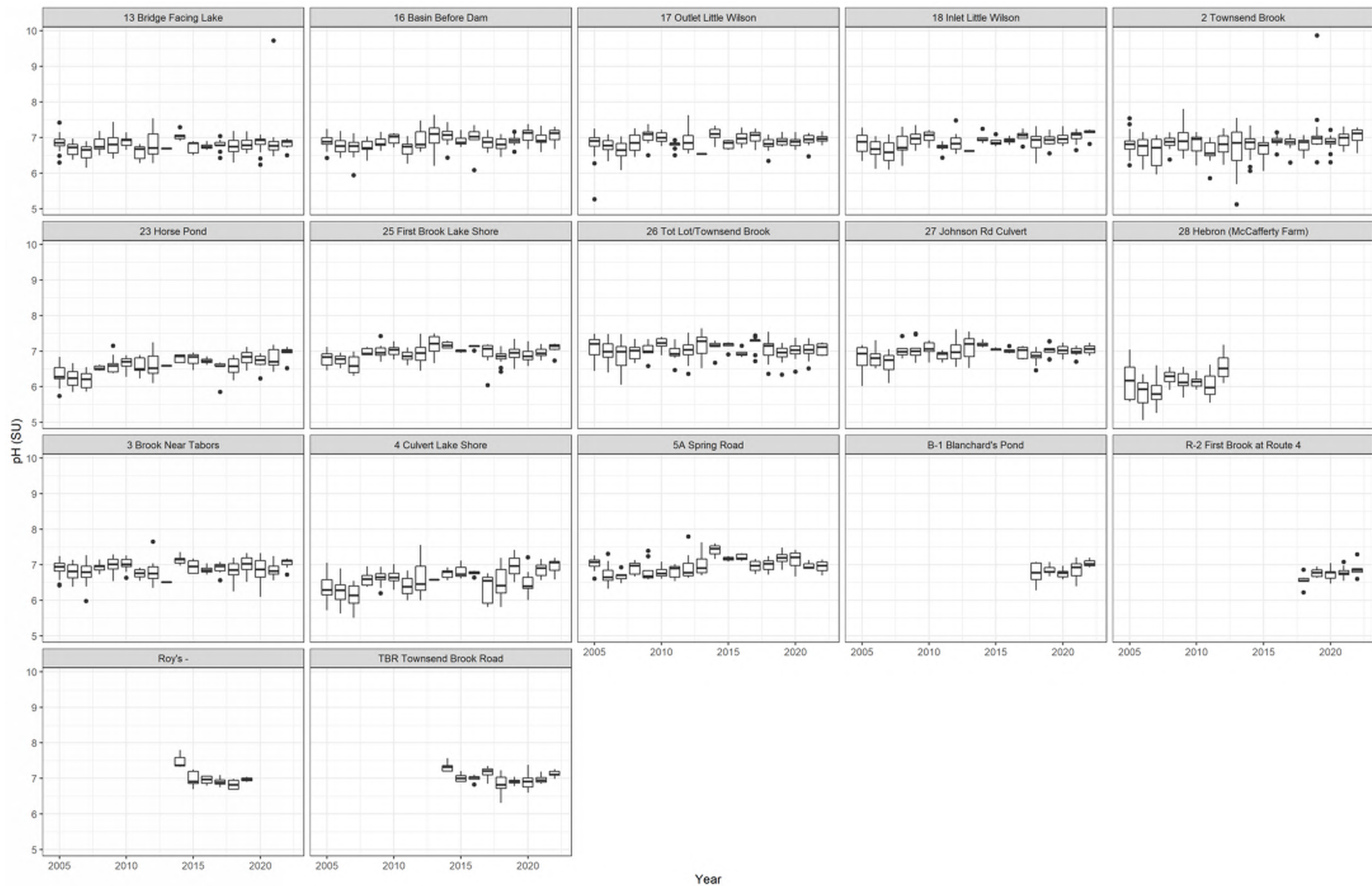


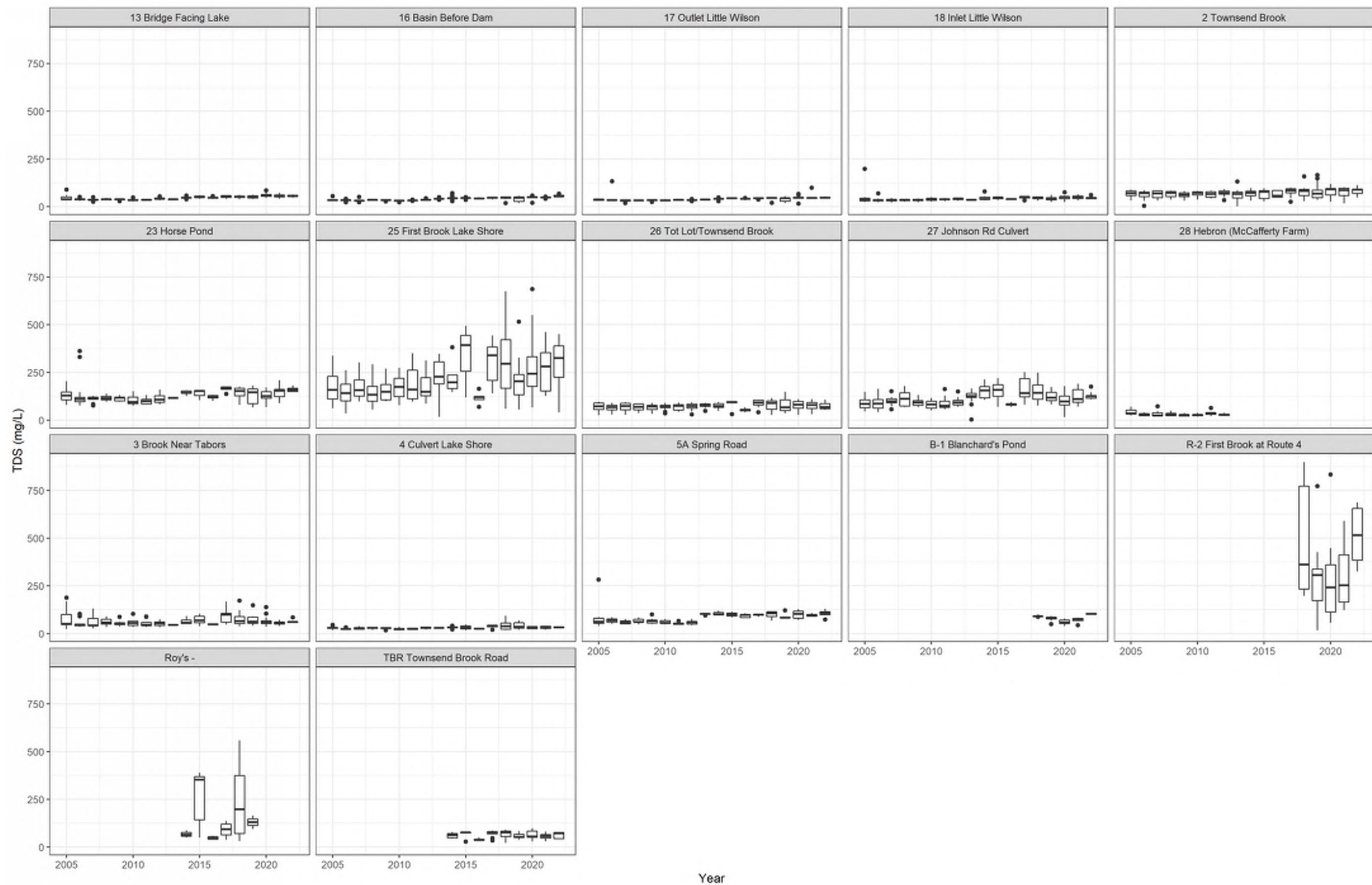


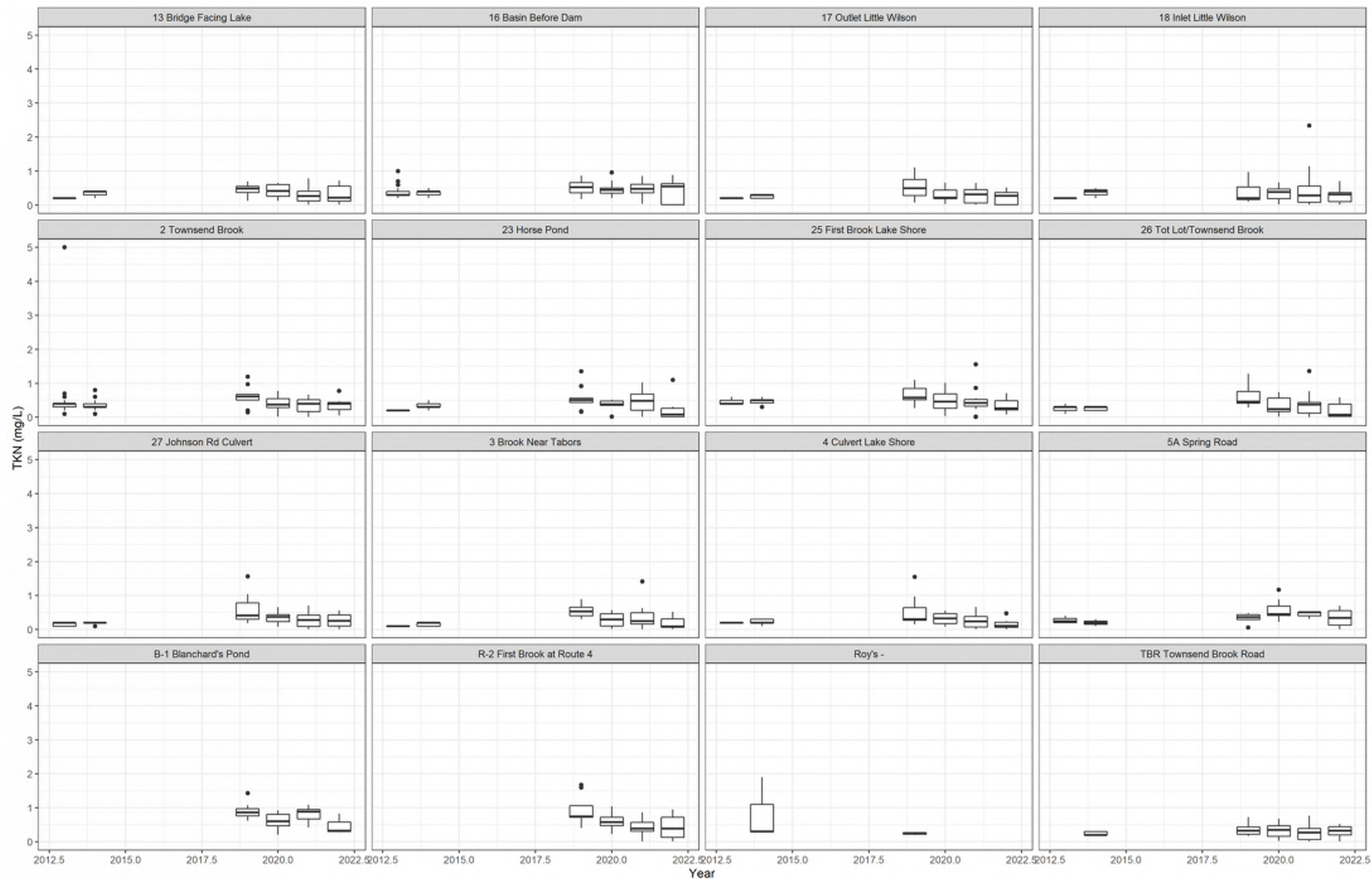


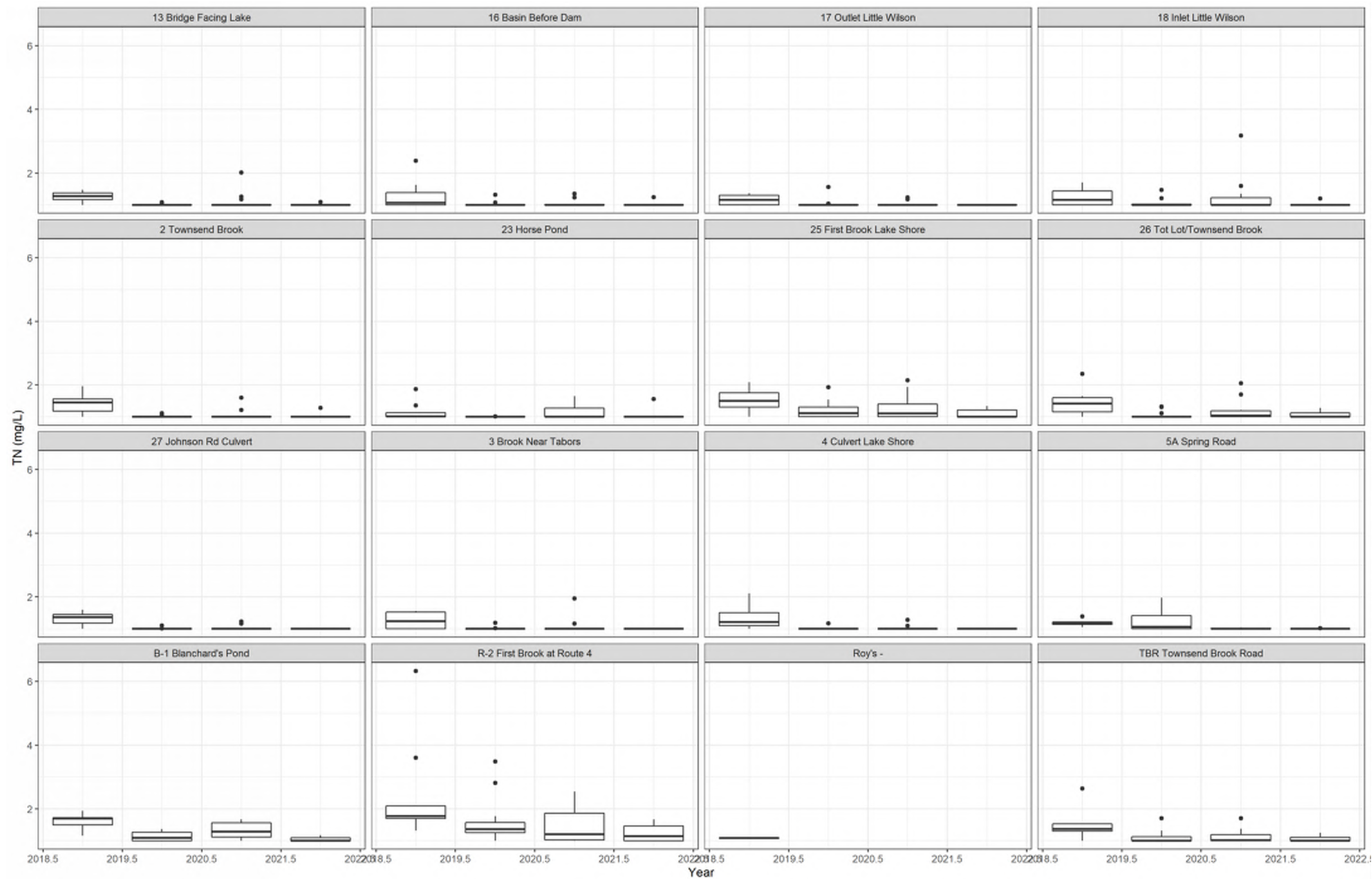


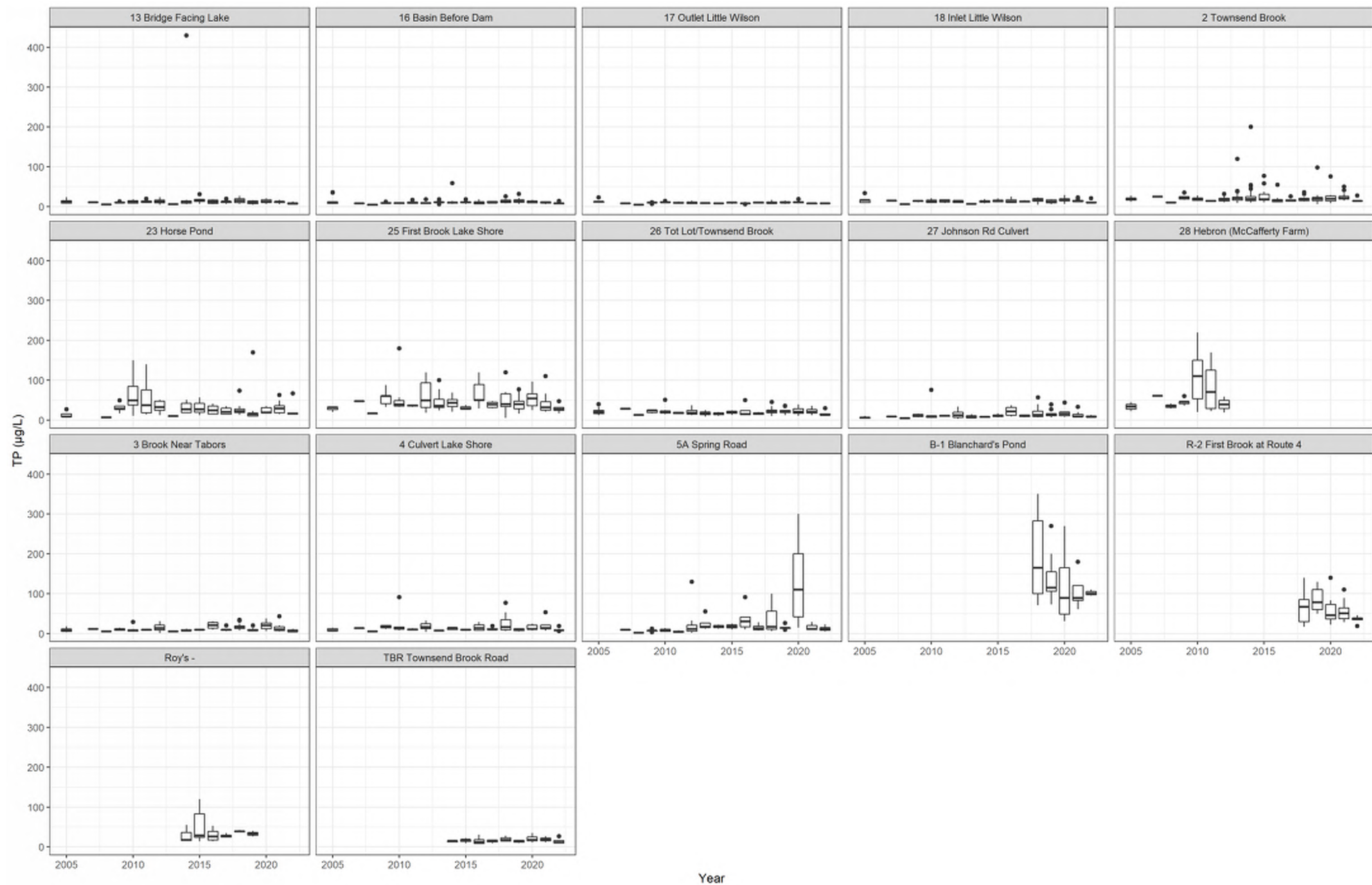


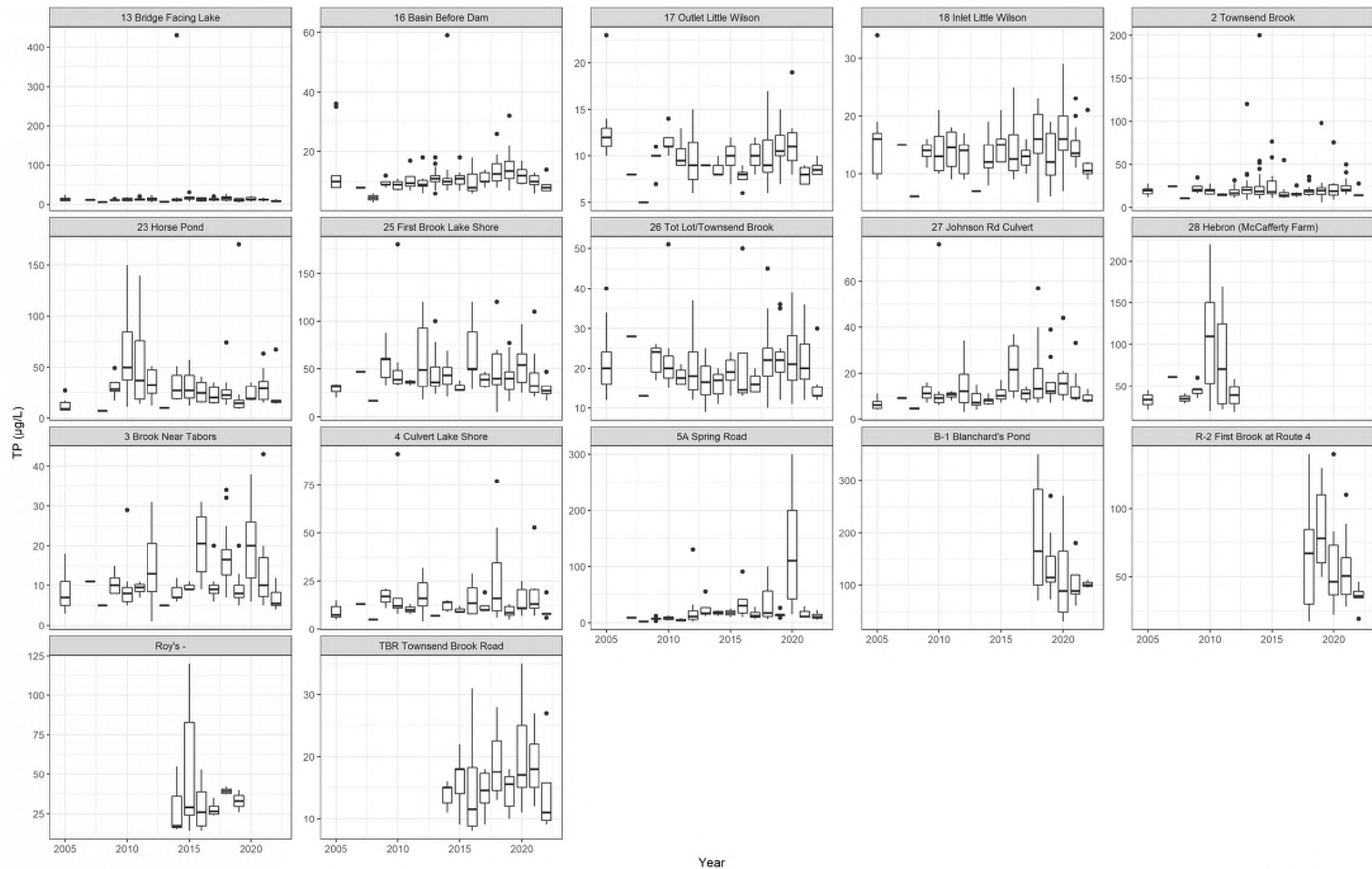




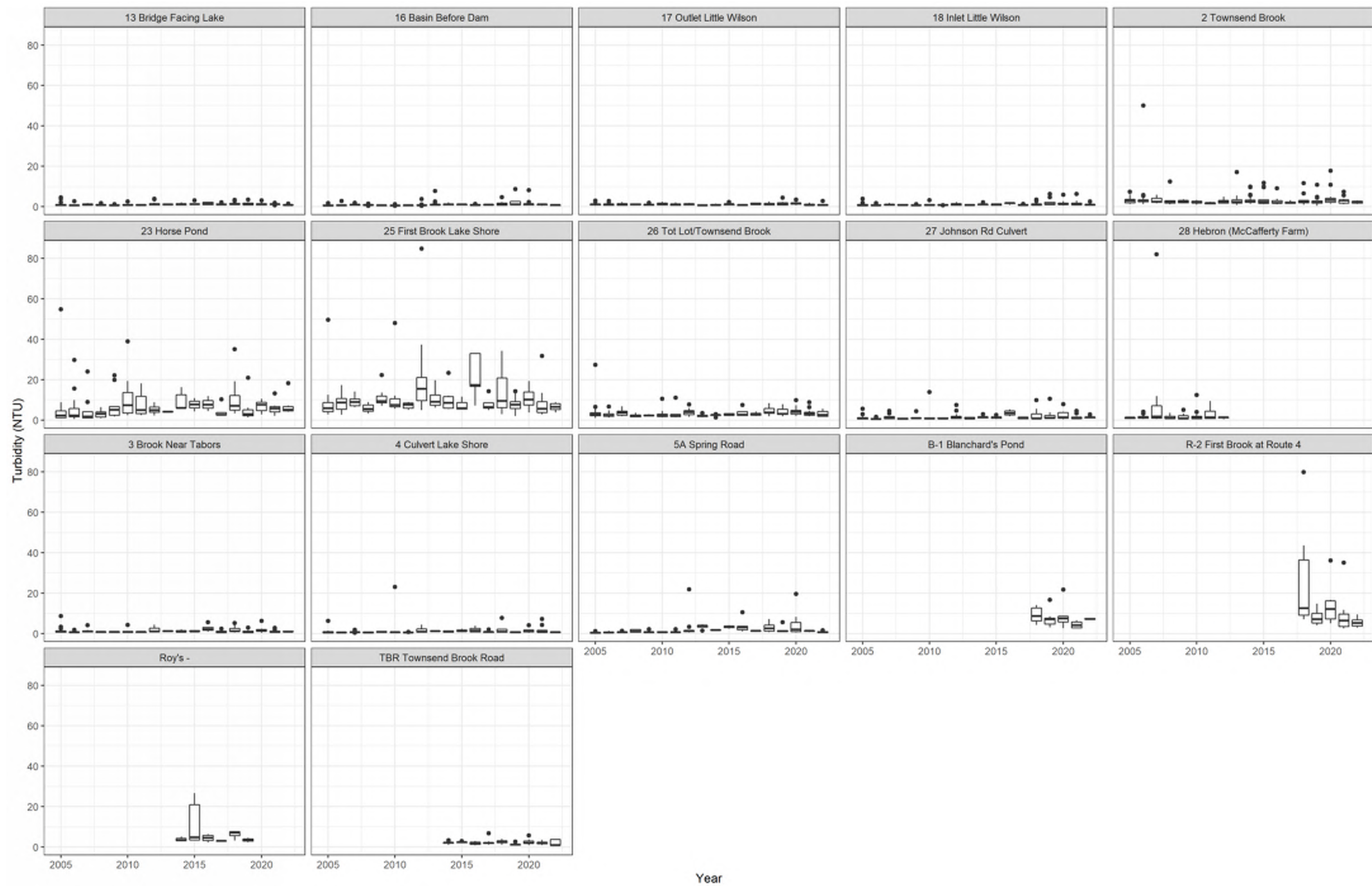


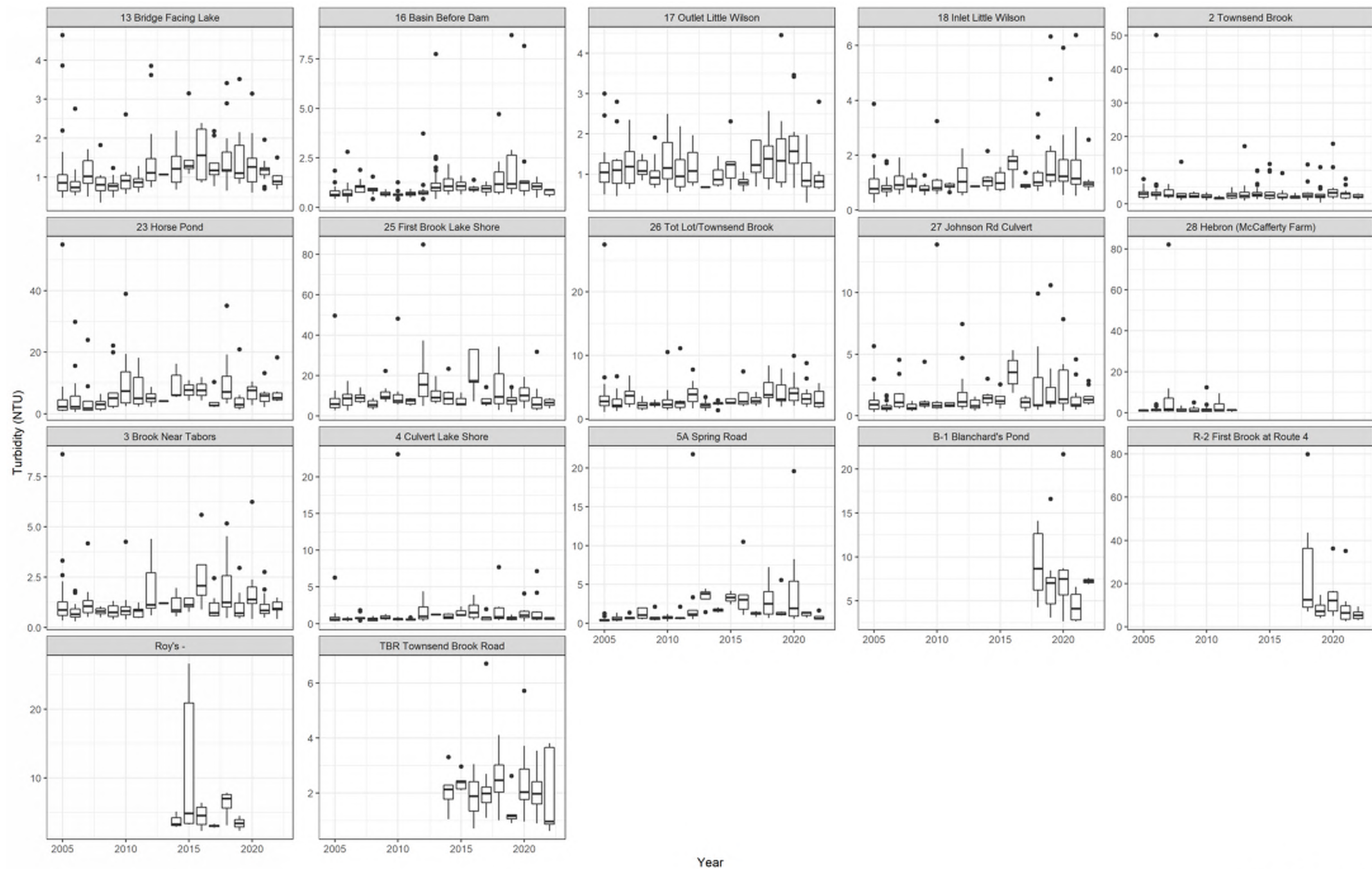






Note: Different y-axis scales



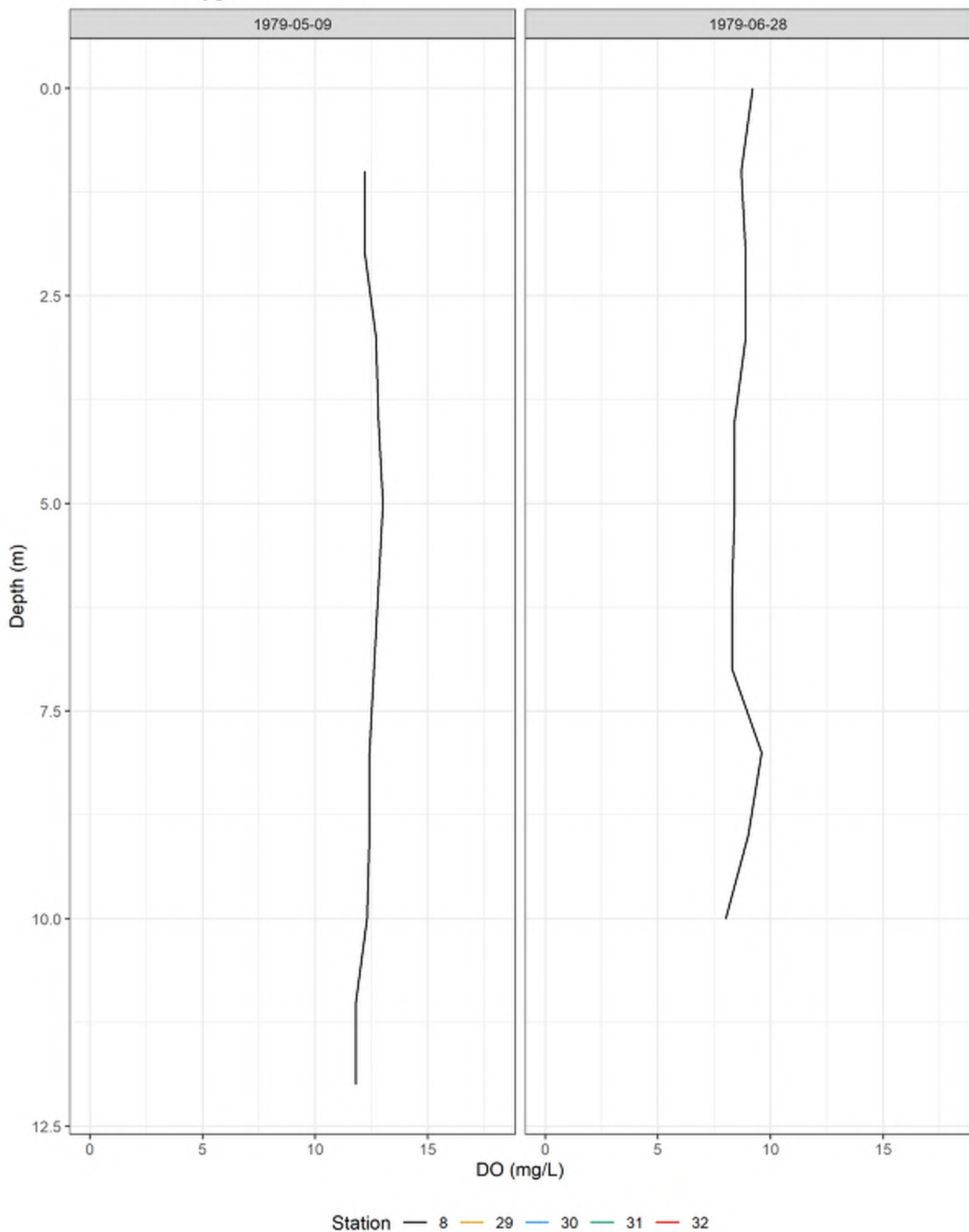


Note: Different y-axis scales

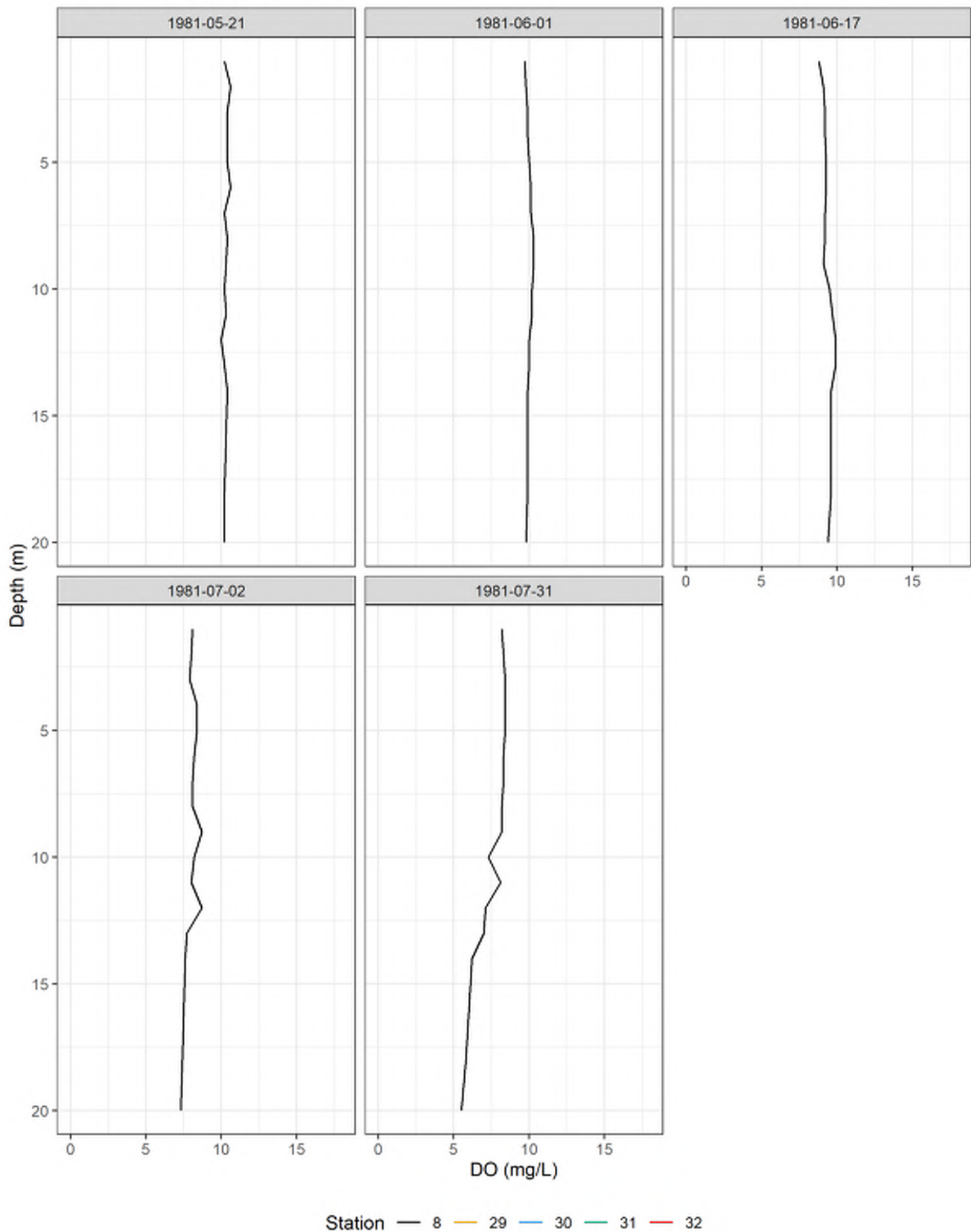
Appendix D

Profile and Isopleth Plots

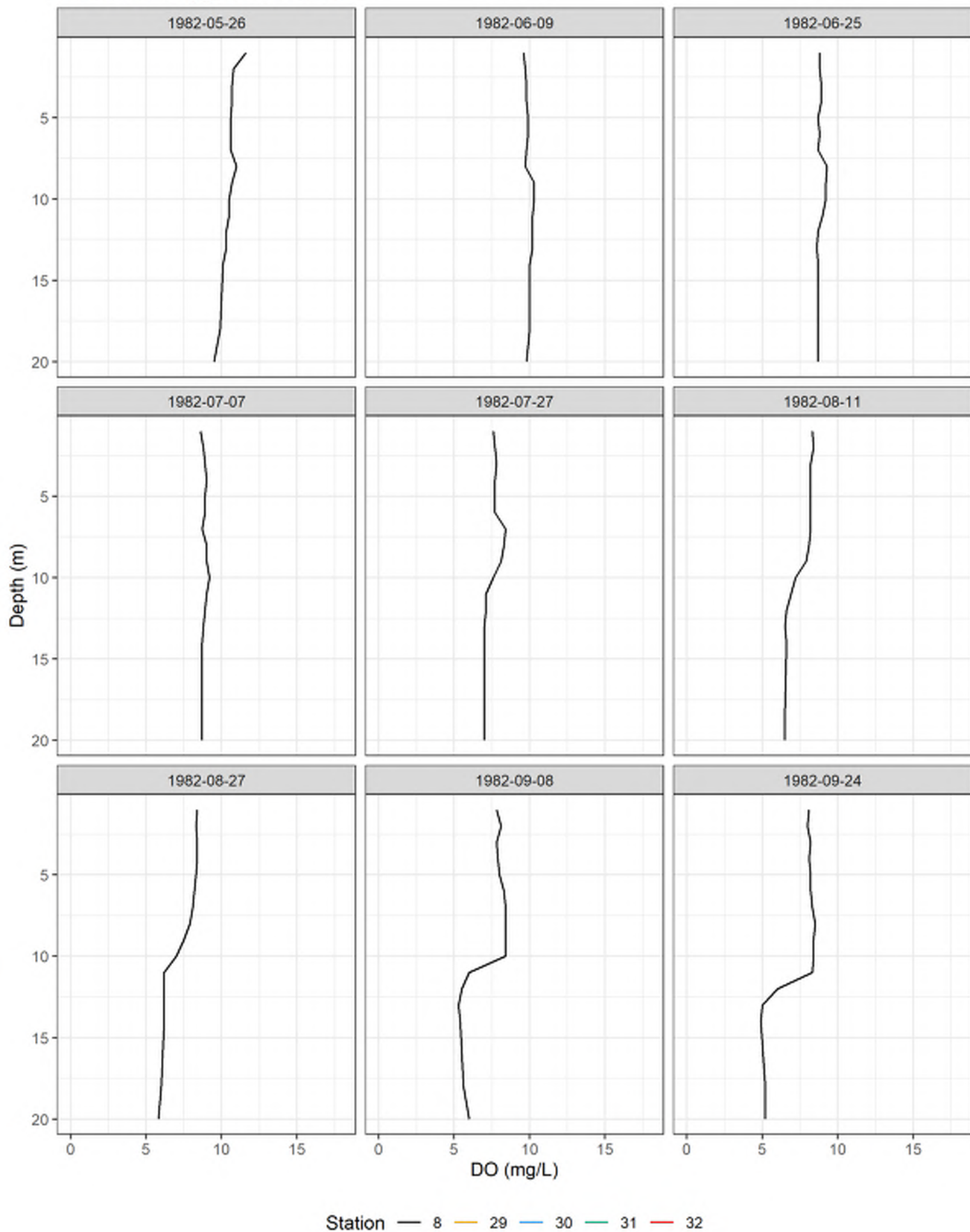
Dissolved Oxygen Profile: 1979



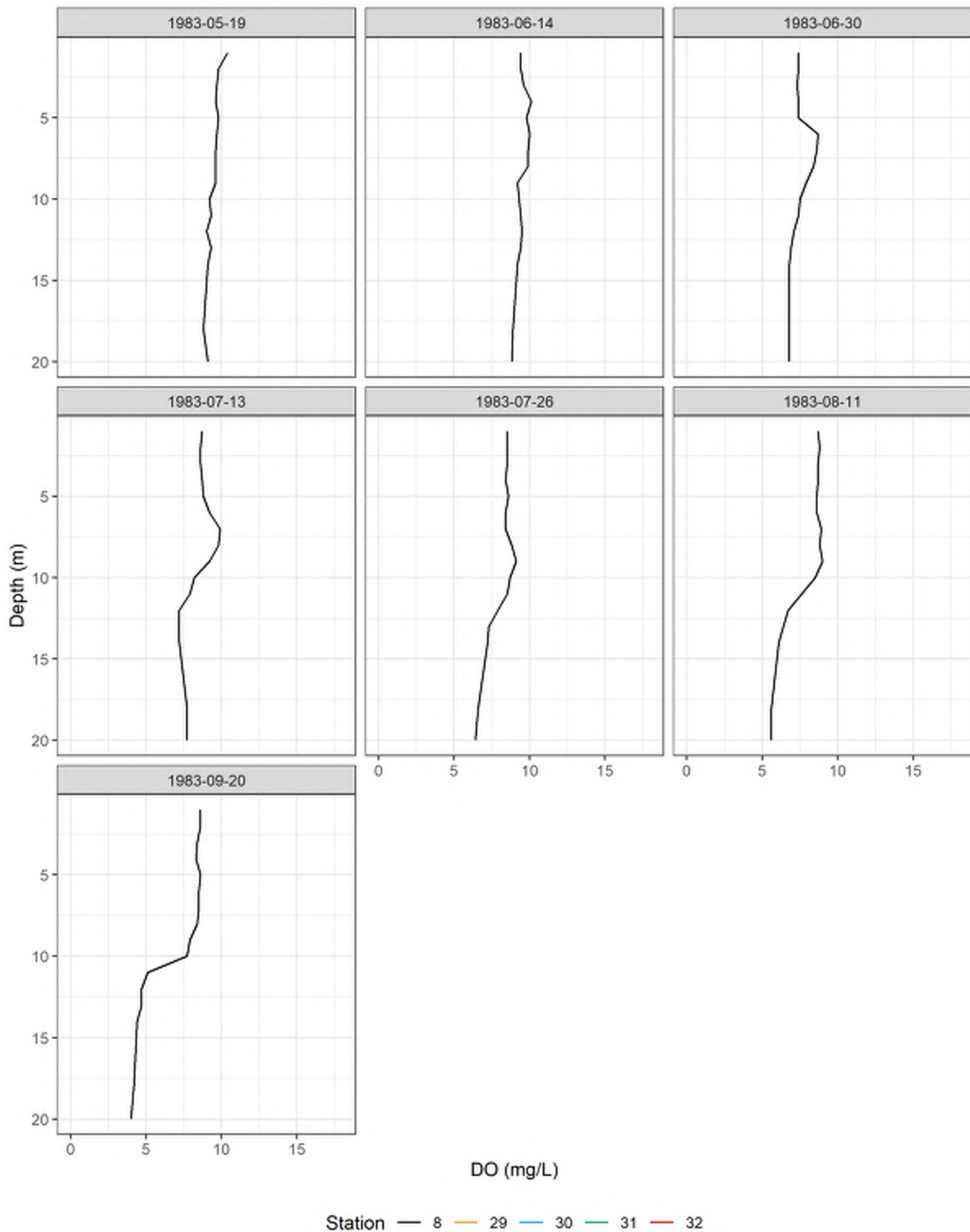
Dissolved Oxygen Profile: 1981



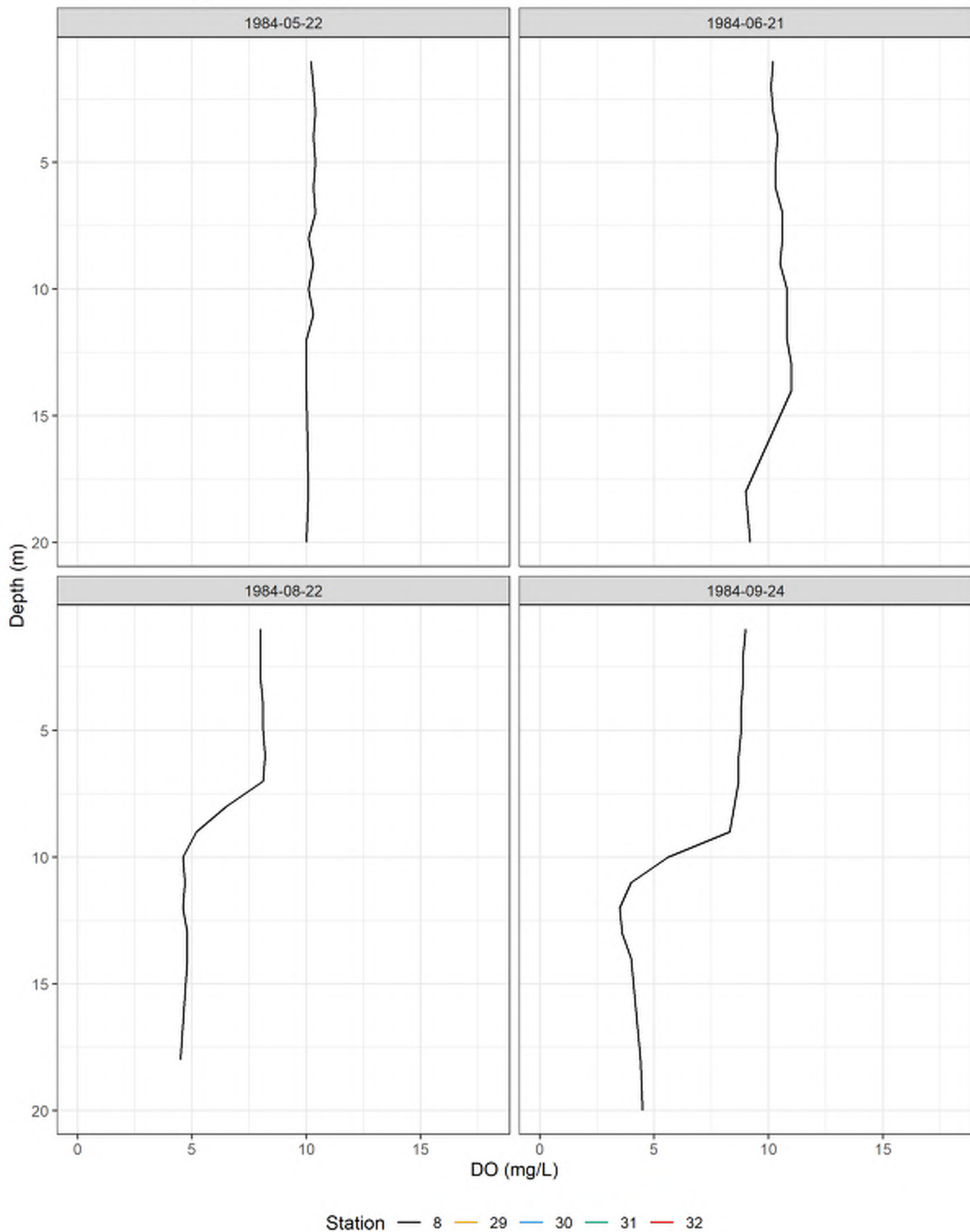
Dissolved Oxygen Profile: 1982



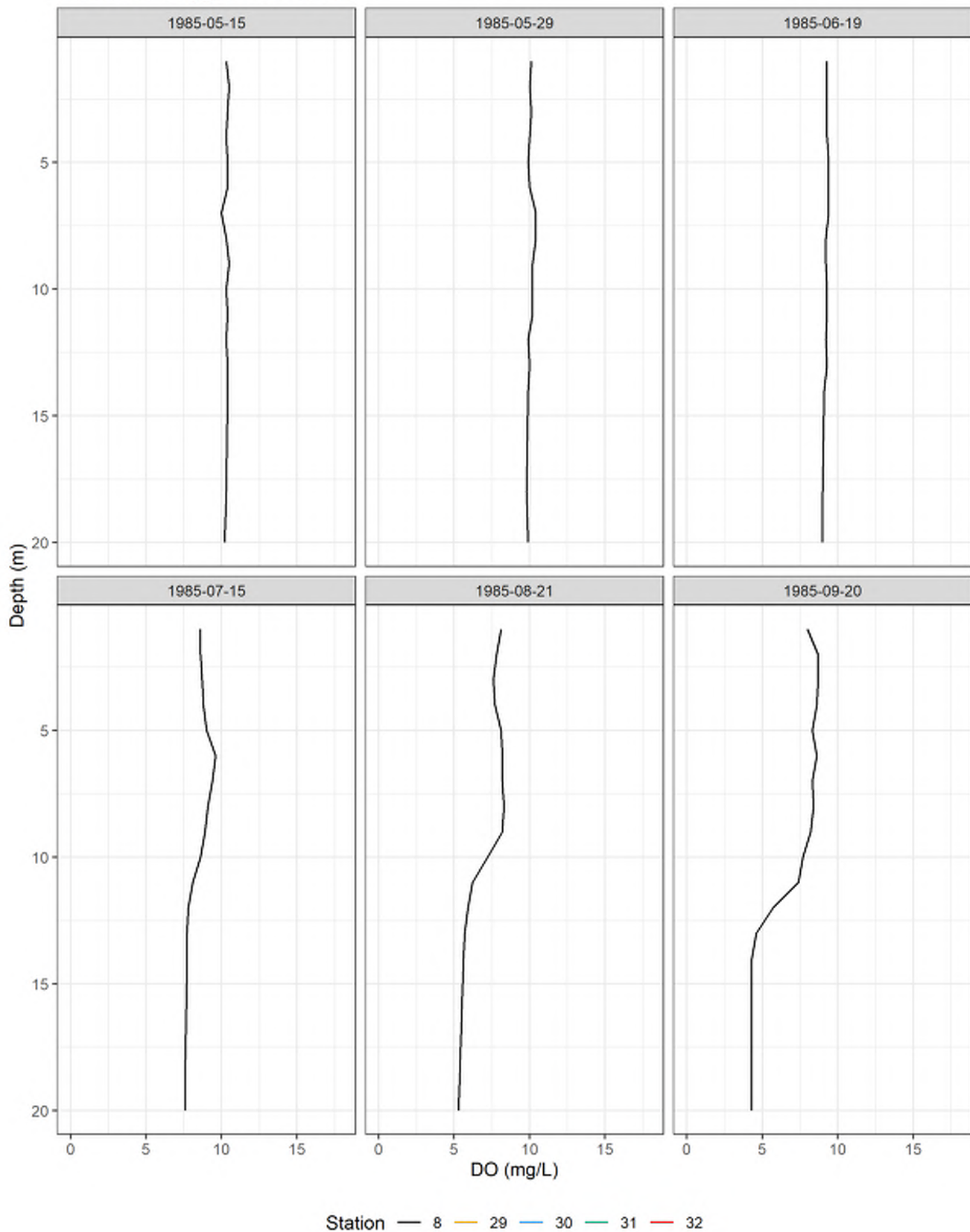
Dissolved Oxygen Profile: 1983



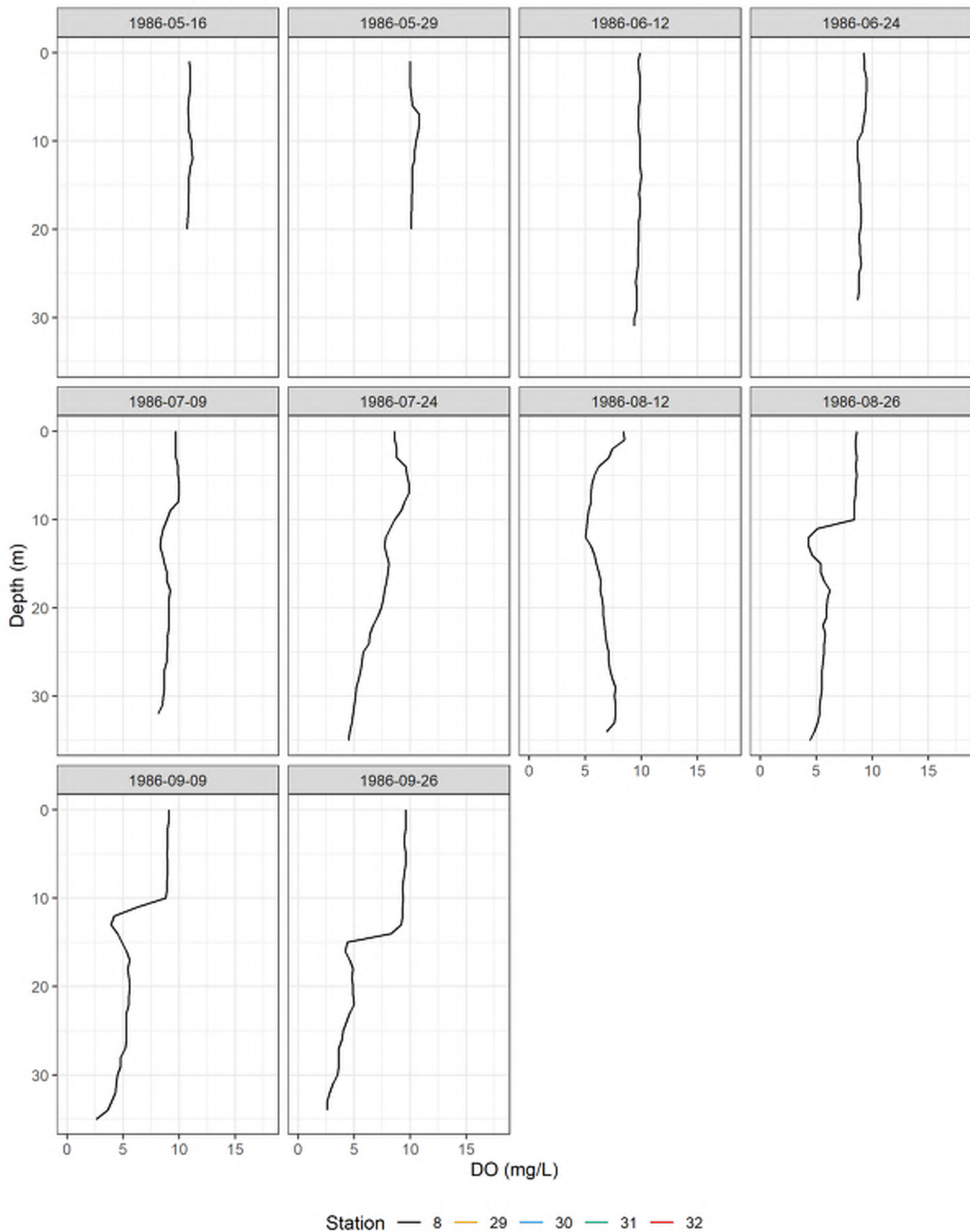
Dissolved Oxygen Profile: 1984



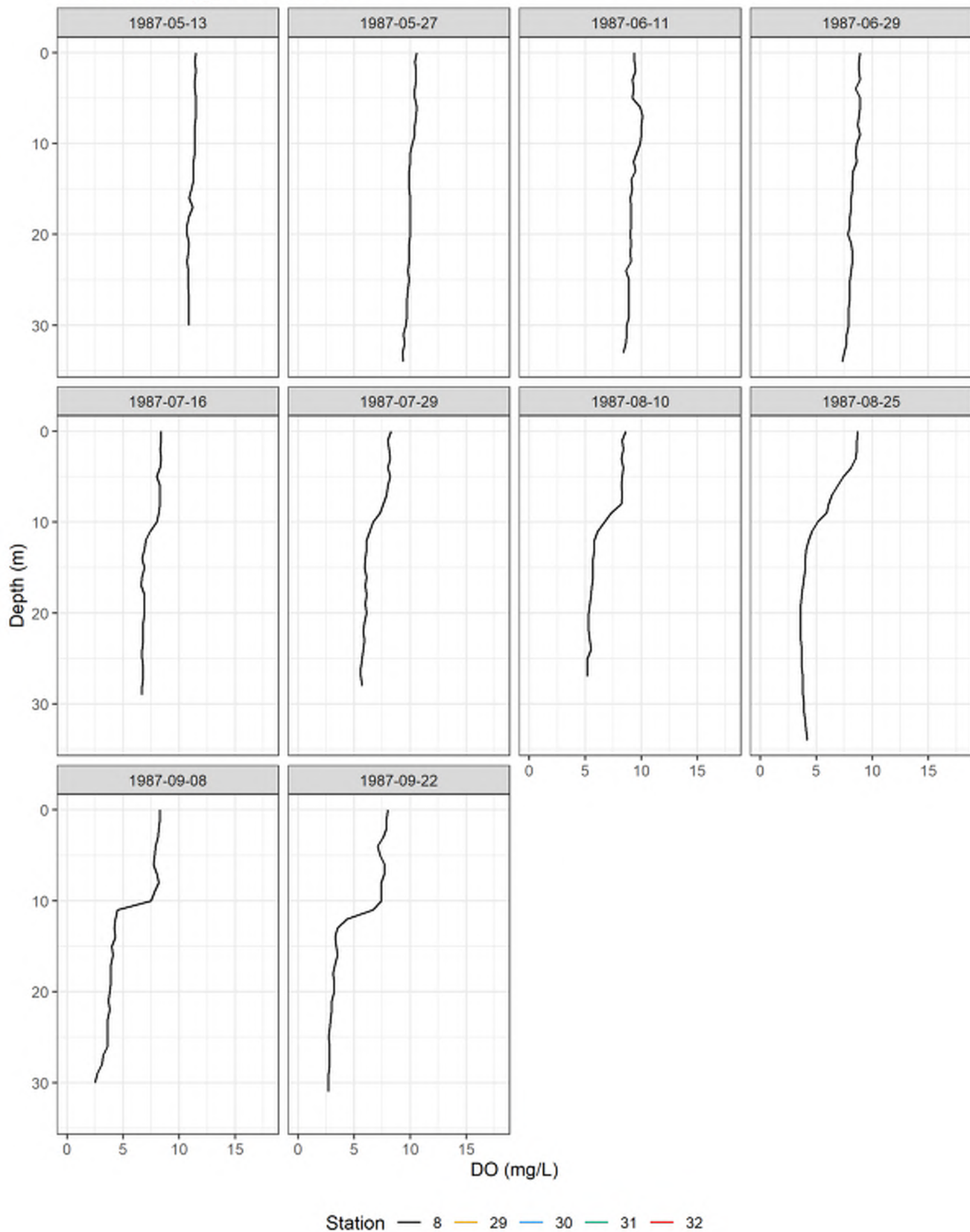
Dissolved Oxygen Profile: 1985



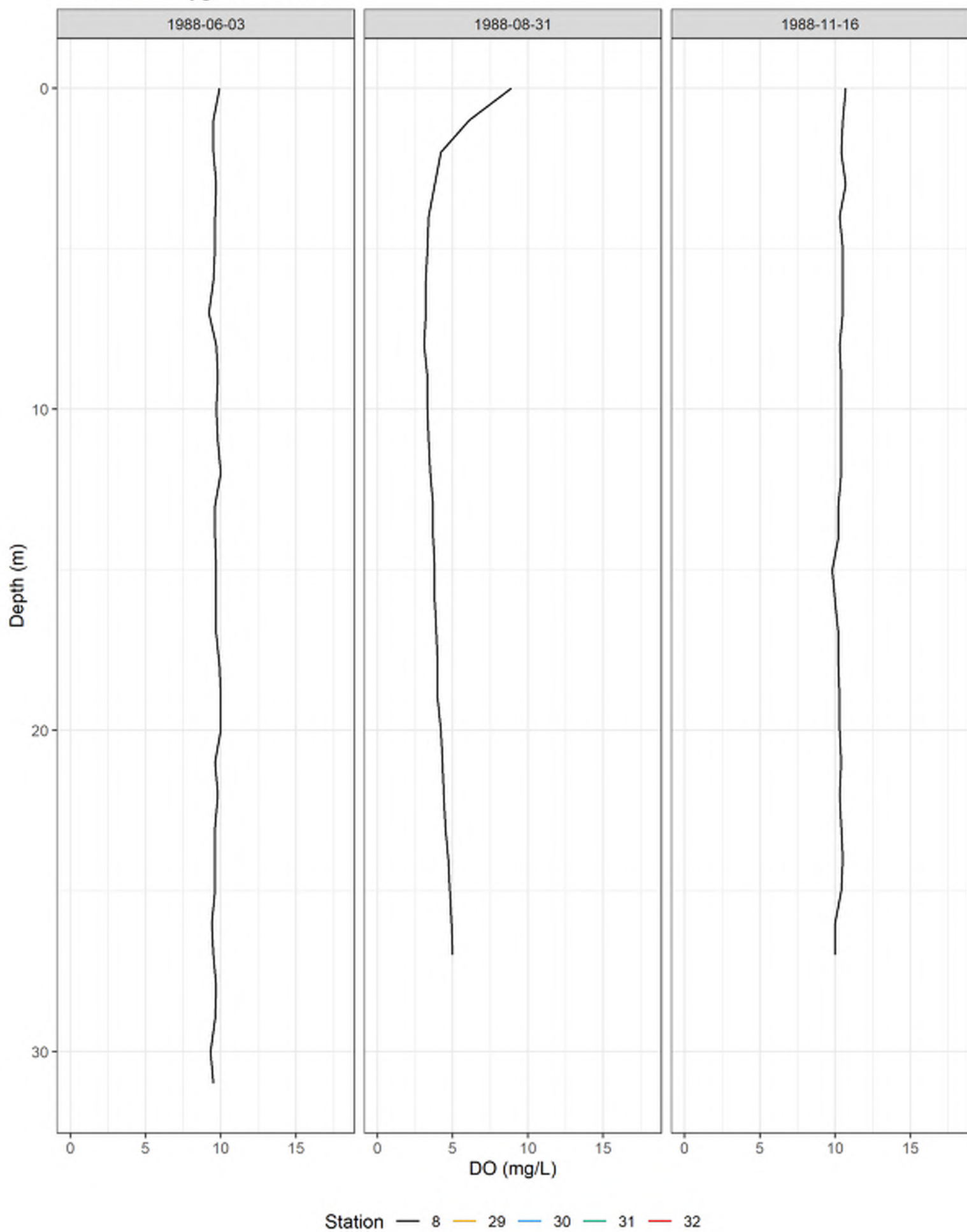
Dissolved Oxygen Profile: 1986



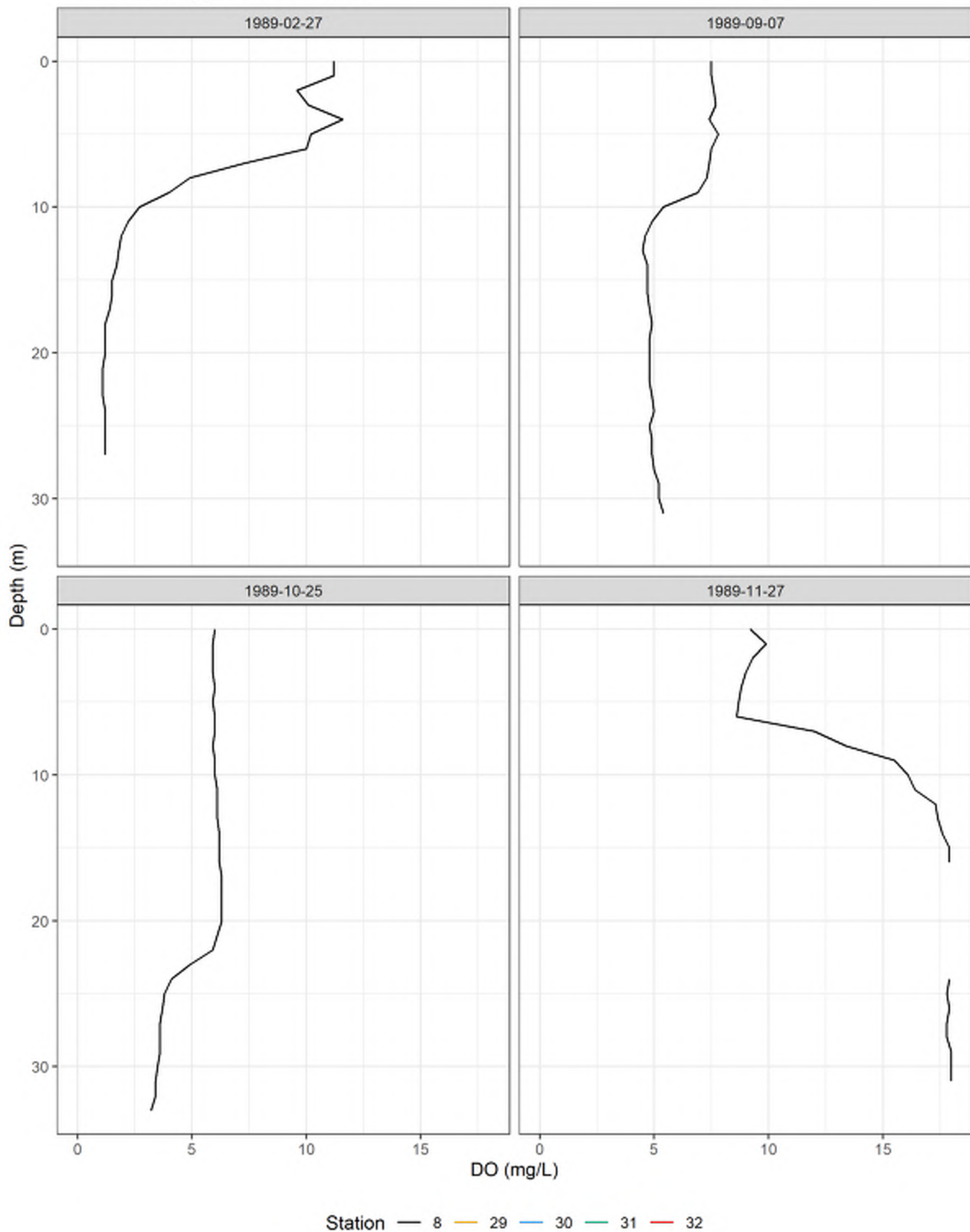
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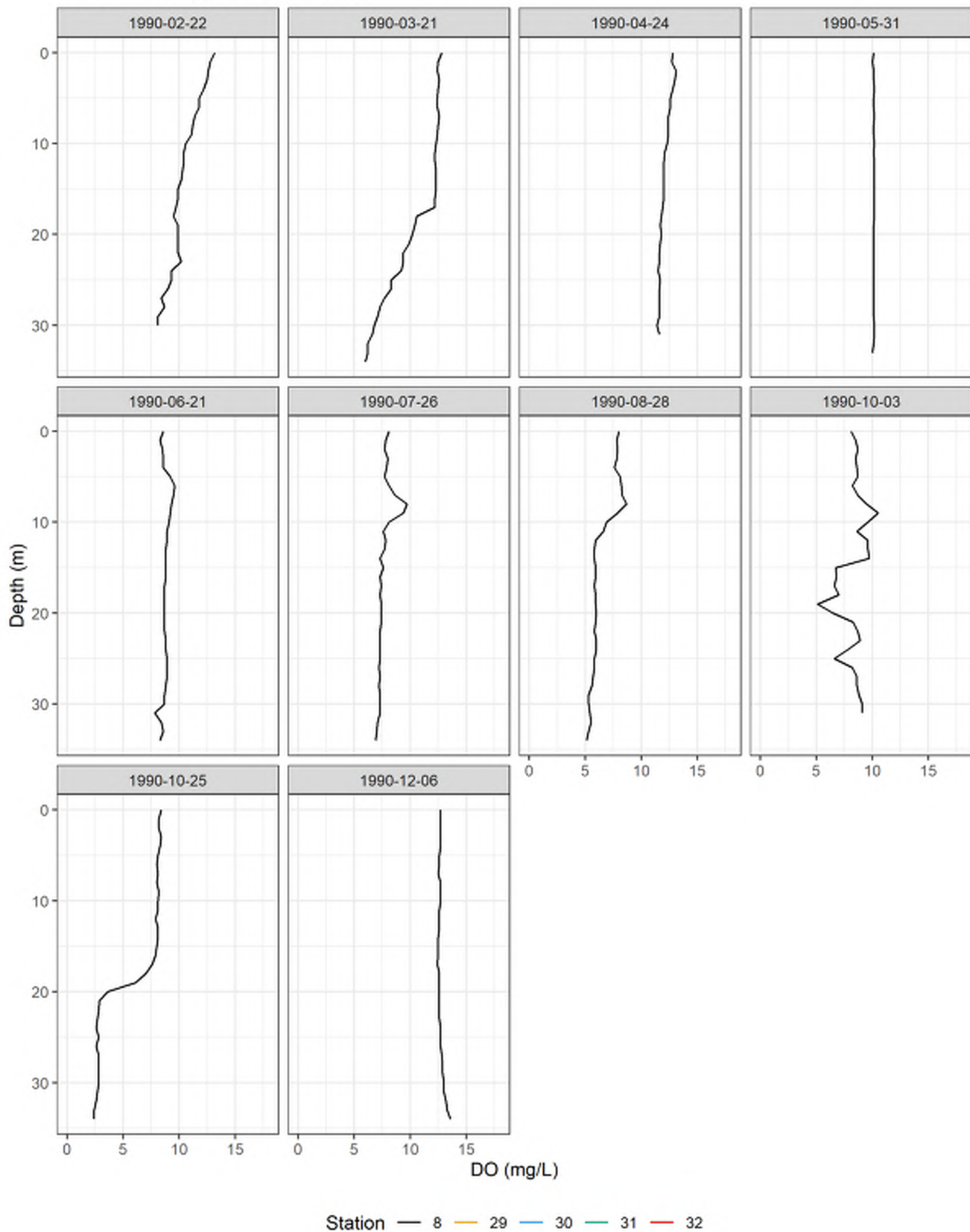
Dissolved Oxygen Profile: 1988



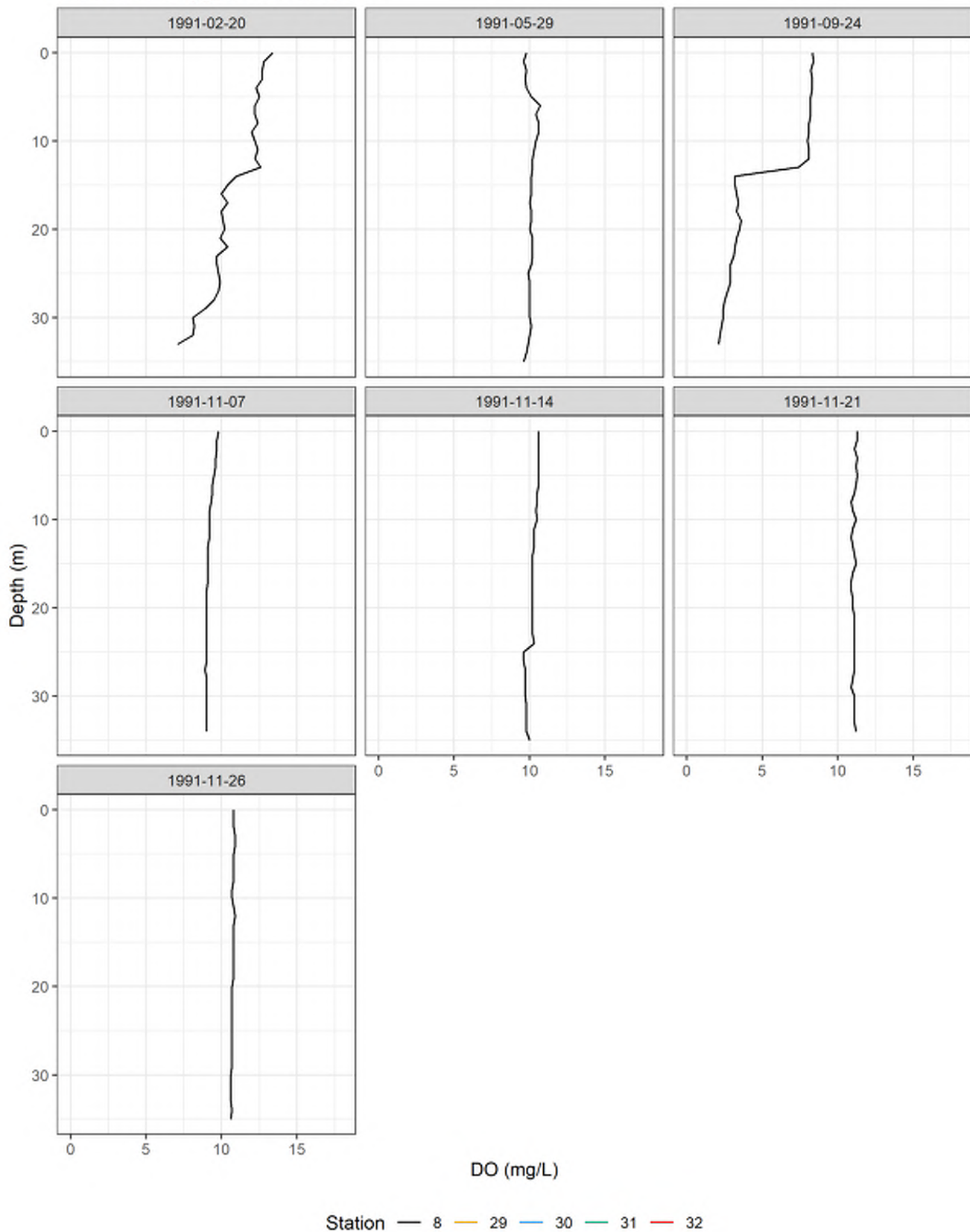
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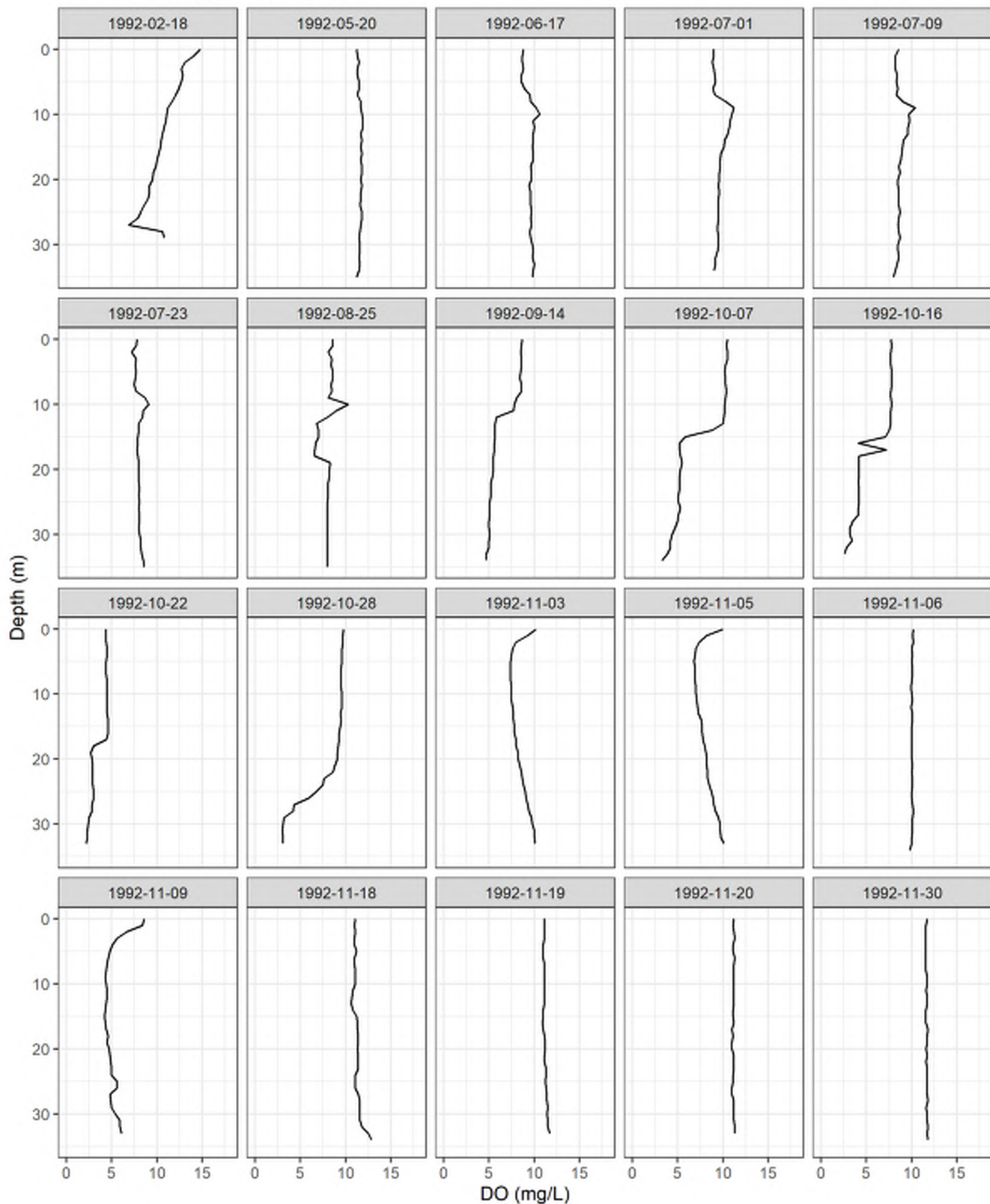
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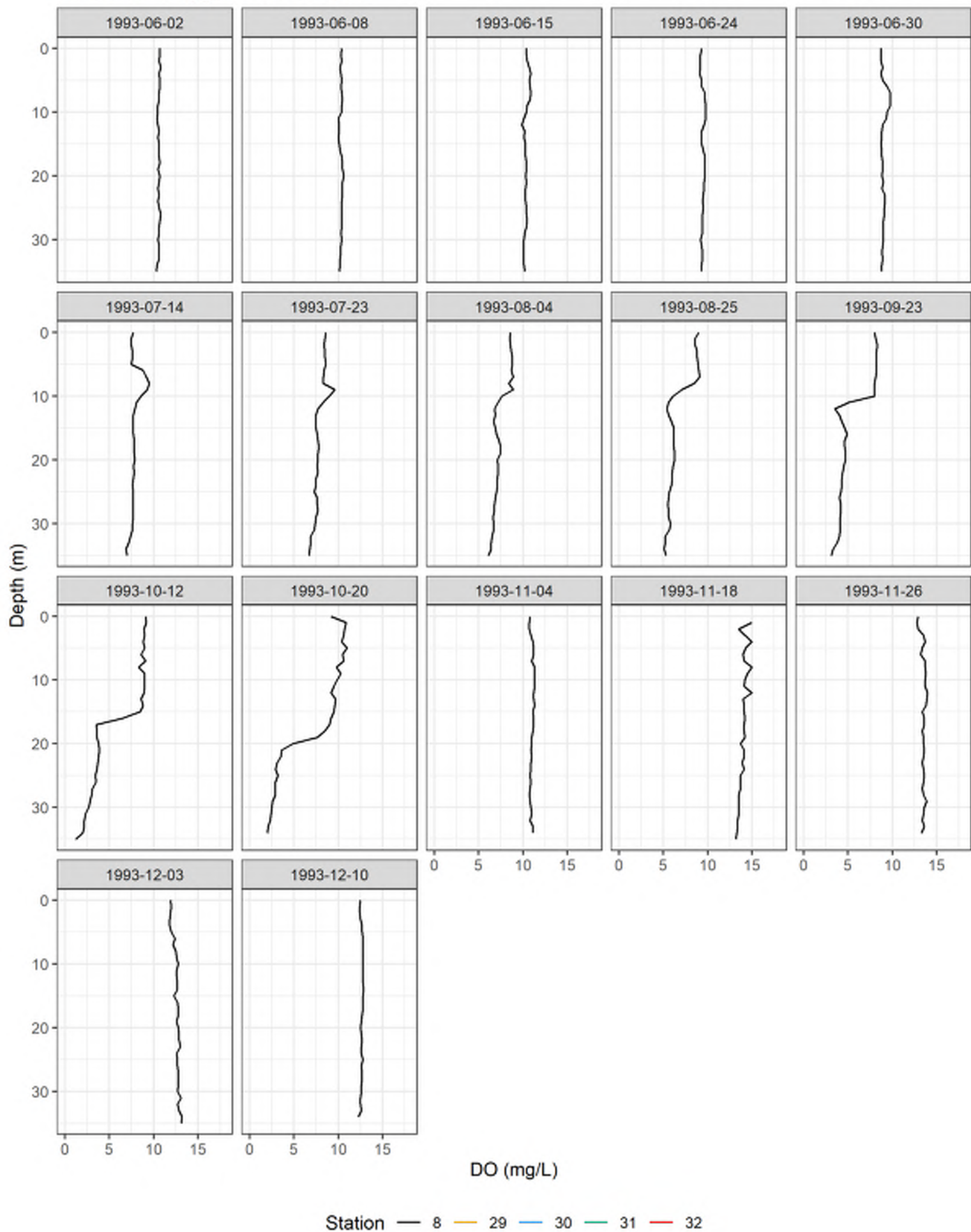
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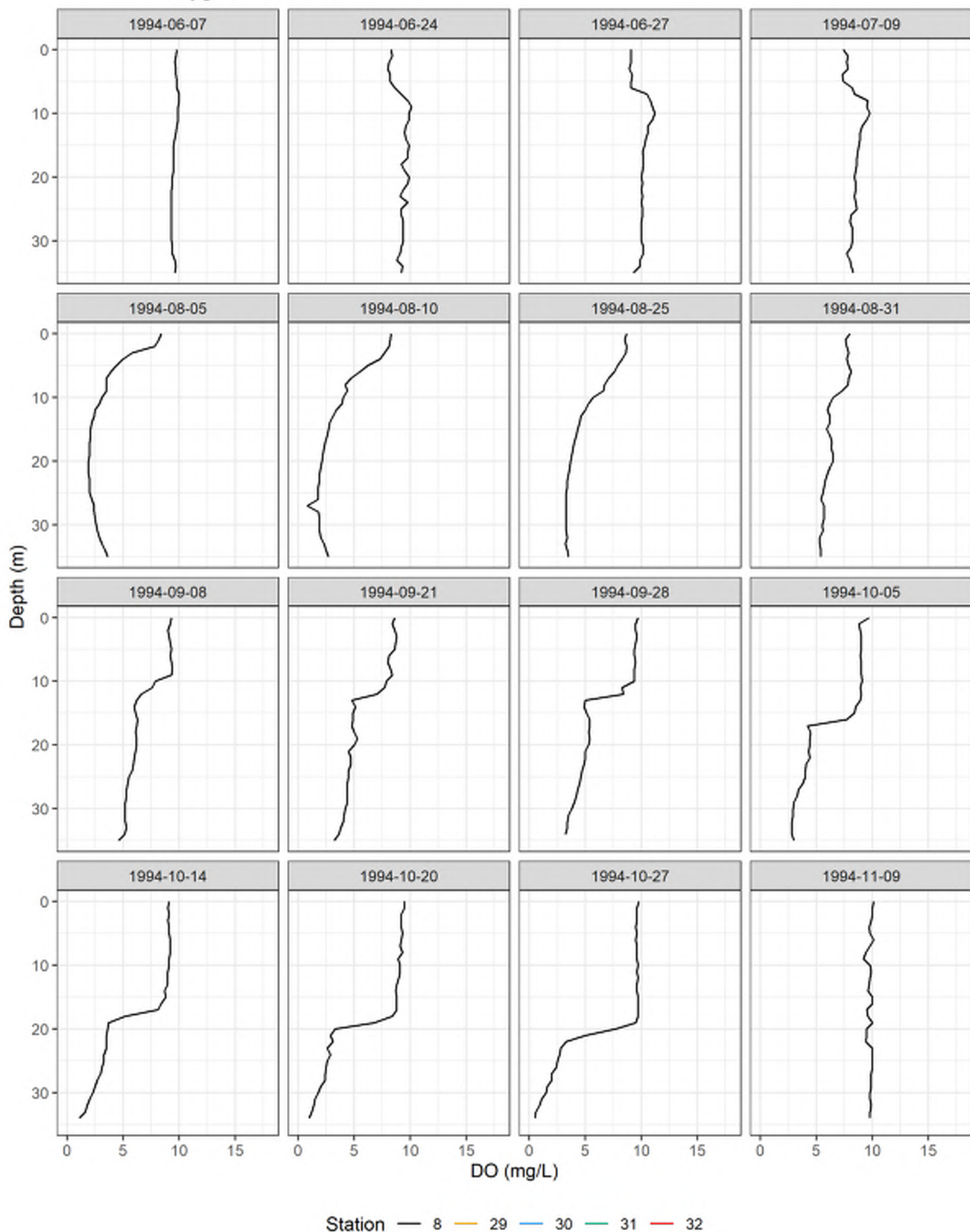
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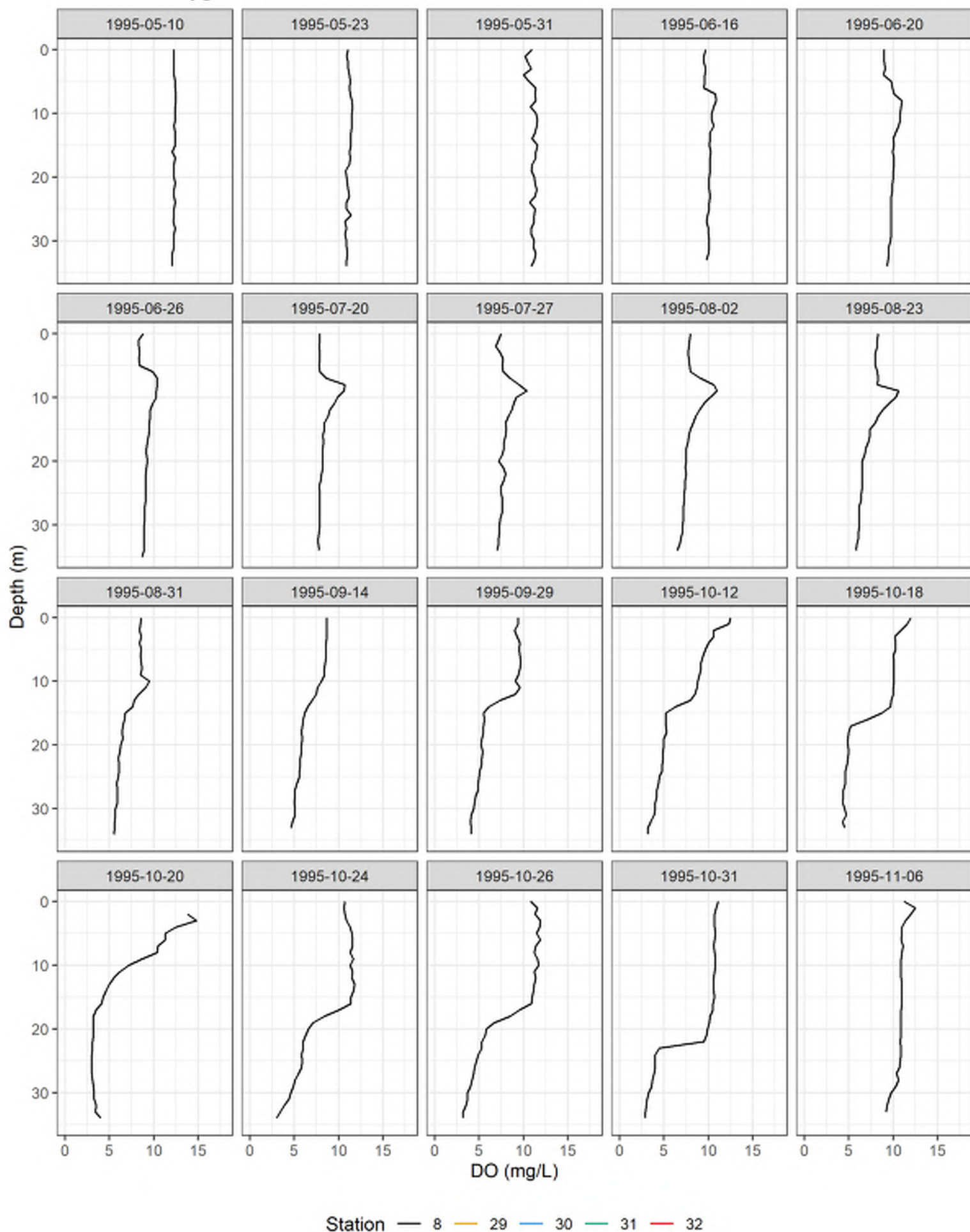
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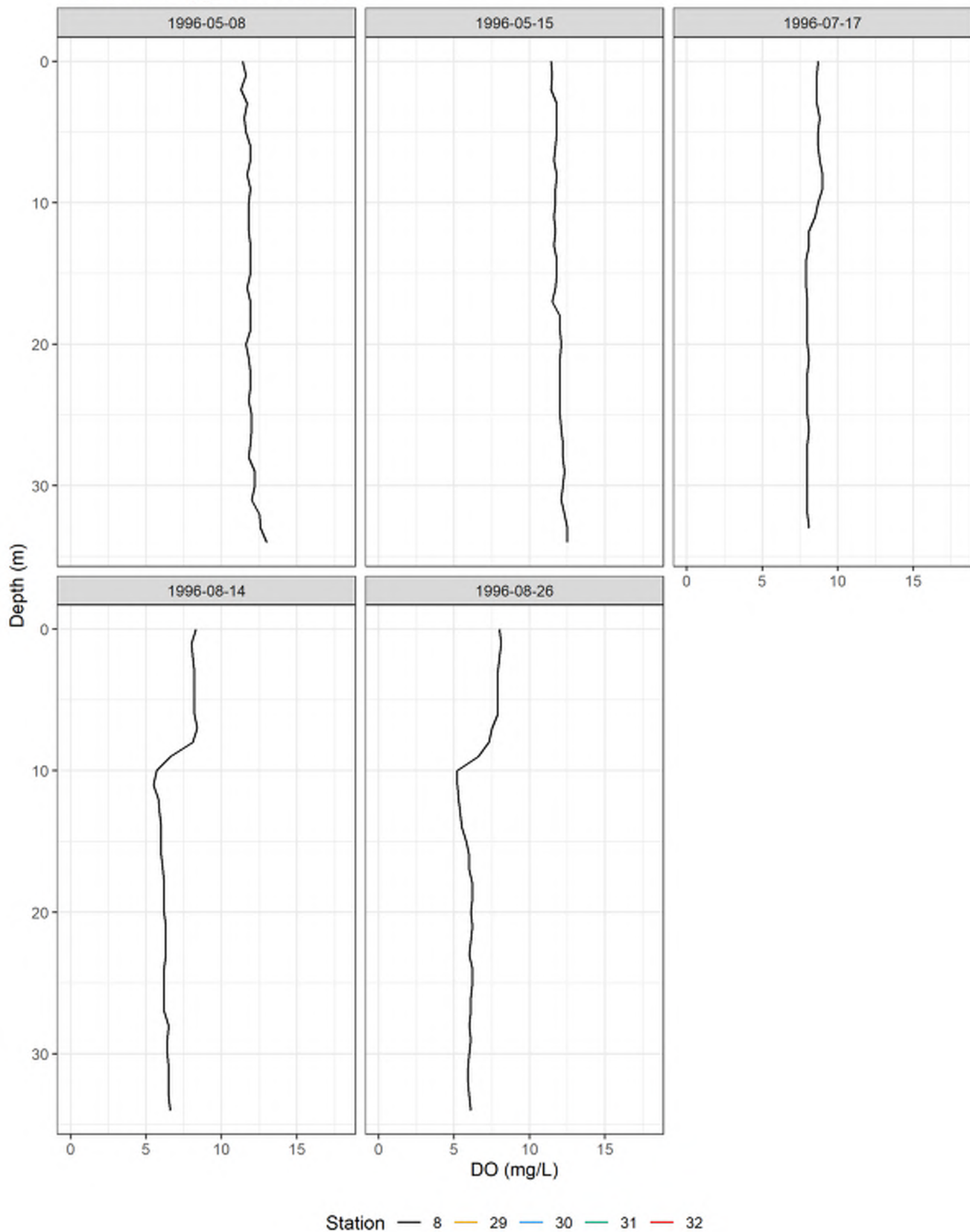
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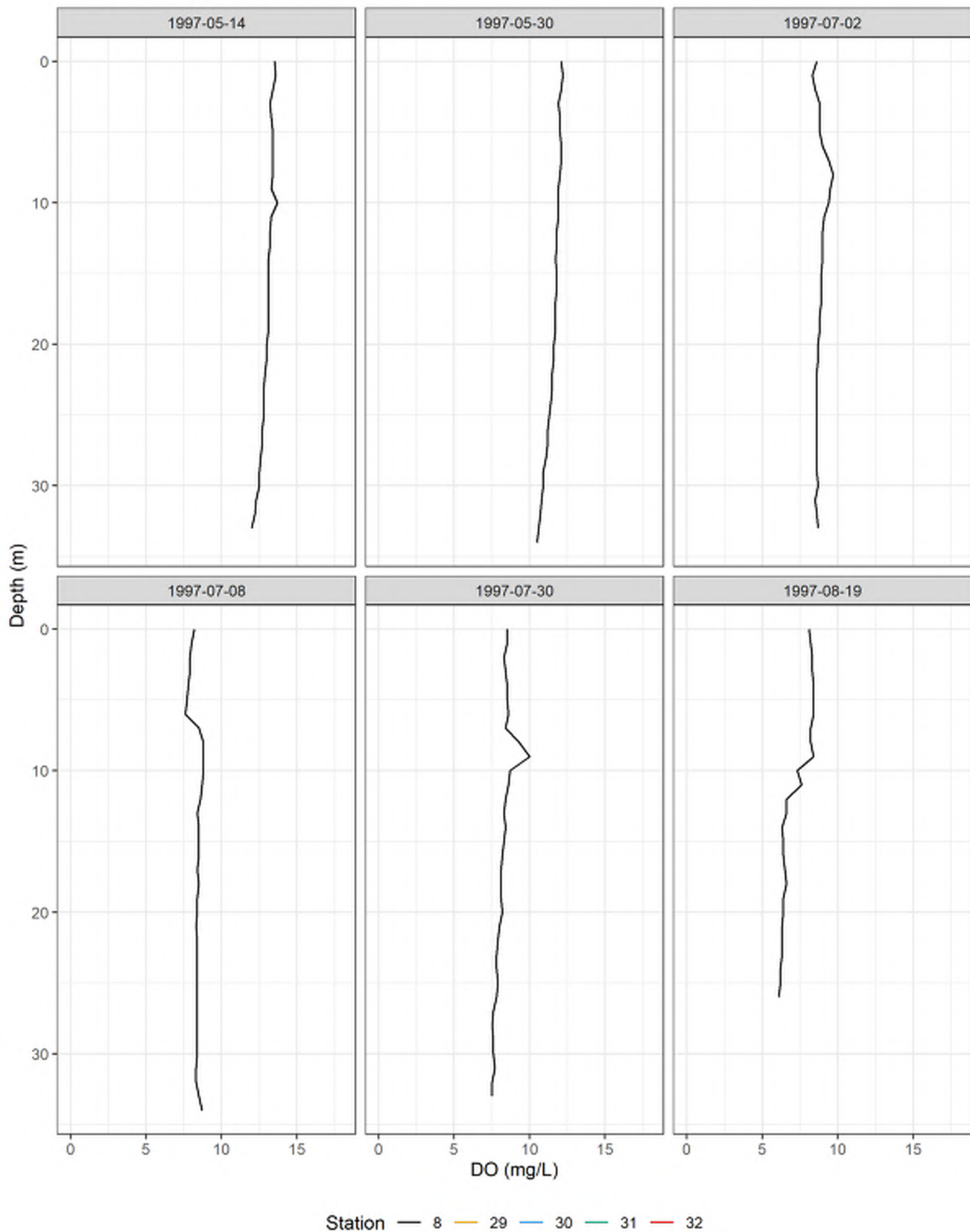
Dissolved Oxygen Profile: 1995



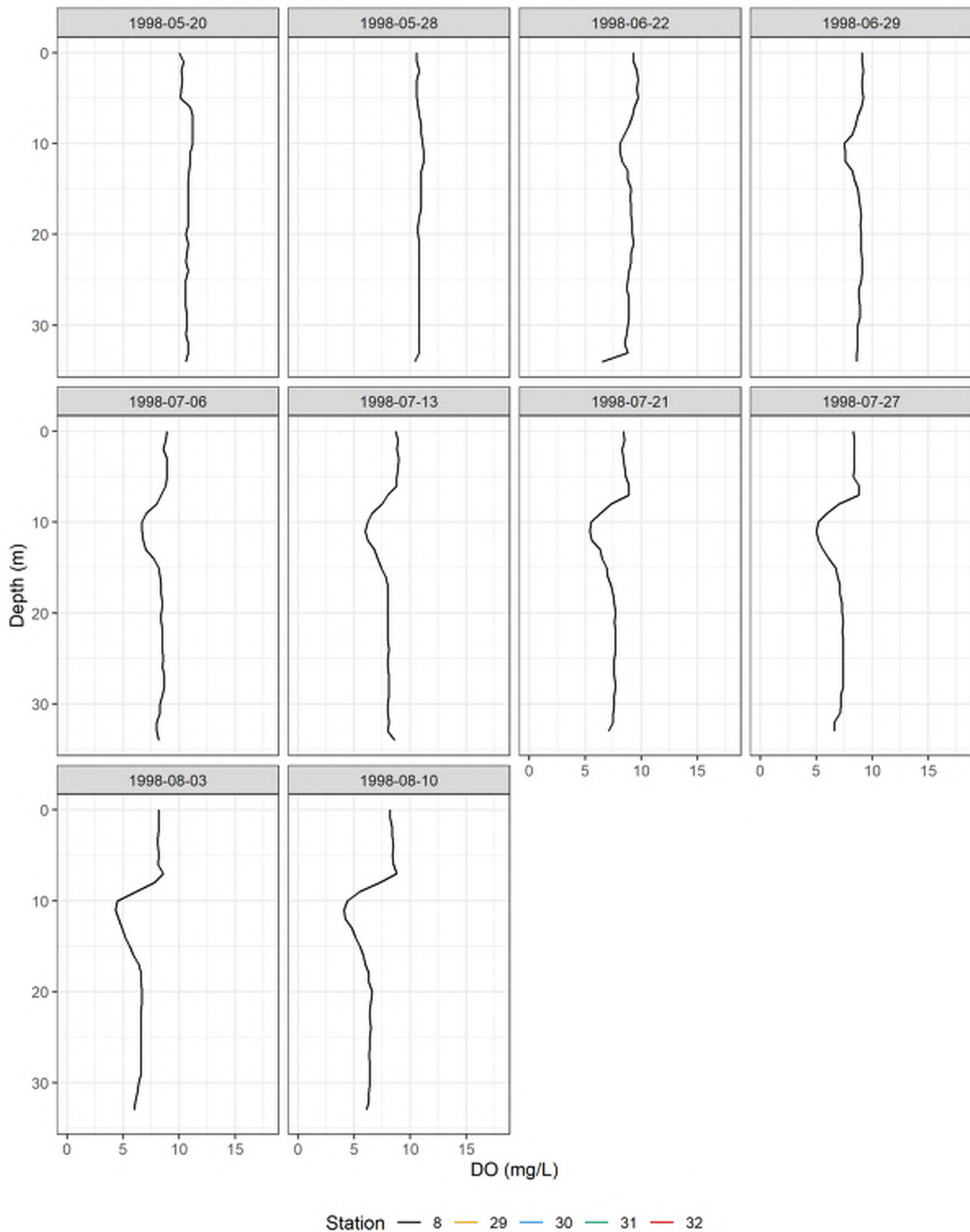
Dissolved Oxygen Profile: 1996



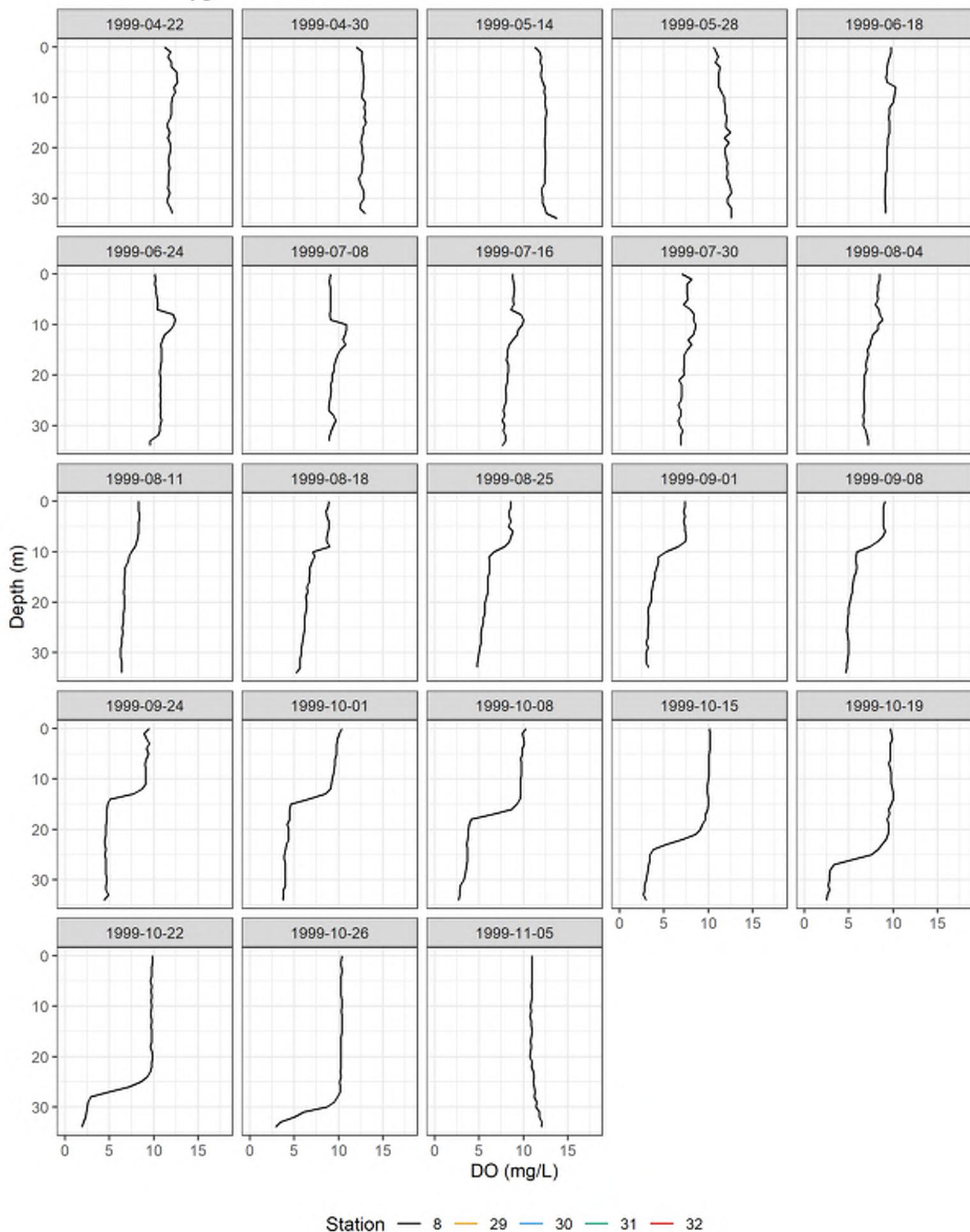
Dissolved Oxygen Profile: 1997



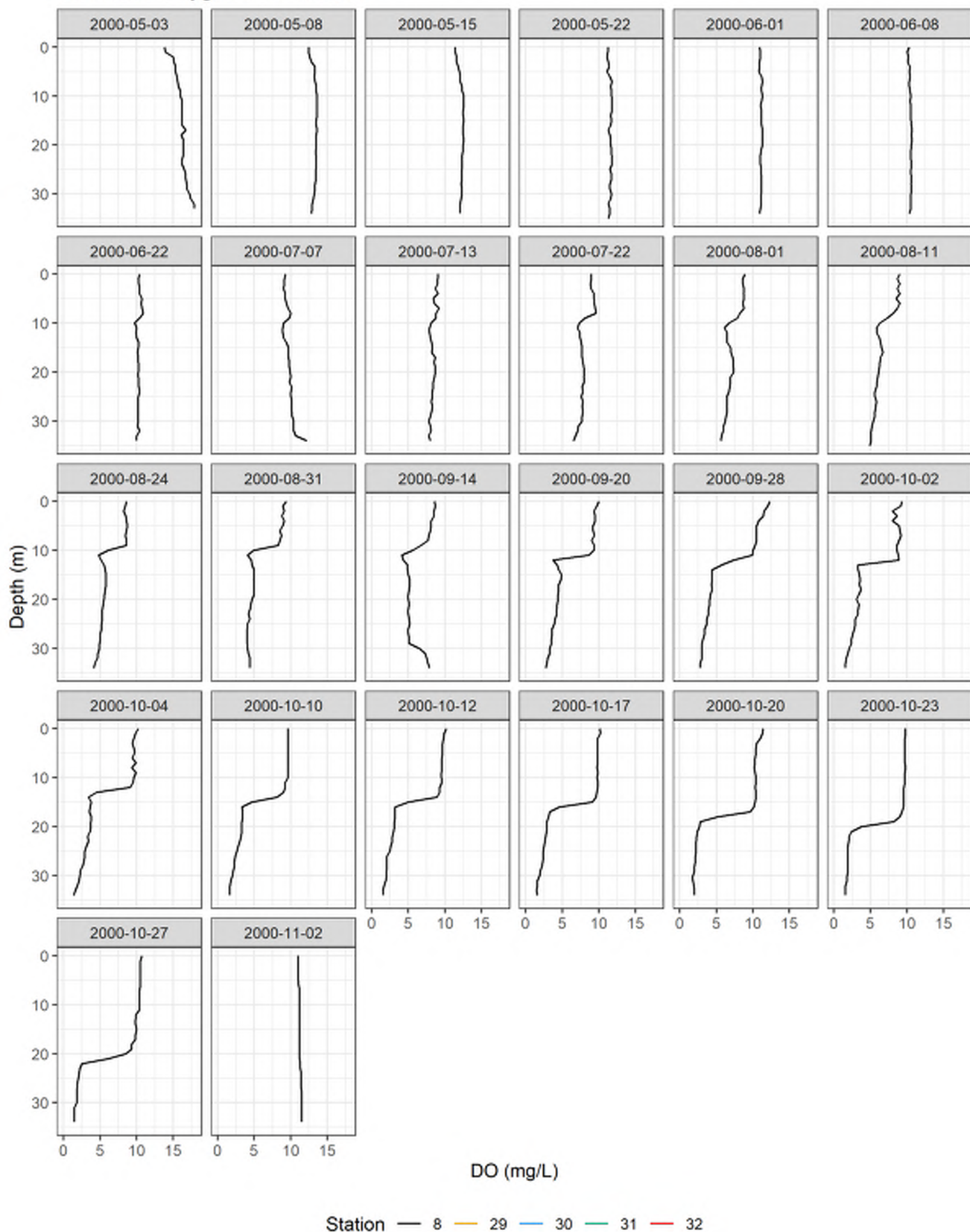
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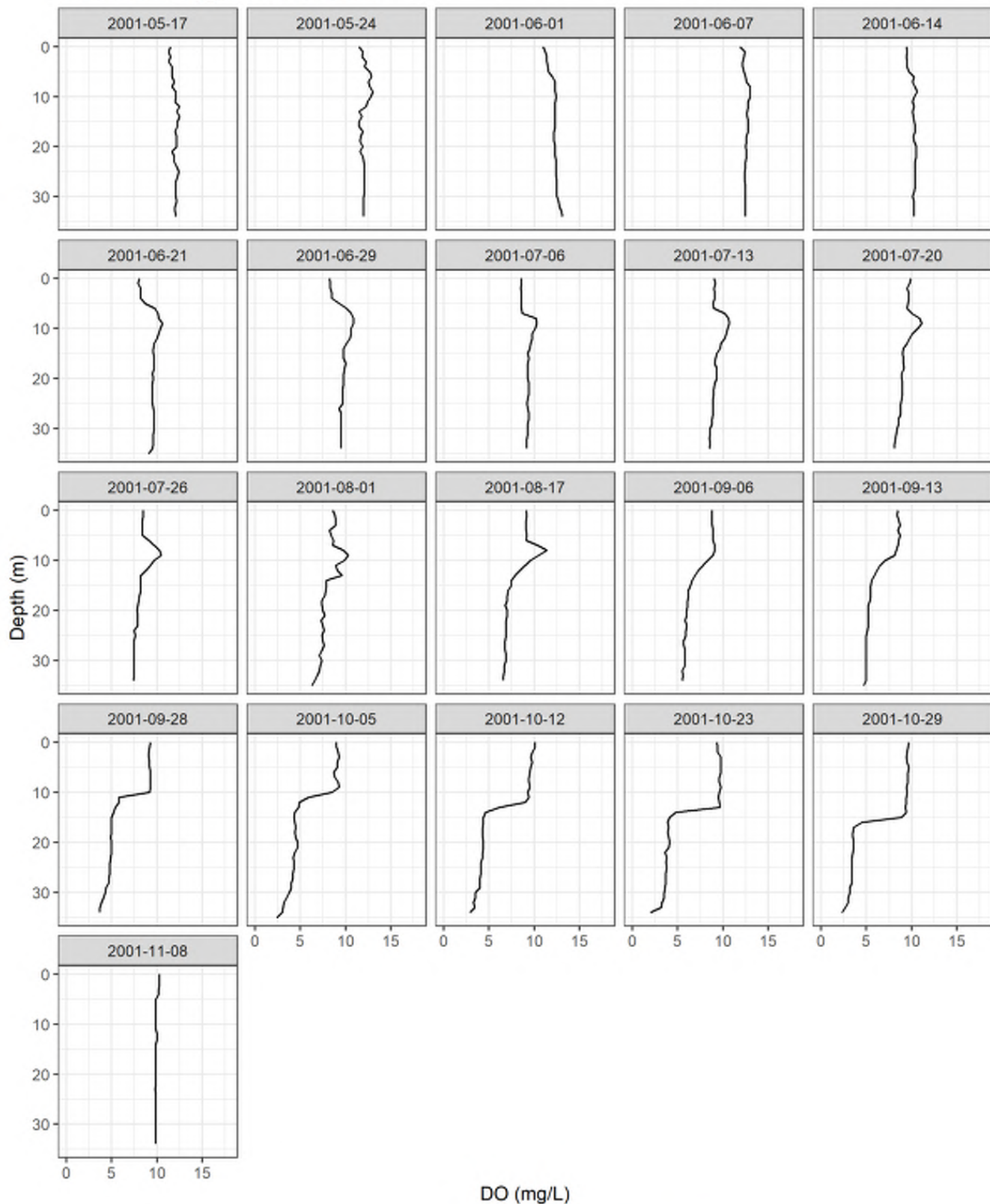
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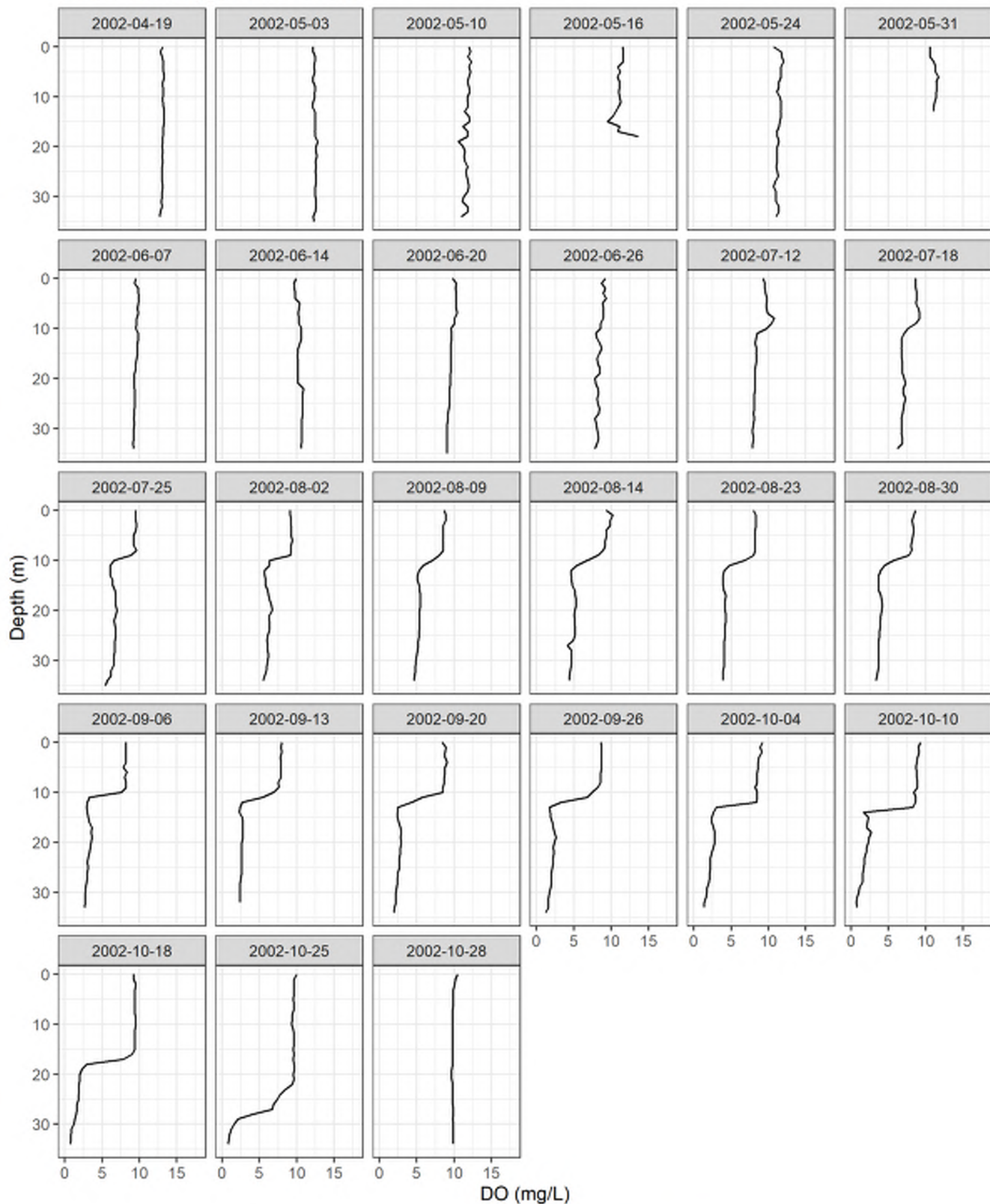
Dissolved Oxygen Profile: 2000



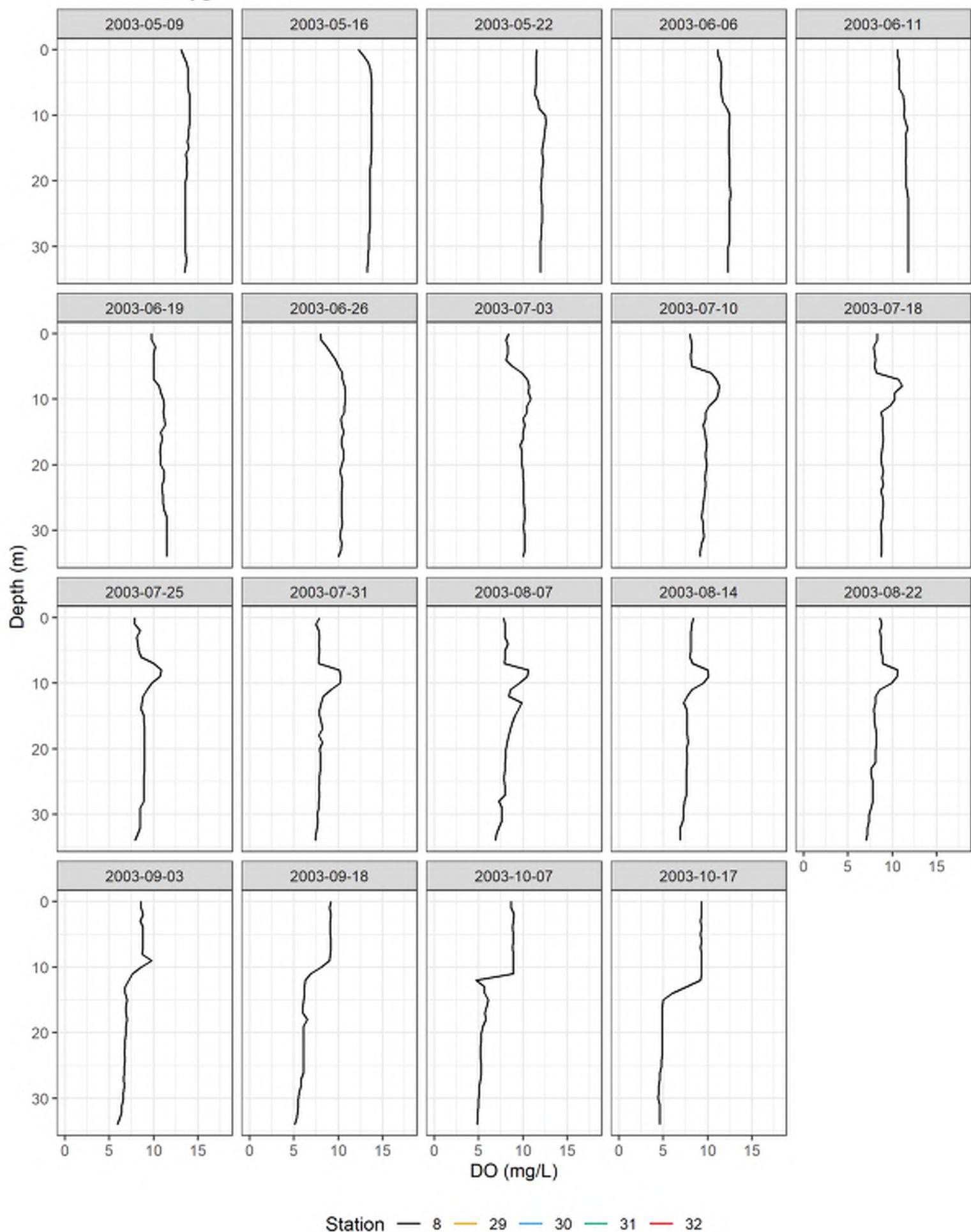
Dissolved Oxygen Profile: 2001



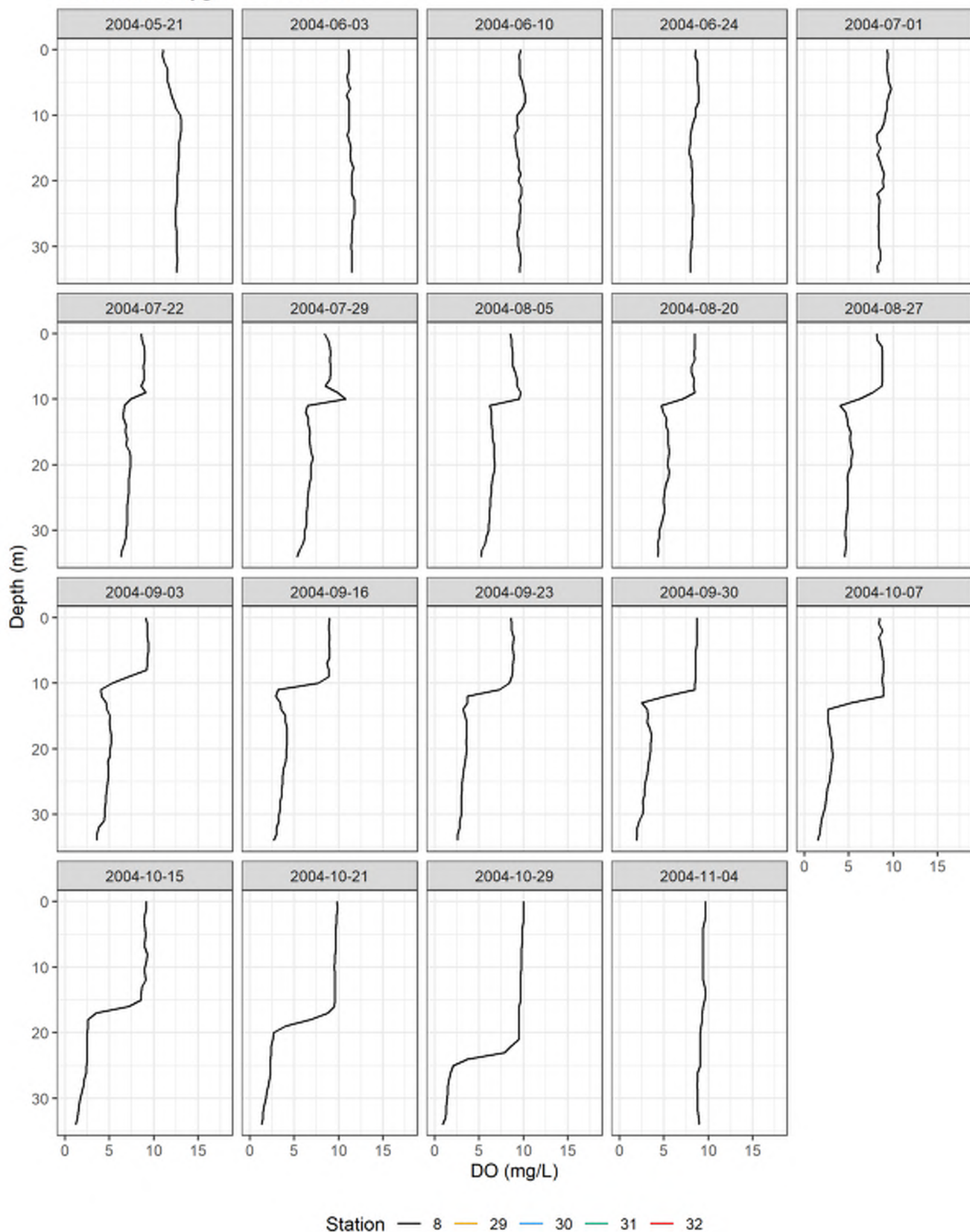
Dissolved Oxygen Profile: 2002



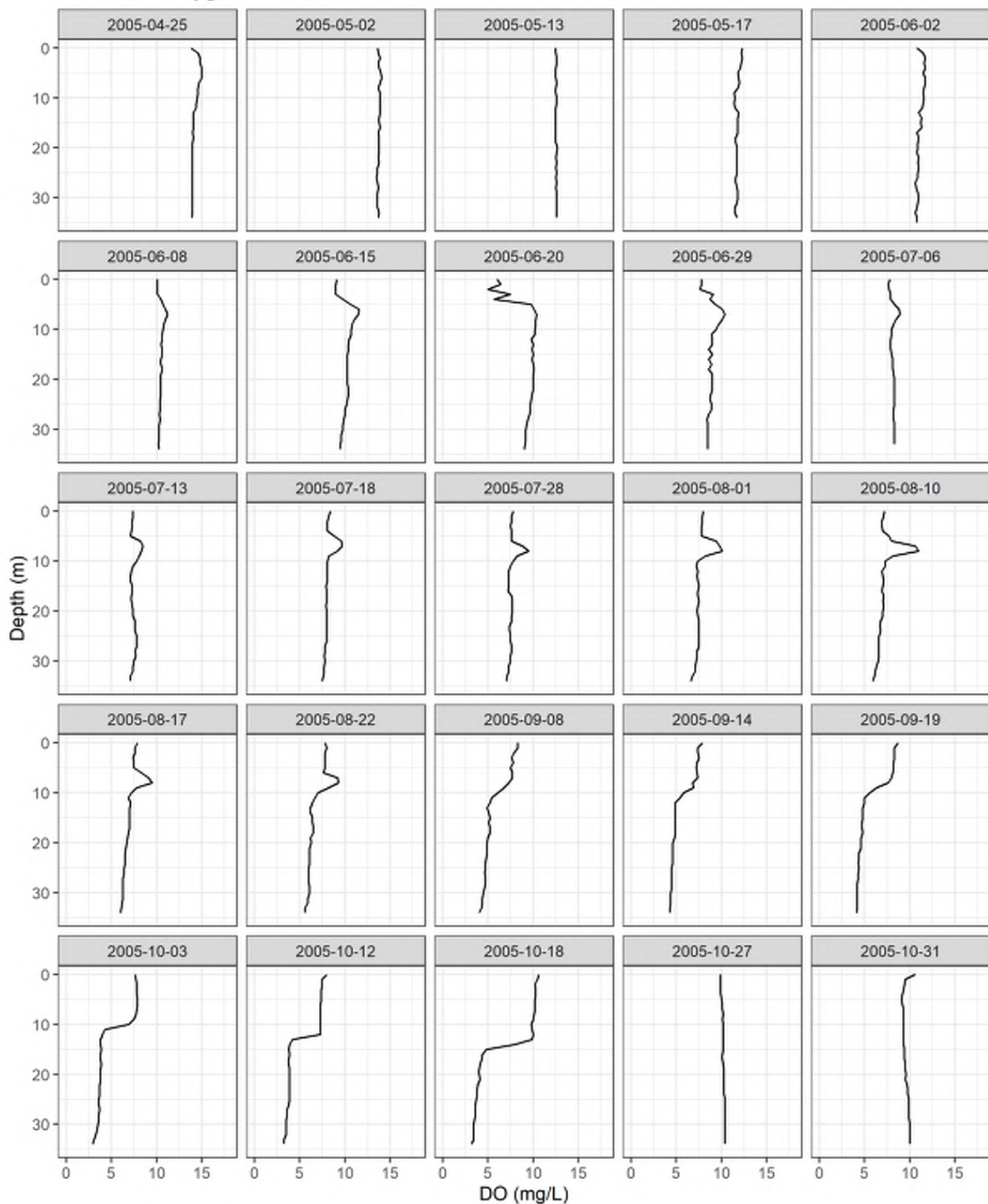
Dissolved Oxygen Profile: 2003



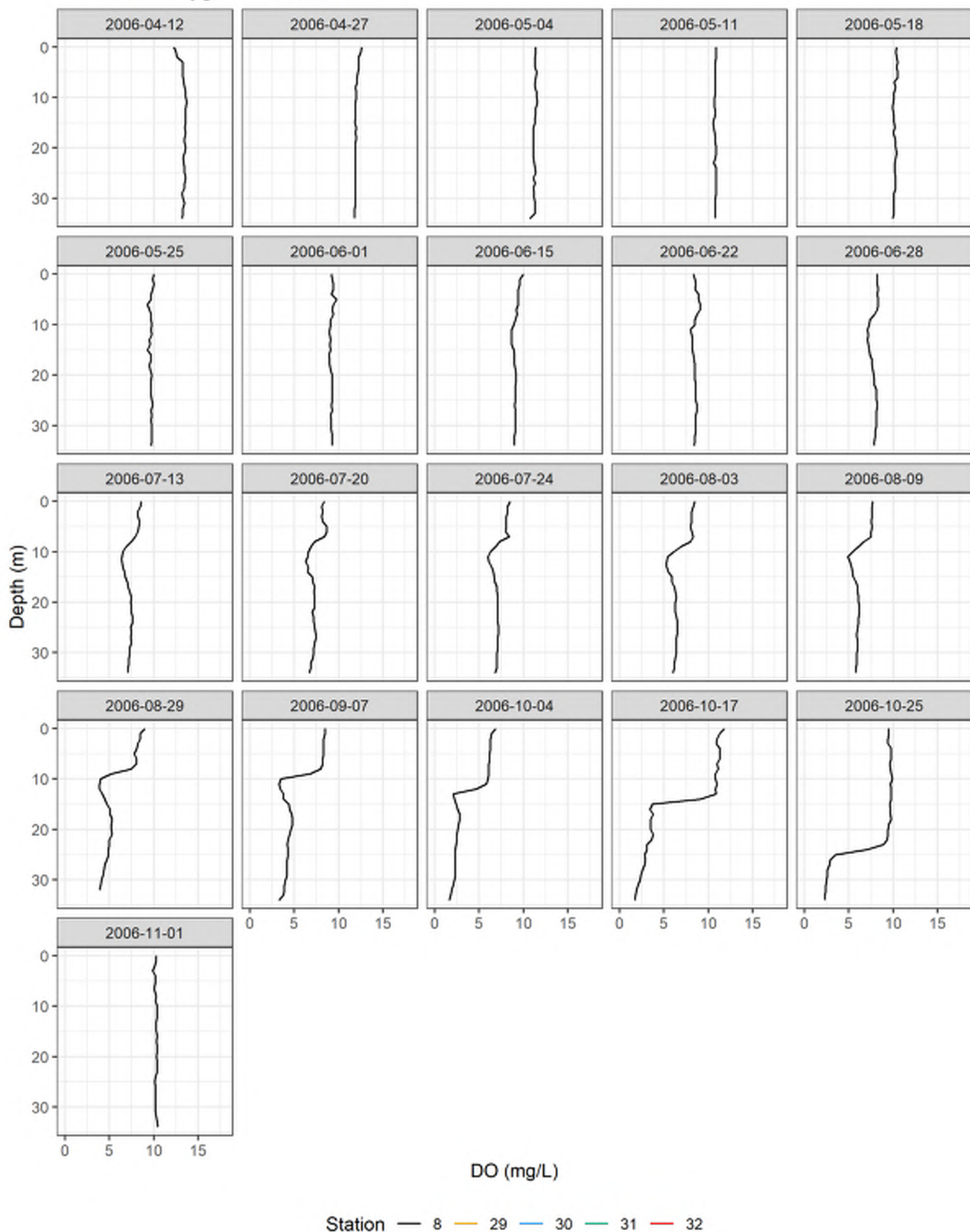
Dissolved Oxygen Profile: 2004



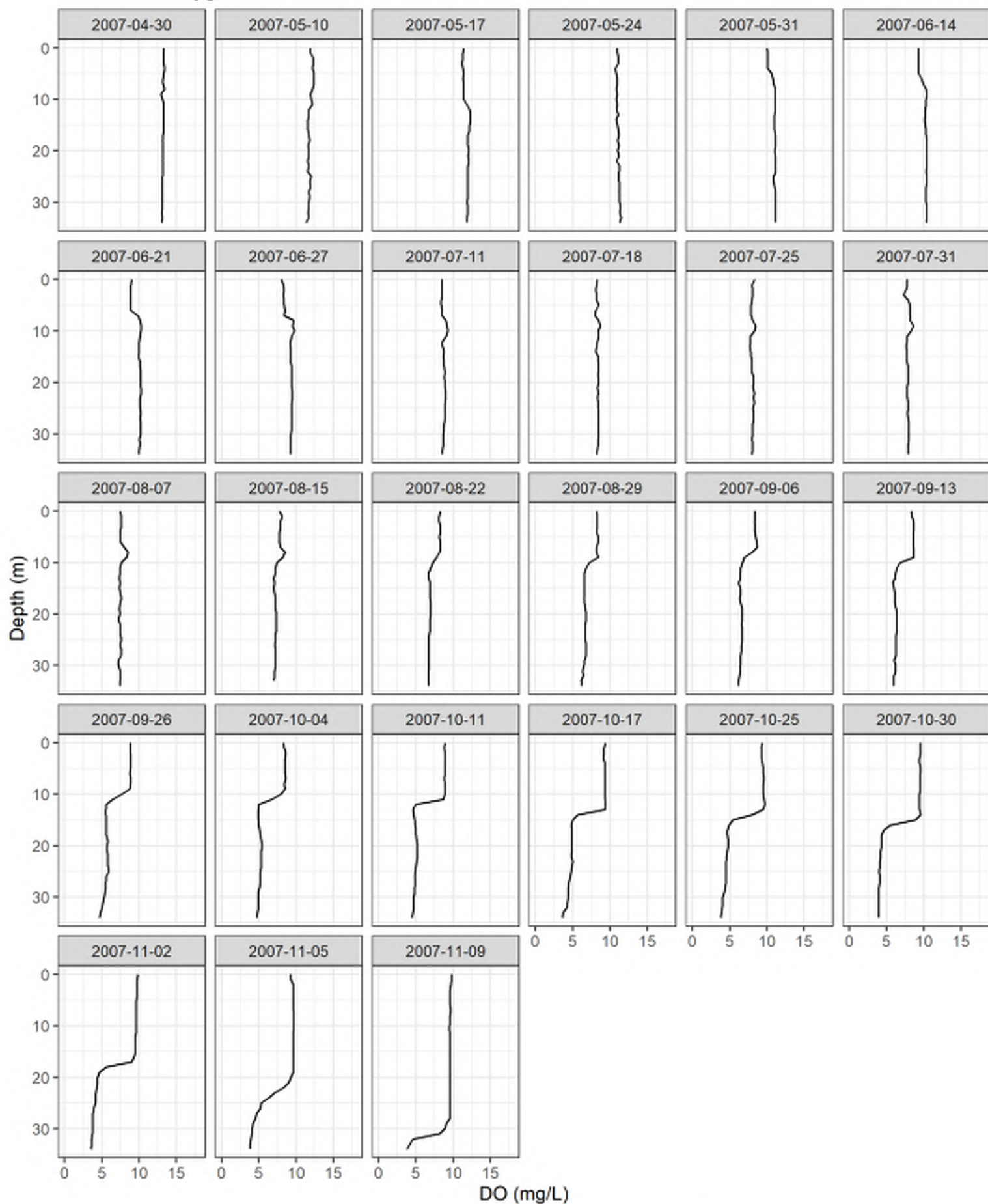
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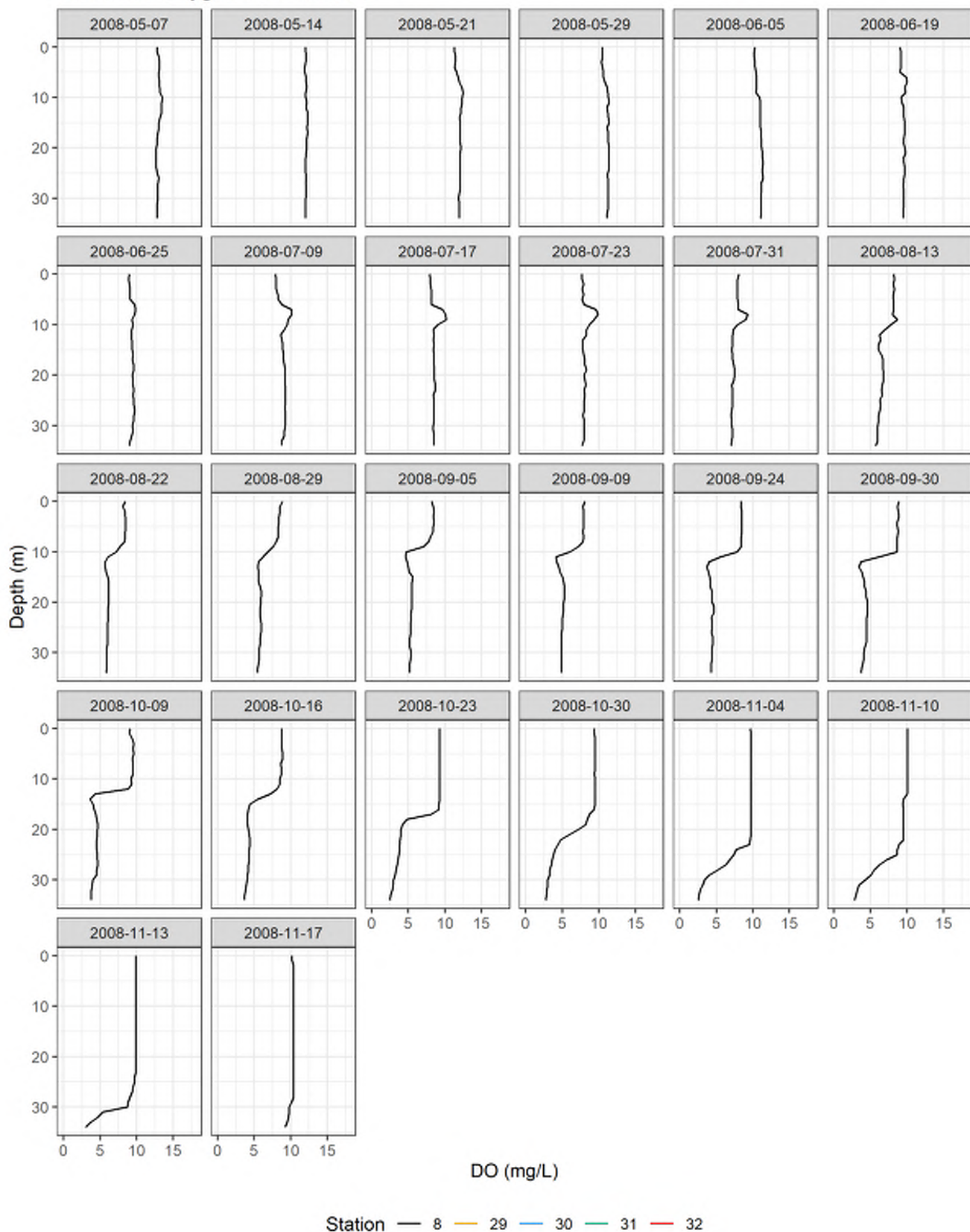
Dissolved Oxygen Profile: 2006



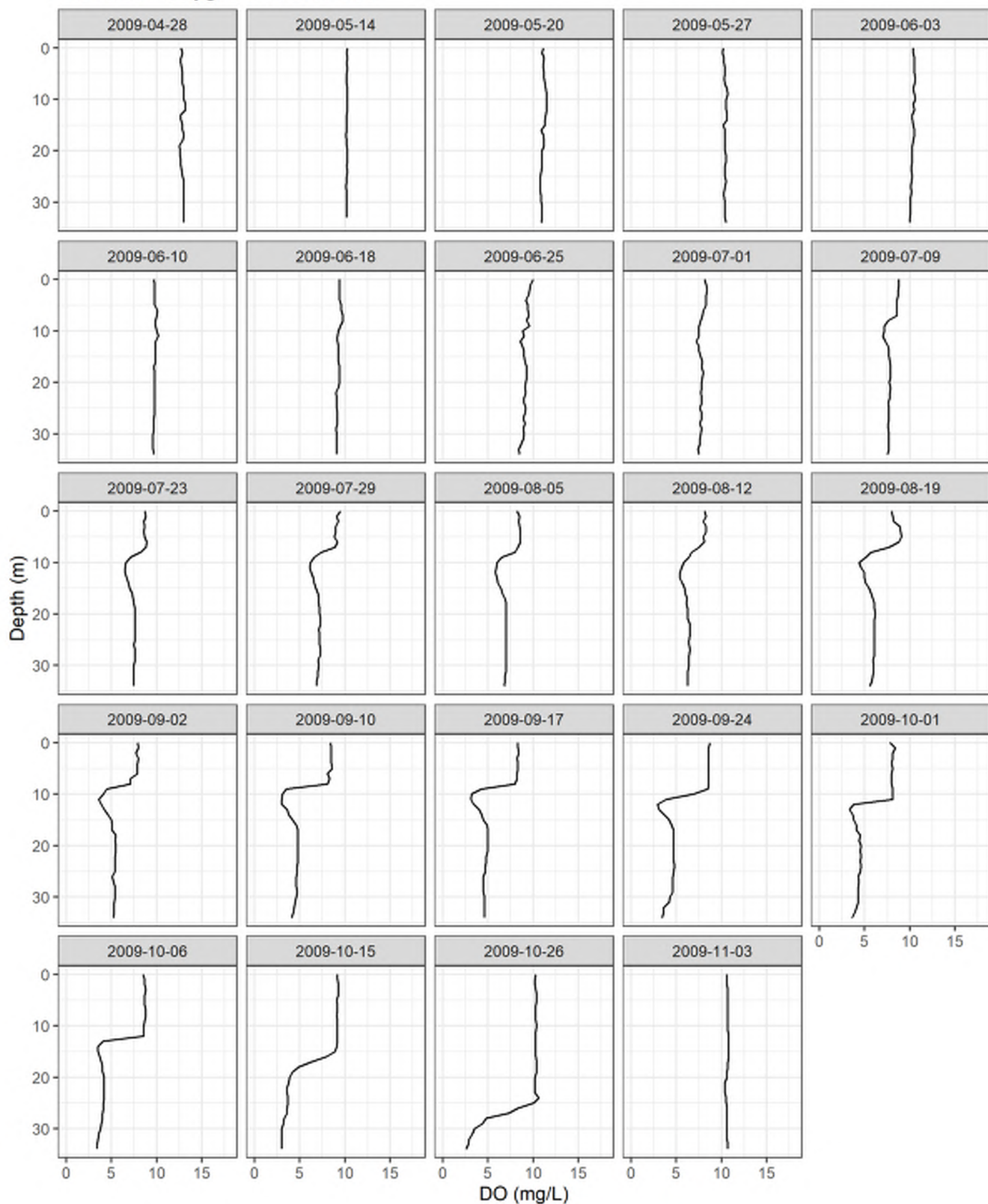
Dissolved Oxygen Profile: 2007



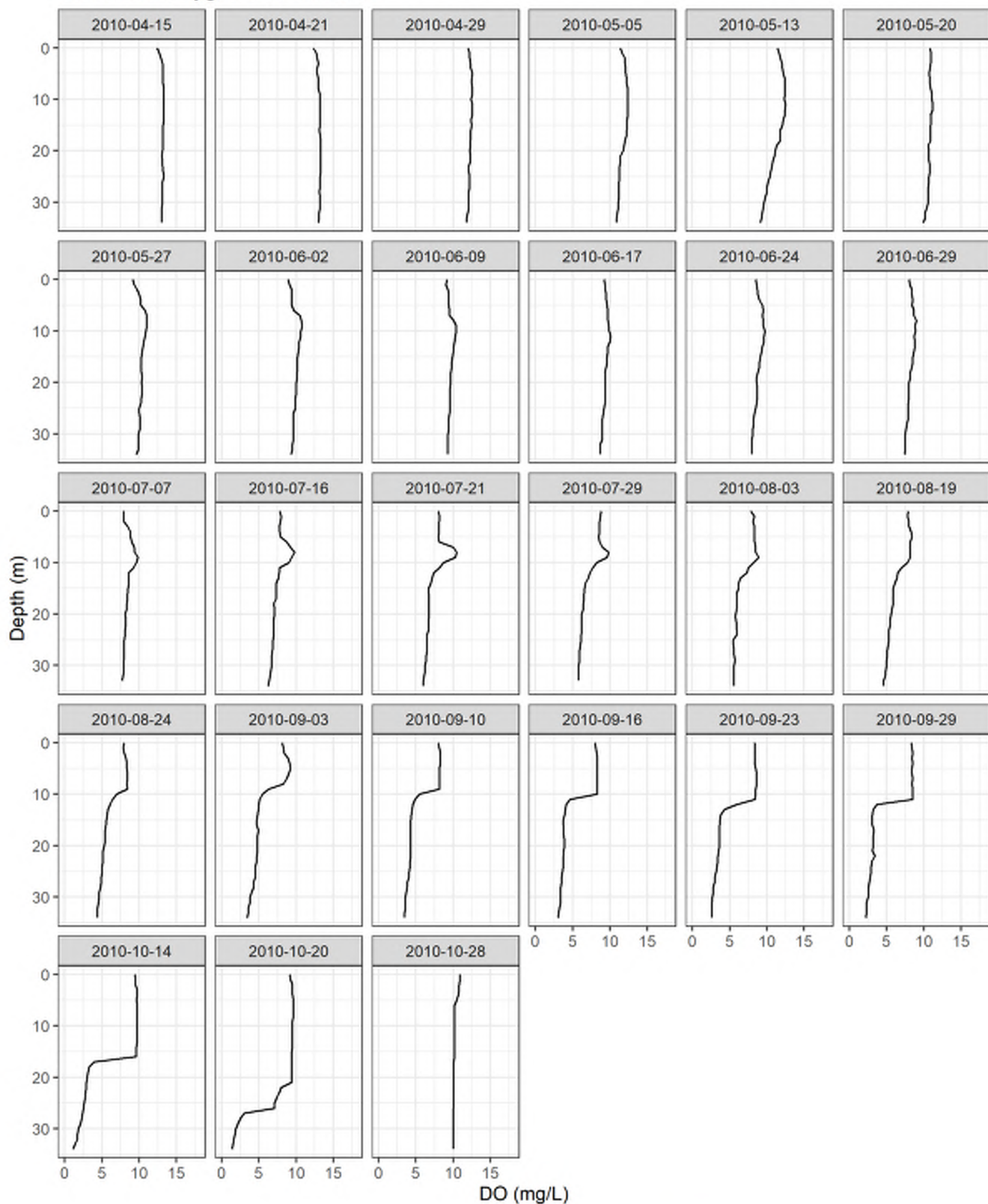
Dissolved Oxygen Profile: 2008



Dissolved Oxygen Profile: 2009

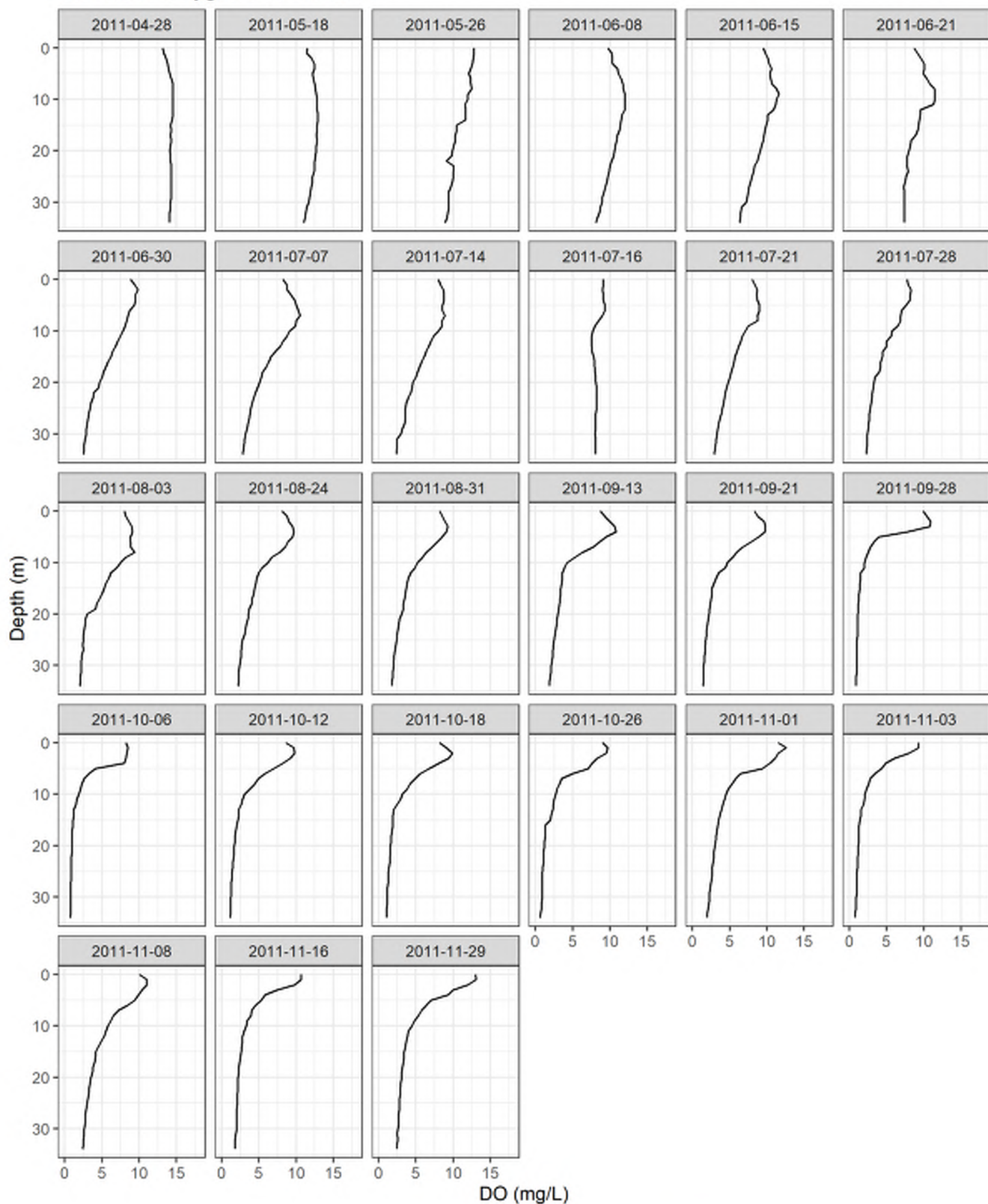


Dissolved Oxygen Profile: 2010

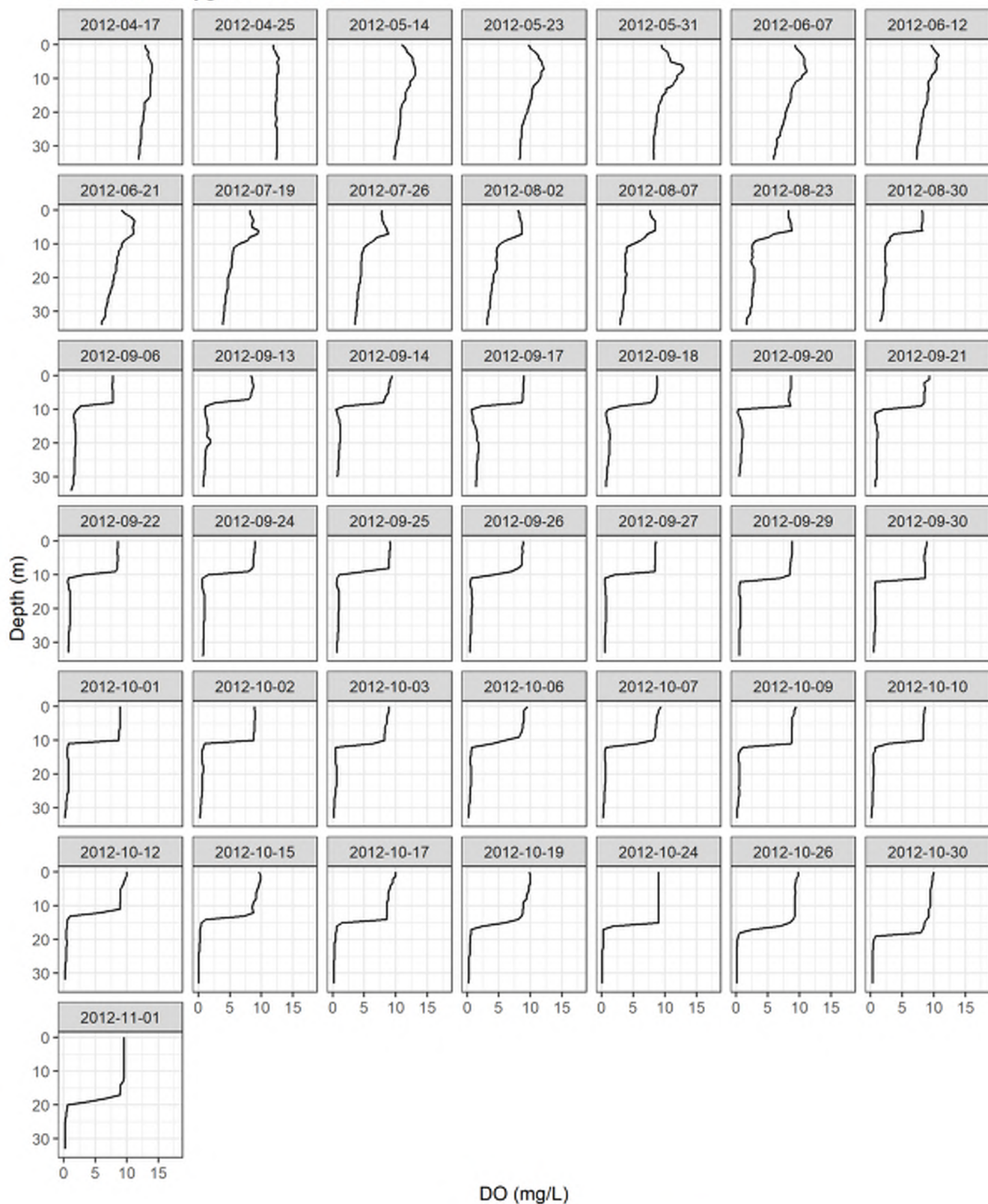


Station — 8 — 29 — 30 — 31 — 32

Dissolved Oxygen Profile: 2011

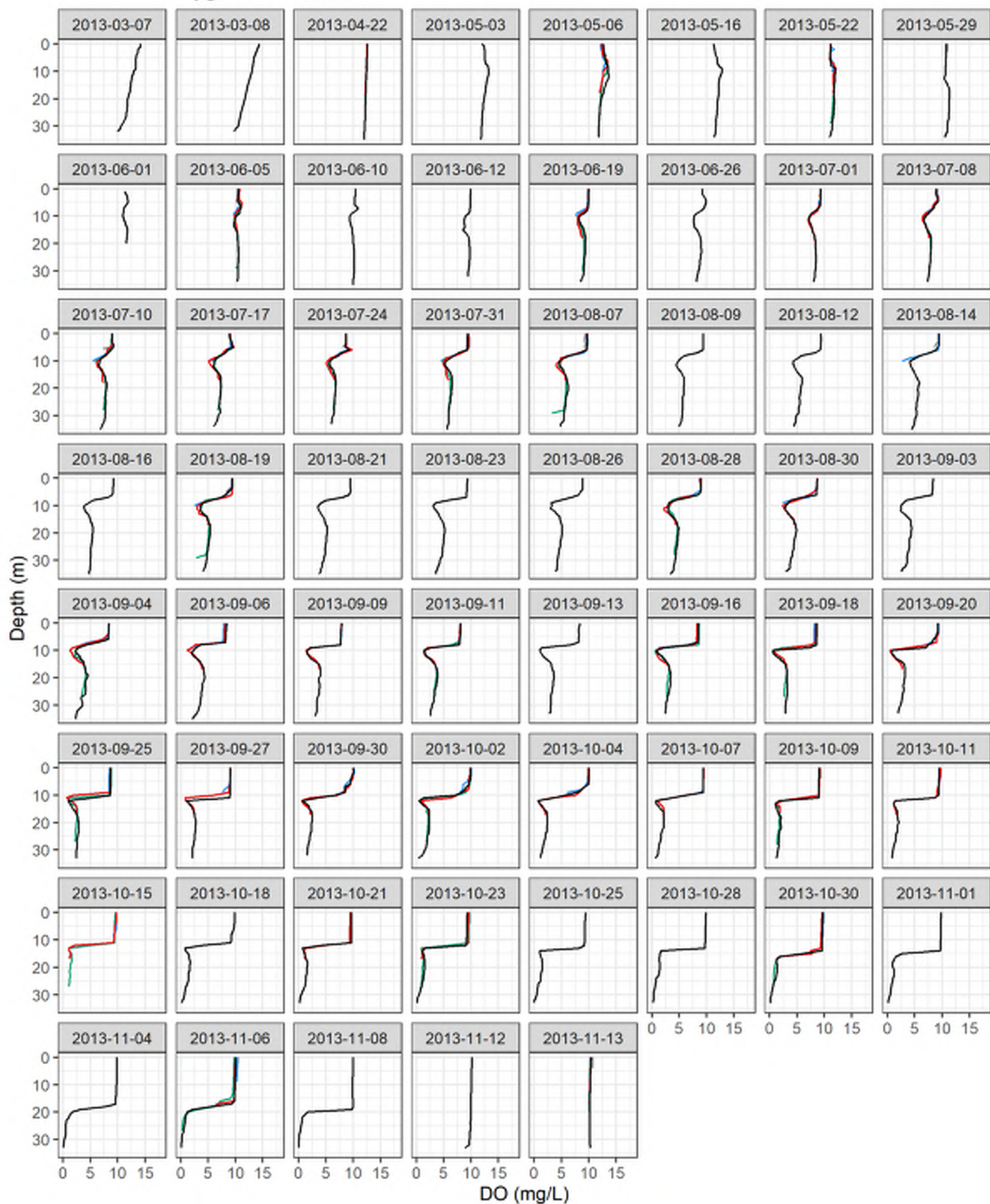


Dissolved Oxygen Profile: 2012

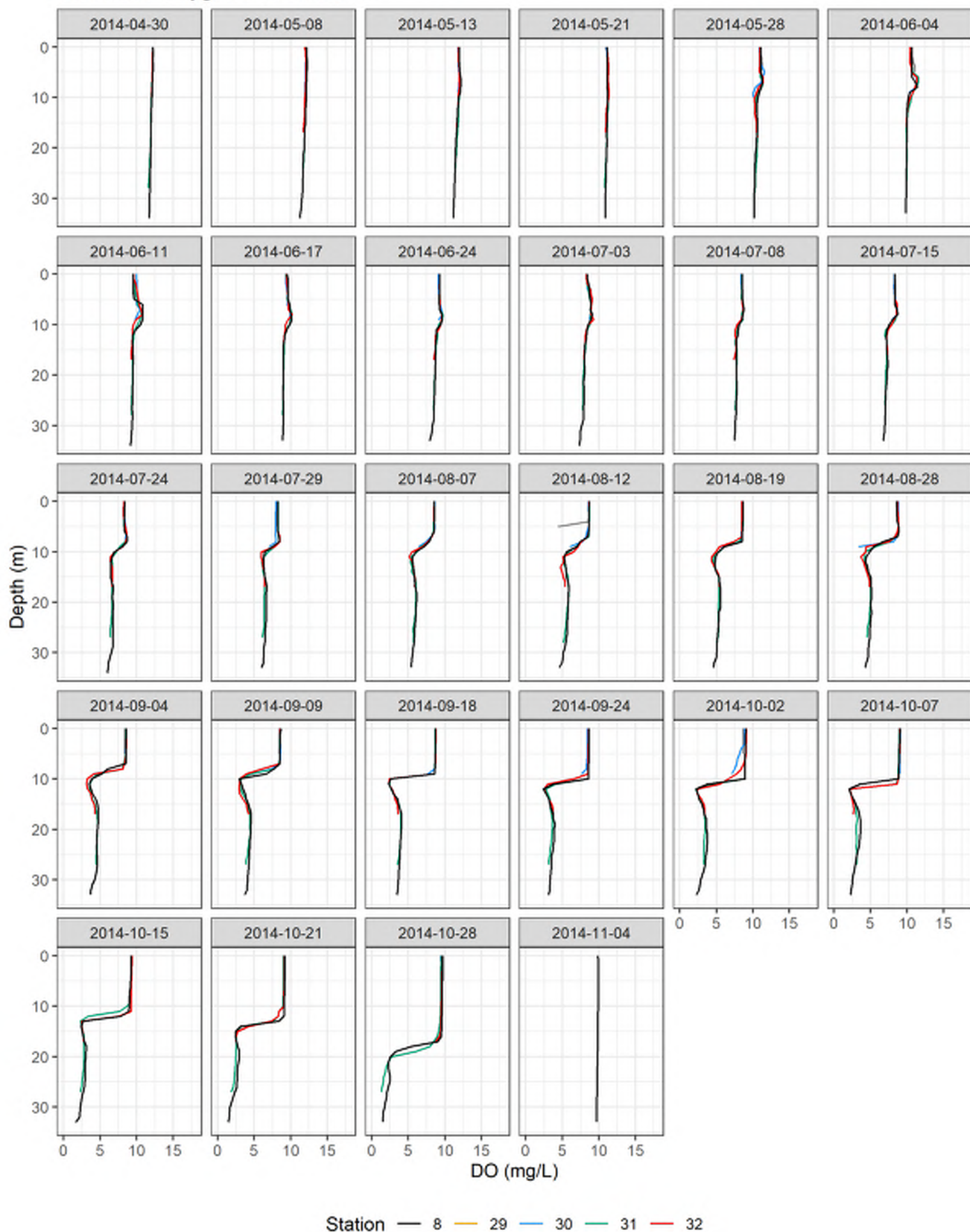


Station — 8 — 29 — 30 — 31 — 32

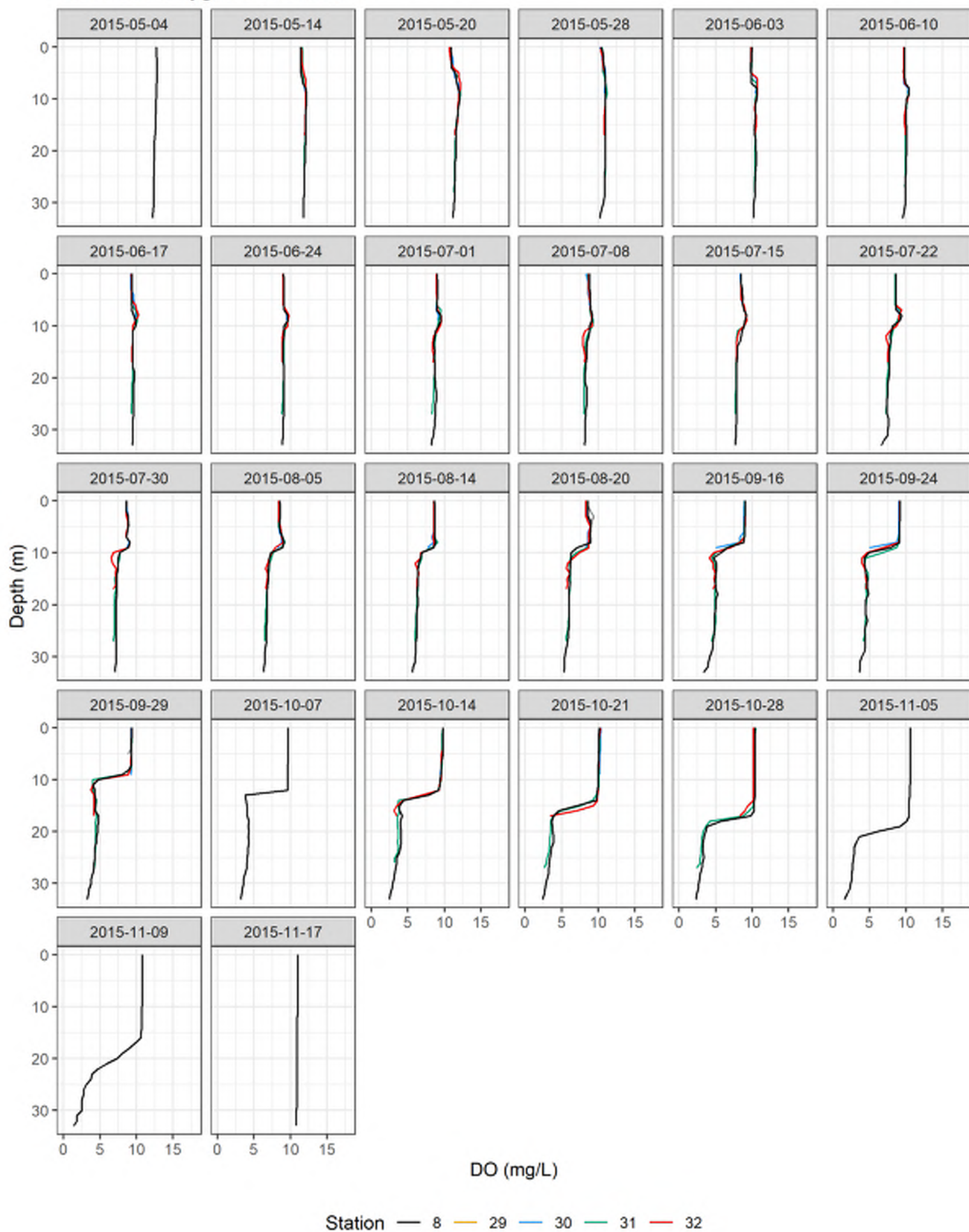
Dissolved Oxygen Profile: 2013



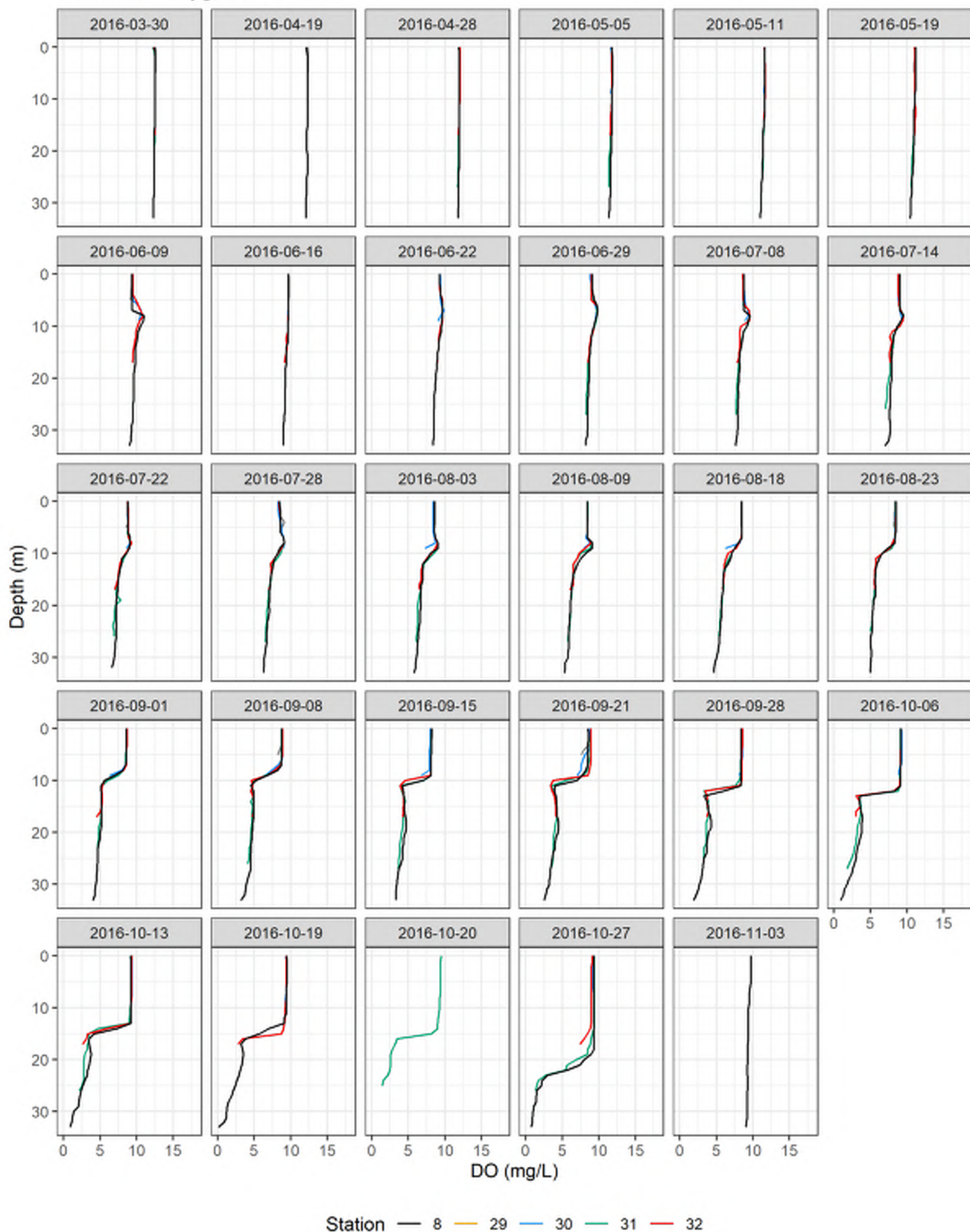
Dissolved Oxygen Profile: 2014



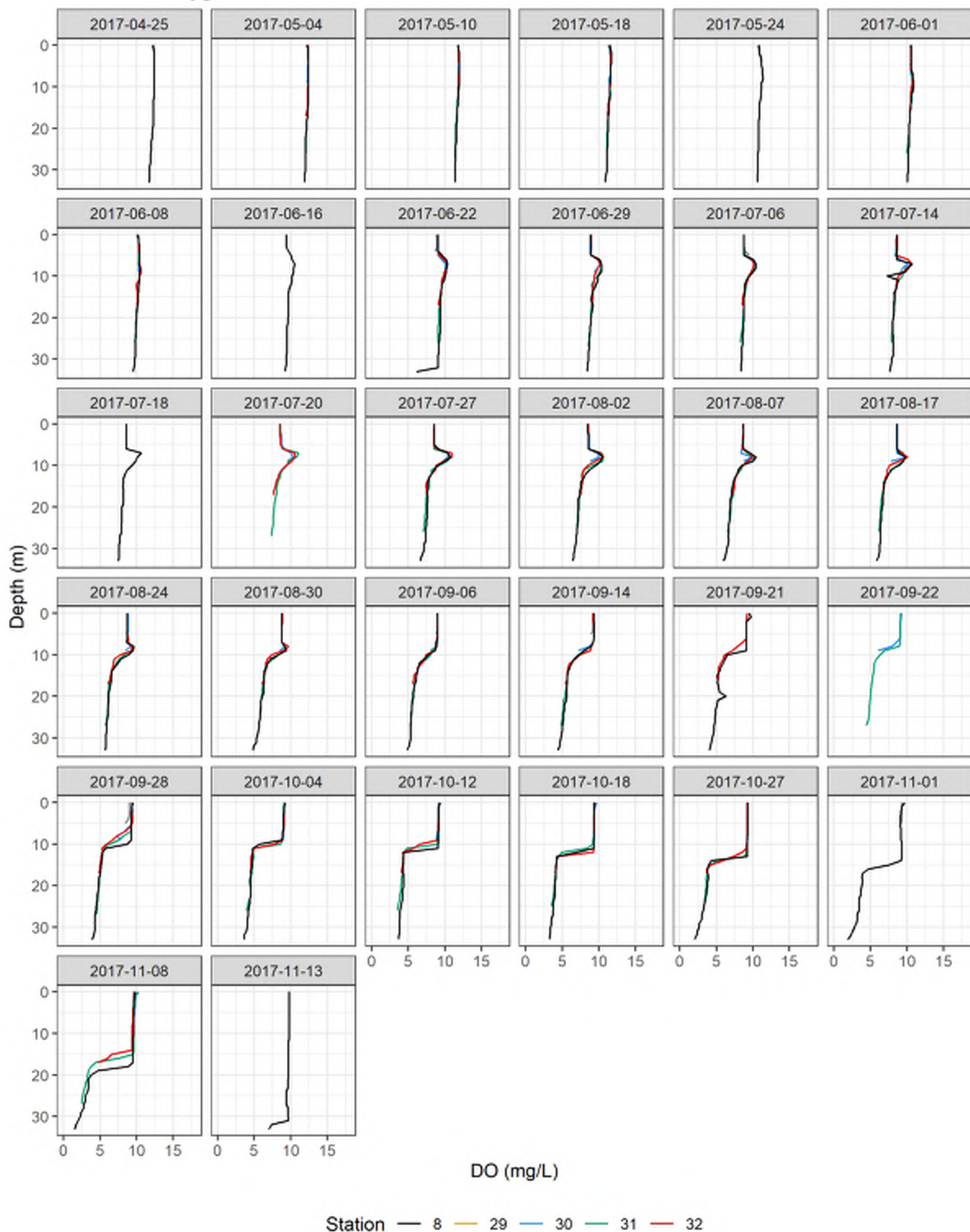
Dissolved Oxygen Profile: 2015



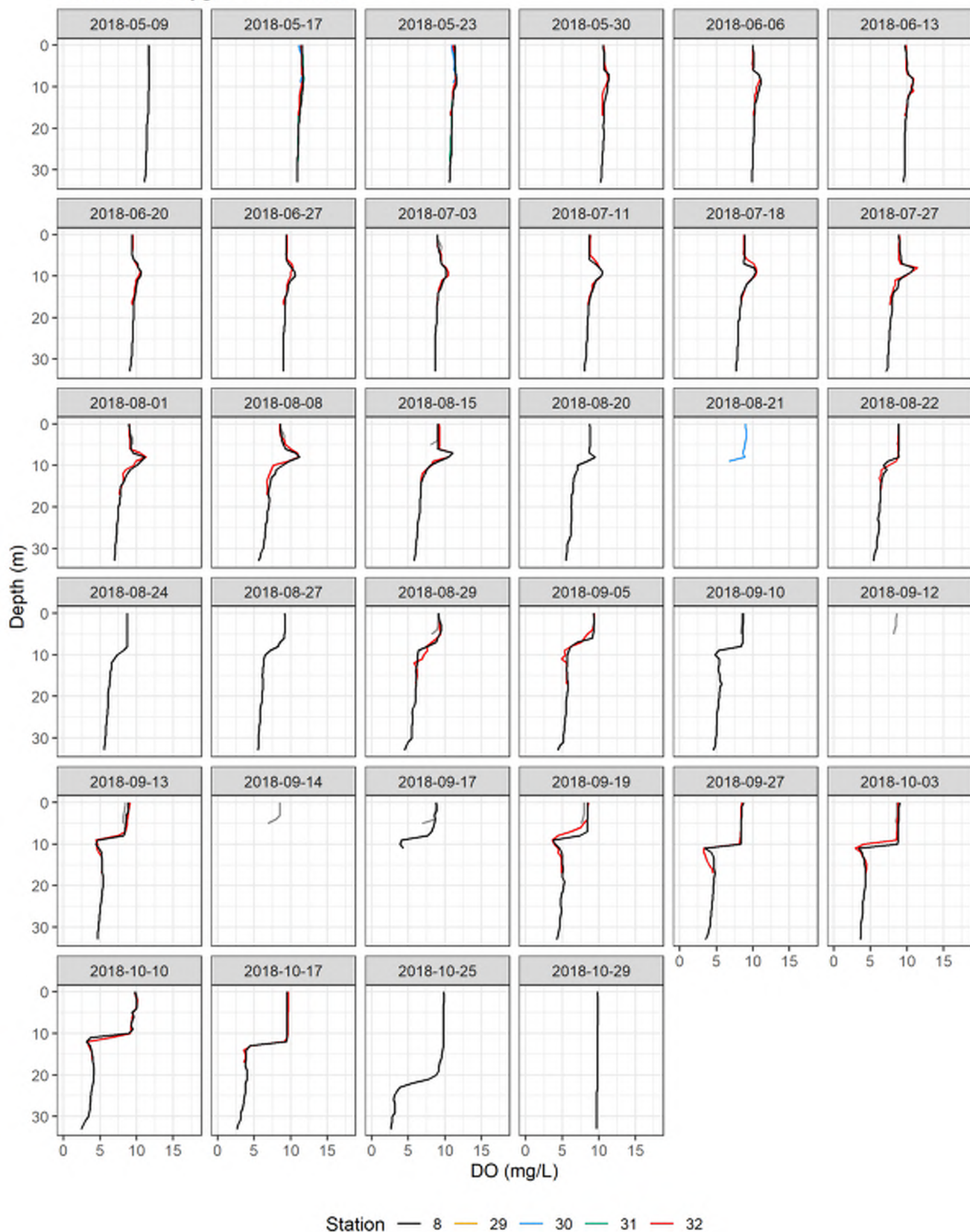
Dissolved Oxygen Profile: 2016



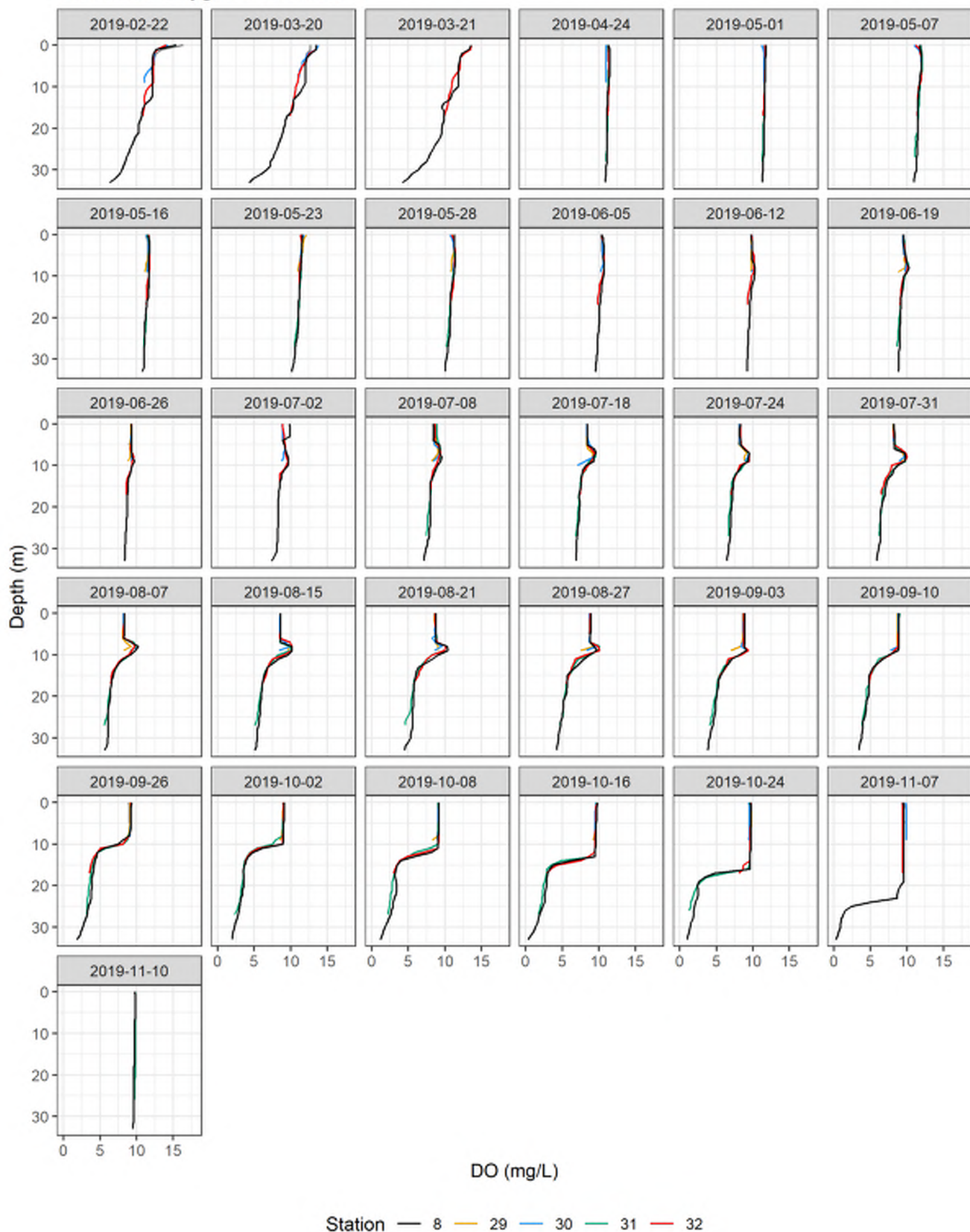
Dissolved Oxygen Profile: 2017



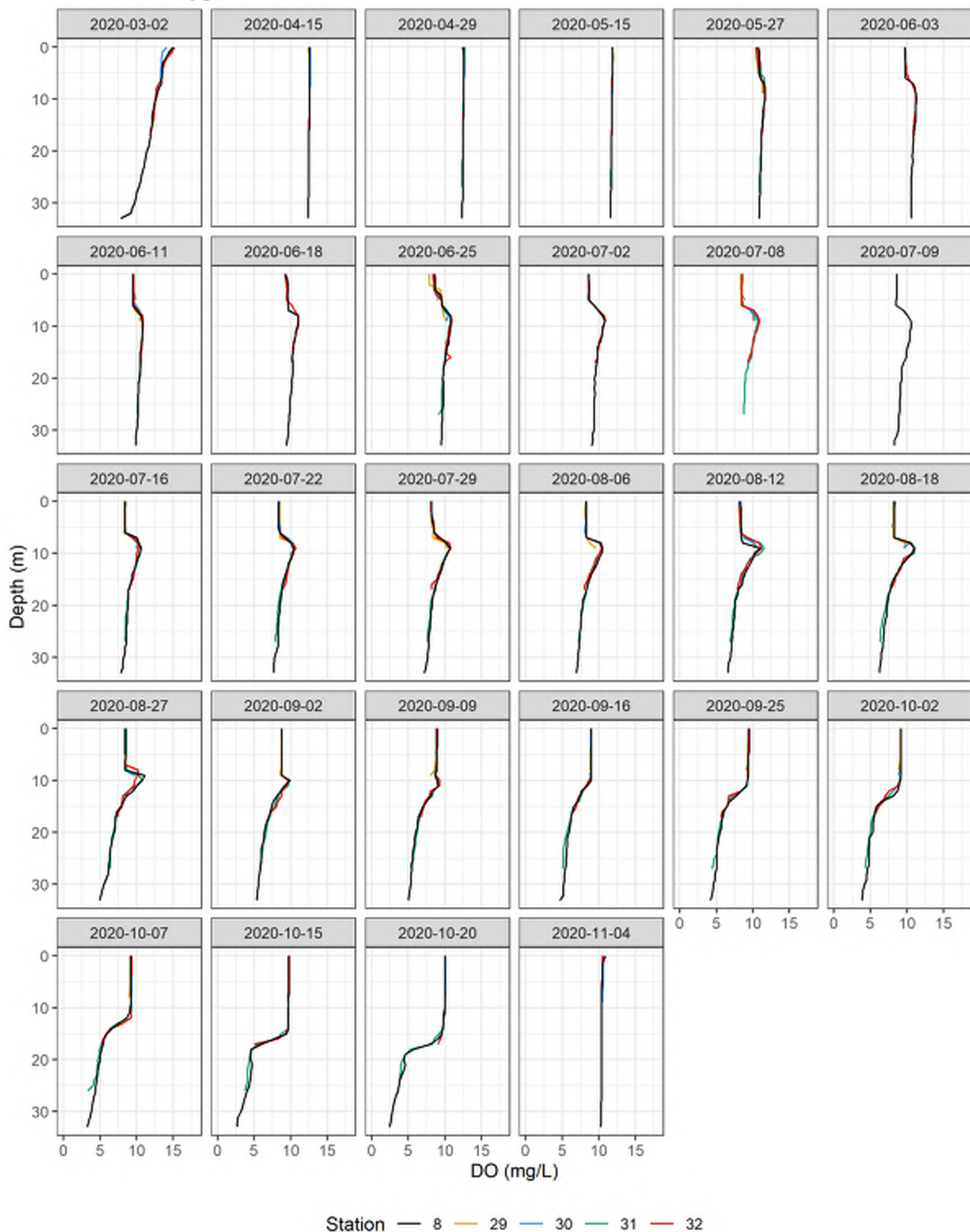
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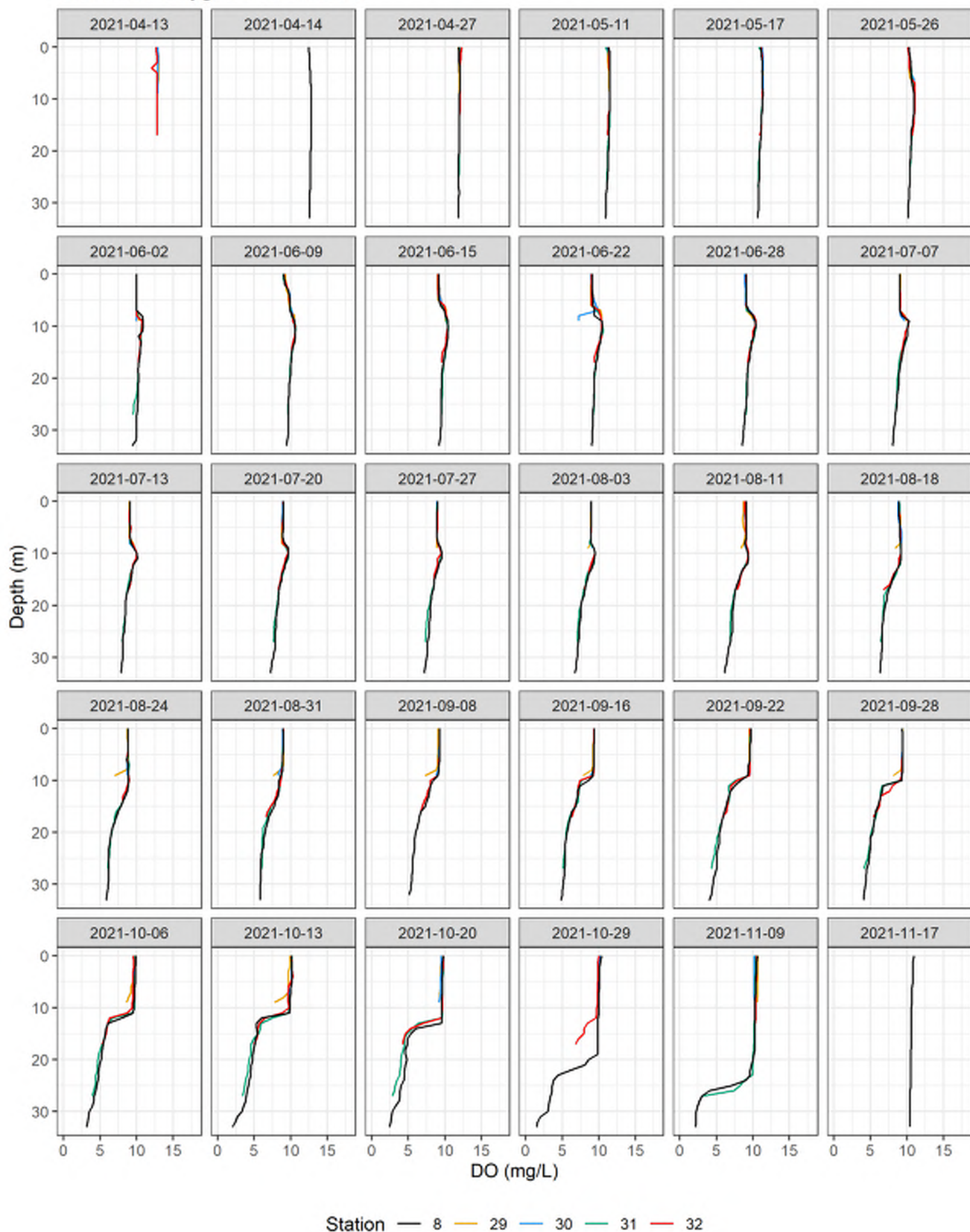
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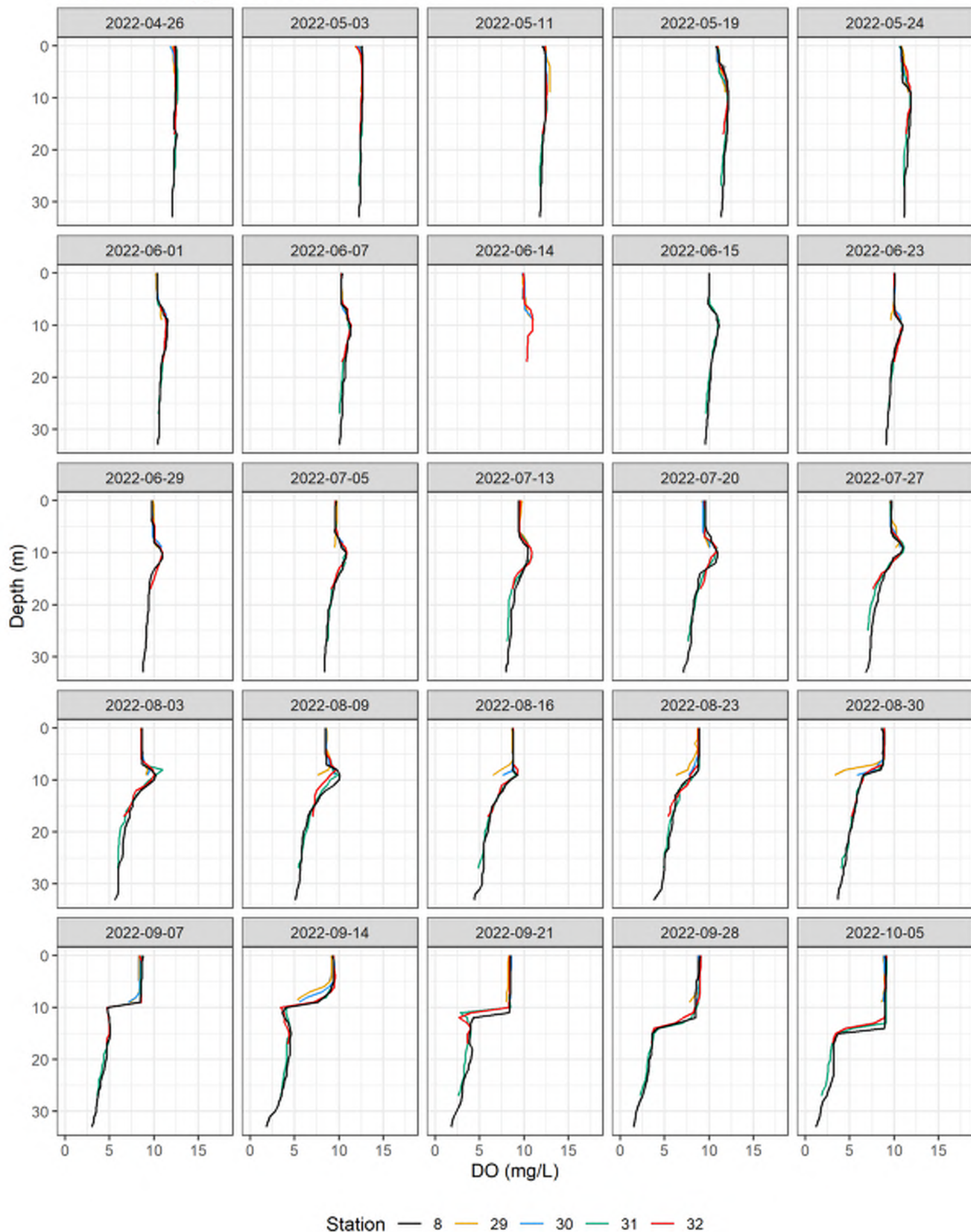
Dissolved Oxygen Profile: 2020



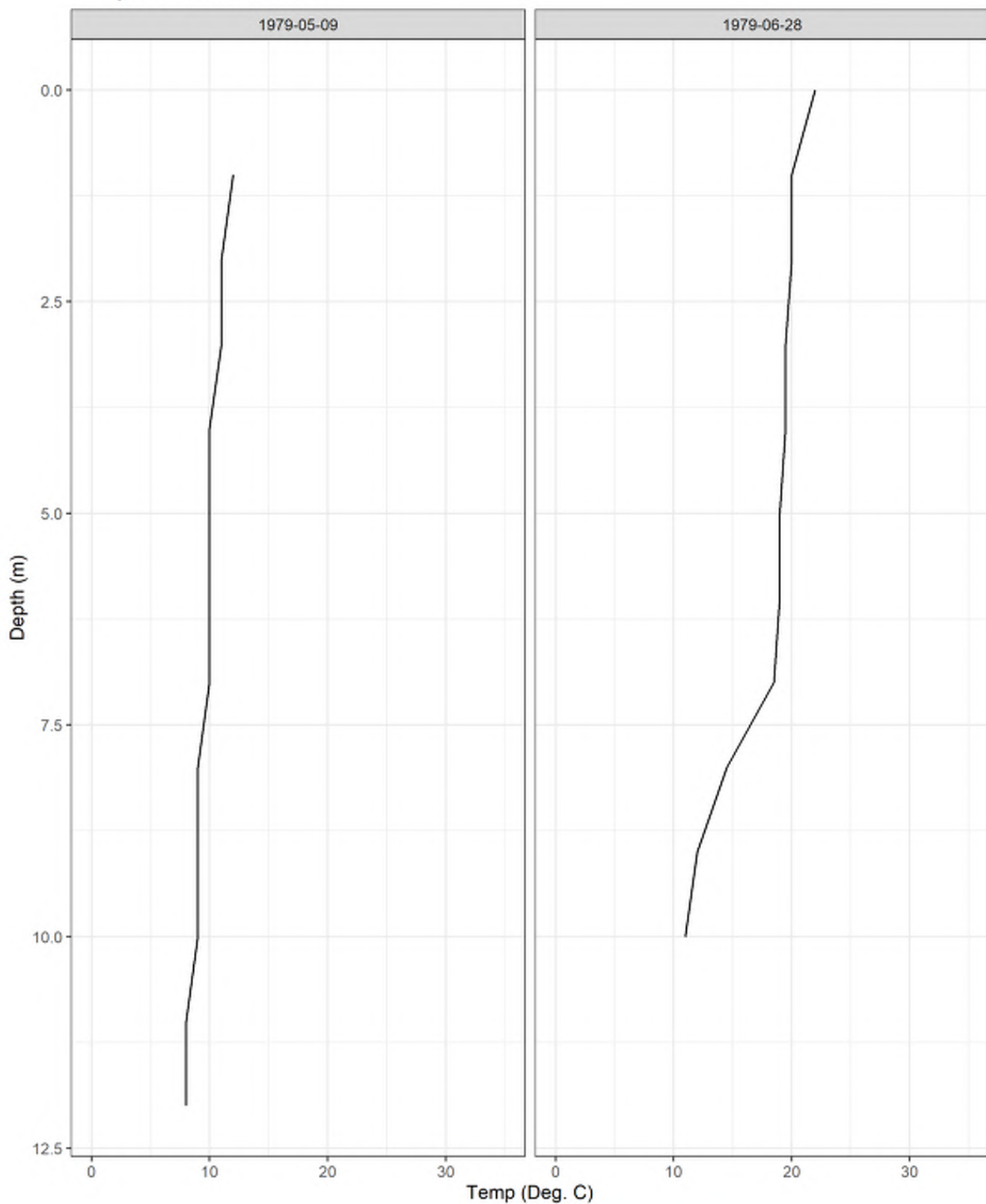
Dissolved Oxygen Profile: 2021



Dissolved Oxygen Profile: 2022

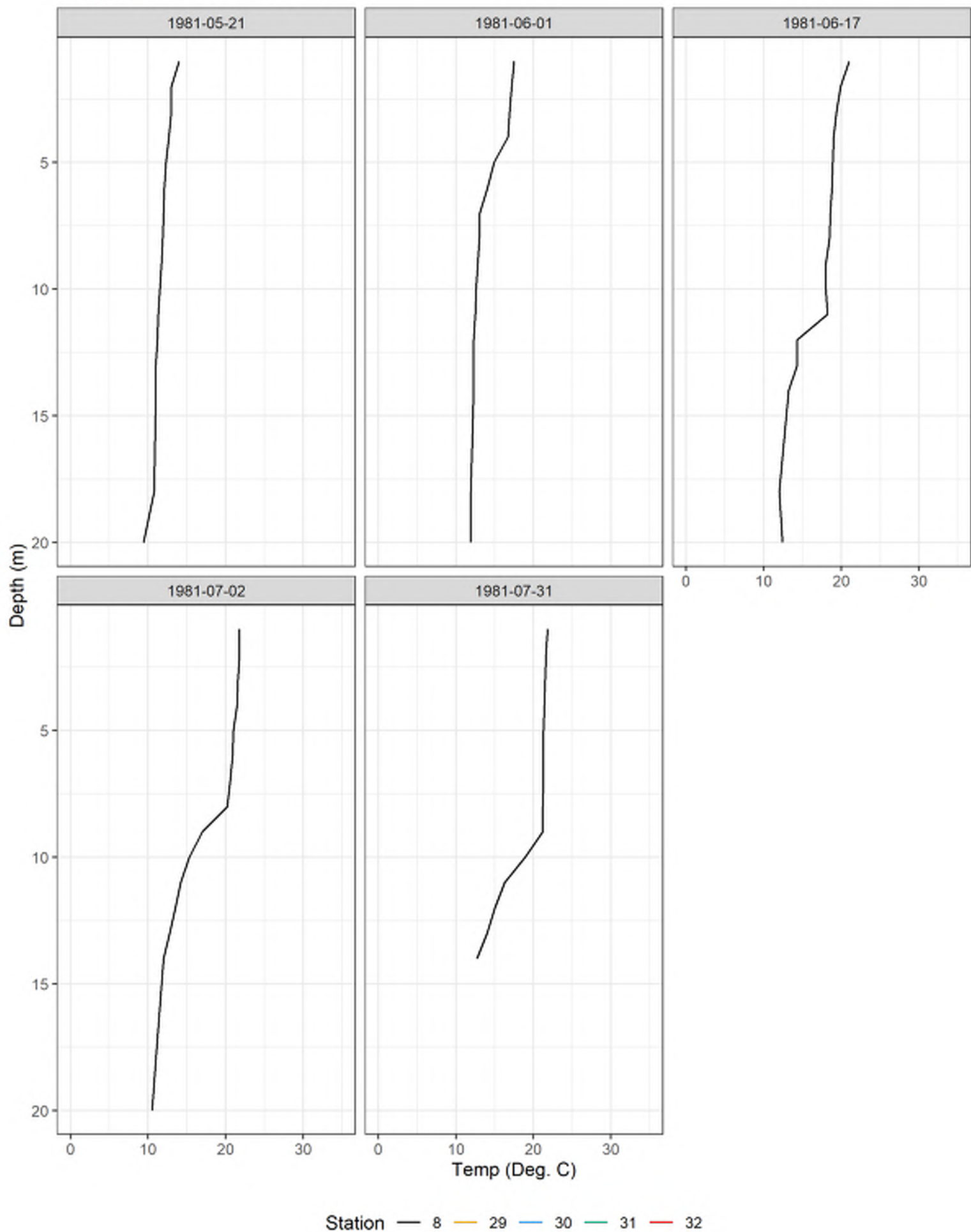


Temperature Profile: 1979

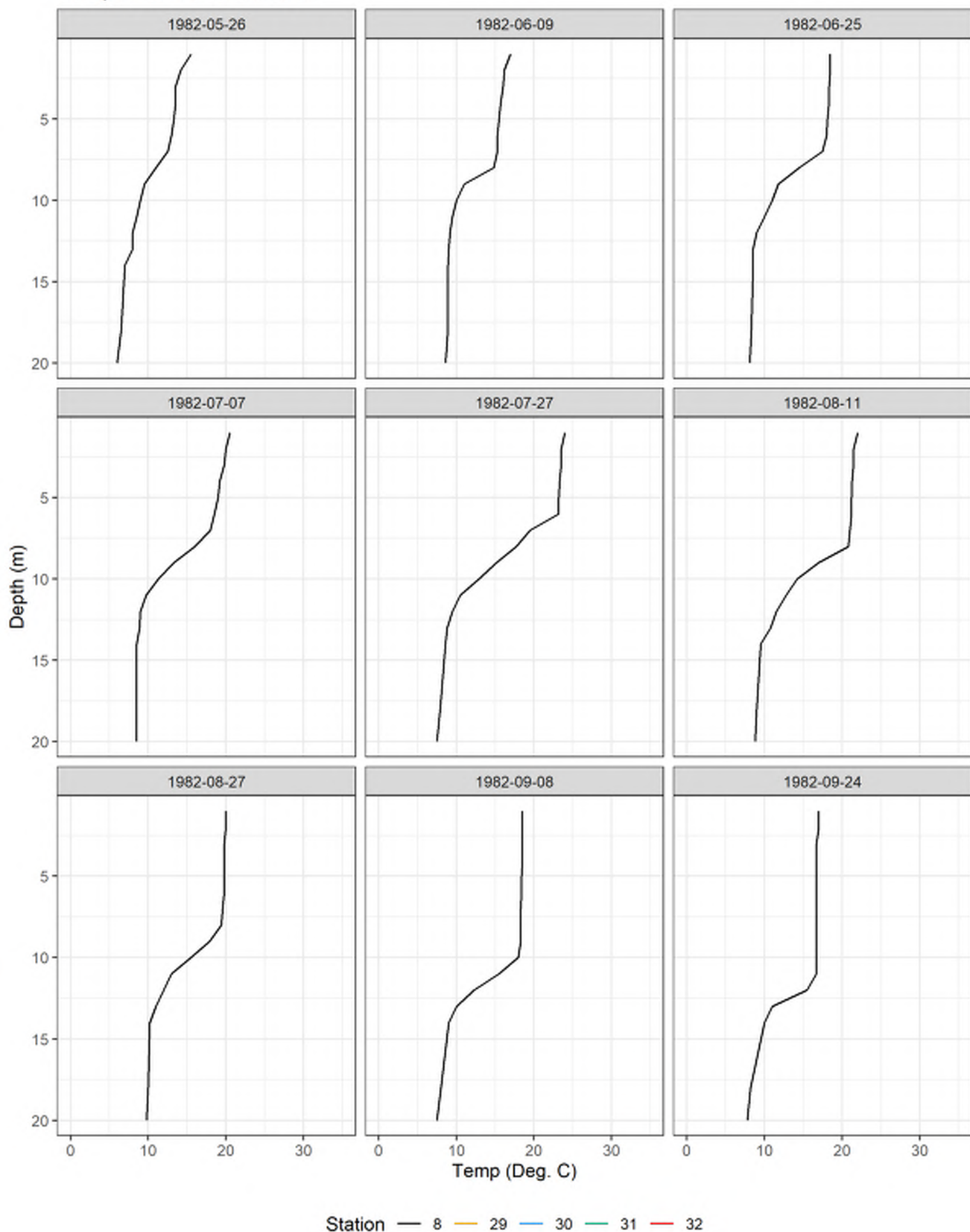


Station — 8 — 29 — 30 — 31 — 32

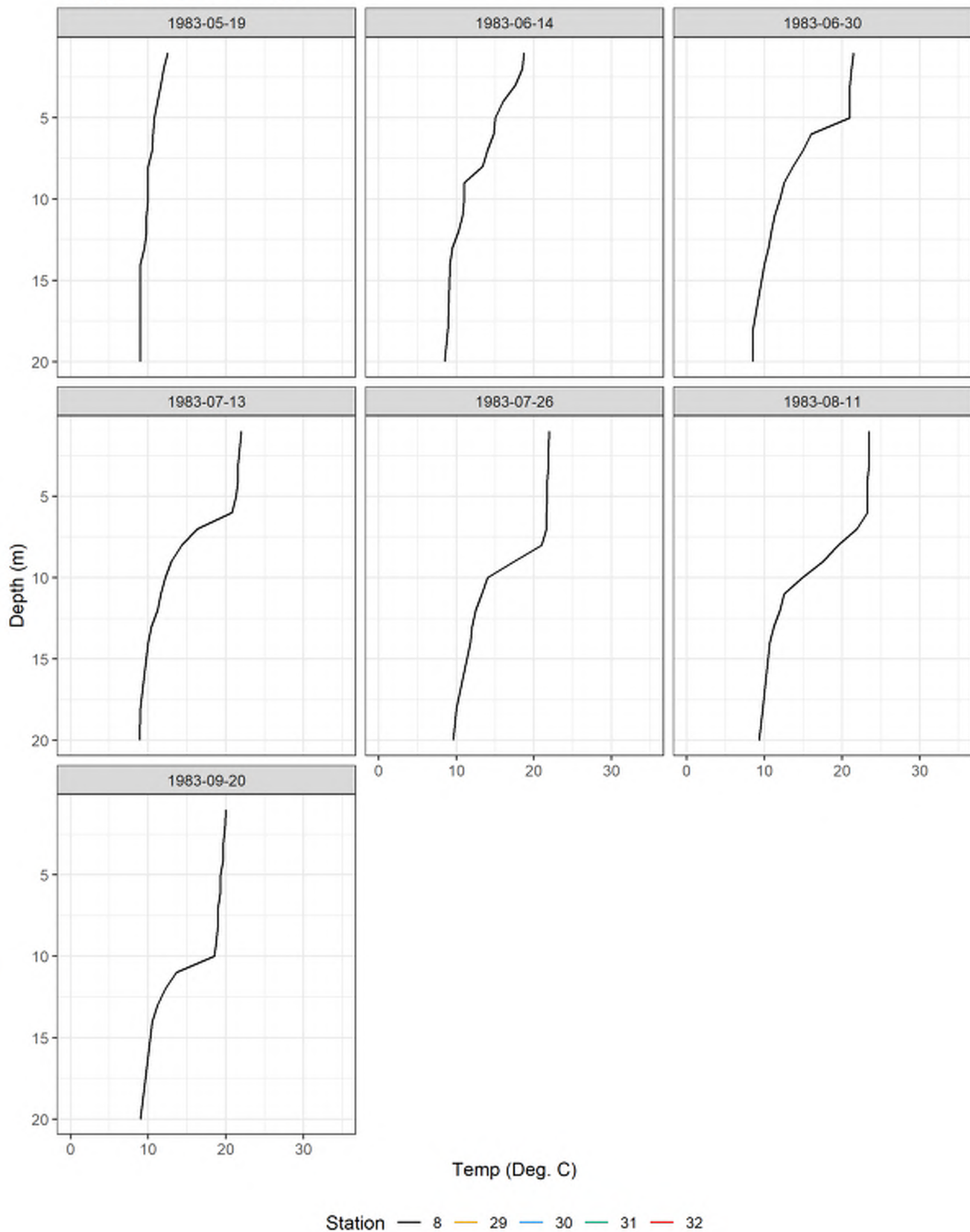
Temperature Profile: 1981



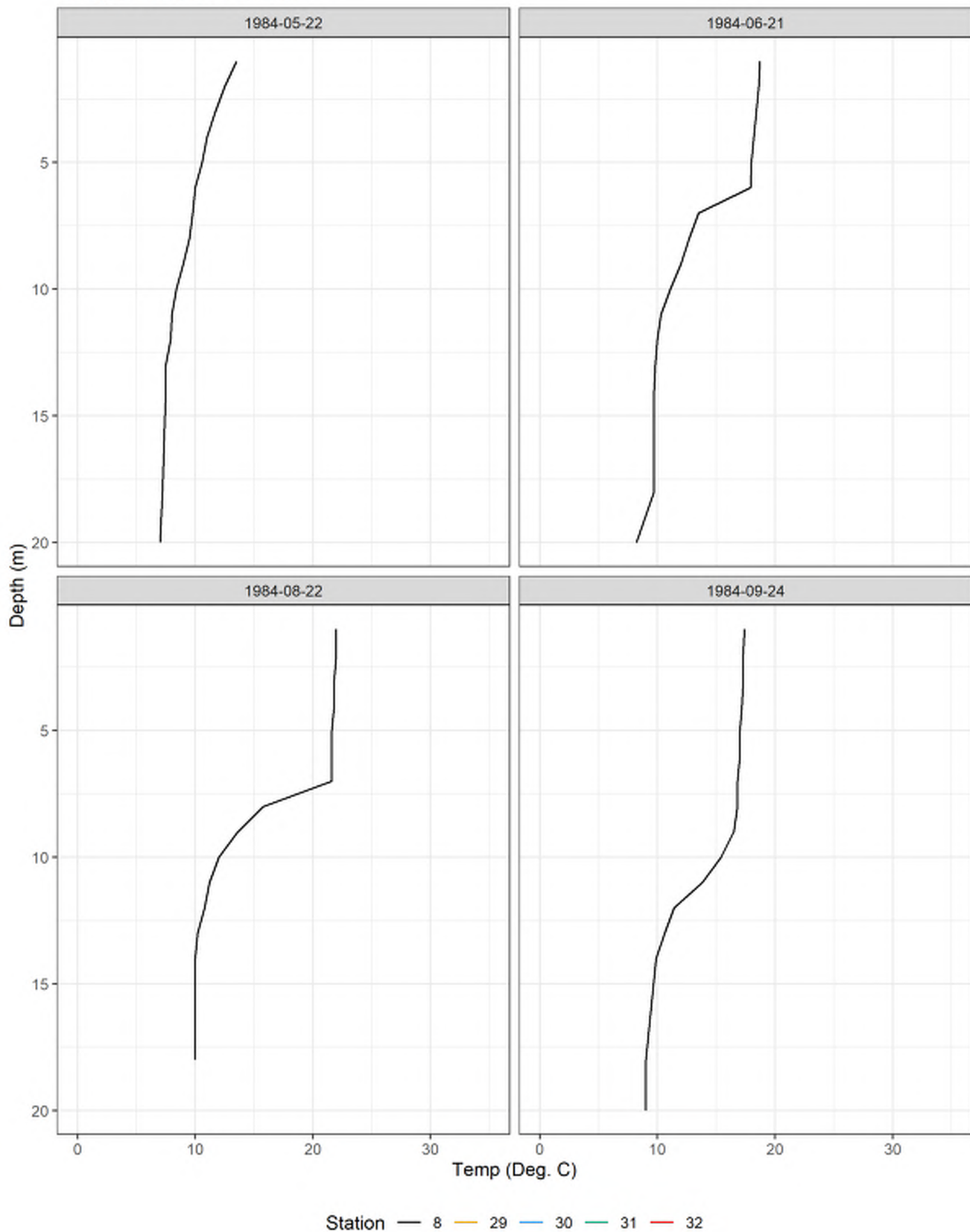
Temperature Profile: 1982



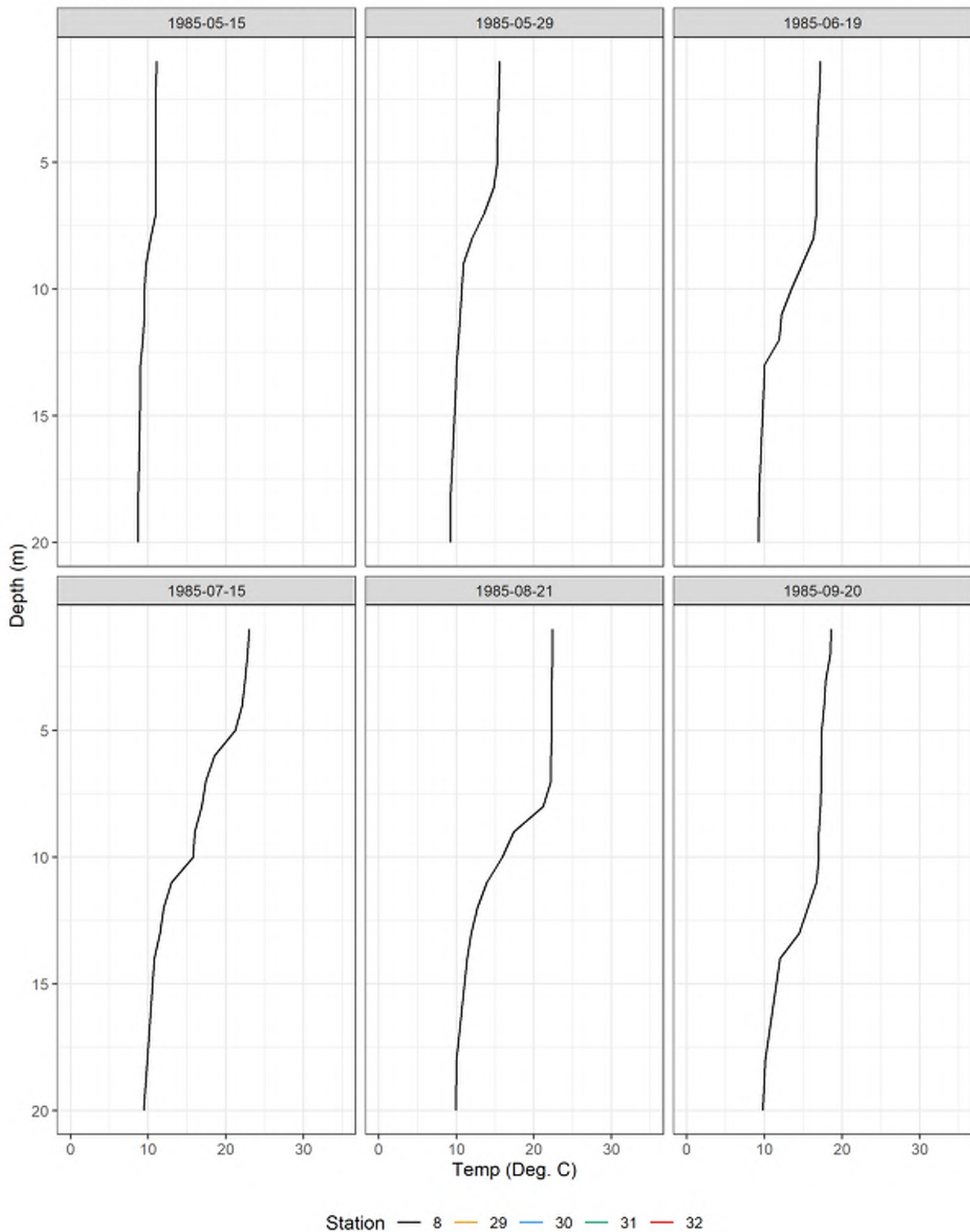
Temperature Profile: 1983



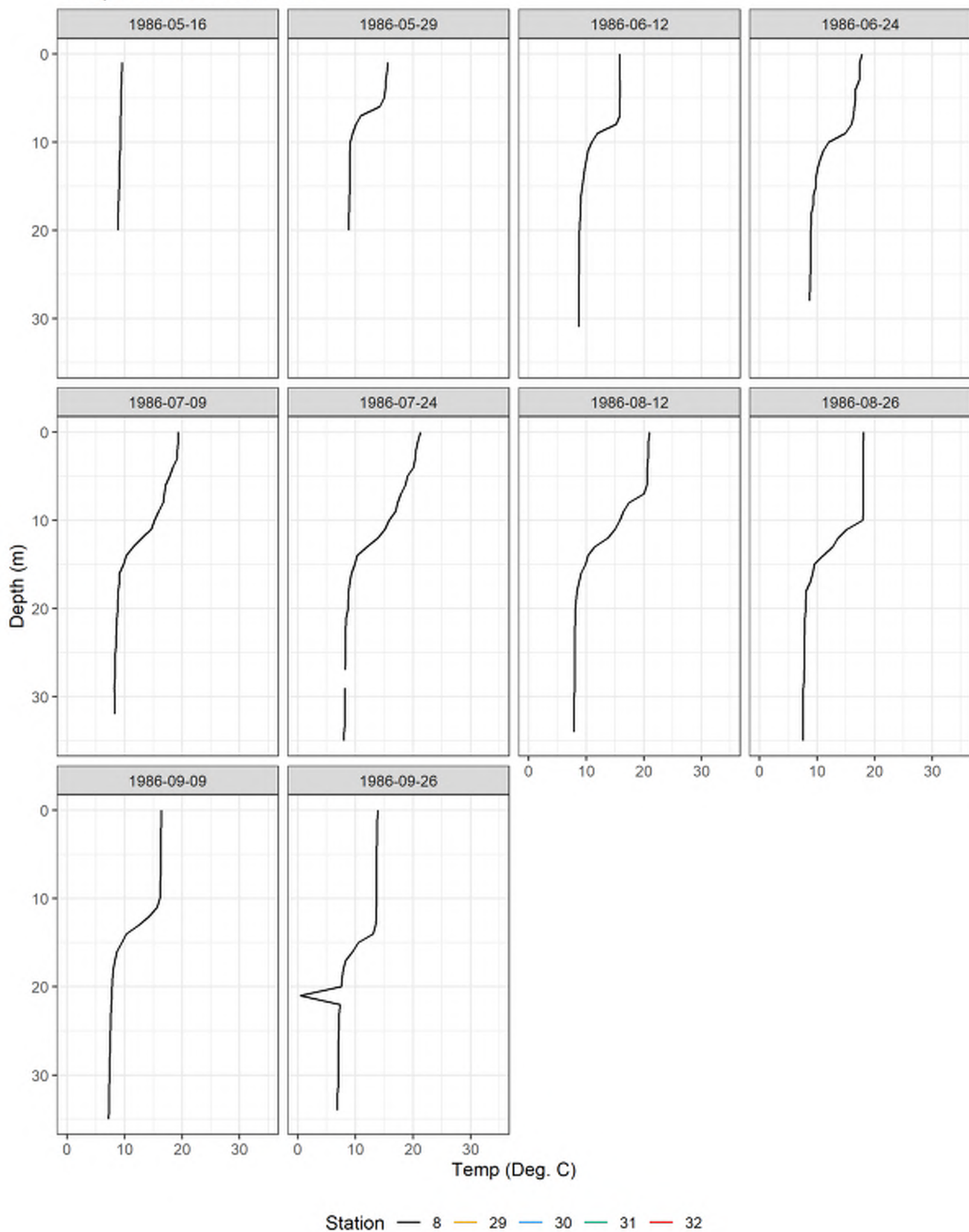
Temperature Profile: 1984



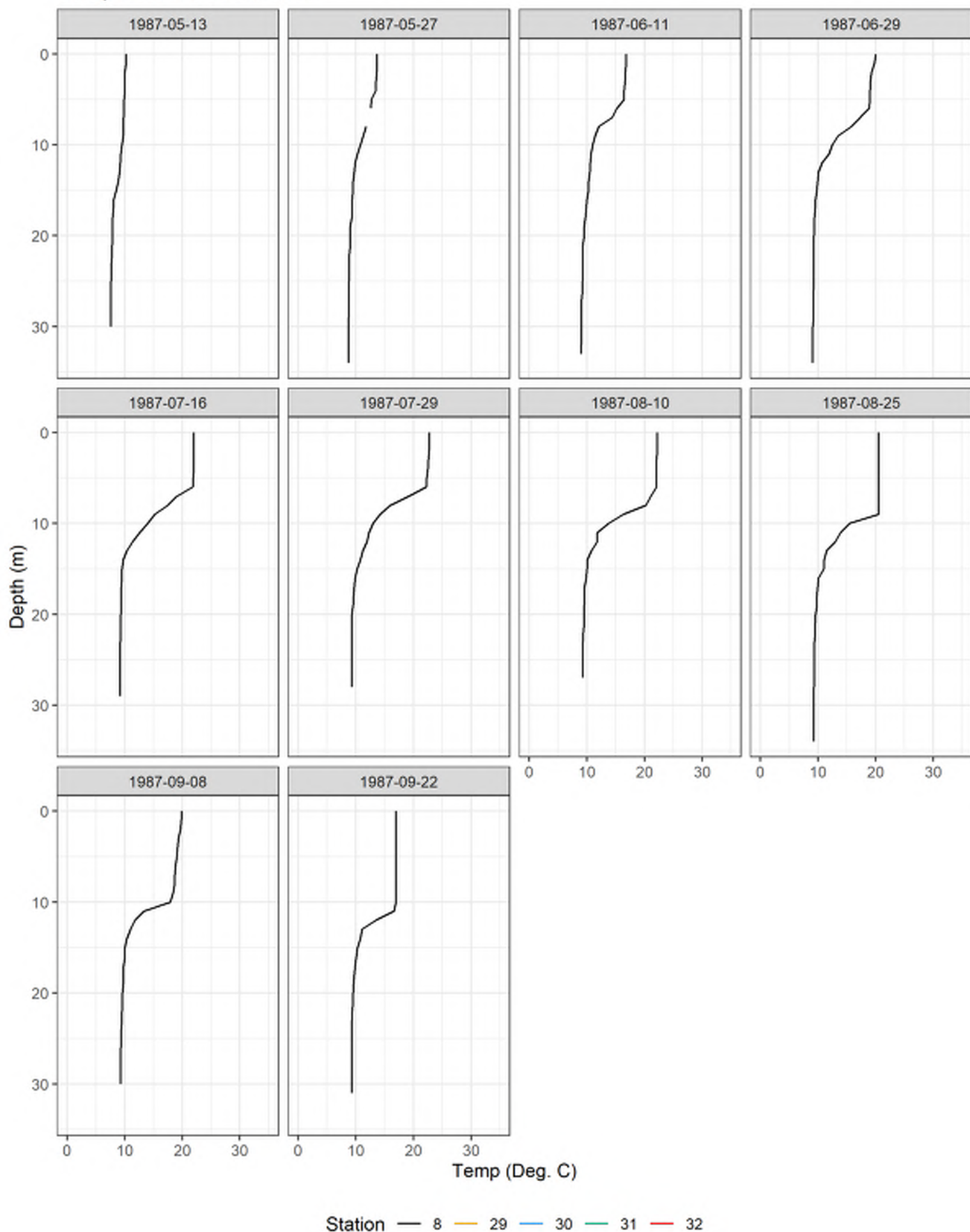
Temperature Profile: 1985



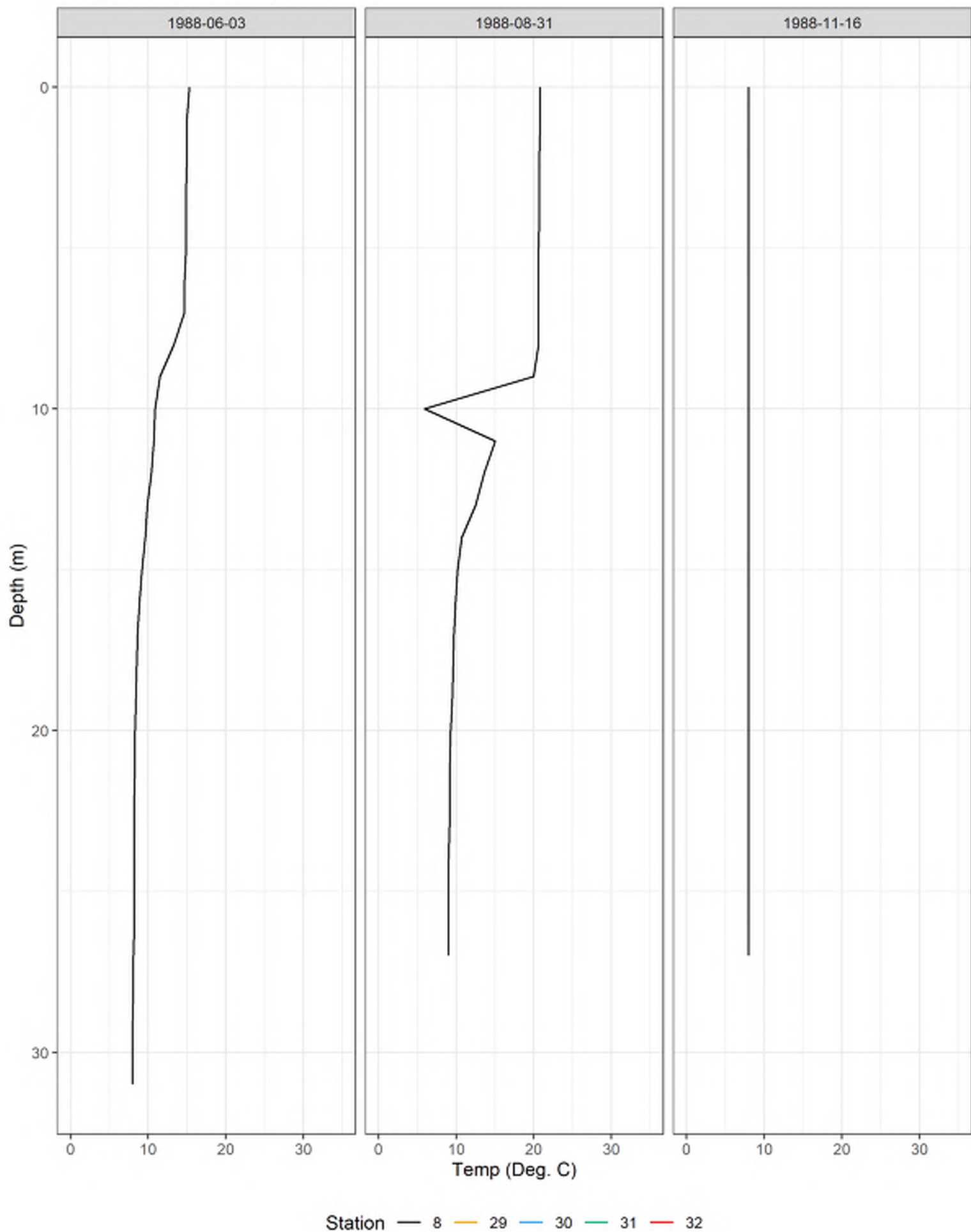
Temperature Profile: 1986



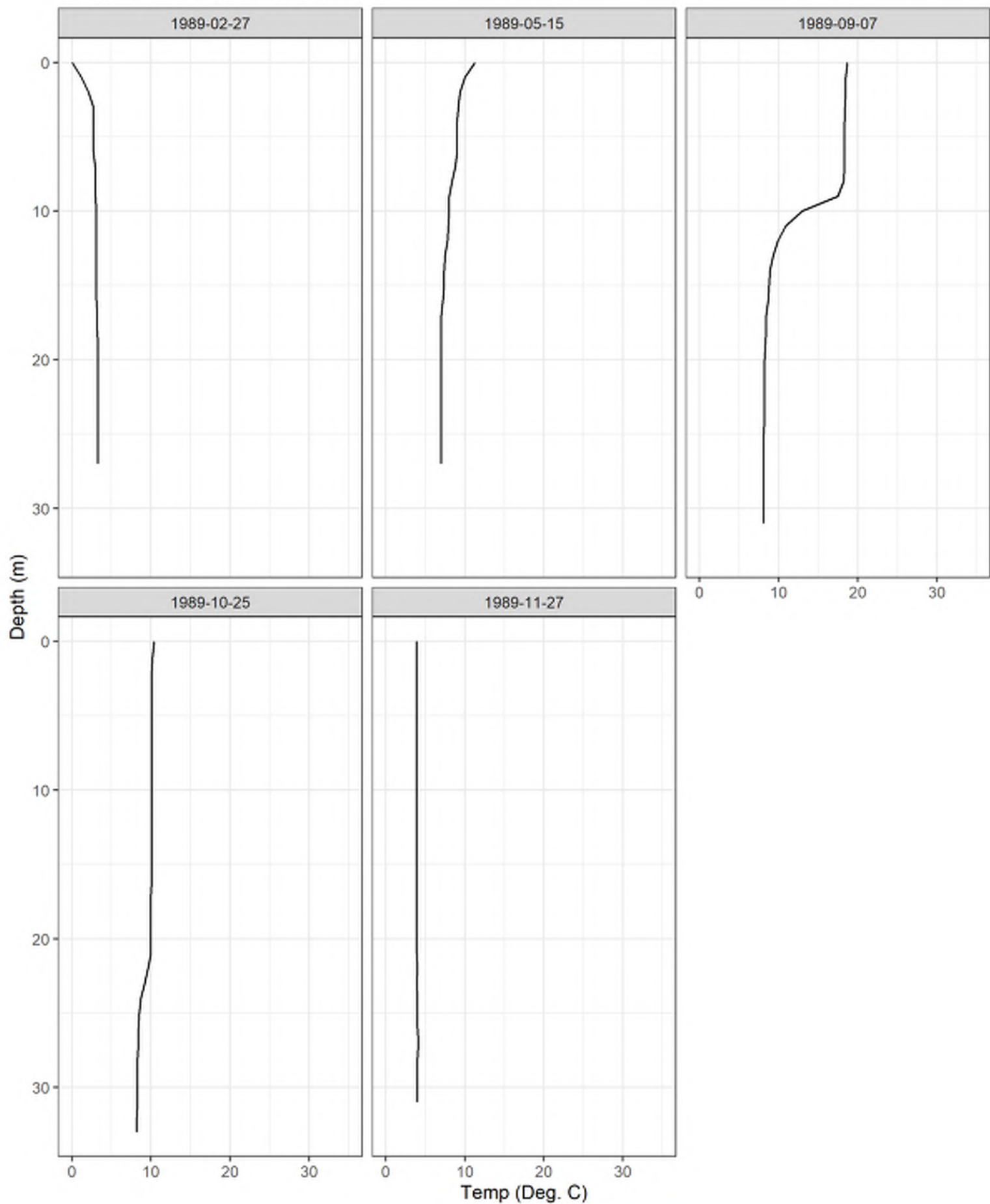
Temperature Profile: 1987



Temperature Profile: 1988

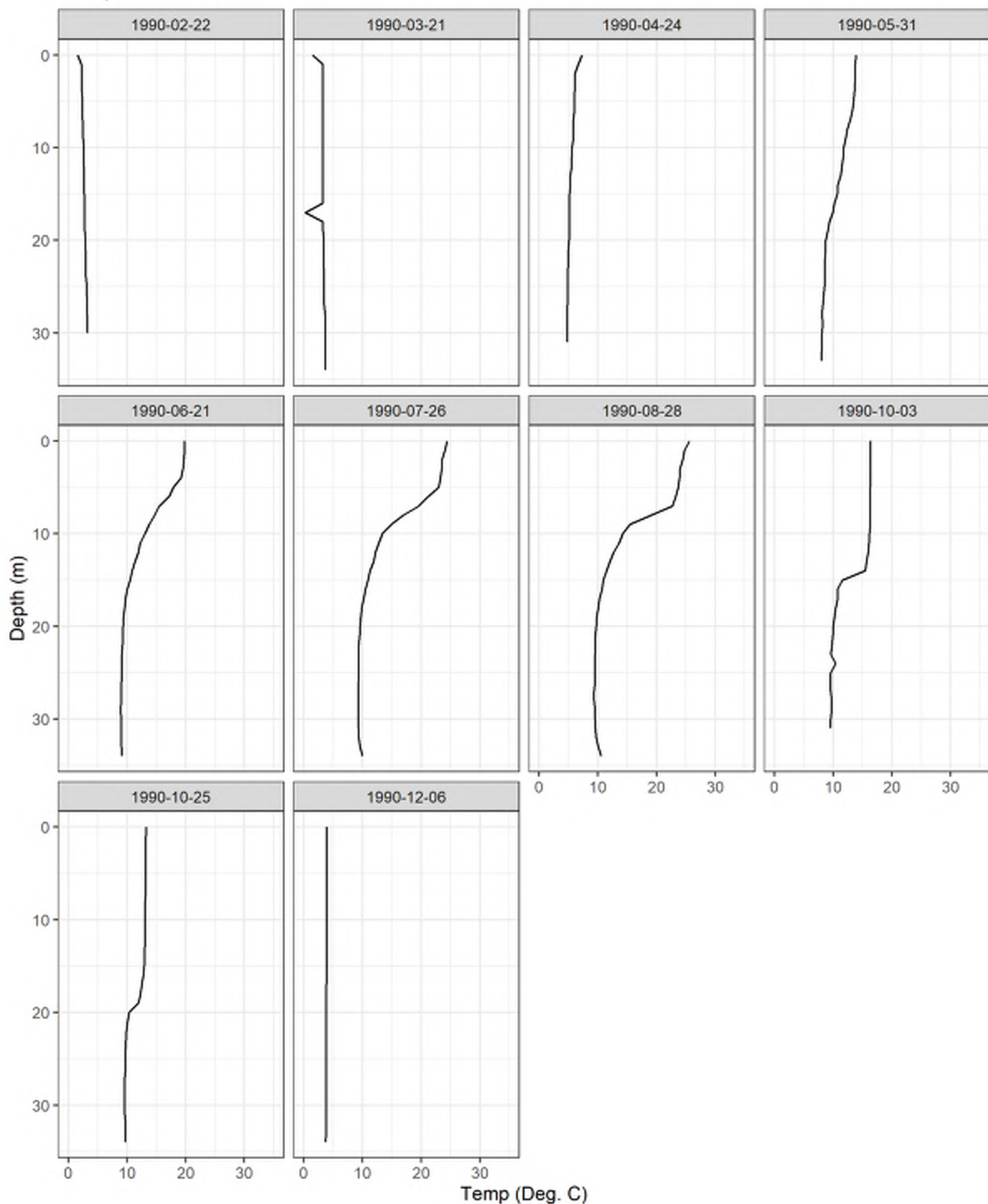


Temperature Profile: 1989

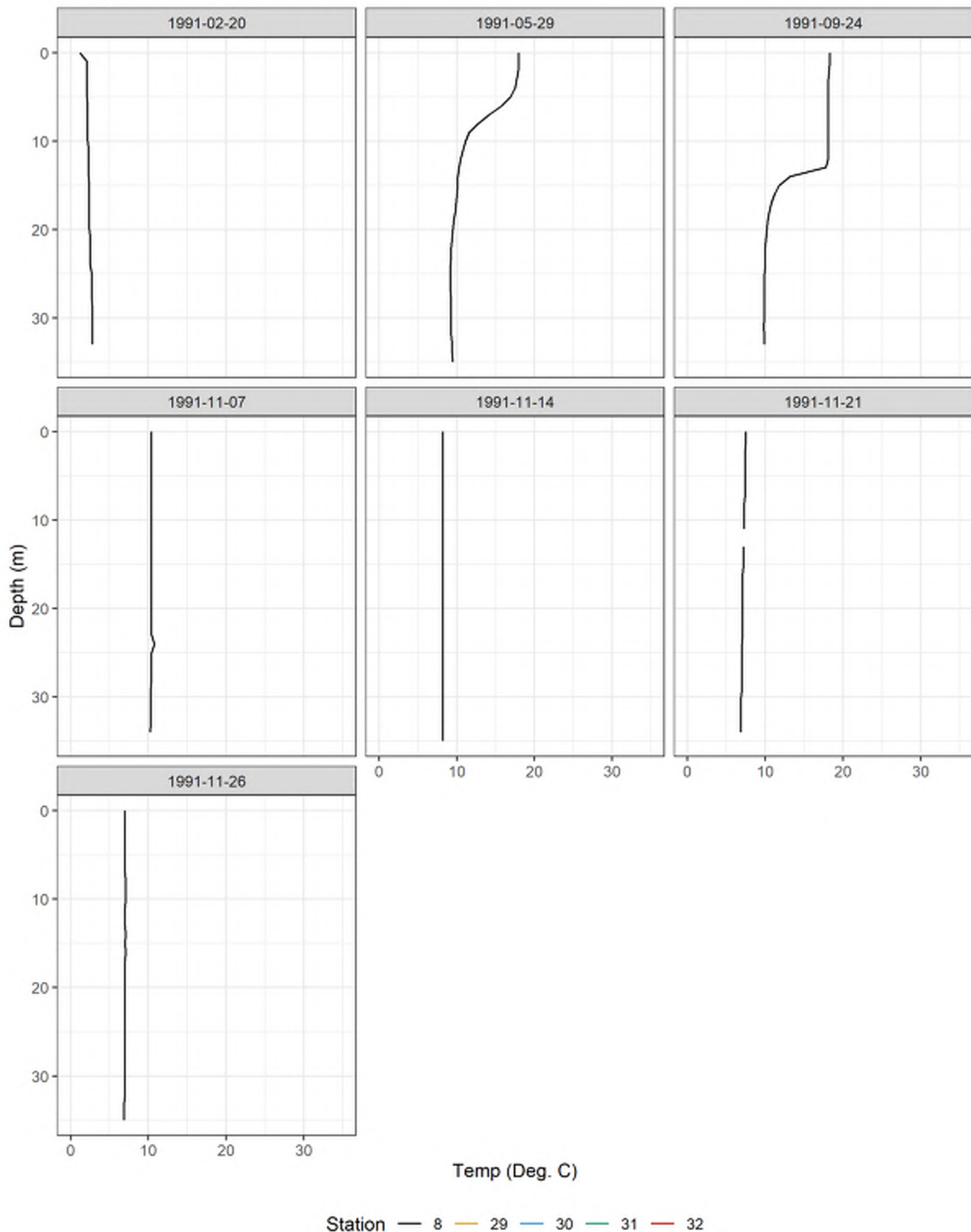


Station — 8 — 29 — 30 — 31 — 32

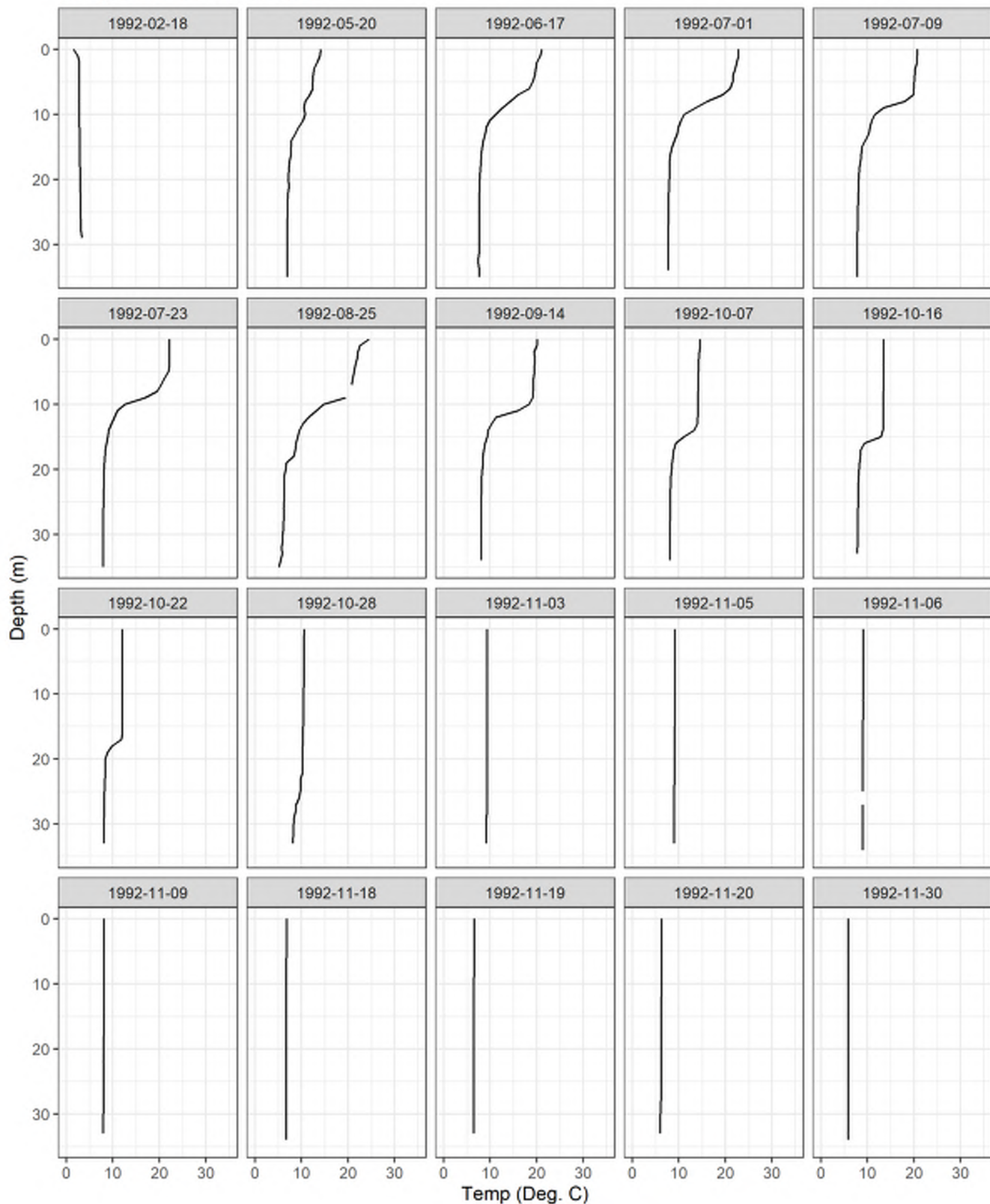
Temperature Profile: 1990



Temperature Profile: 1991

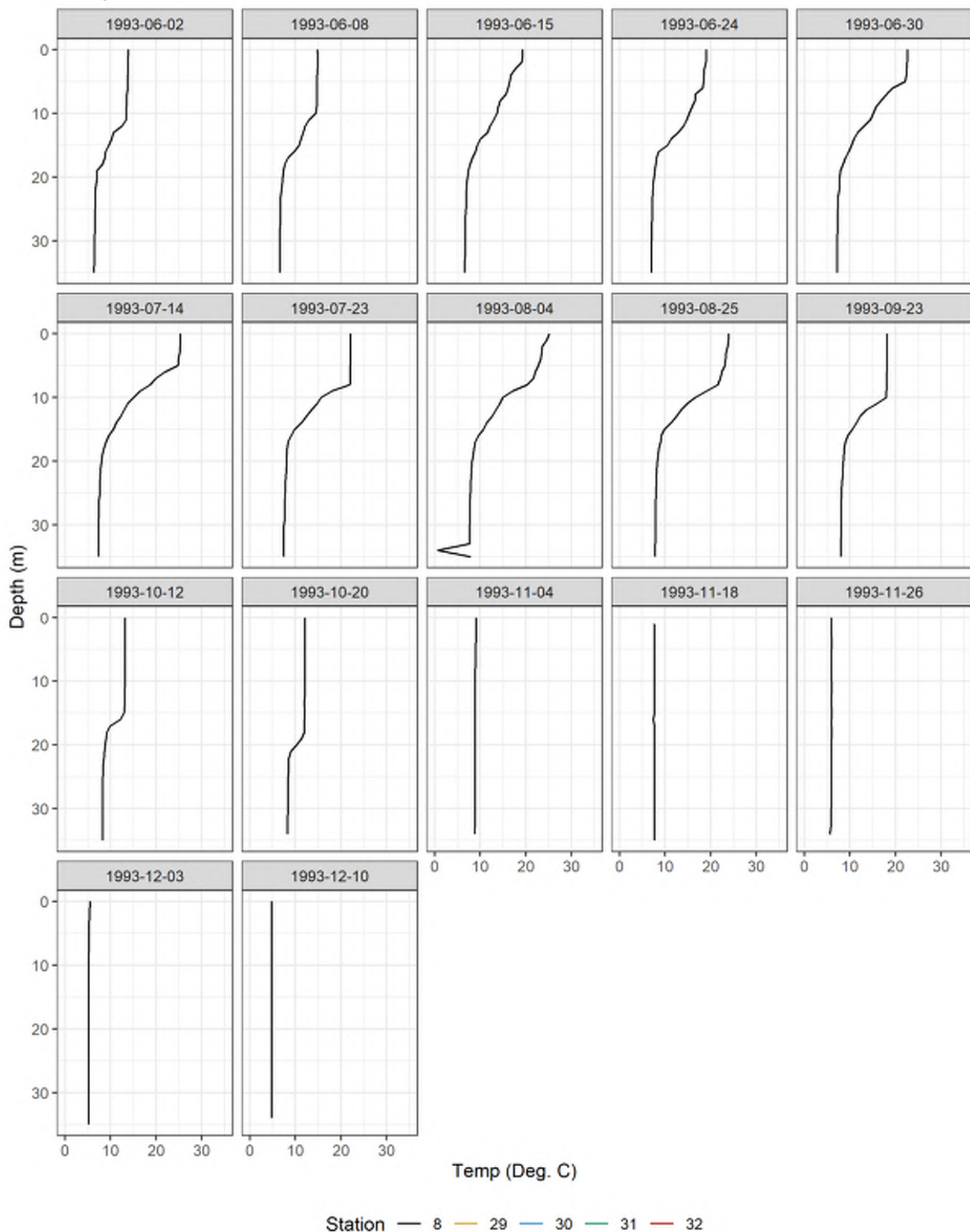


Temperature Profile: 1992

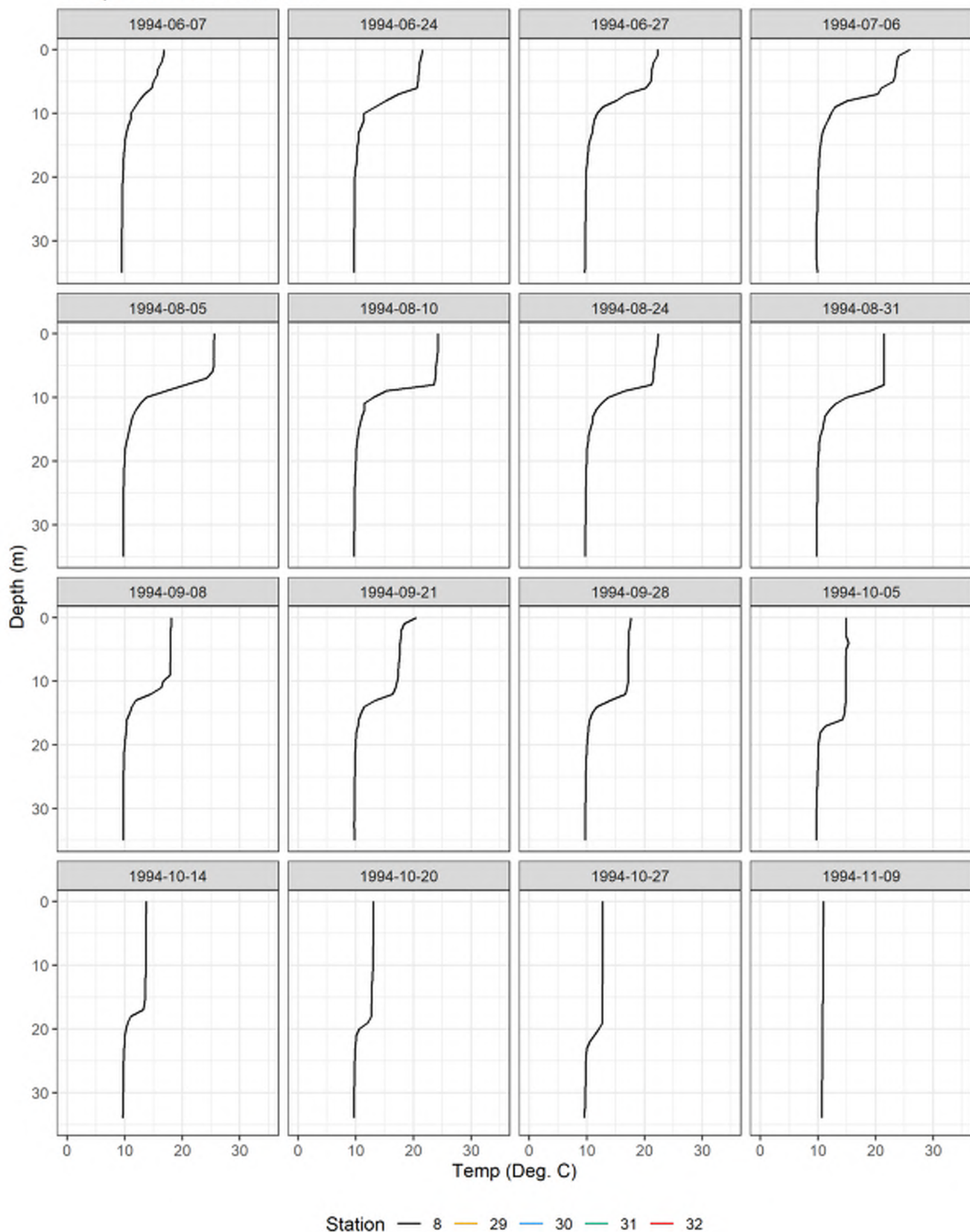


Station — 8 — 29 — 30 — 31 — 32

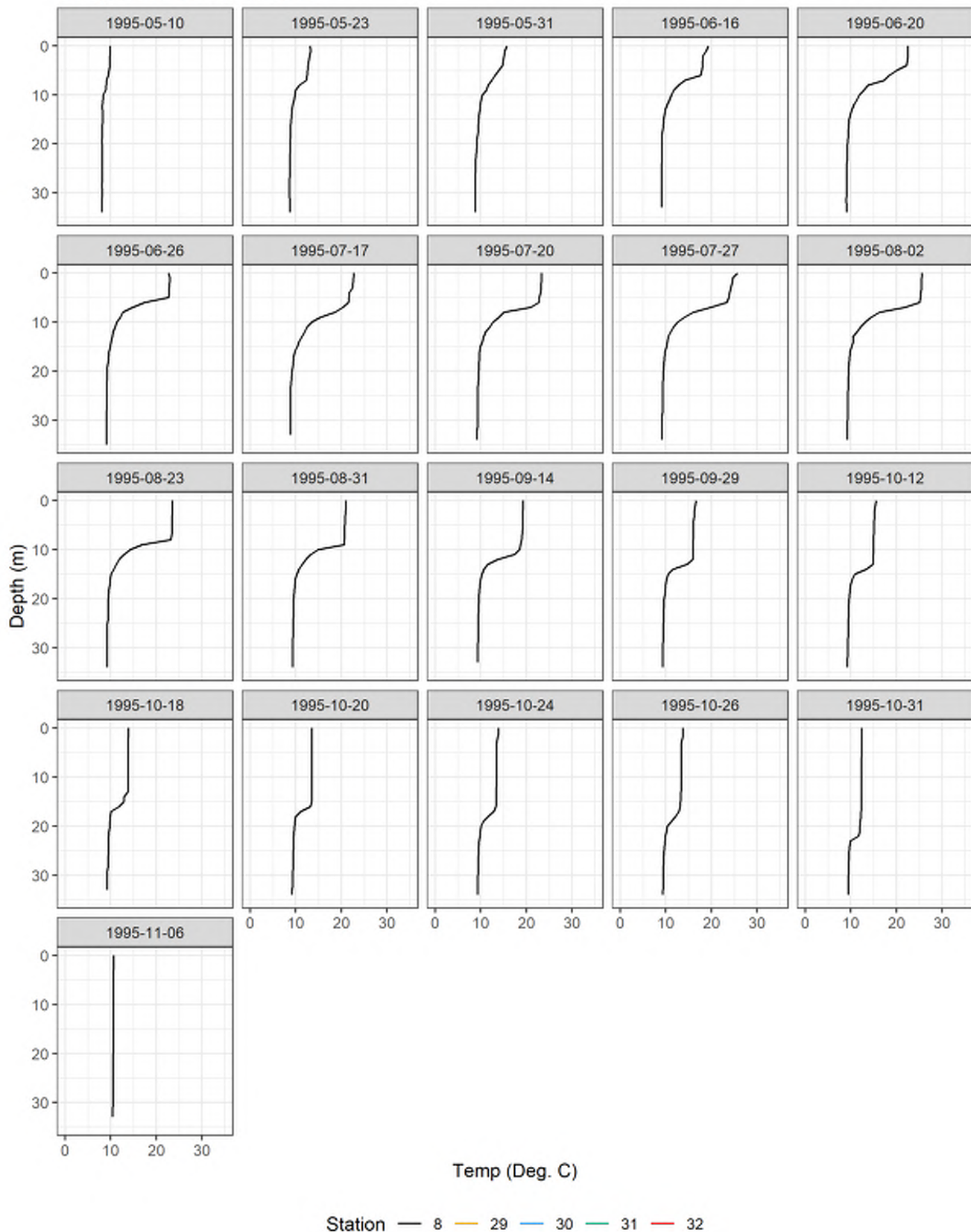
Temperature Profile: 1993



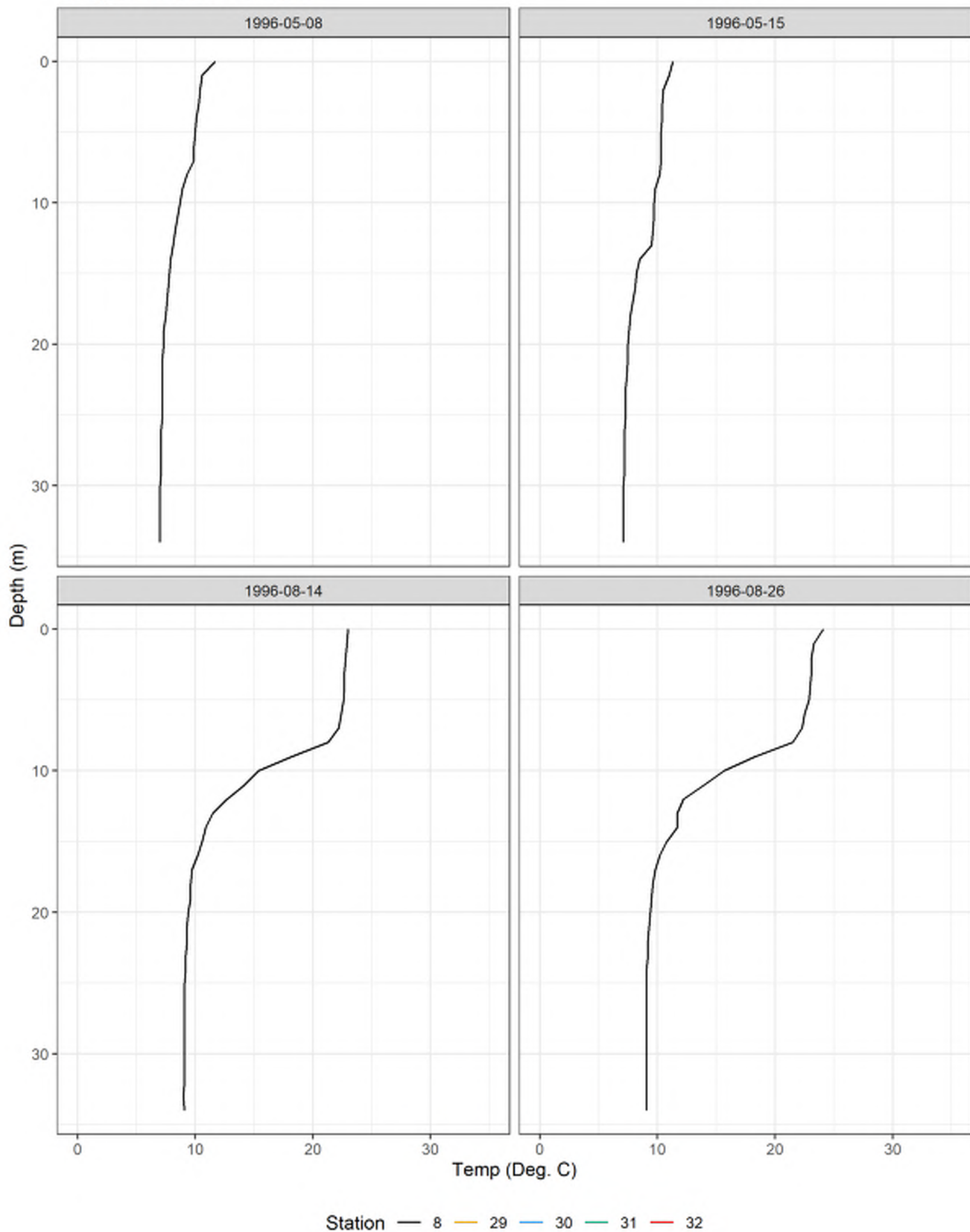
Temperature Profile: 1994



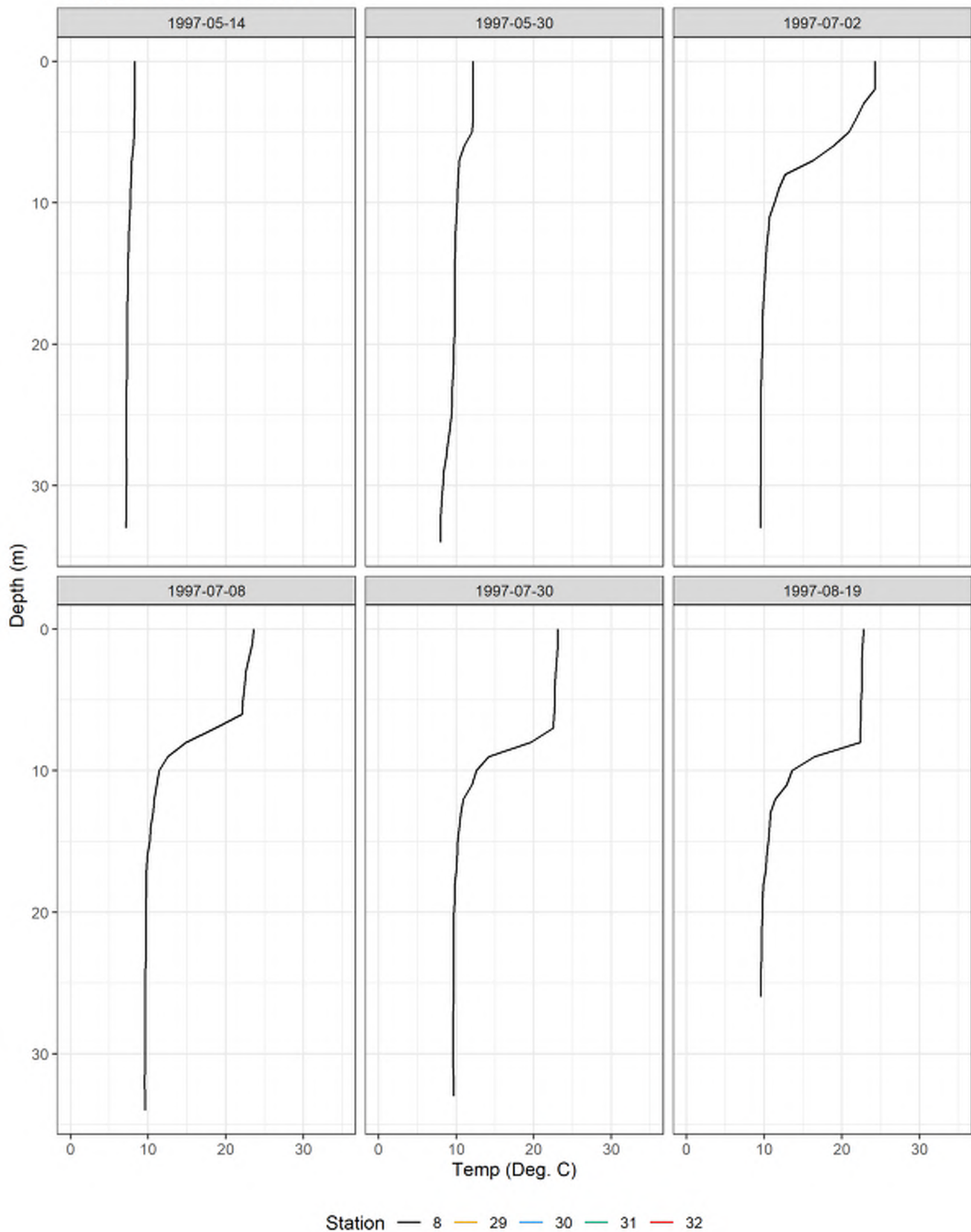
Temperature Profile: 1995



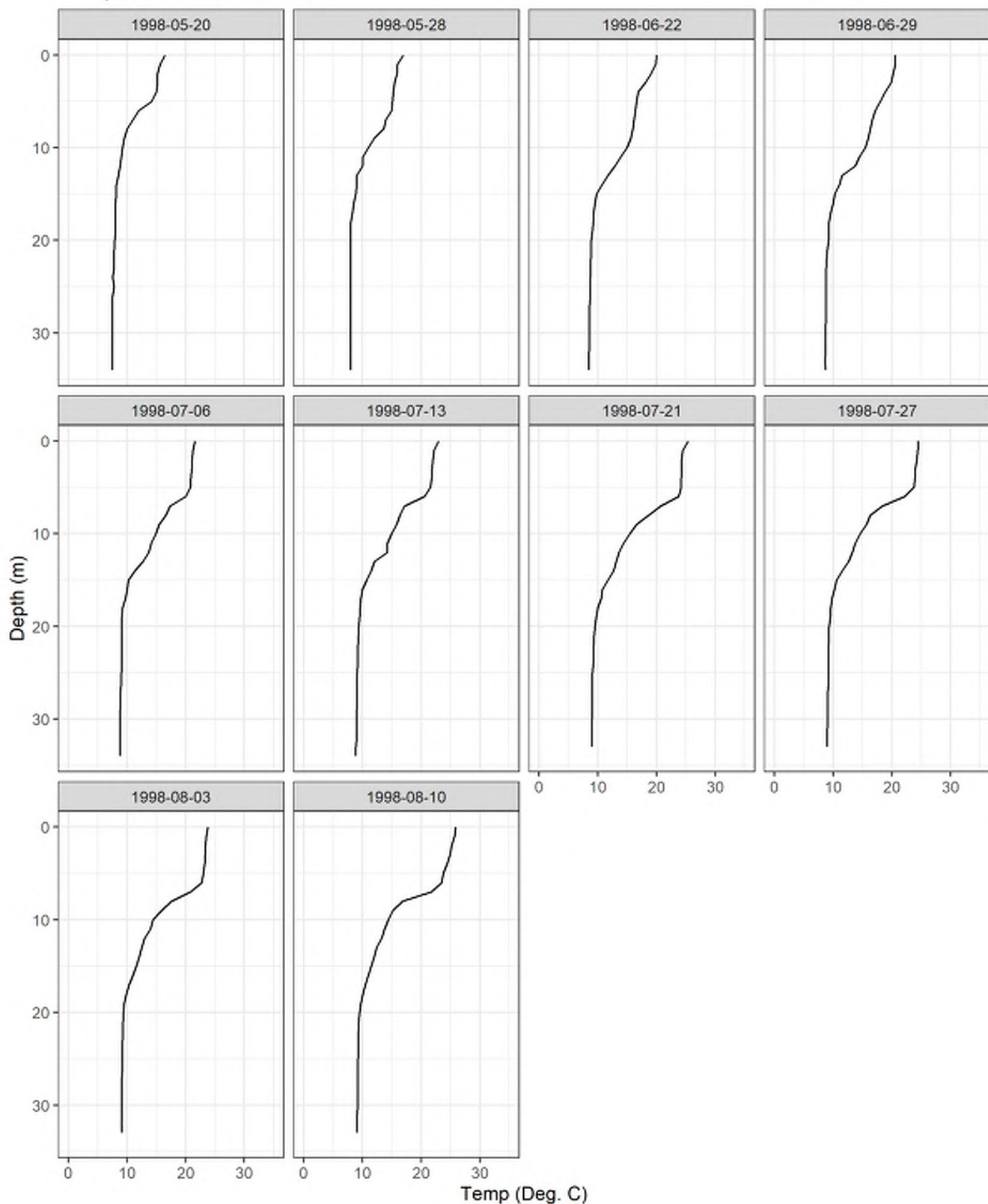
Temperature Profile: 1996



Temperature Profile: 1997

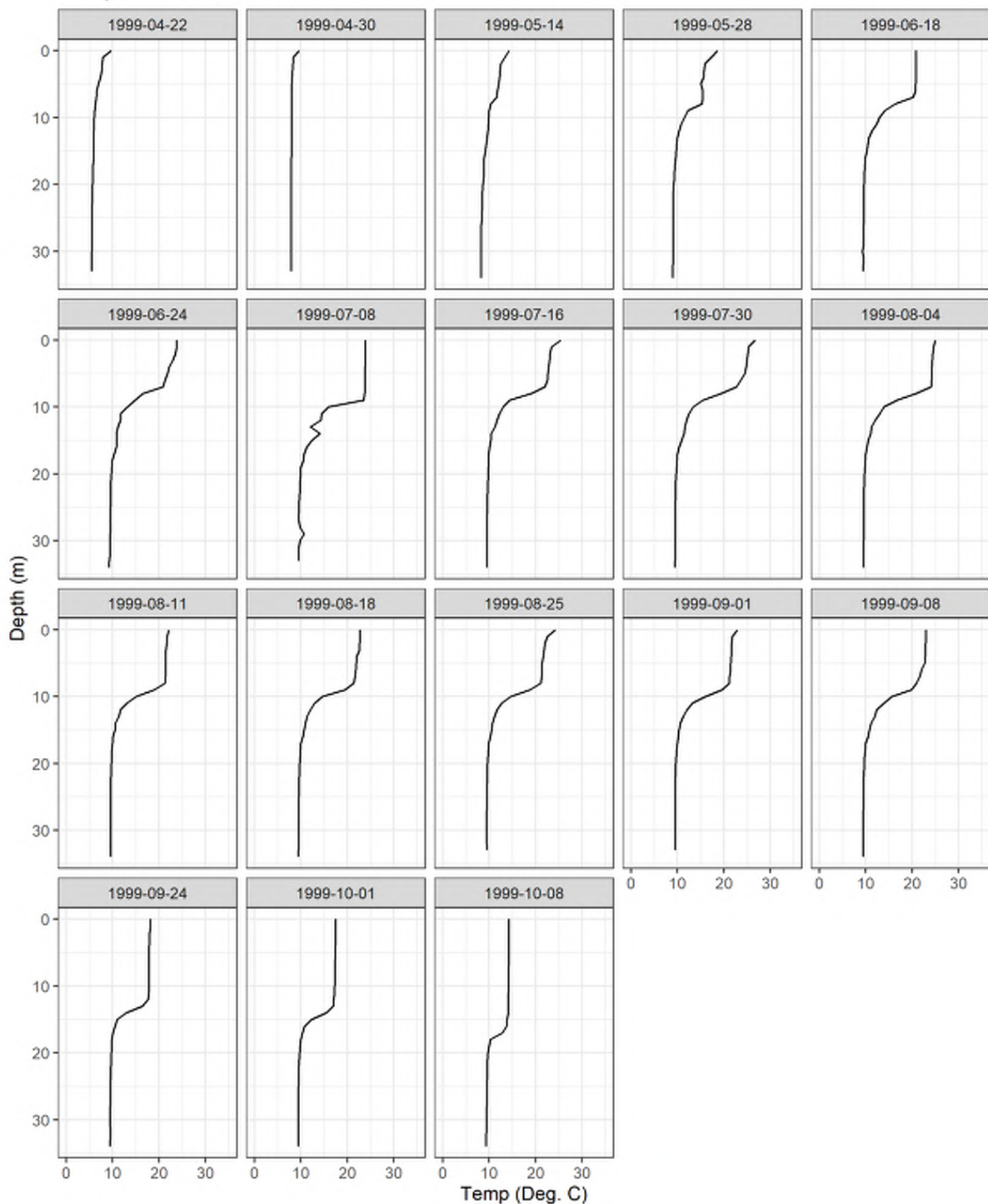


Temperature Profile: 1998



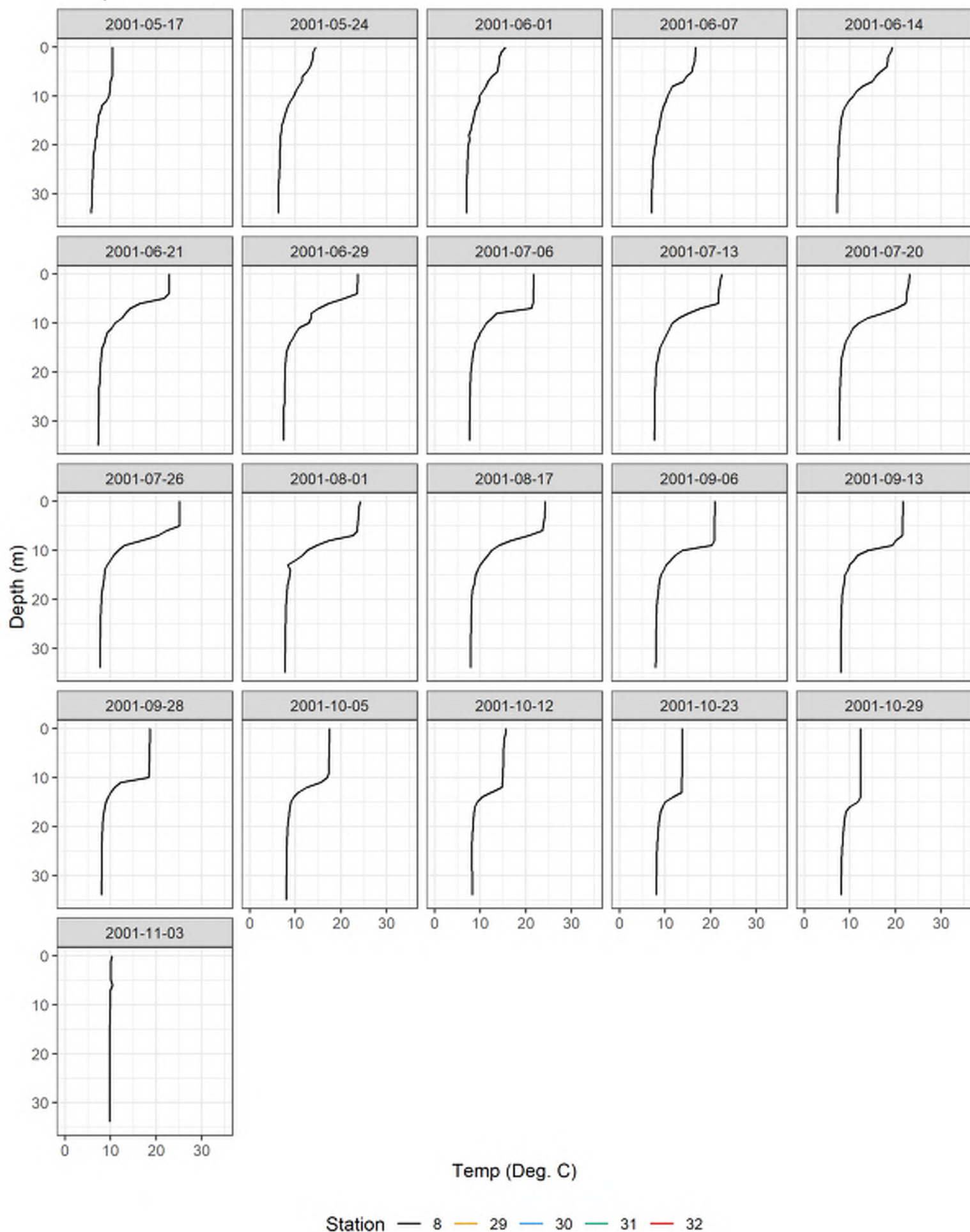
Station — 8 — 29 — 30 — 31 — 32

Temperature Profile: 1999

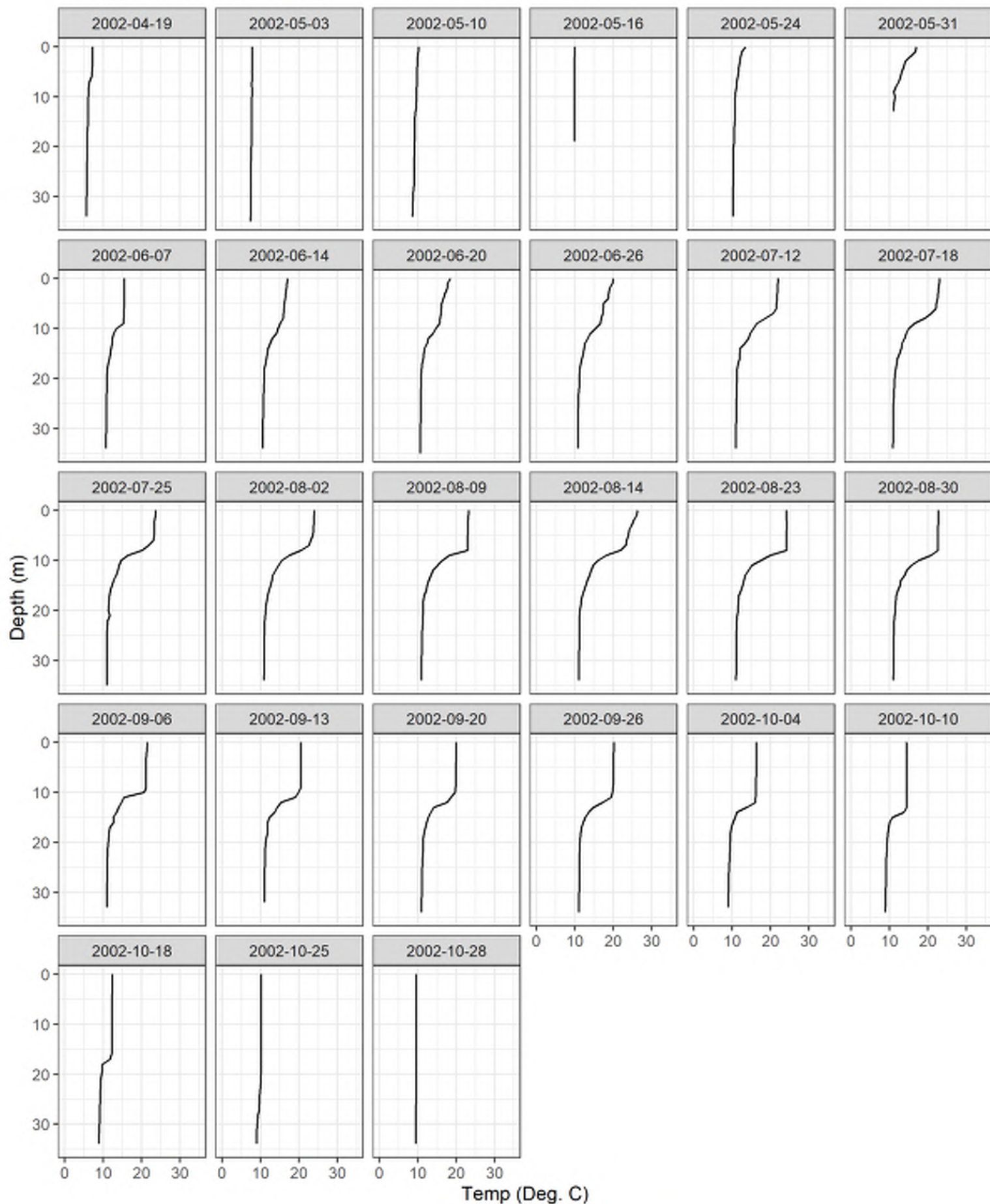


Station — 8 — 29 — 30 — 31 — 32

Temperature Profile: 2001

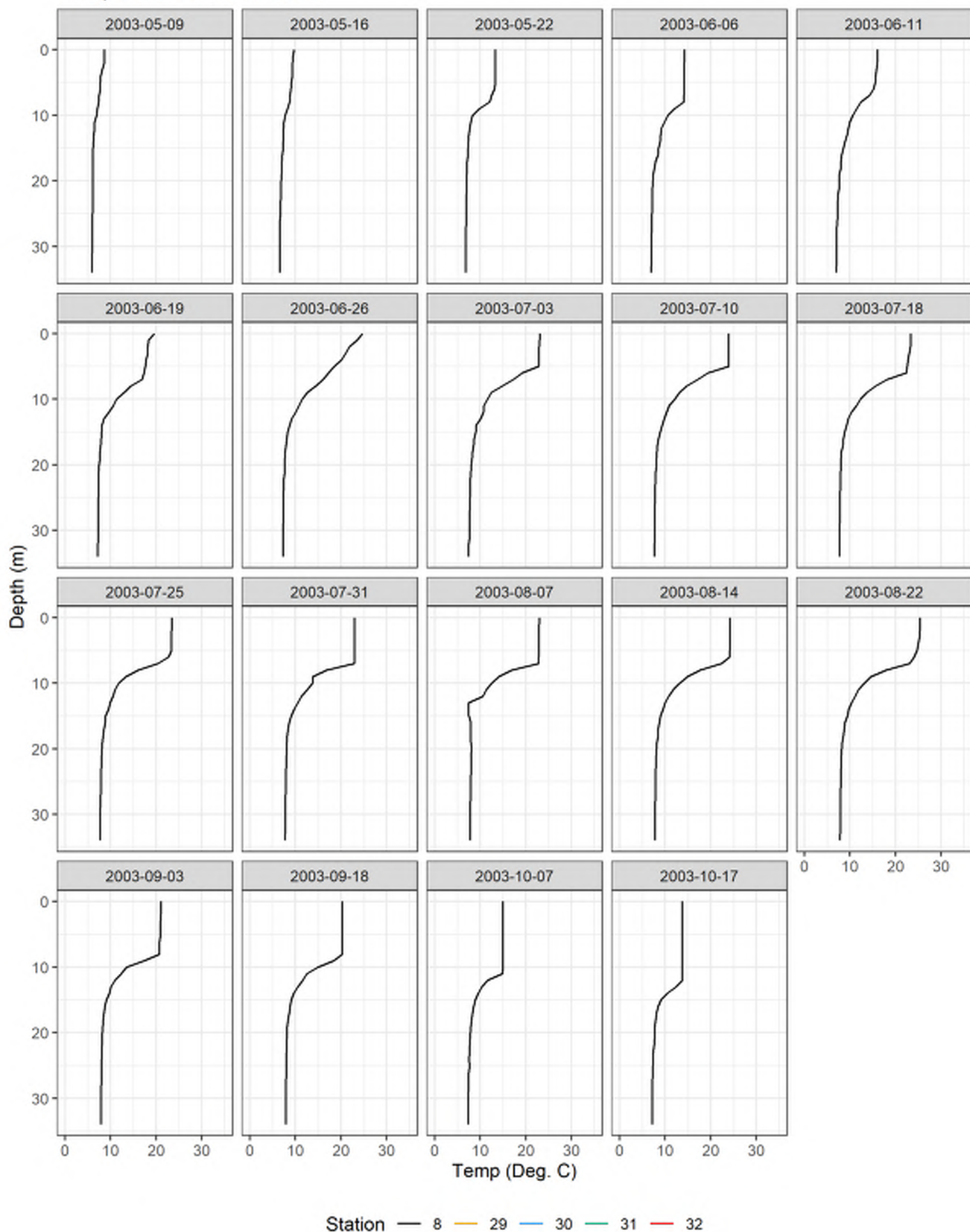


Temperature Profile: 2002

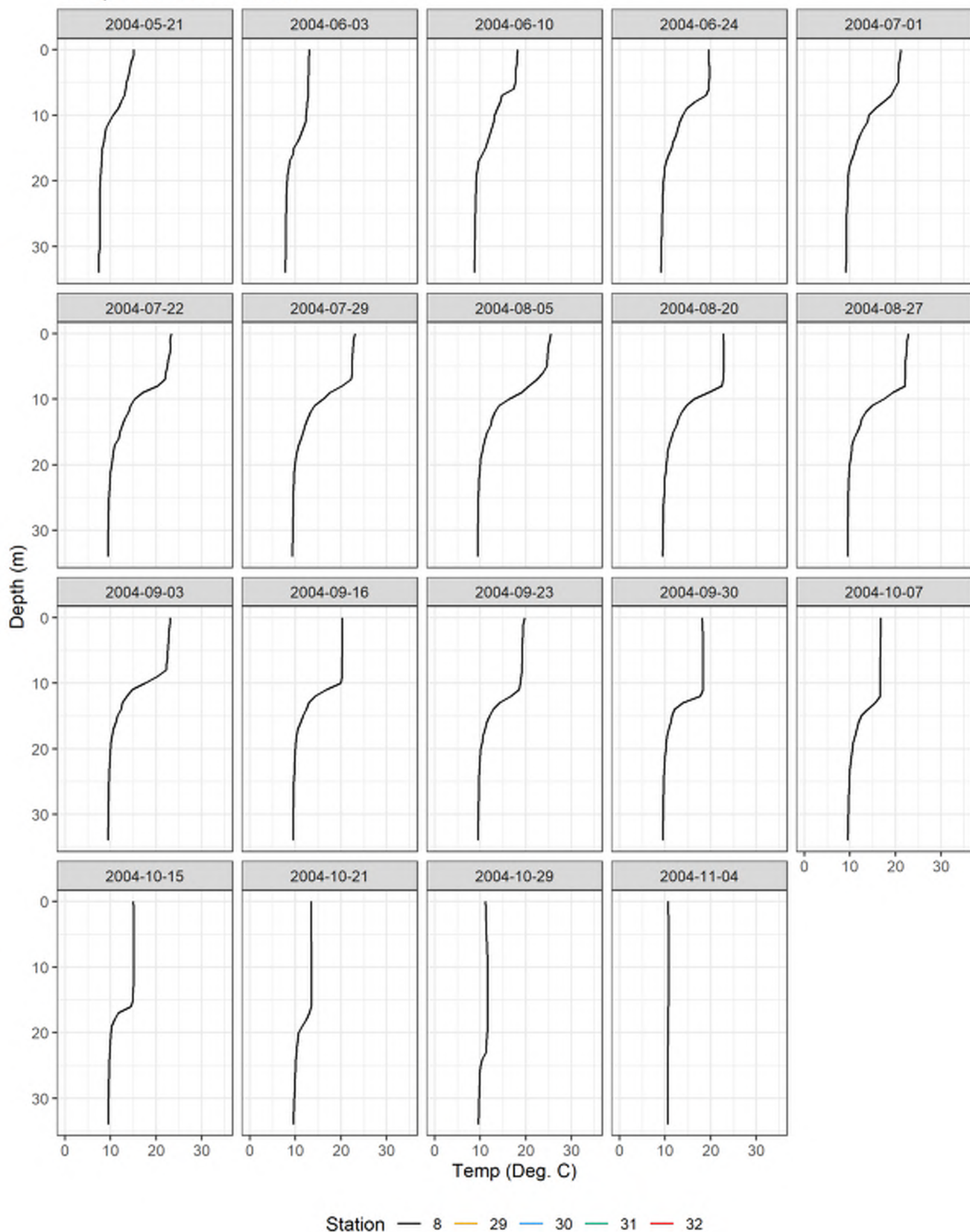


Station — 8 — 29 — 30 — 31 — 32

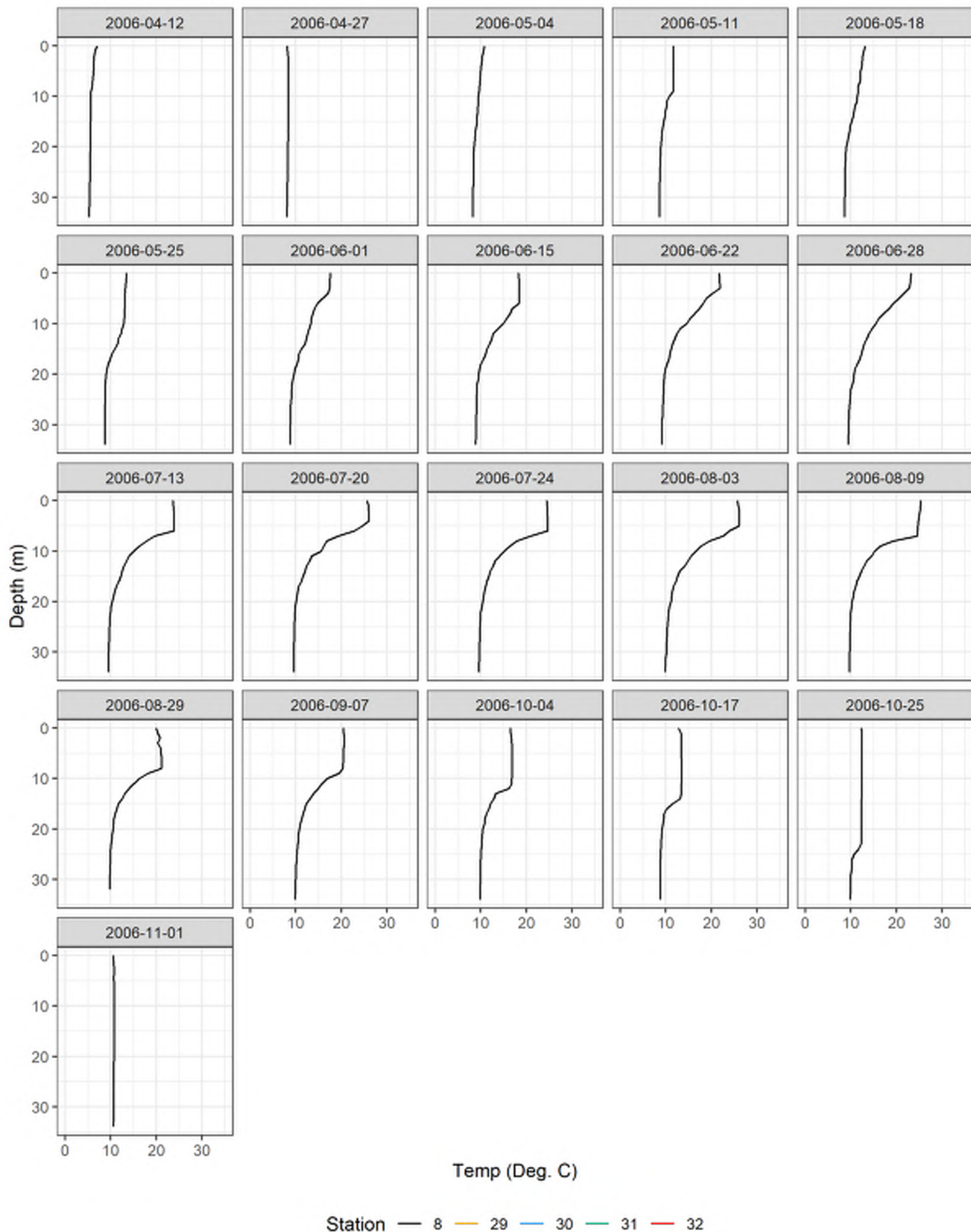
Temperature Profile: 2003



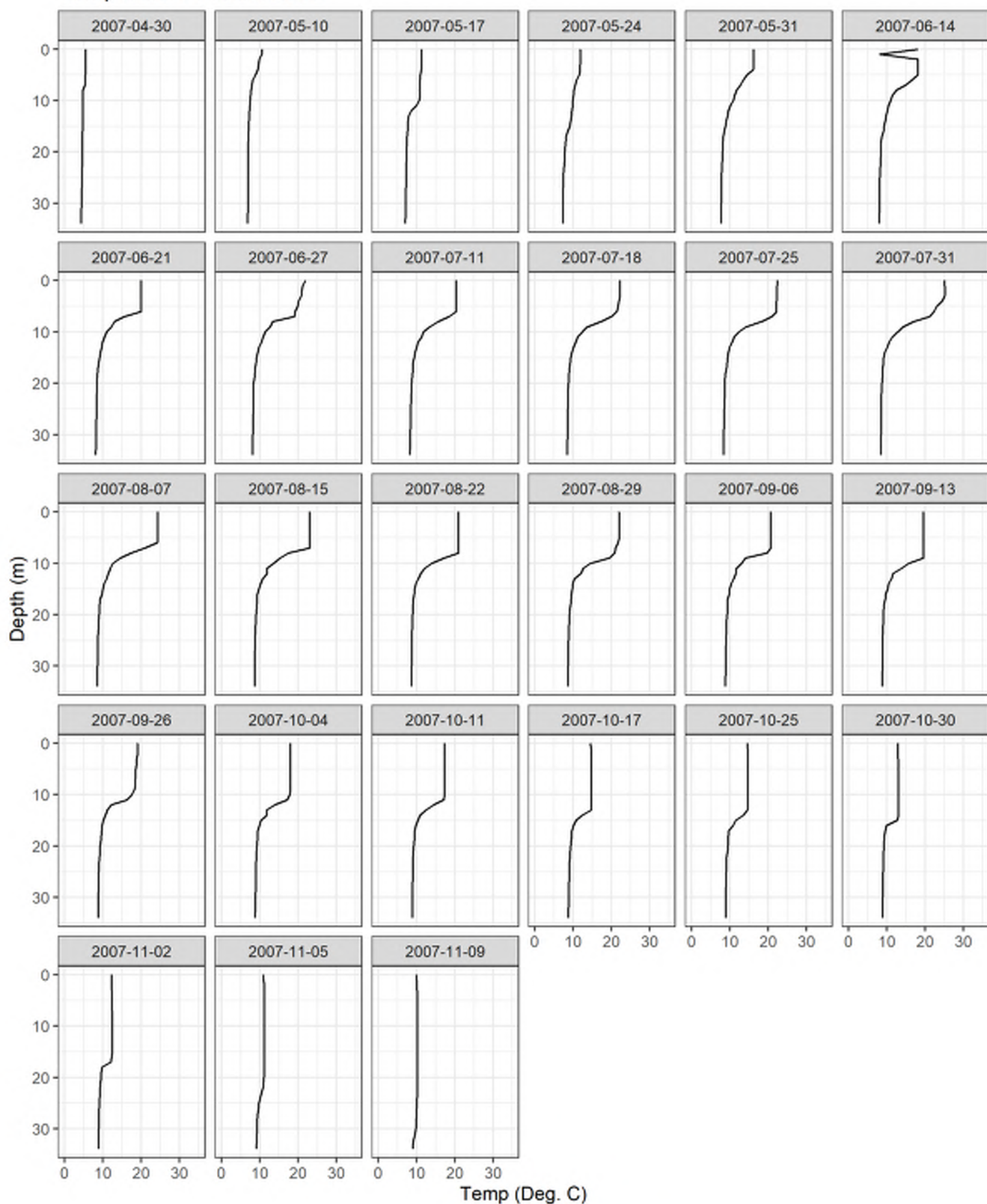
Temperature Profile: 2004



Temperature Profile: 2006

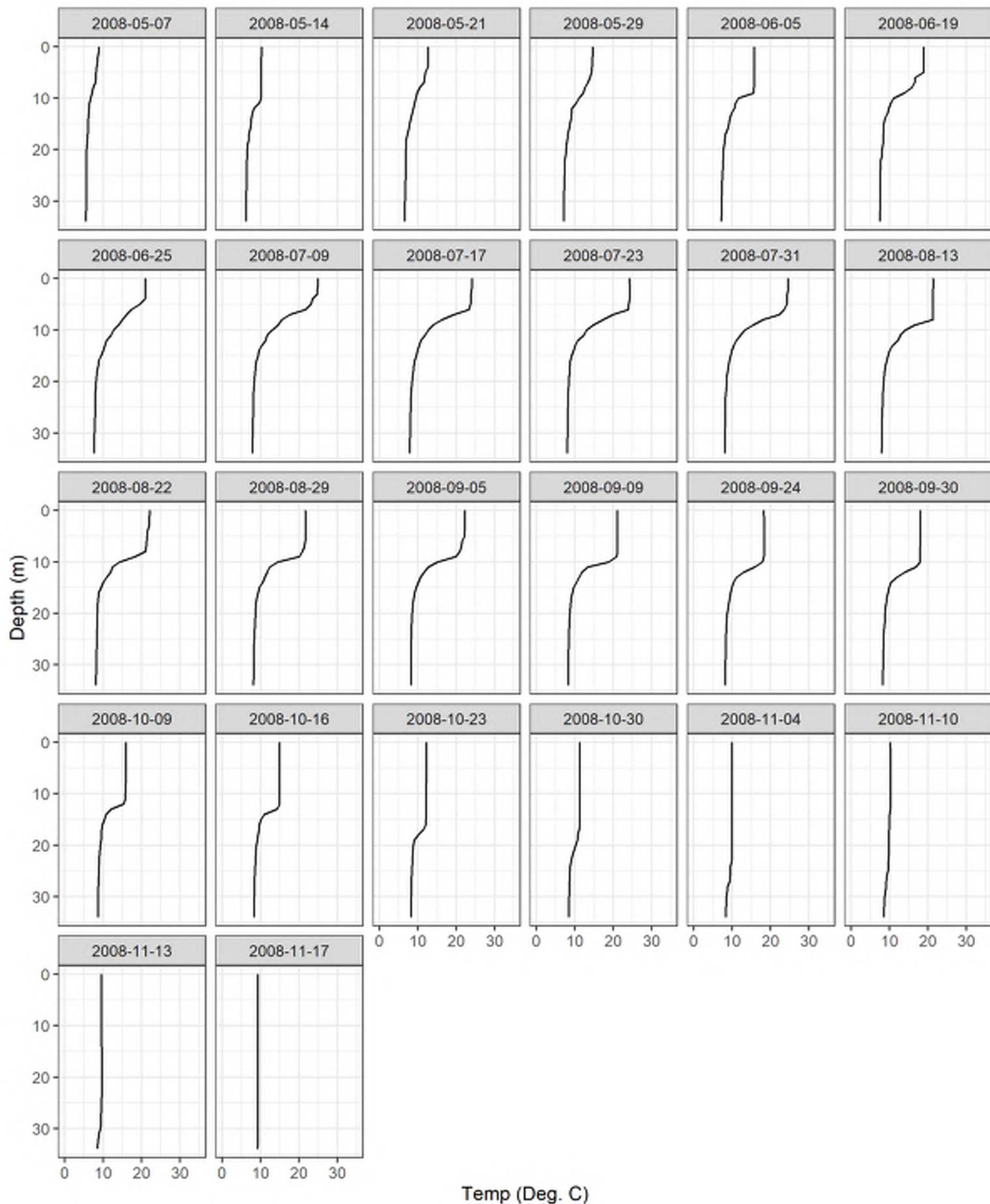


Temperature Profile: 2007



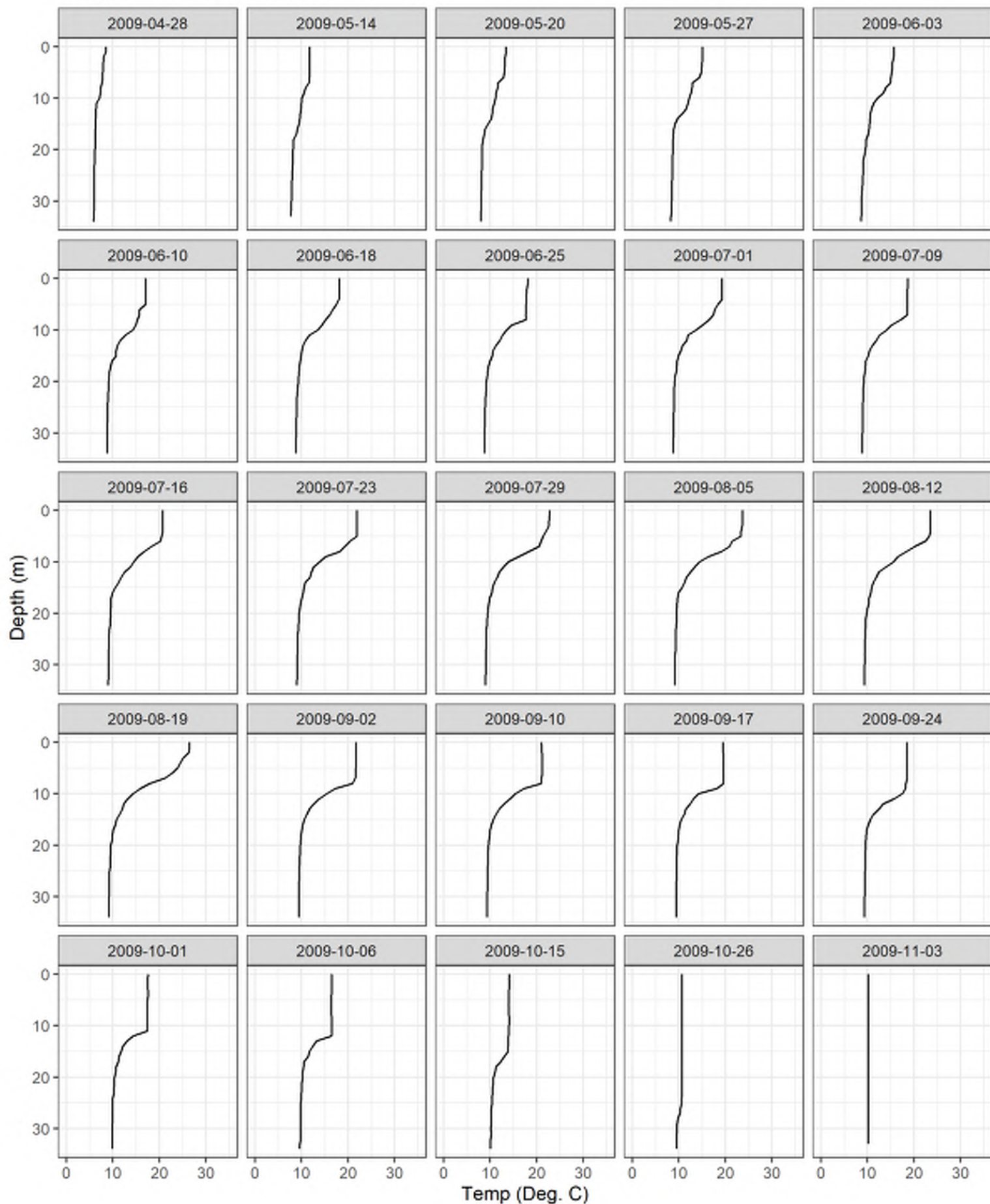
Station — 8 — 29 — 30 — 31 — 32

Temperature Profile: 2008

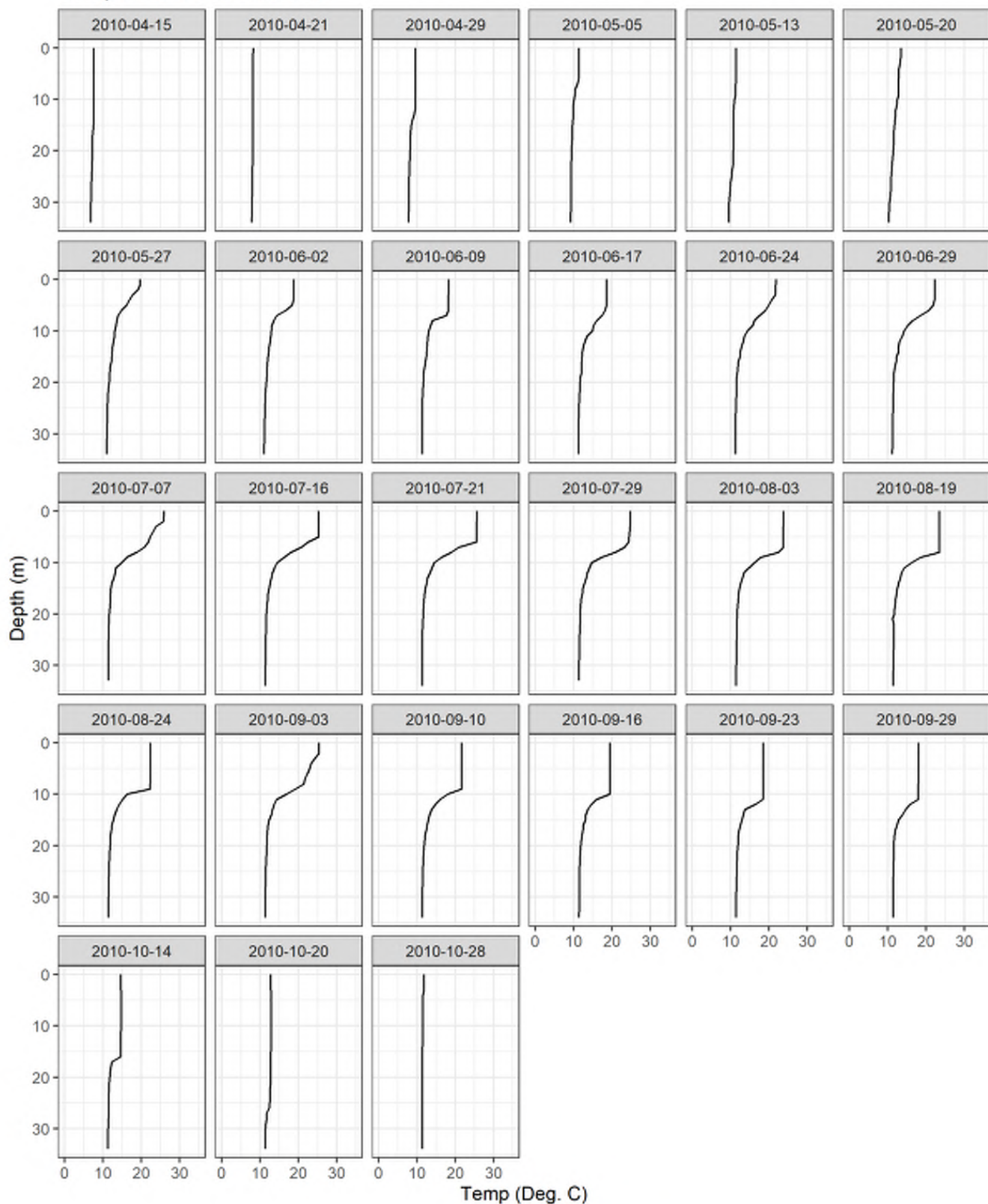


Station — 8 — 29 — 30 — 31 — 32

Temperature Profile: 2009

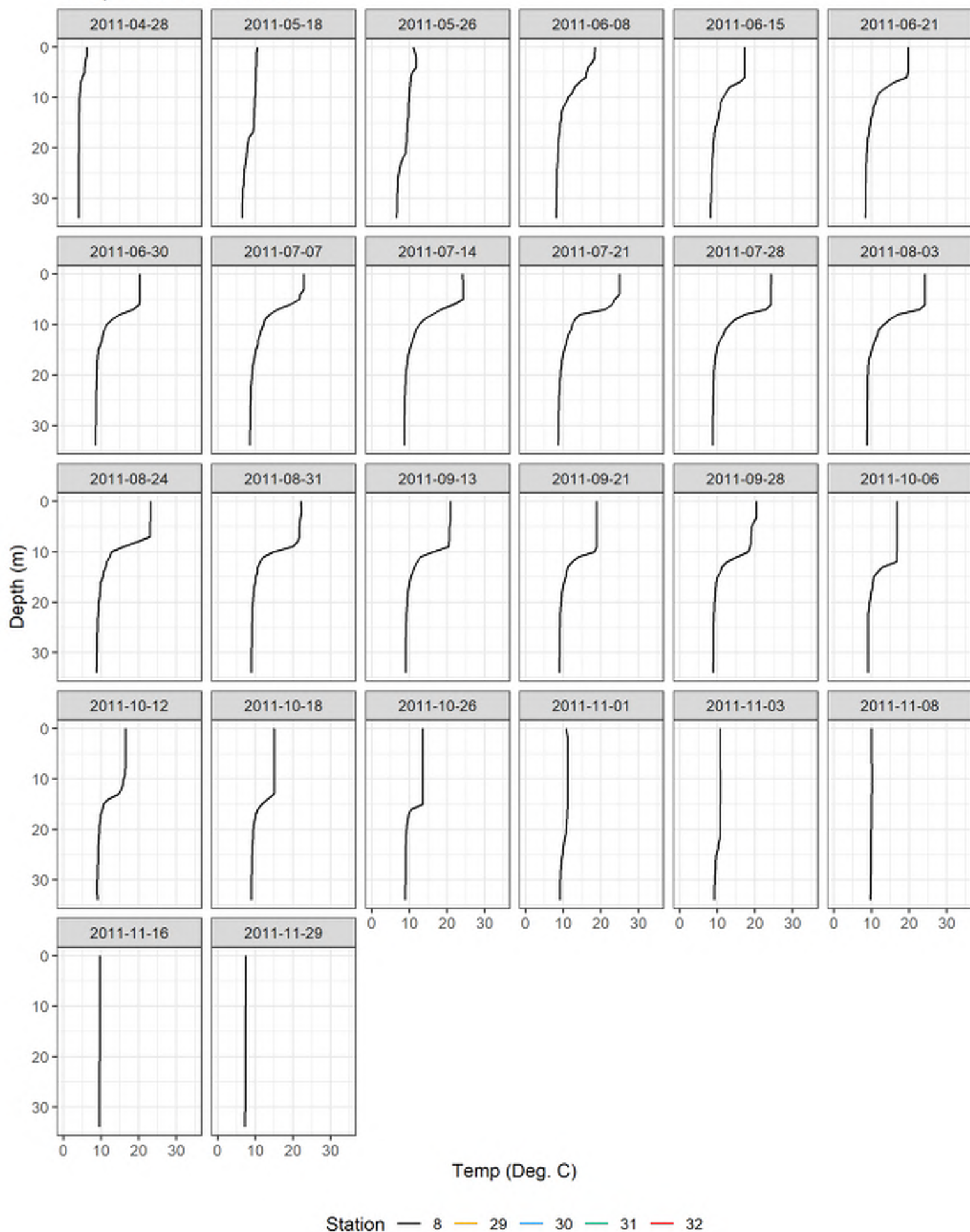


Temperature Profile: 2010

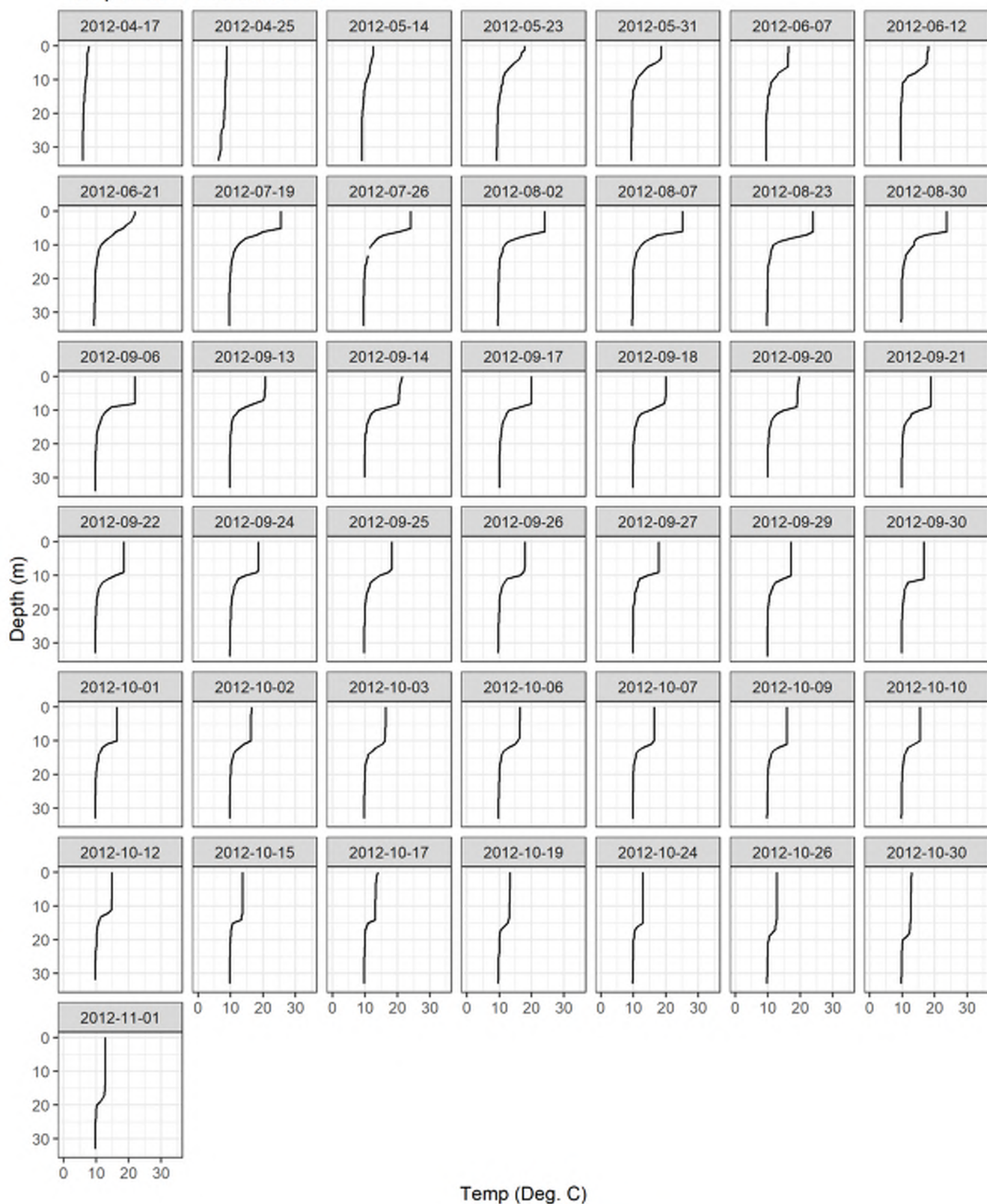


Station — 8 — 29 — 30 — 31 — 32

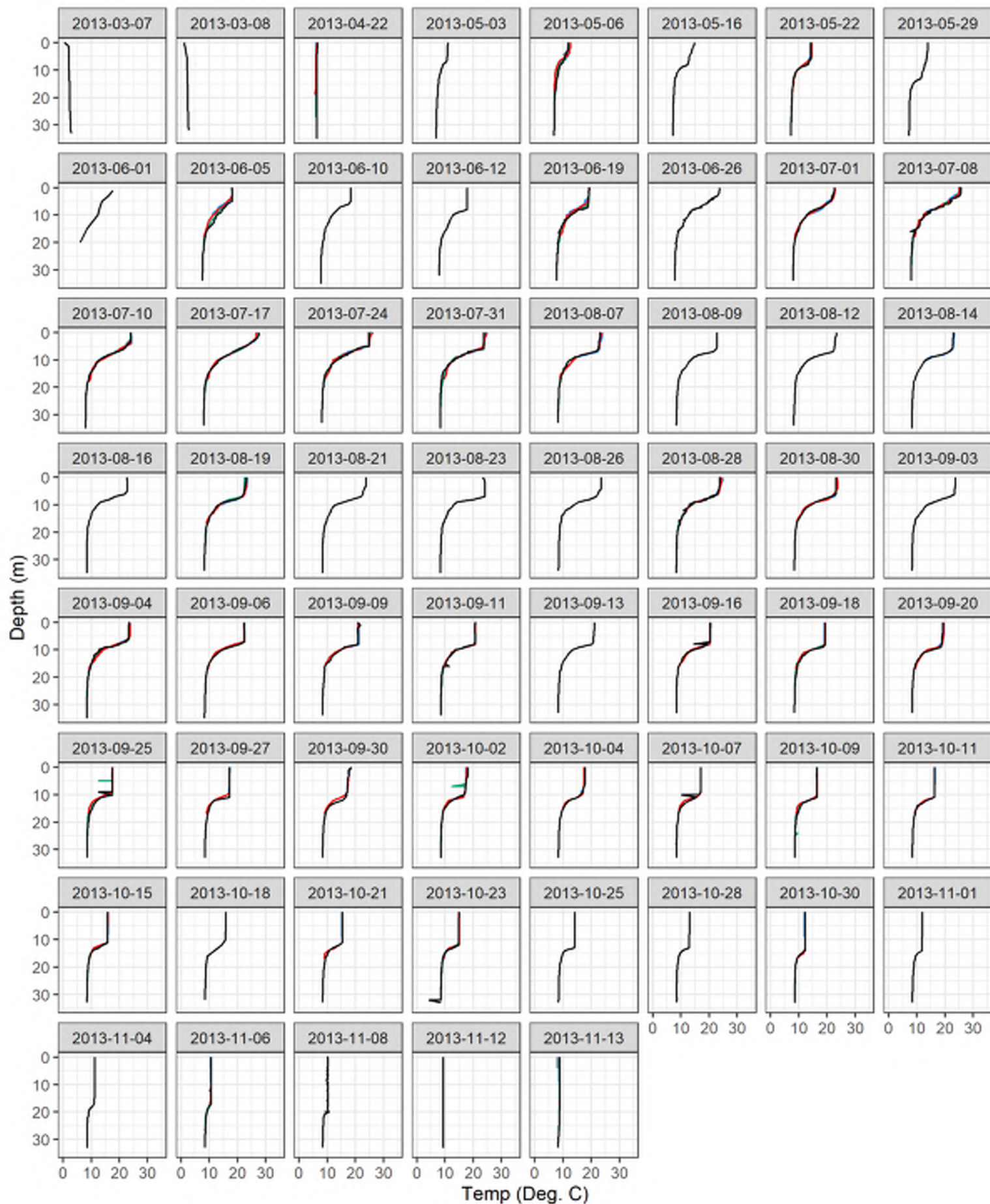
Temperature Profile: 2011



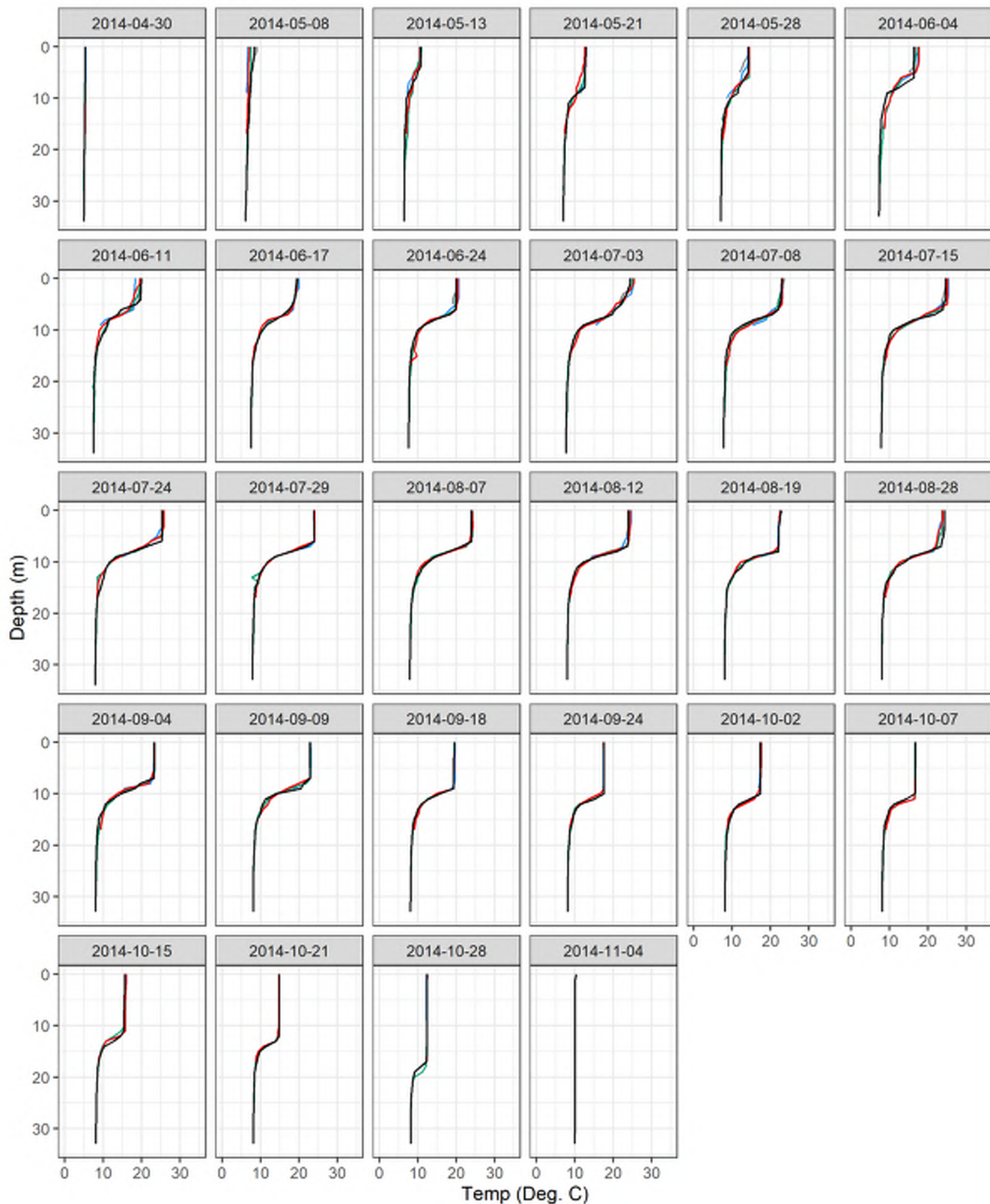
Temperature Profile: 2012



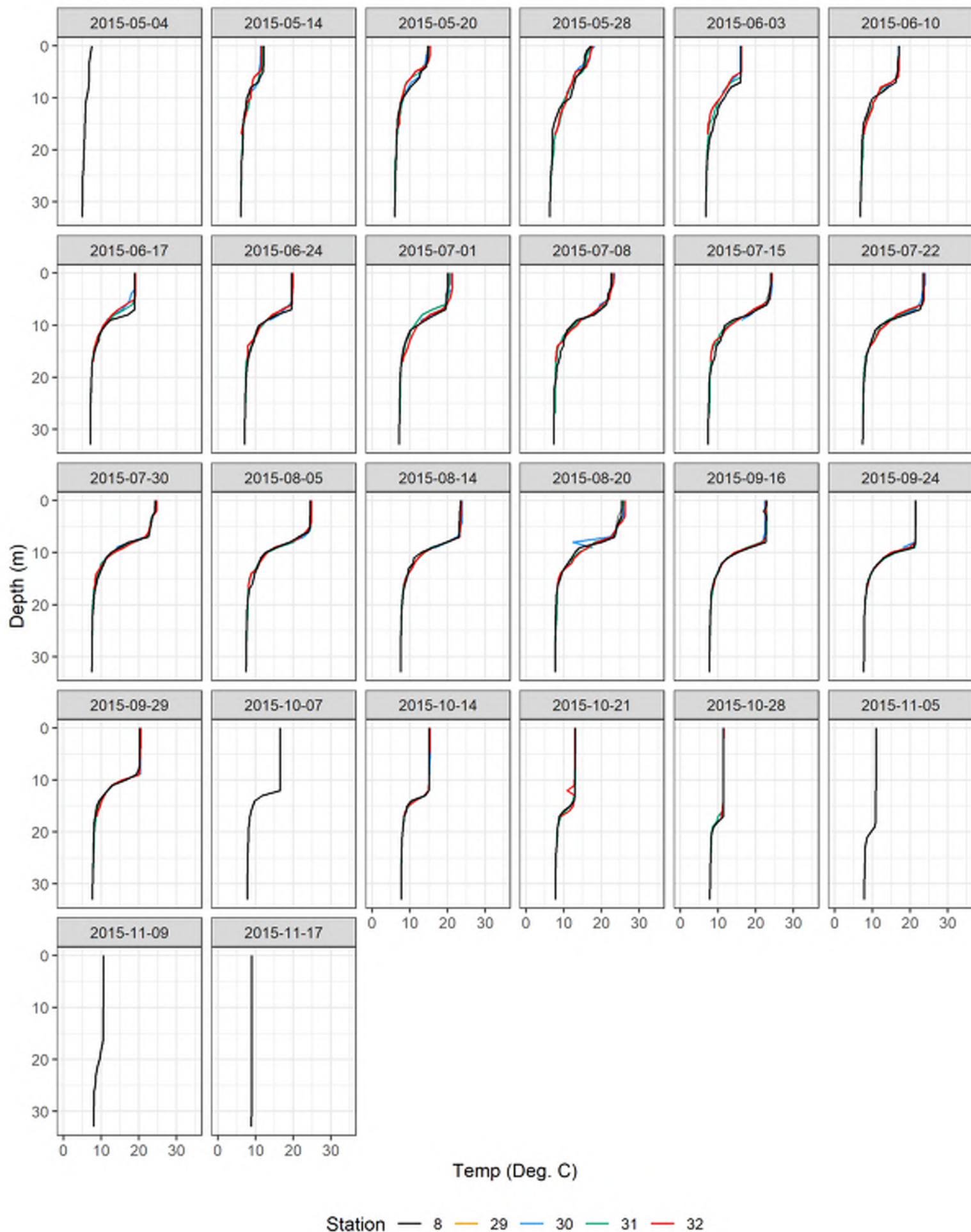
Temperature Profile: 2013



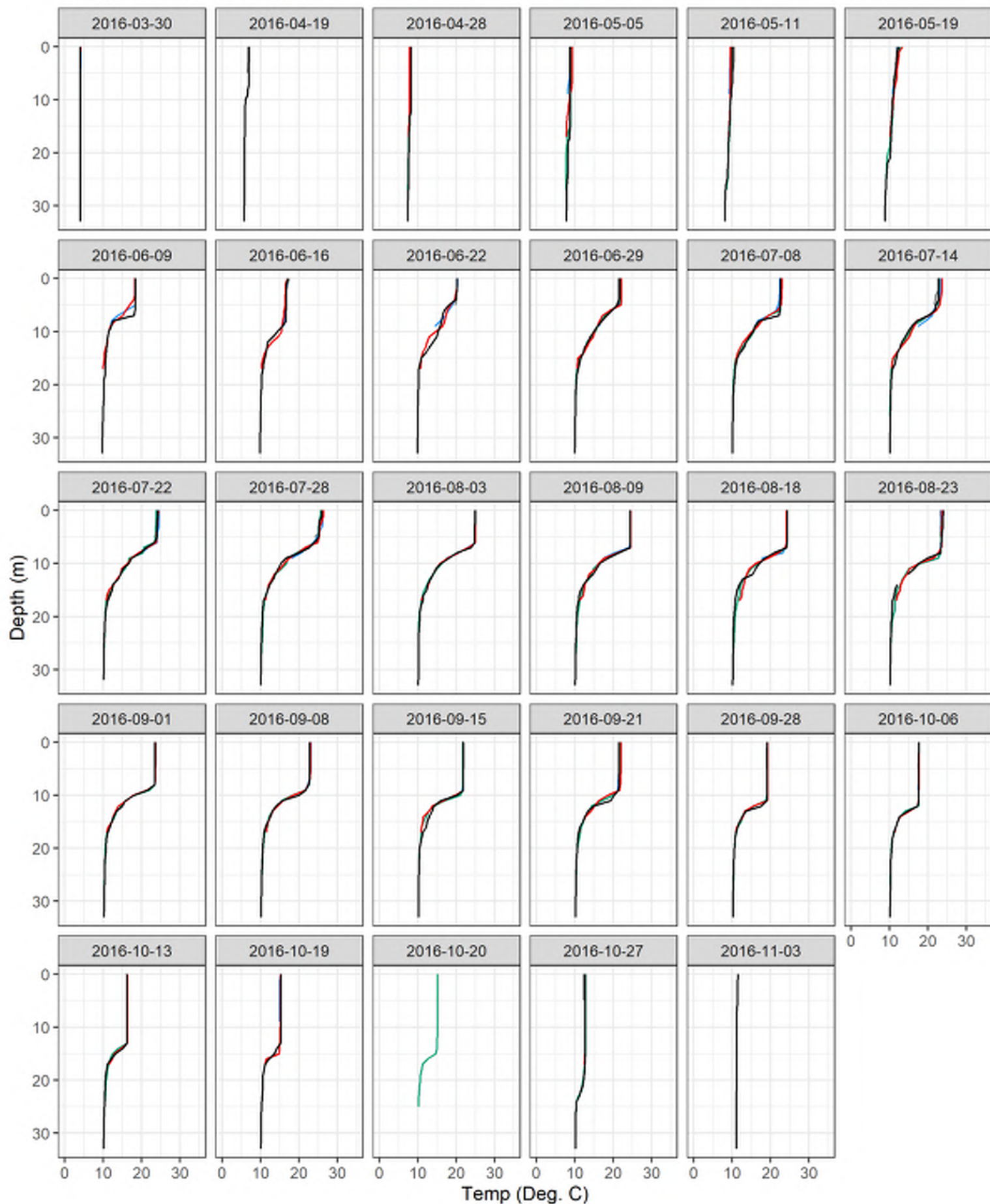
Temperature Profile: 2014



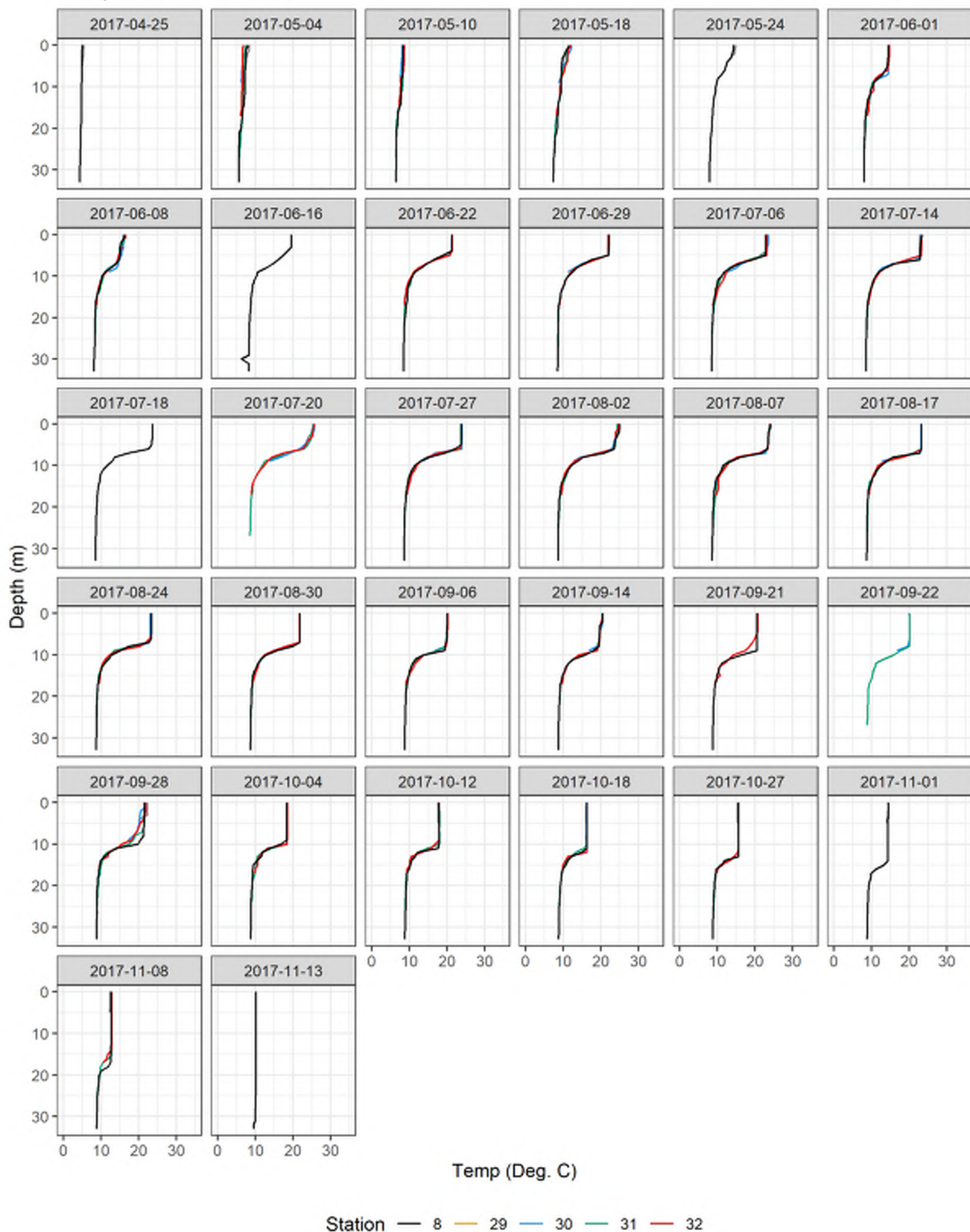
Temperature Profile: 2015



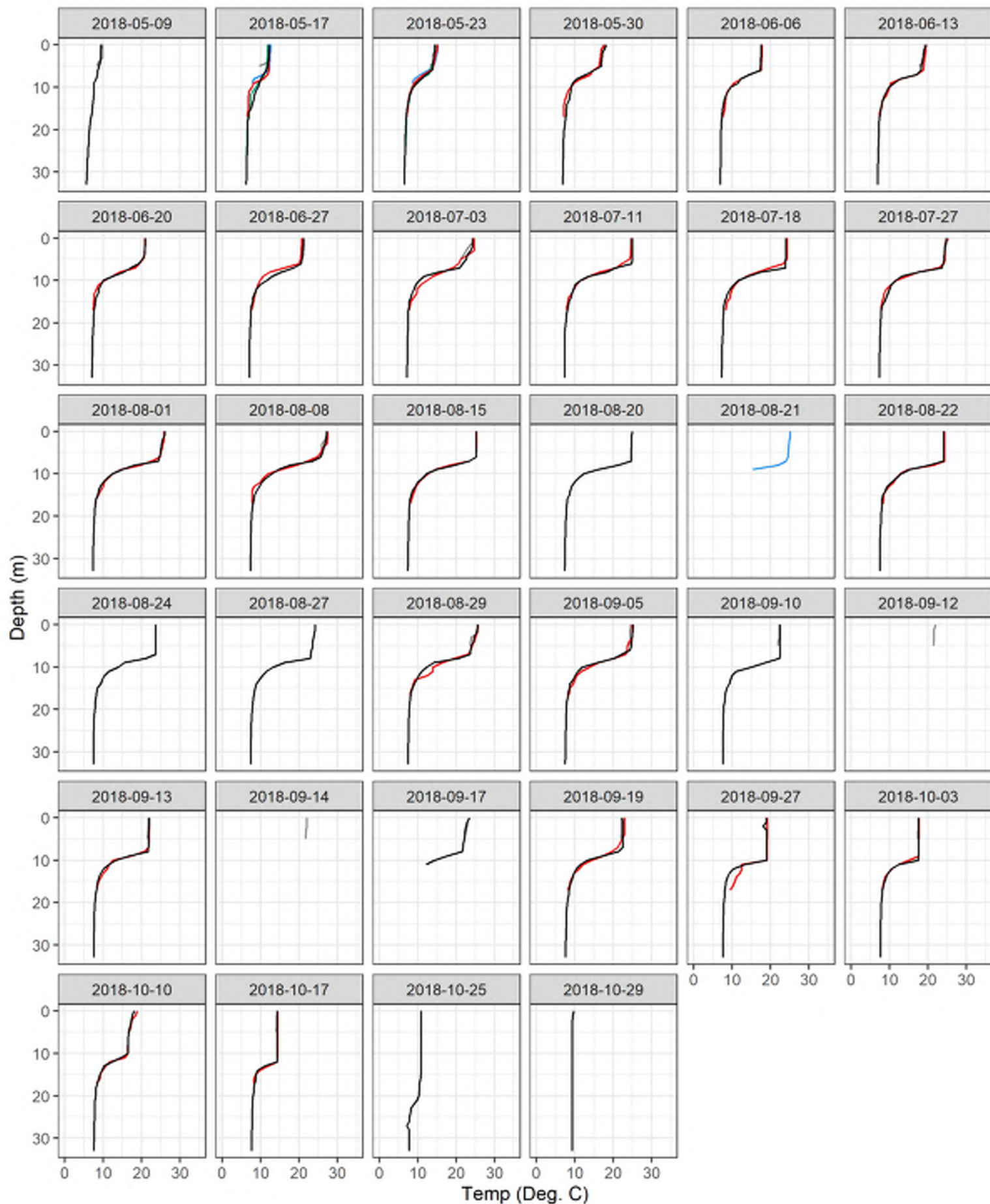
Temperature Profile: 2016



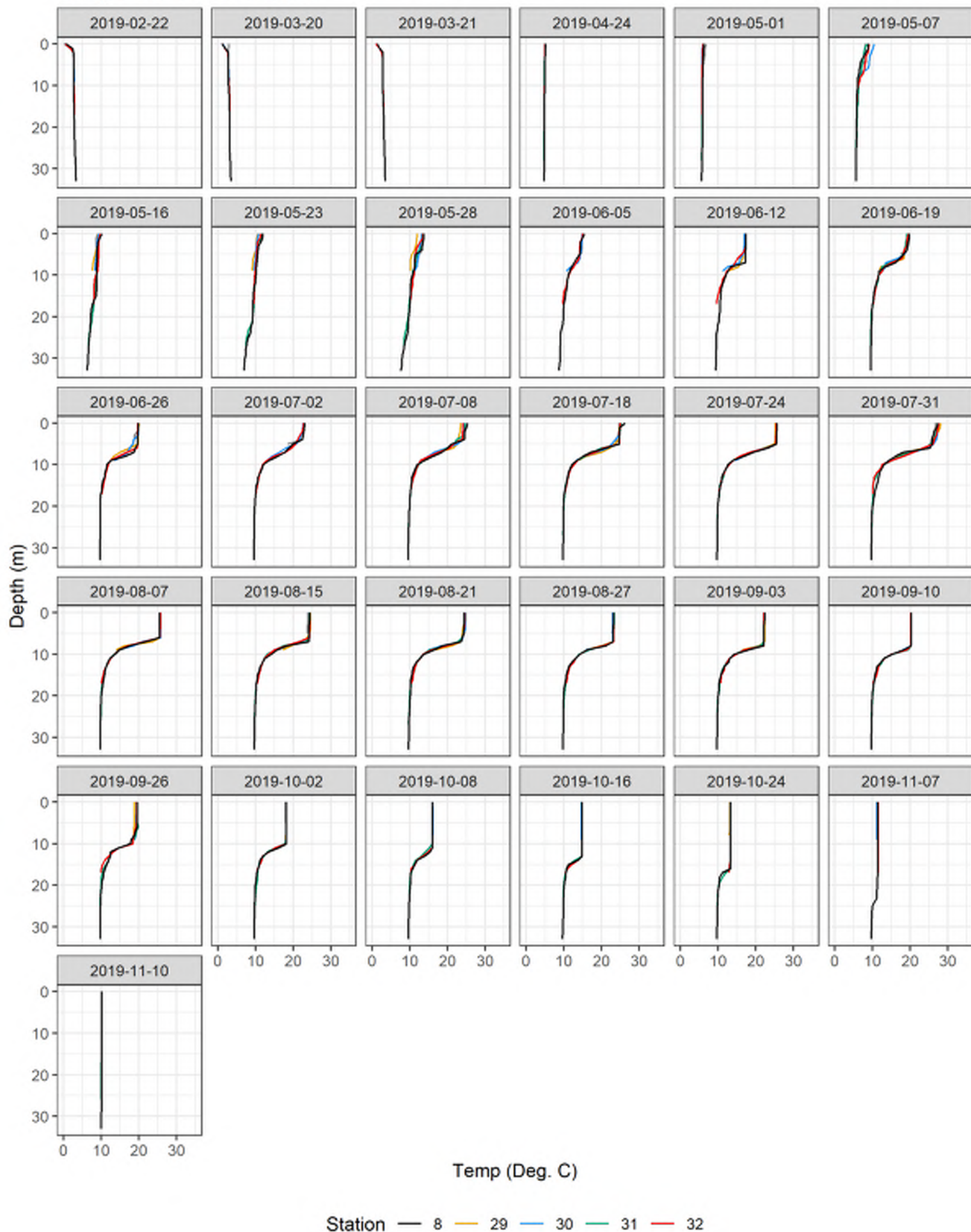
Temperature Profile: 2017



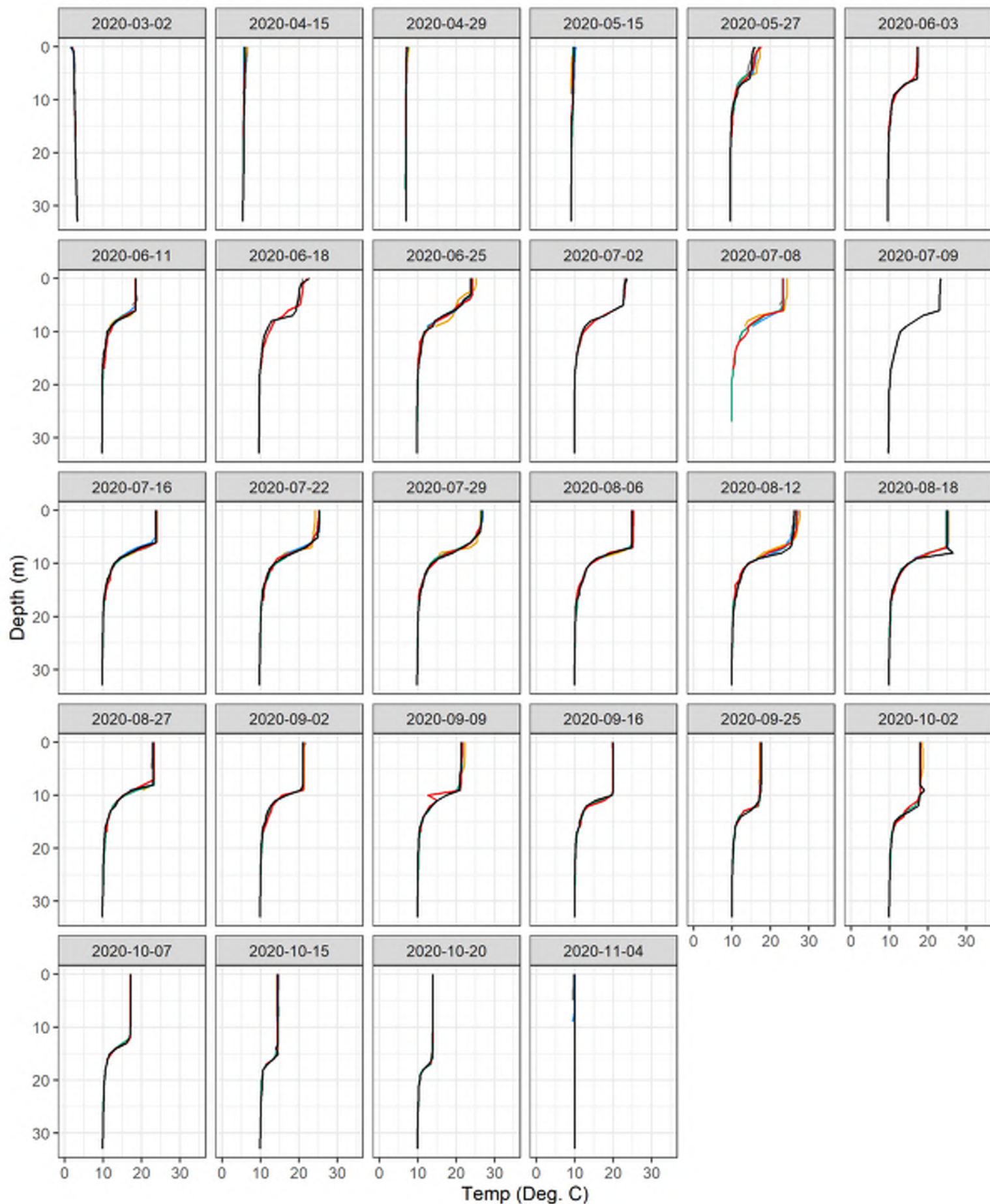
Temperature Profile: 2018



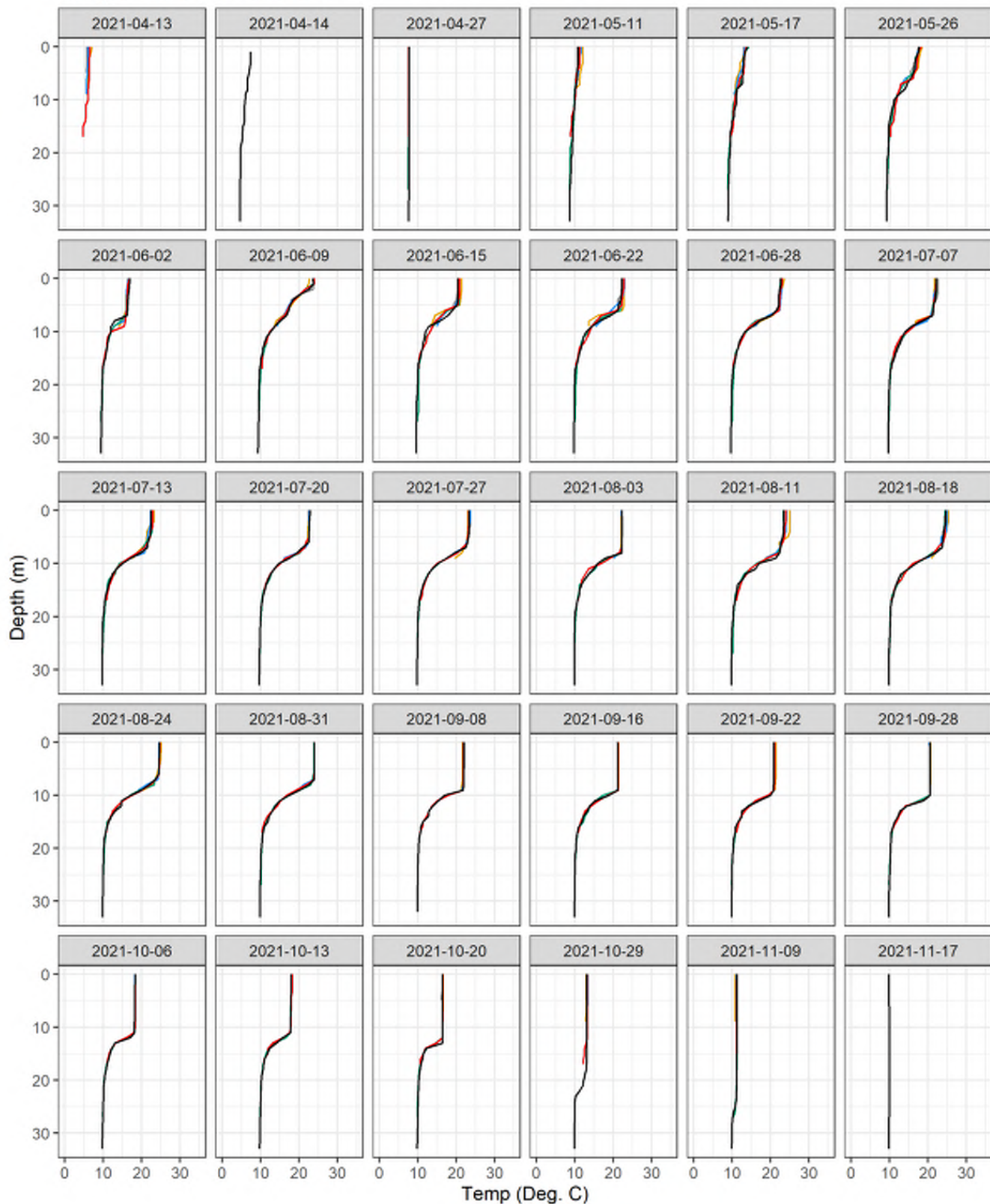
Temperature Profile: 2019



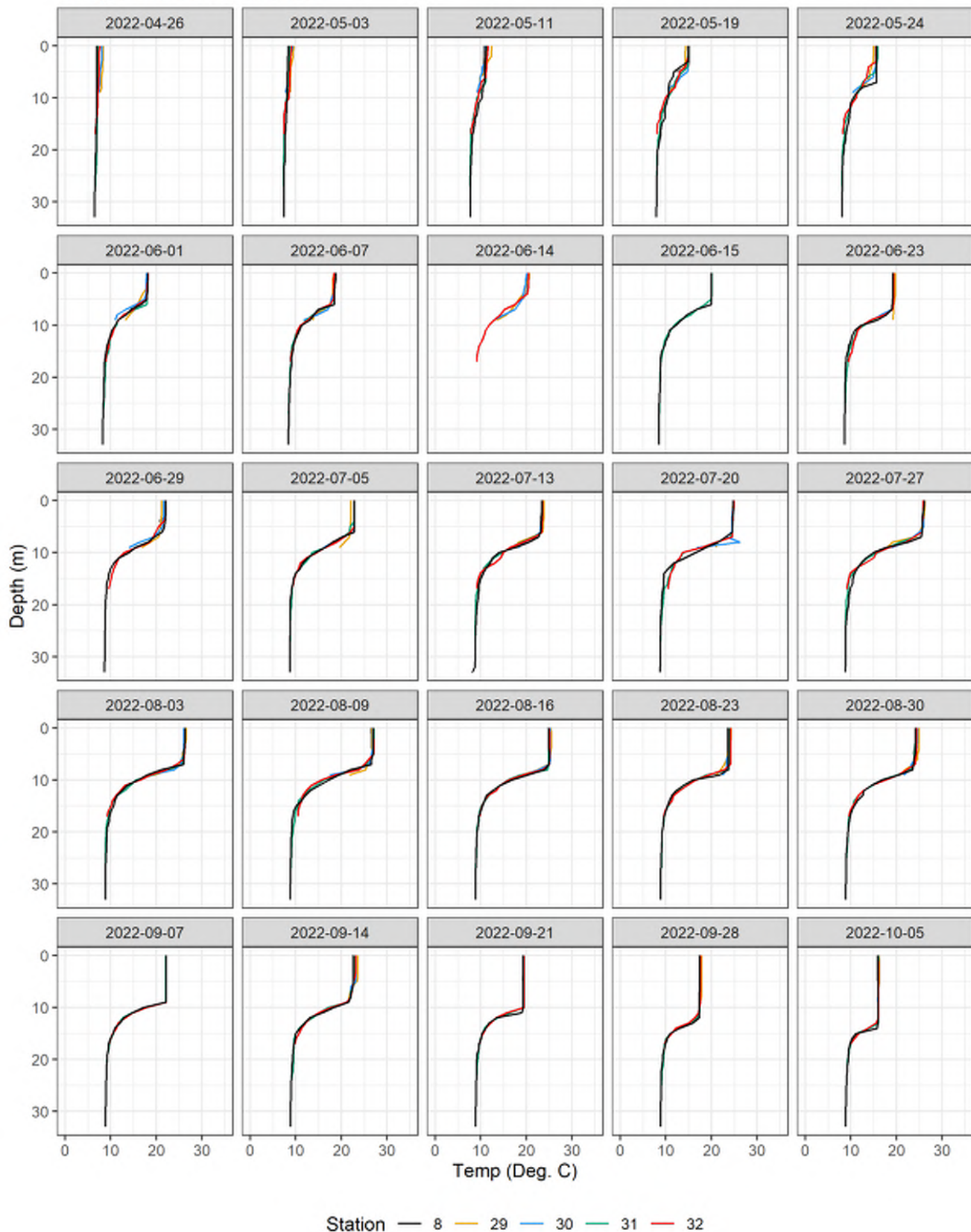
Temperature Profile: 2020



Temperature Profile: 2021

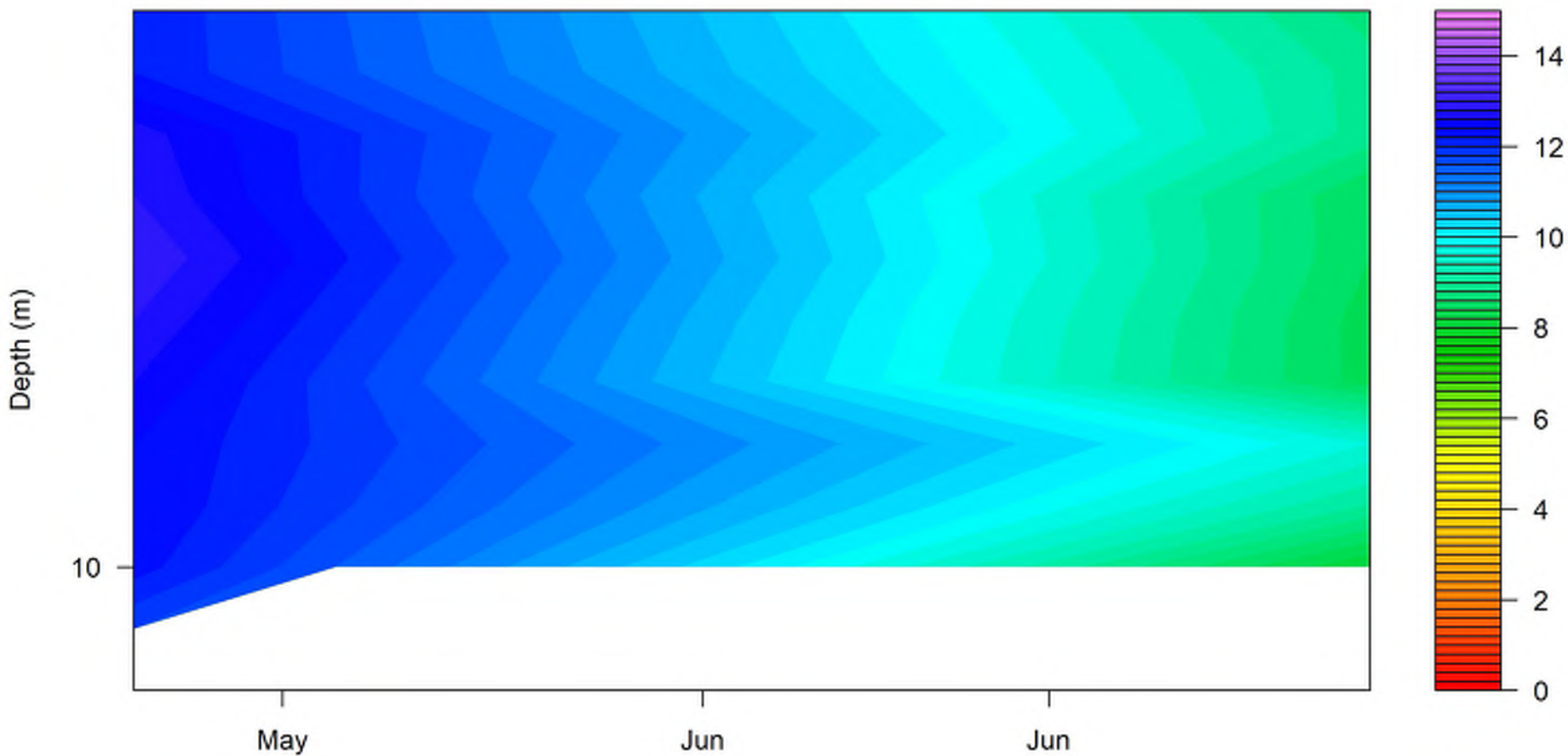


Temperature Profile: 2022



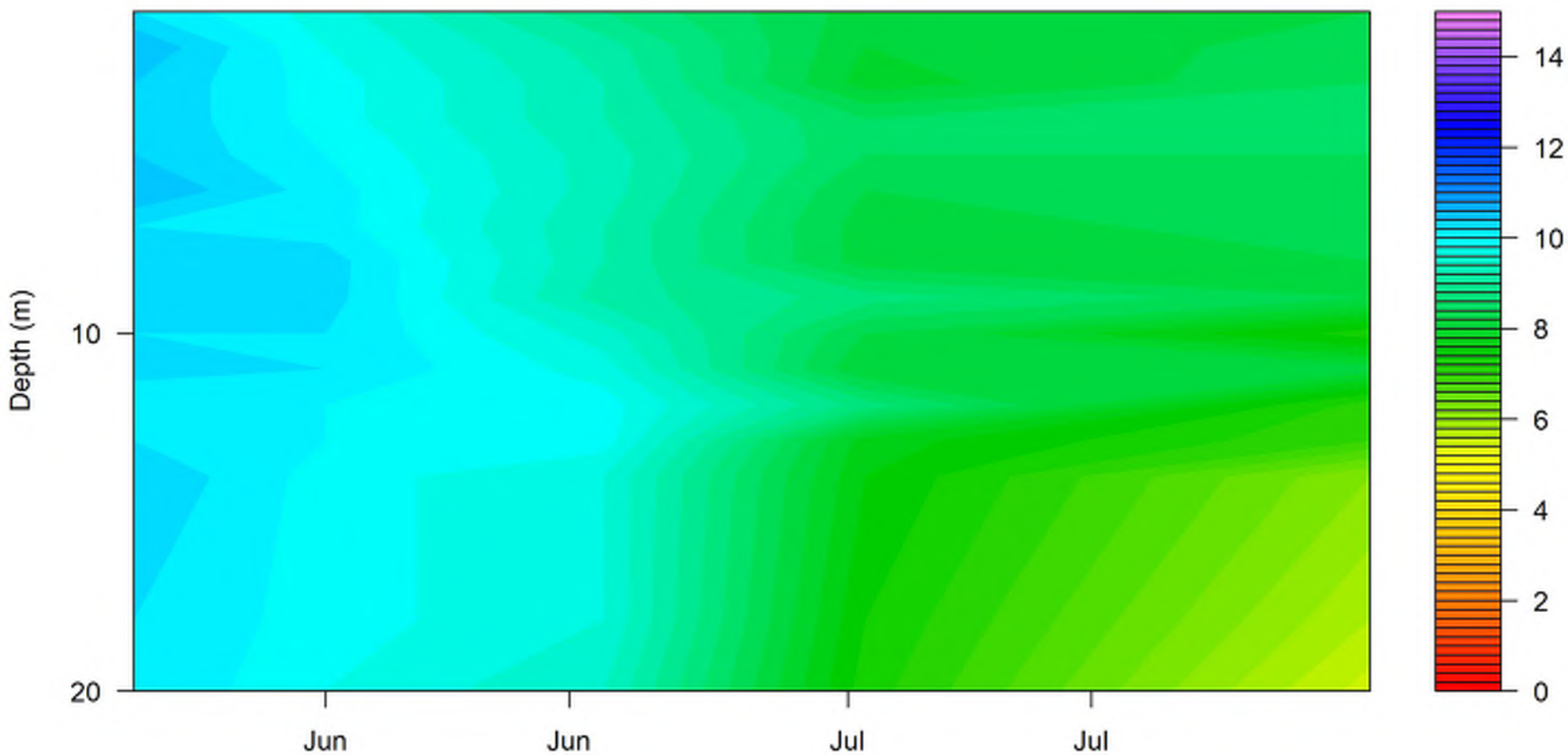
Station: 8 - DO - 1979

DO (mg/L)



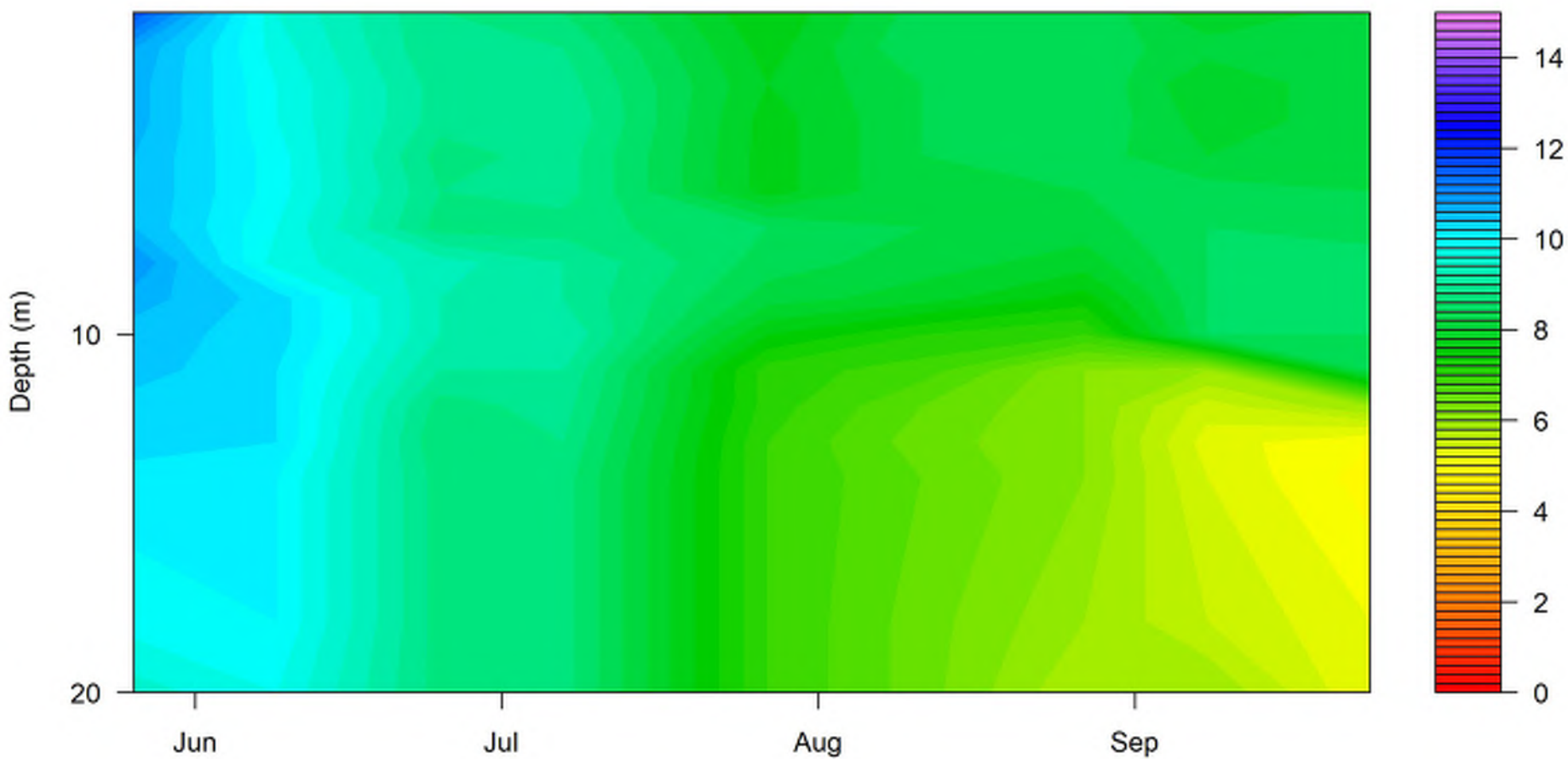
Station: 8 - DO - 1981

DO (mg/L)



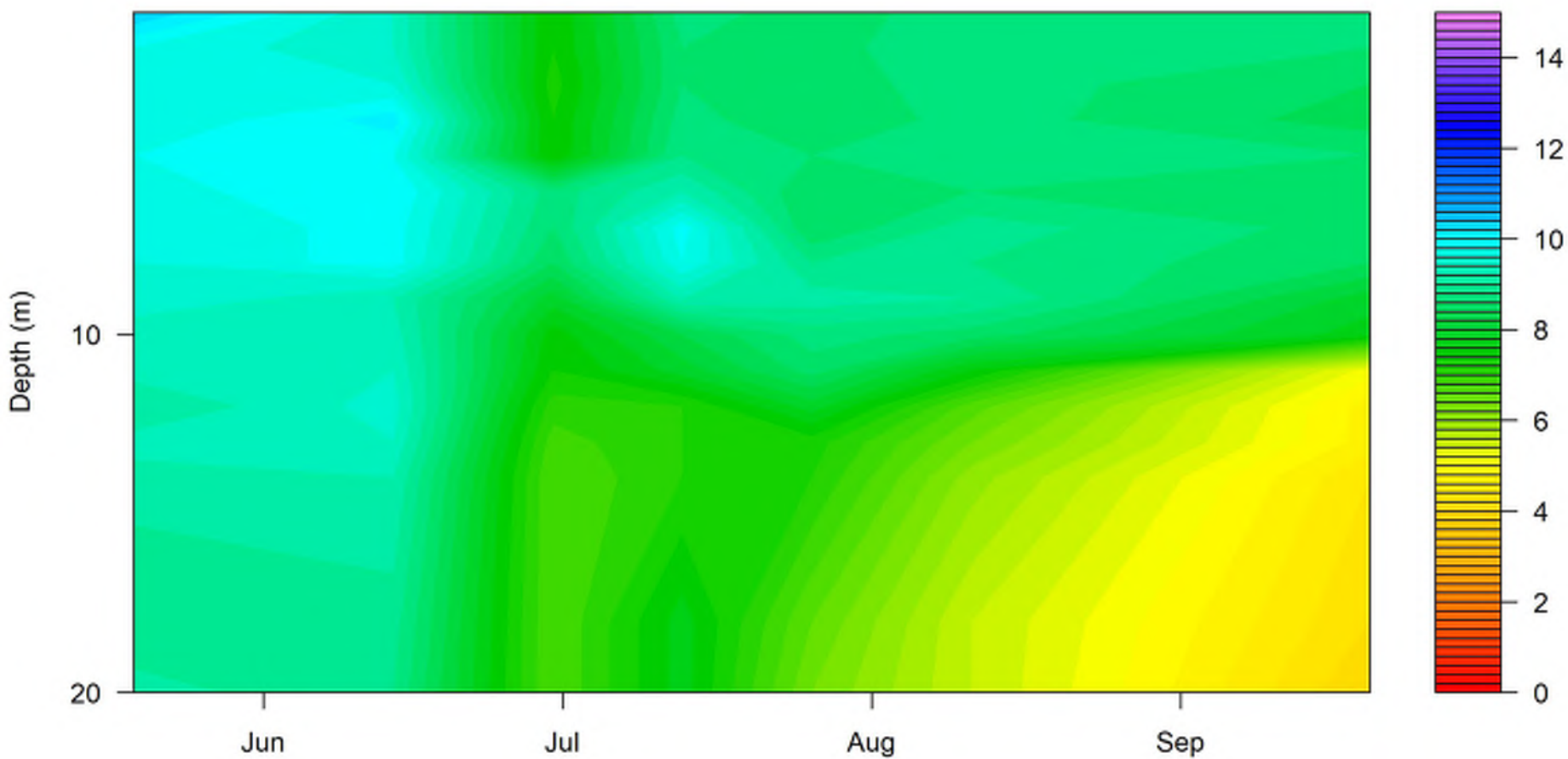
Station: 8 - DO - 1982

DO (mg/L)



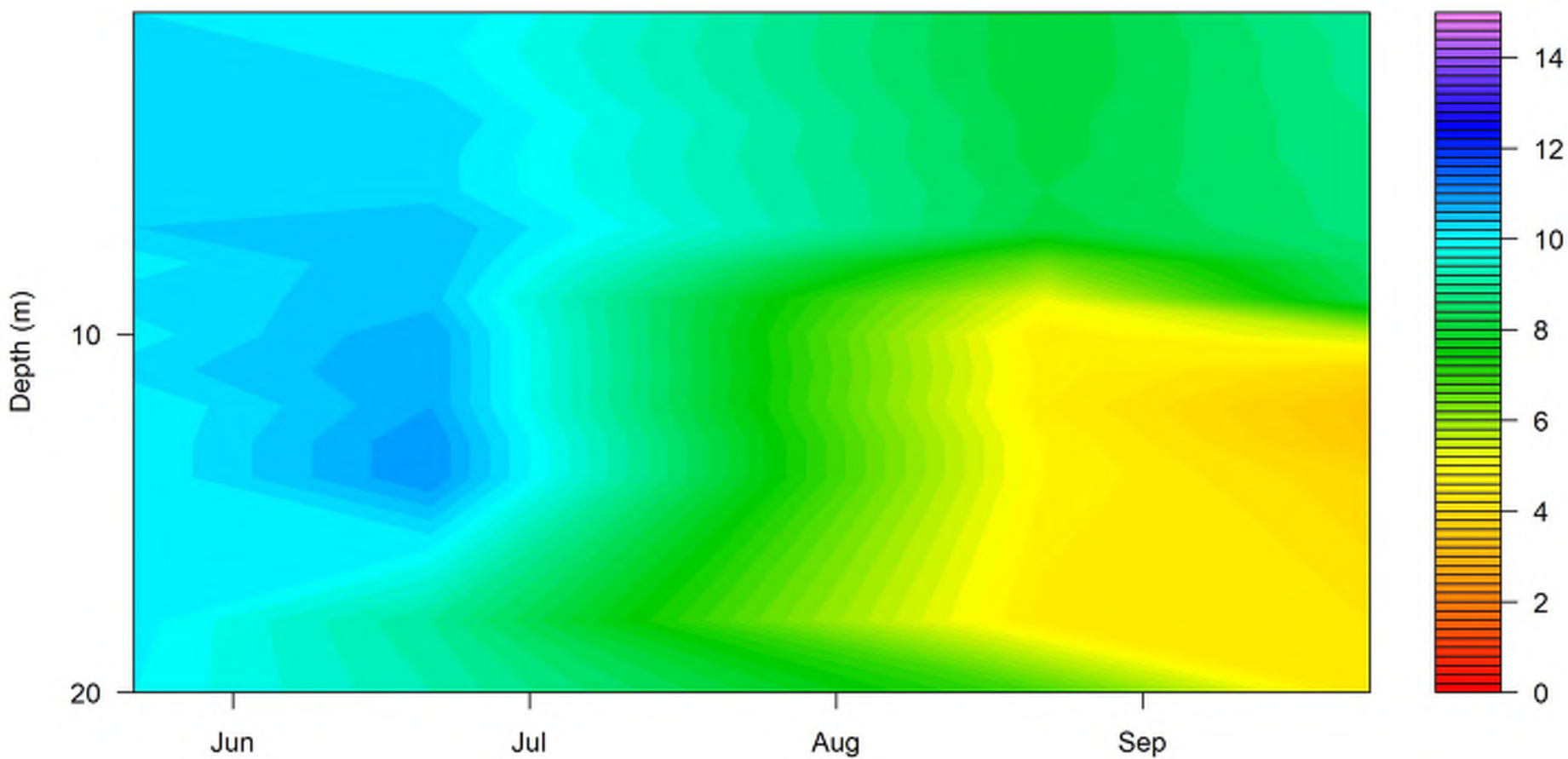
Station: 8 - DO - 1983

DO (mg/L)



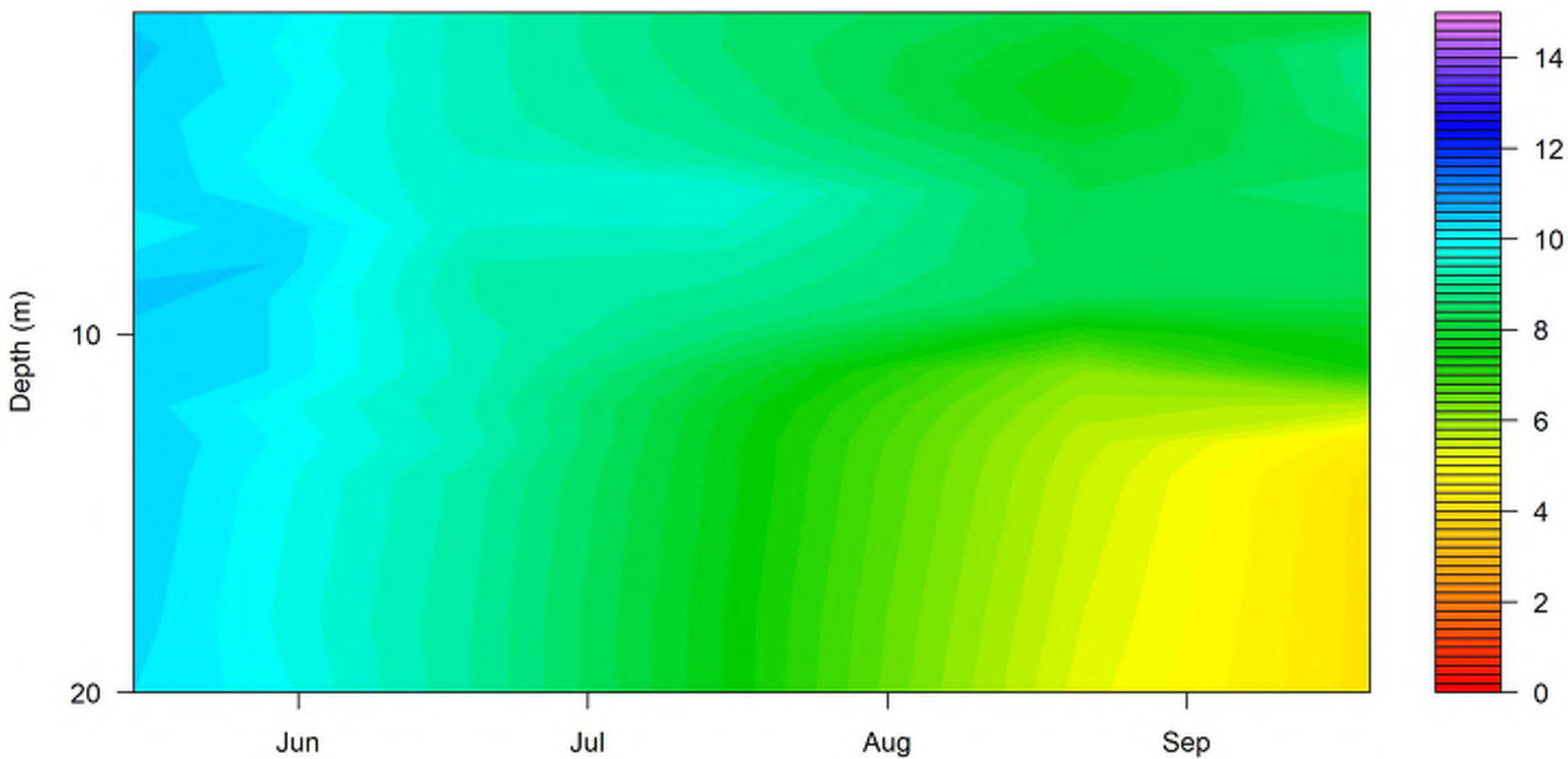
Station: 8 - DO - 1984

DO (mg/L)



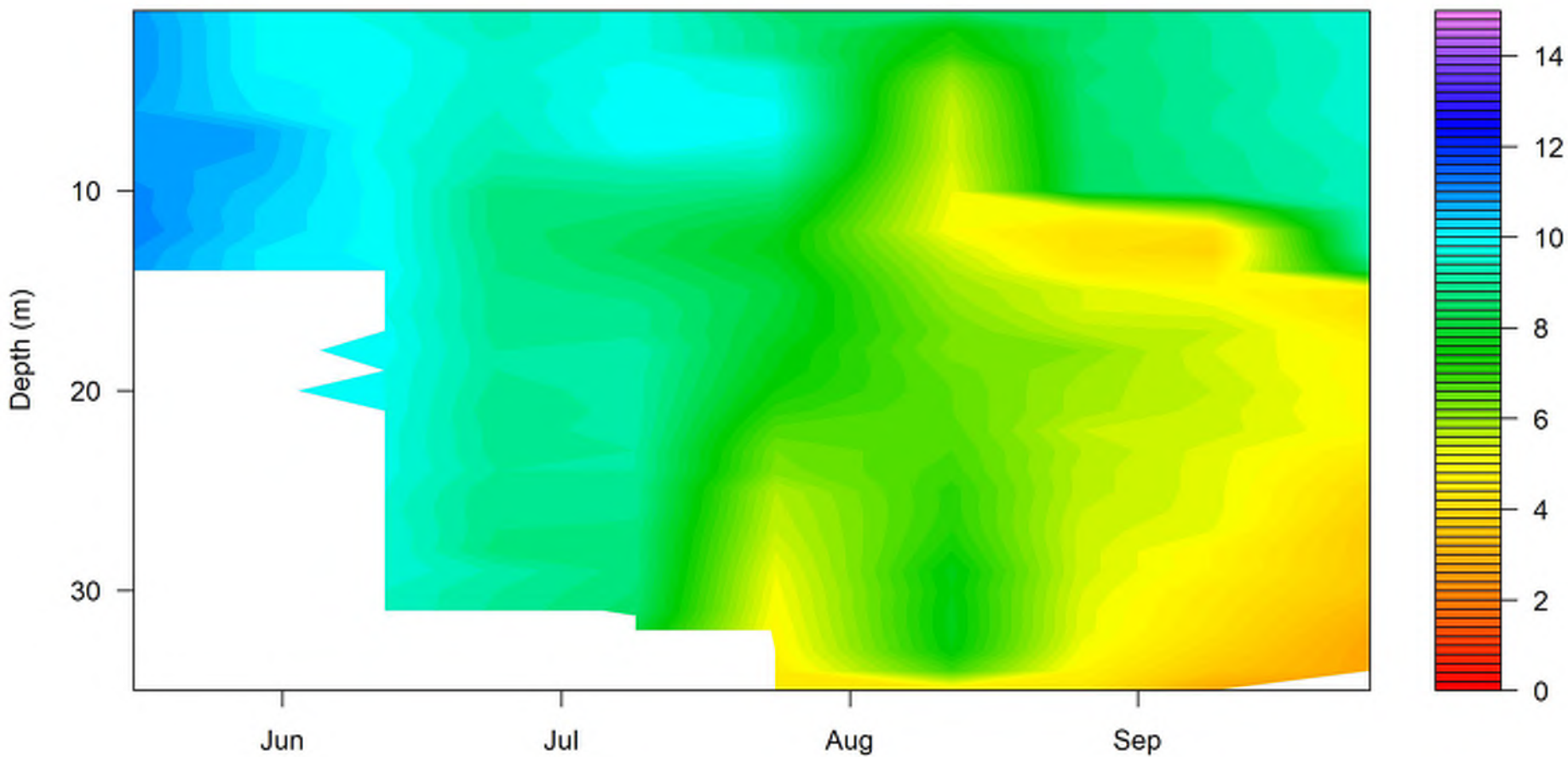
Station: 8 - DO - 1985

DO (mg/L)



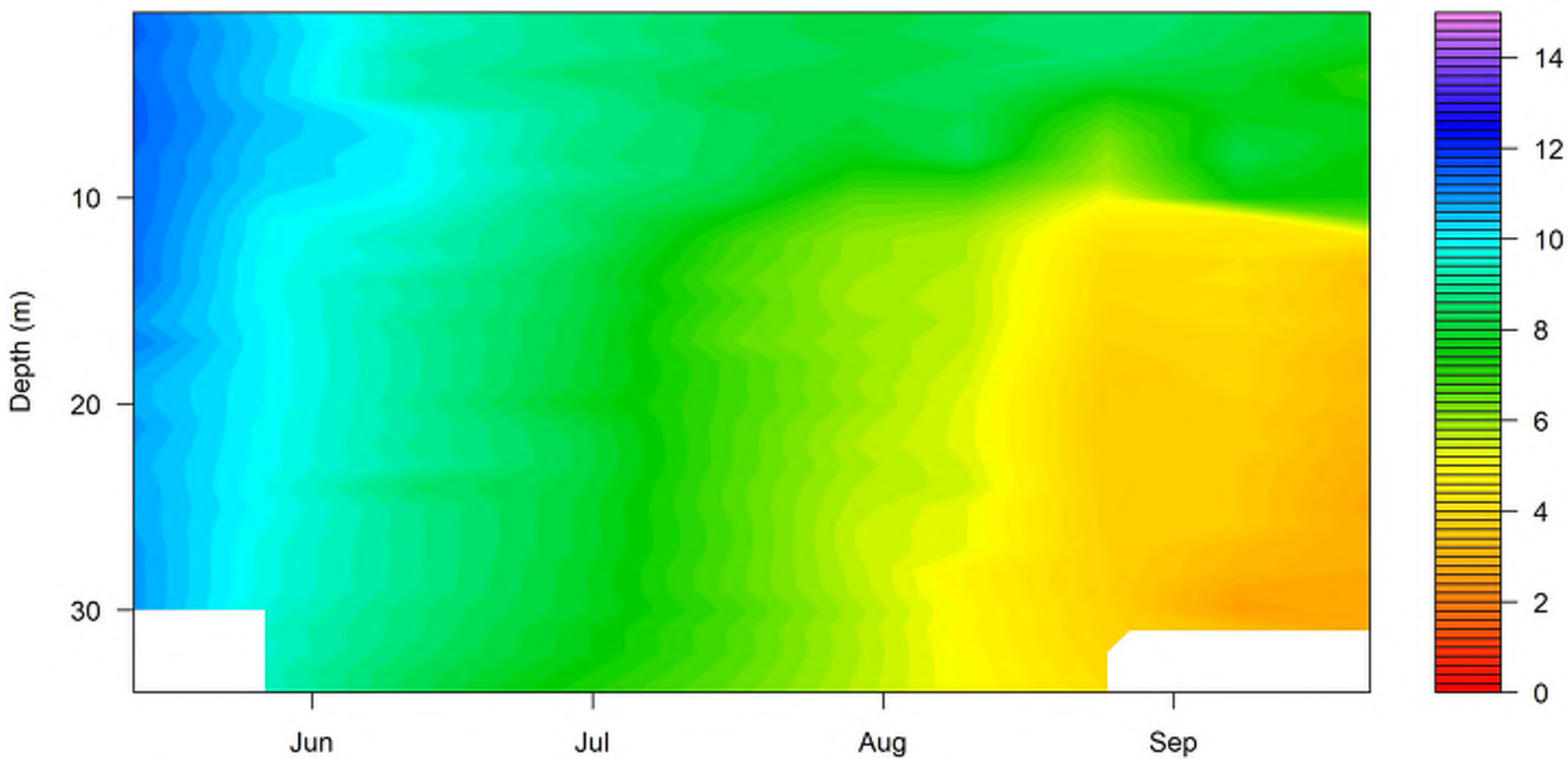
Station: 8 - DO - 1986

DO (mg/L)



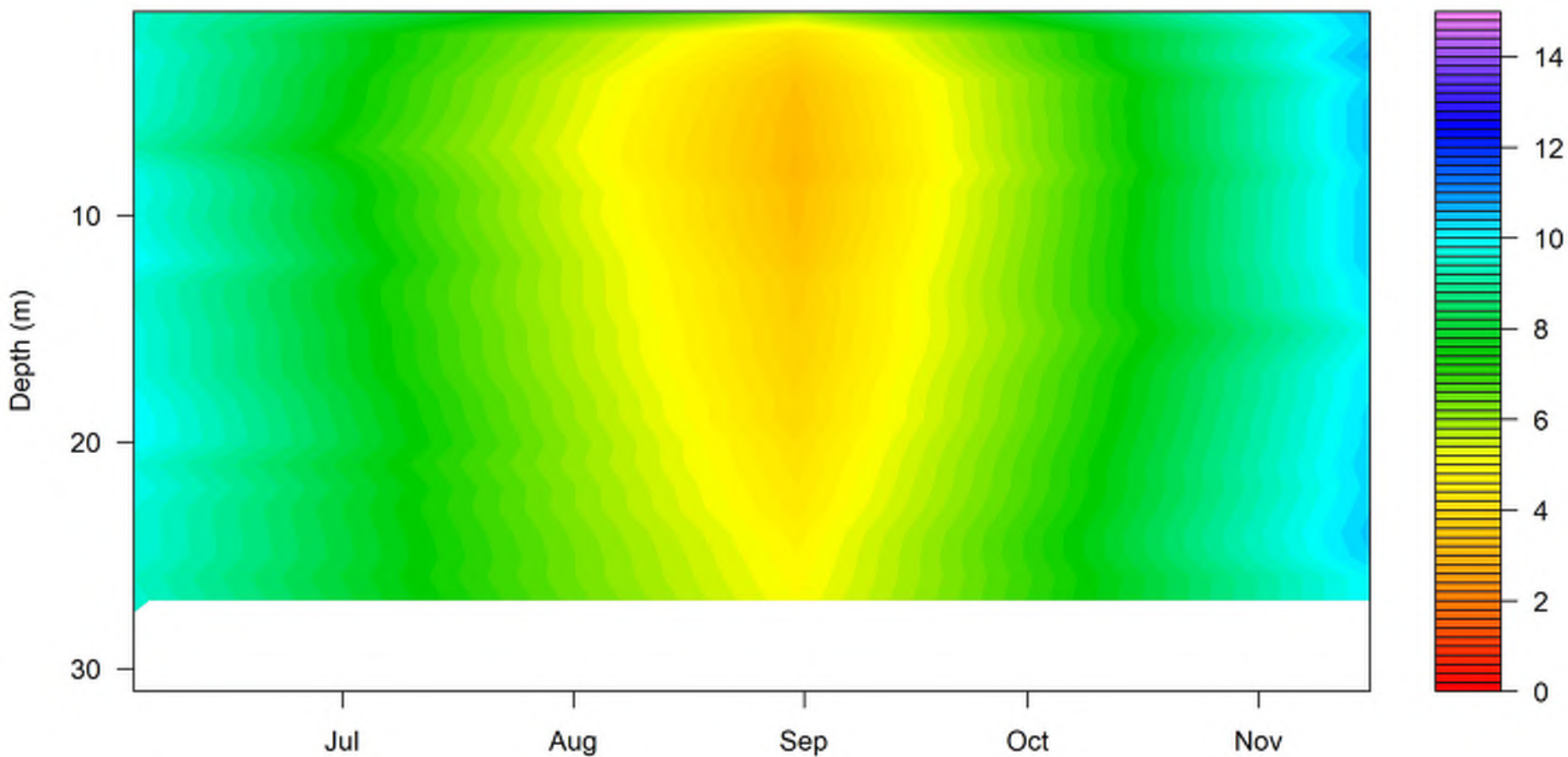
Station: 8 - DO - 1987

DO (mg/L)



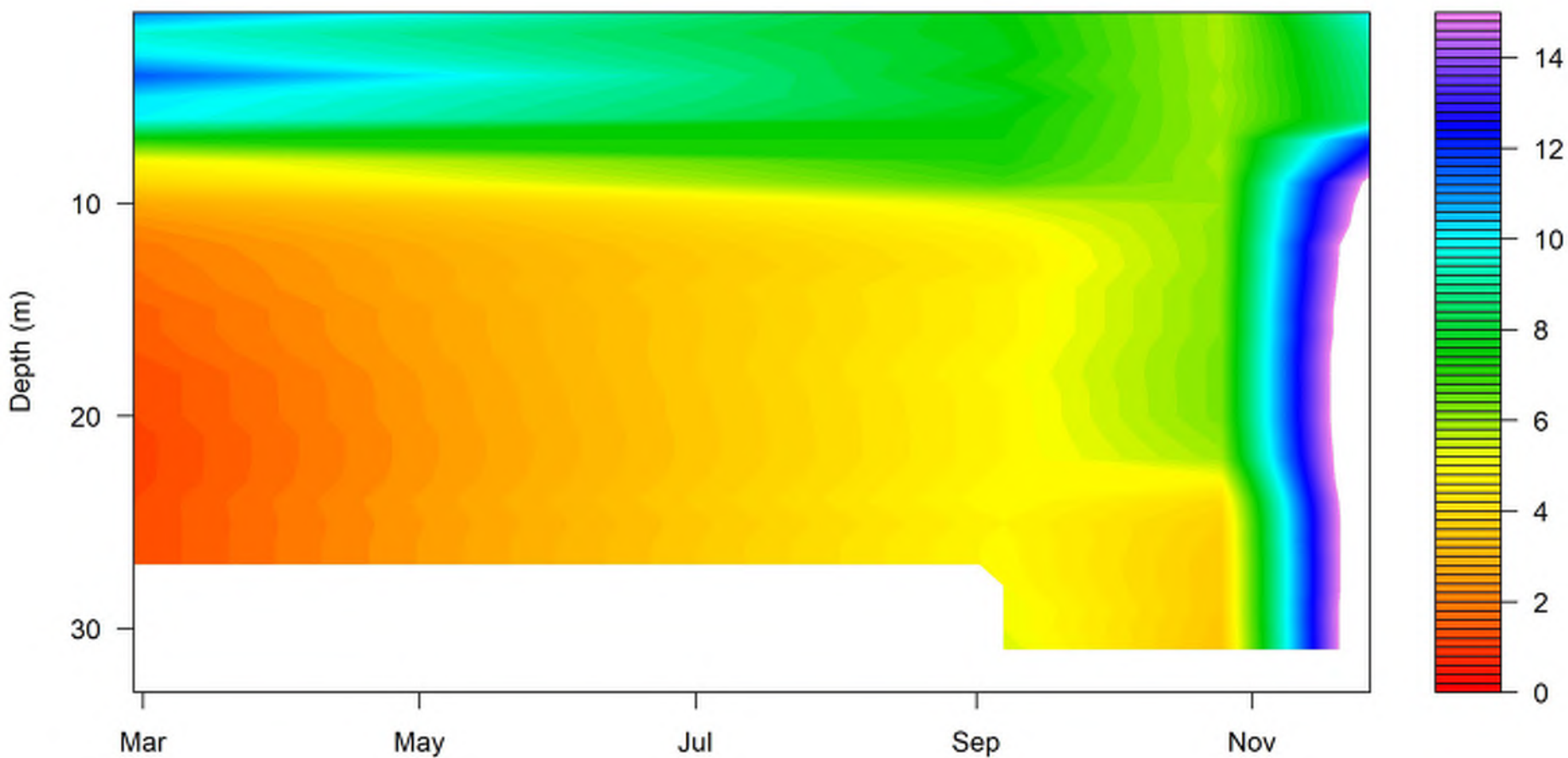
Station: 8 - DO - 1988

DO (mg/L)



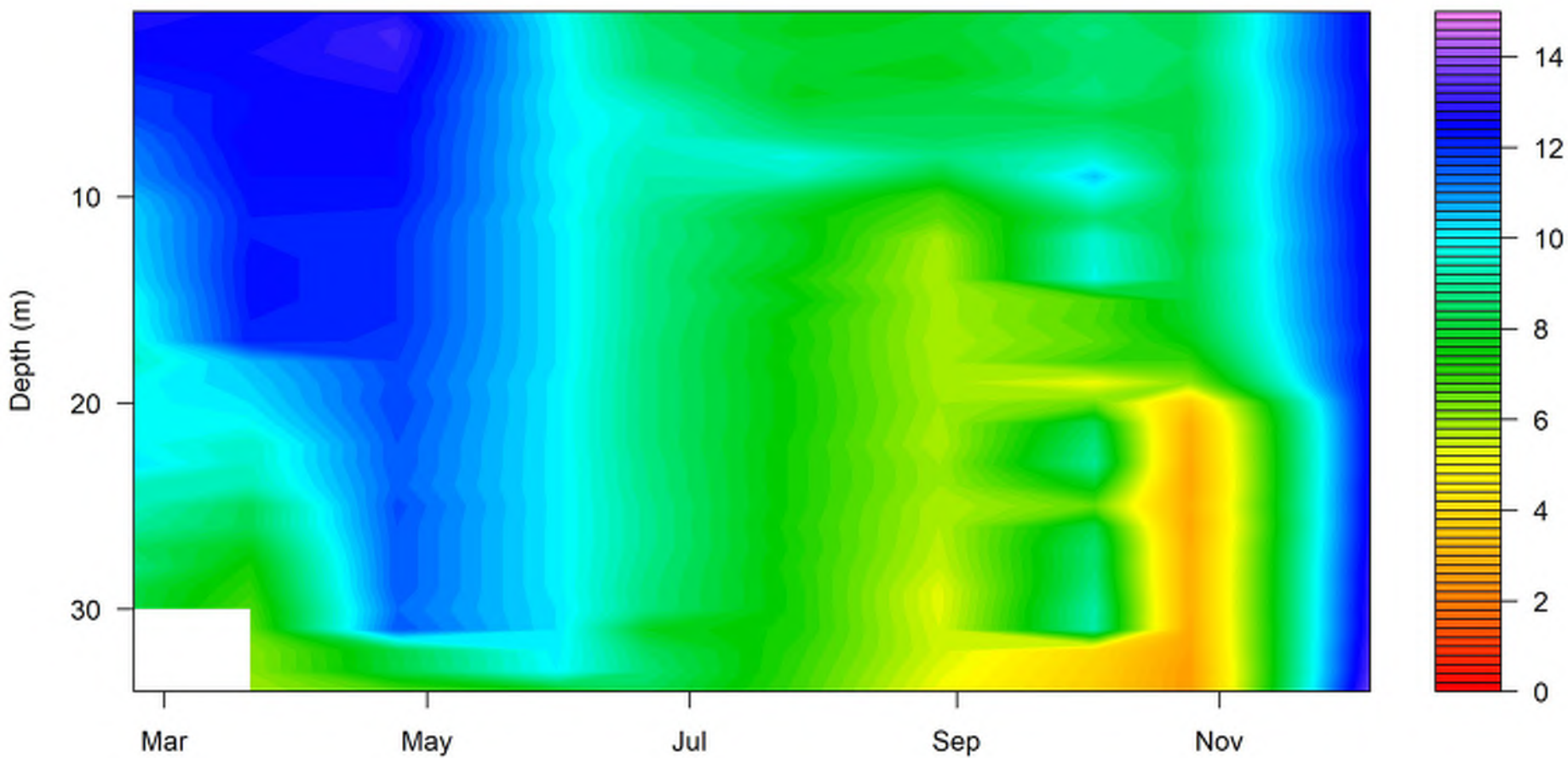
Station: 8 - DO - 1989

DO (mg/L)



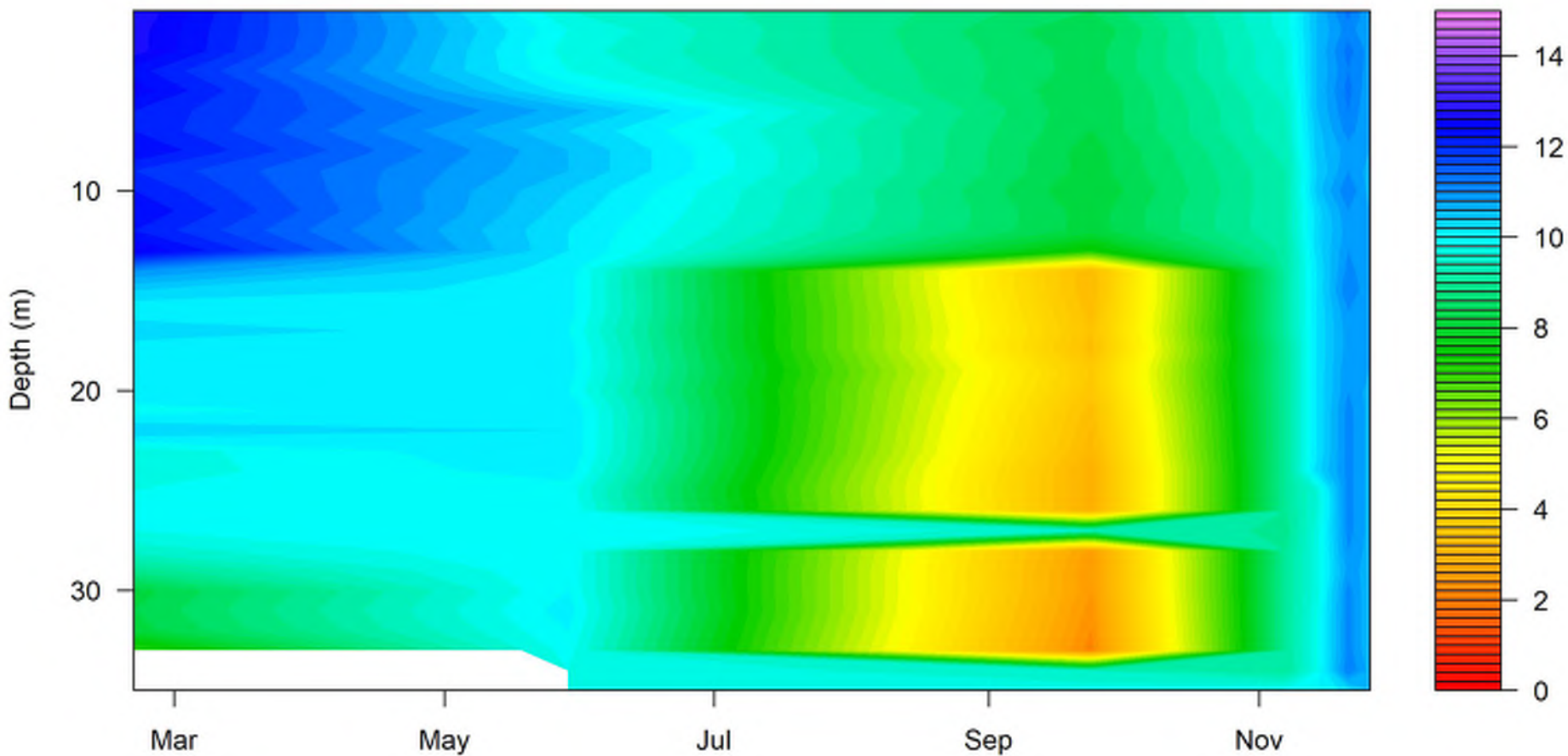
Station: 8 - DO - 1990

DO (mg/L)



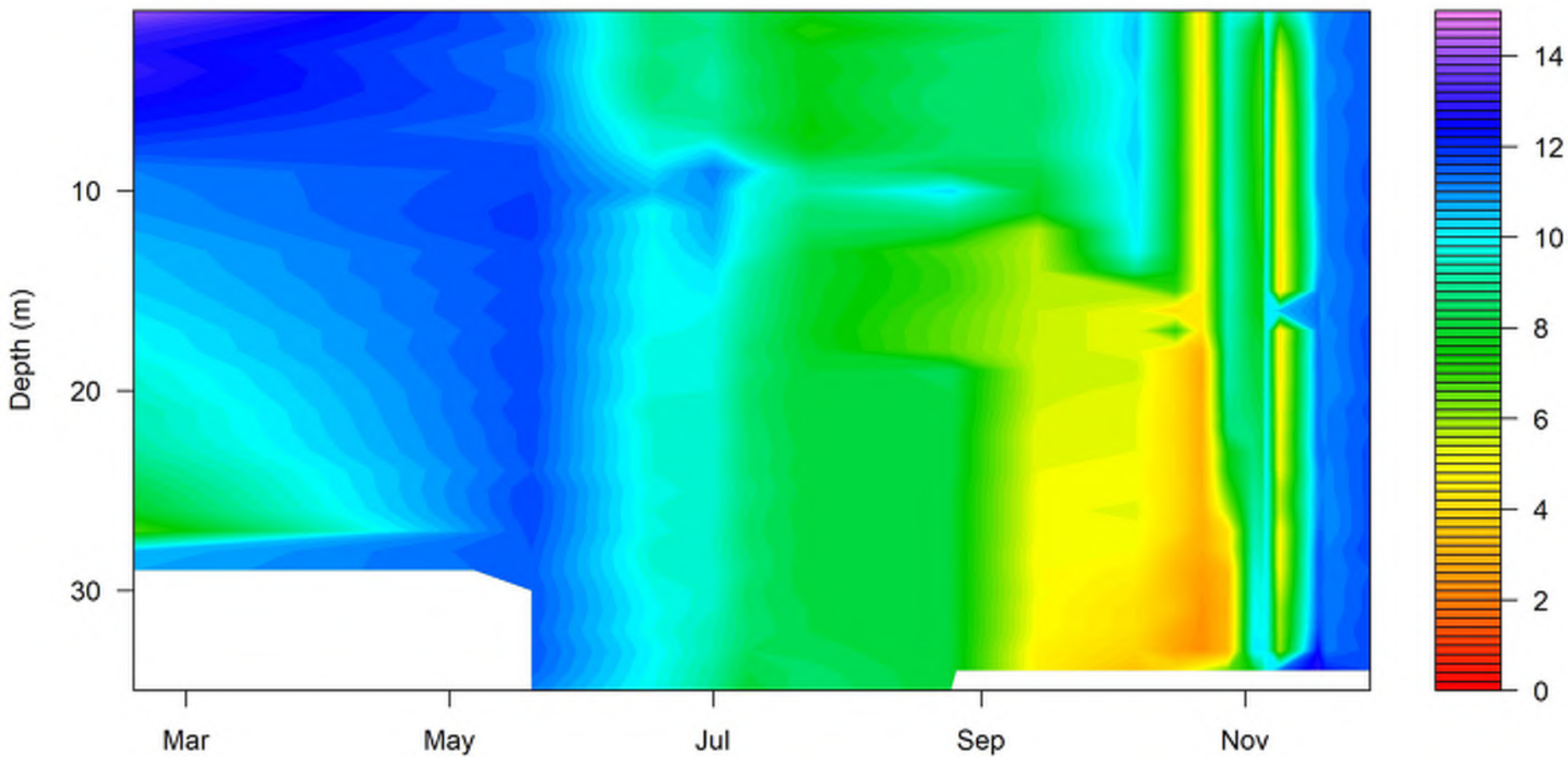
Station: 8 - DO - 1991

DO (mg/L)



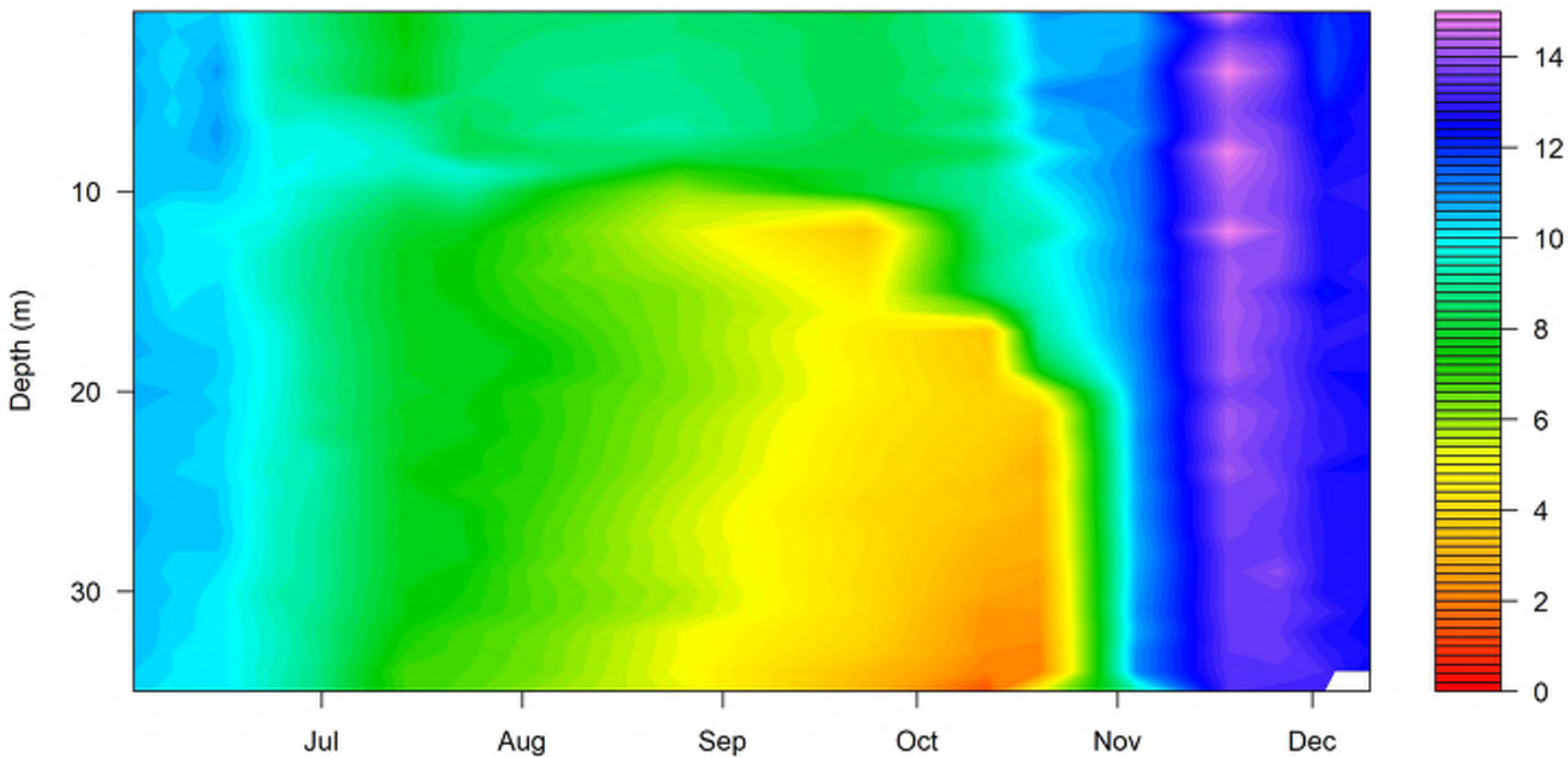
Station: 8 - DO - 1992

DO (mg/L)



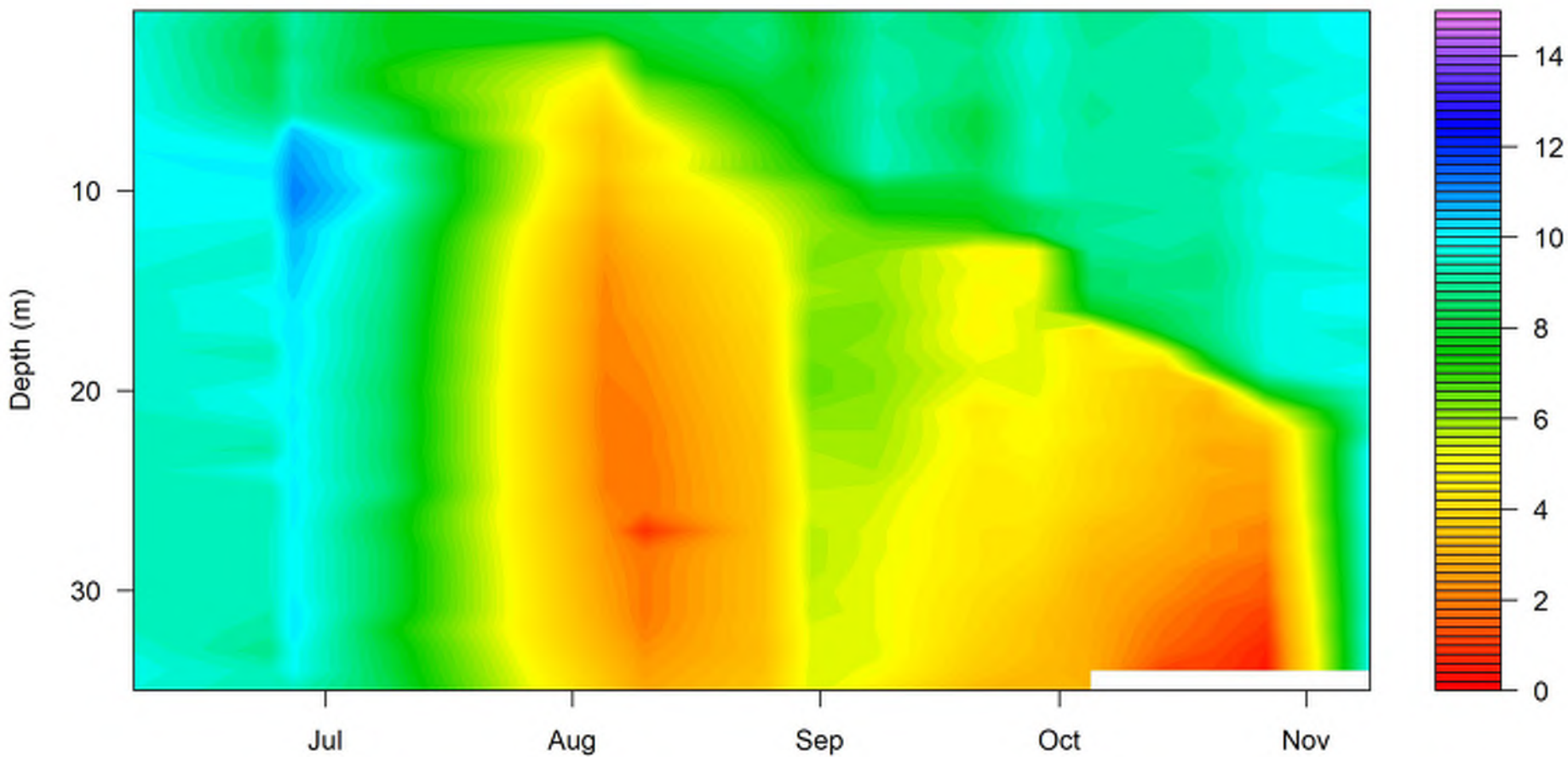
Station: 8 - DO - 1993

DO (mg/L)



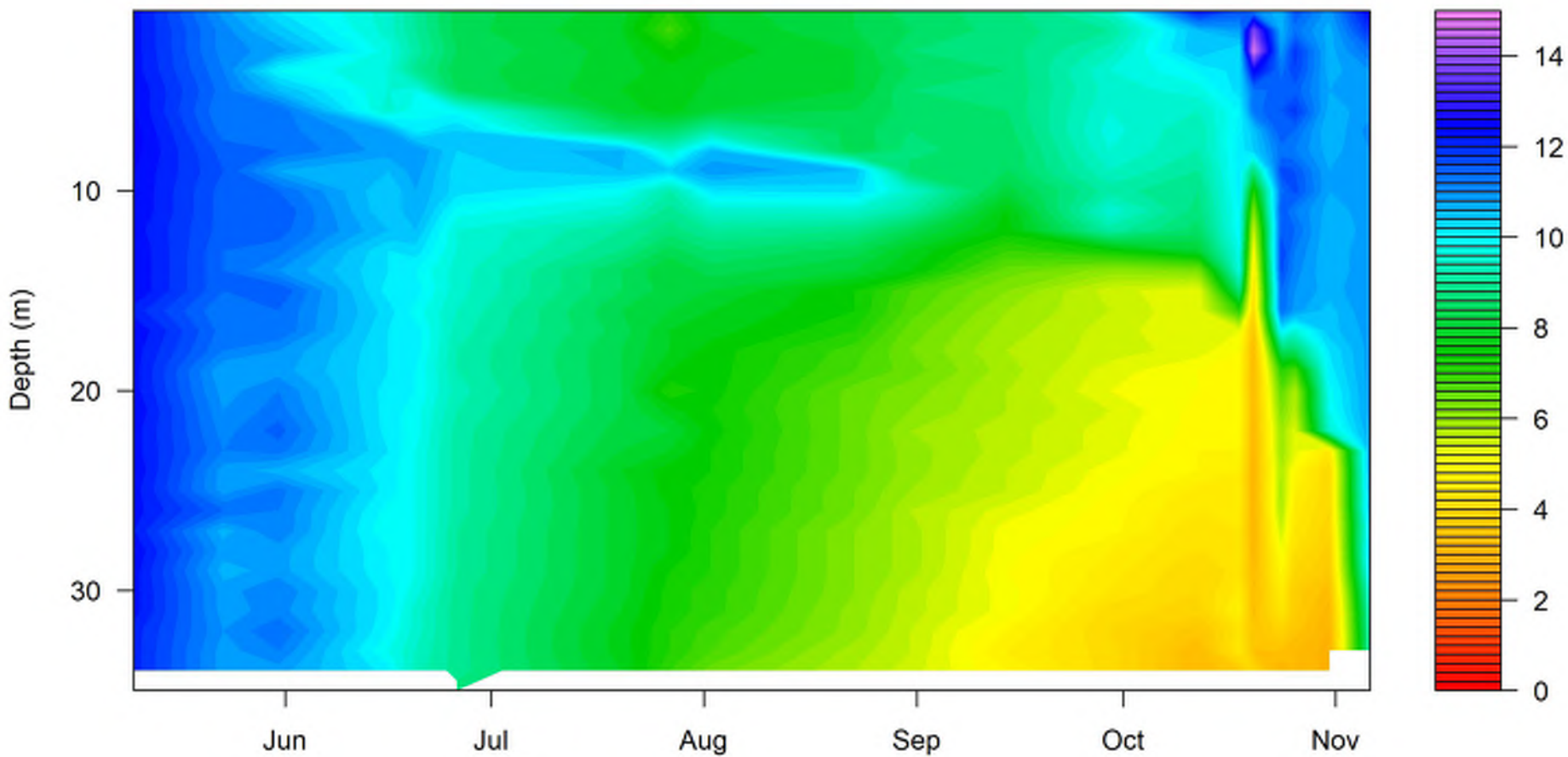
Station: 8 - DO - 1994

DO (mg/L)



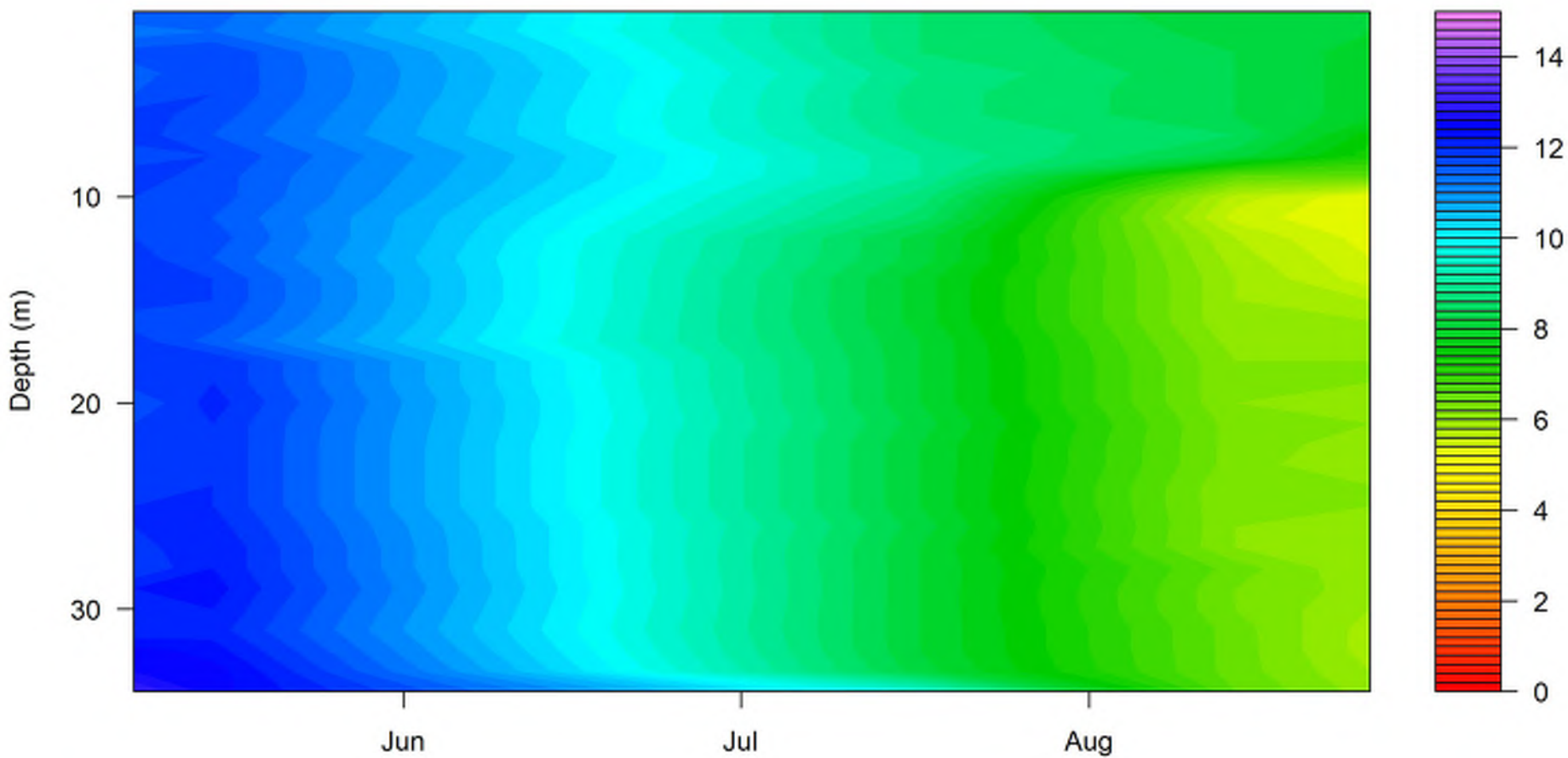
Station: 8 - DO - 1995

DO (mg/L)



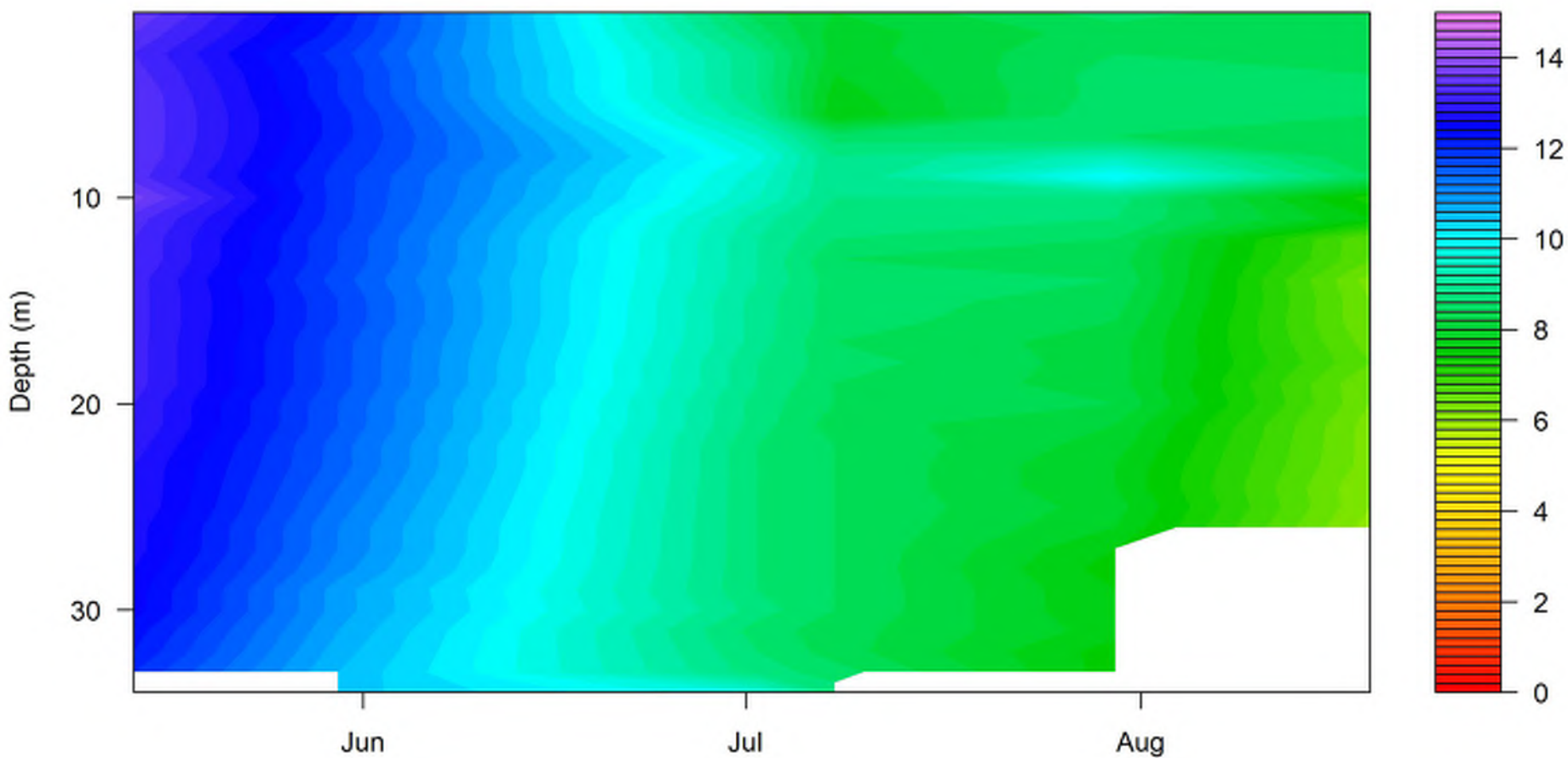
Station: 8 - DO - 1996

DO (mg/L)



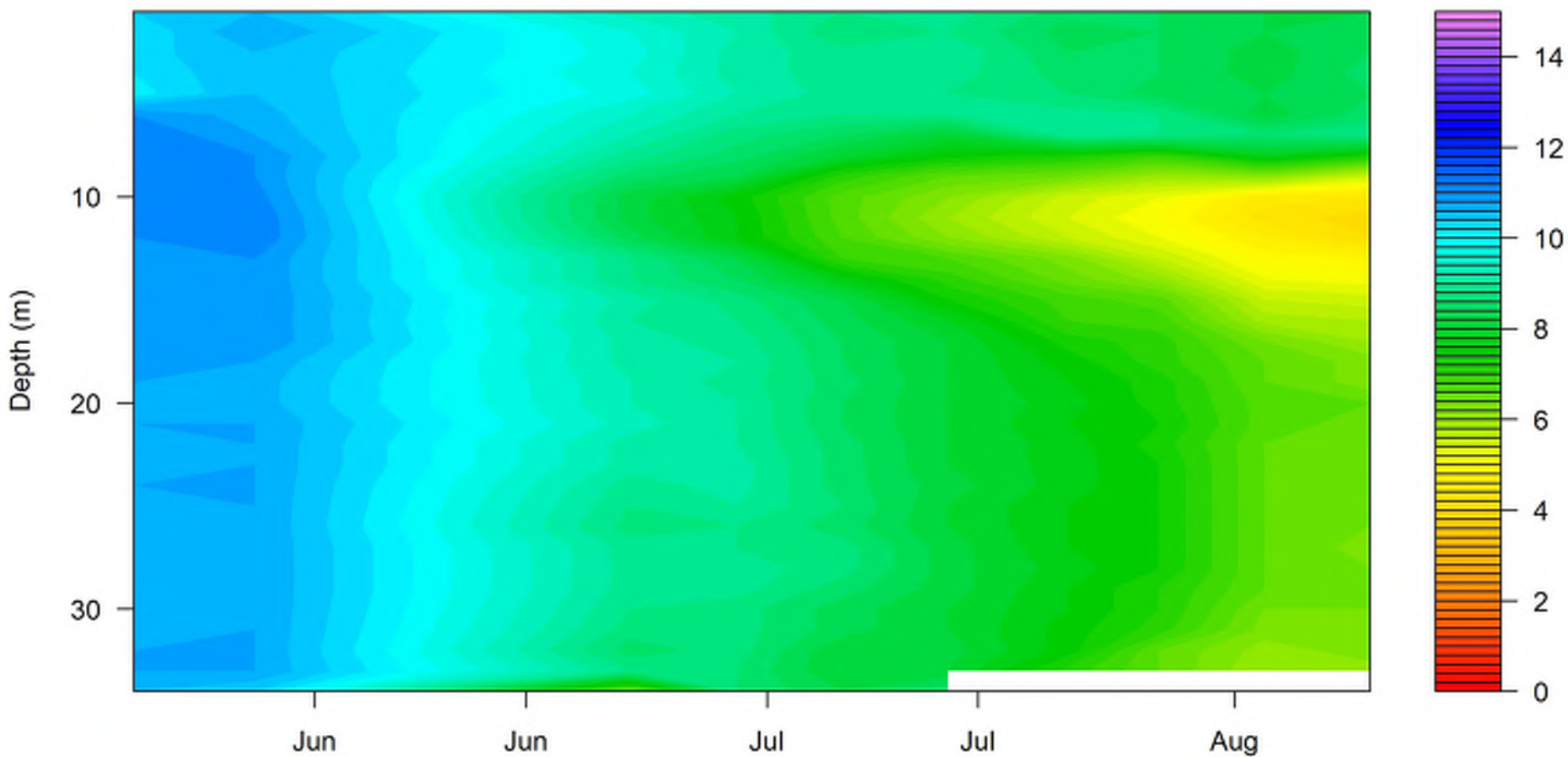
Station: 8 - DO - 1997

DO (mg/L)



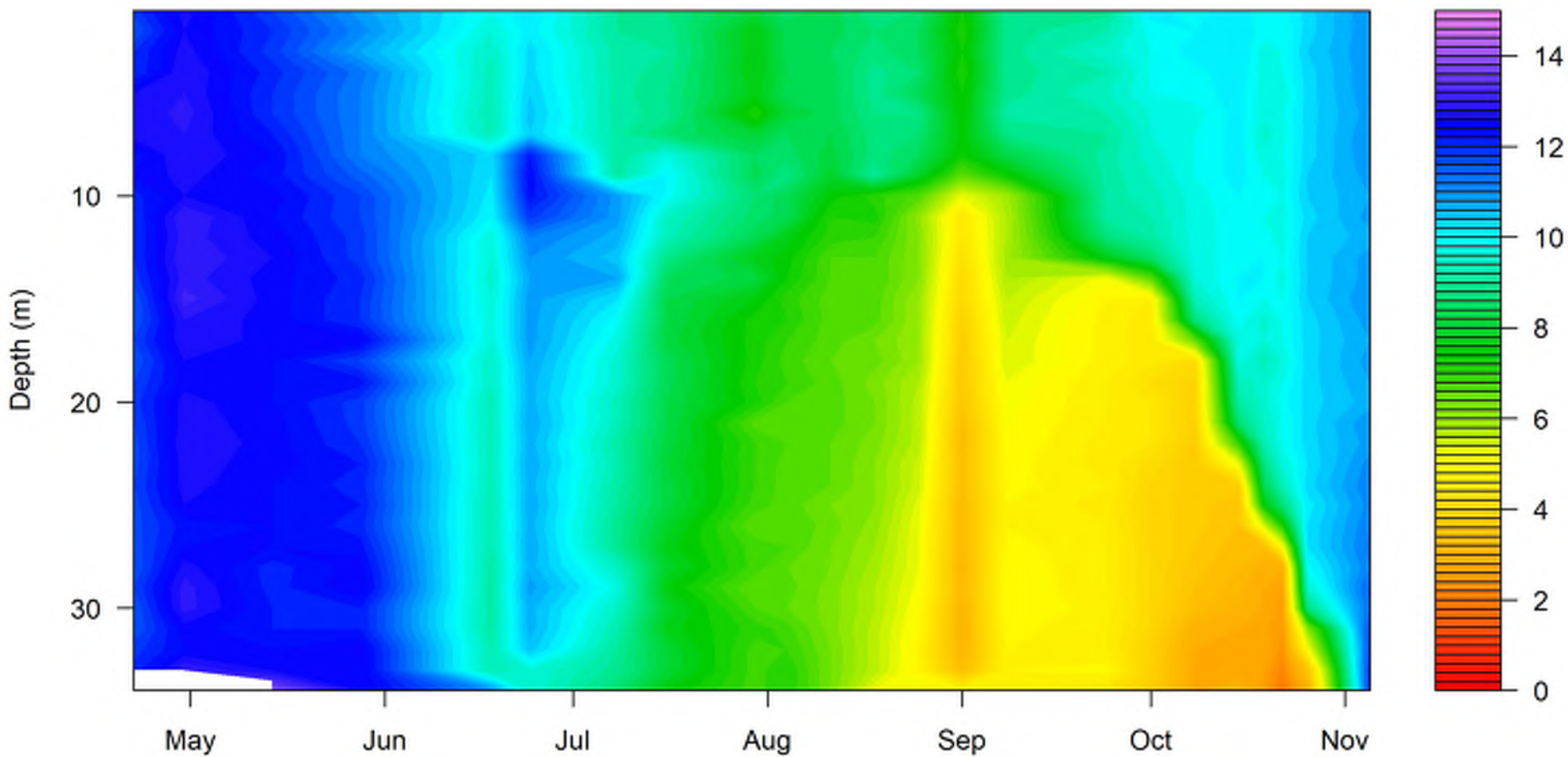
Station: 8 - DO - 1998

DO (mg/L)



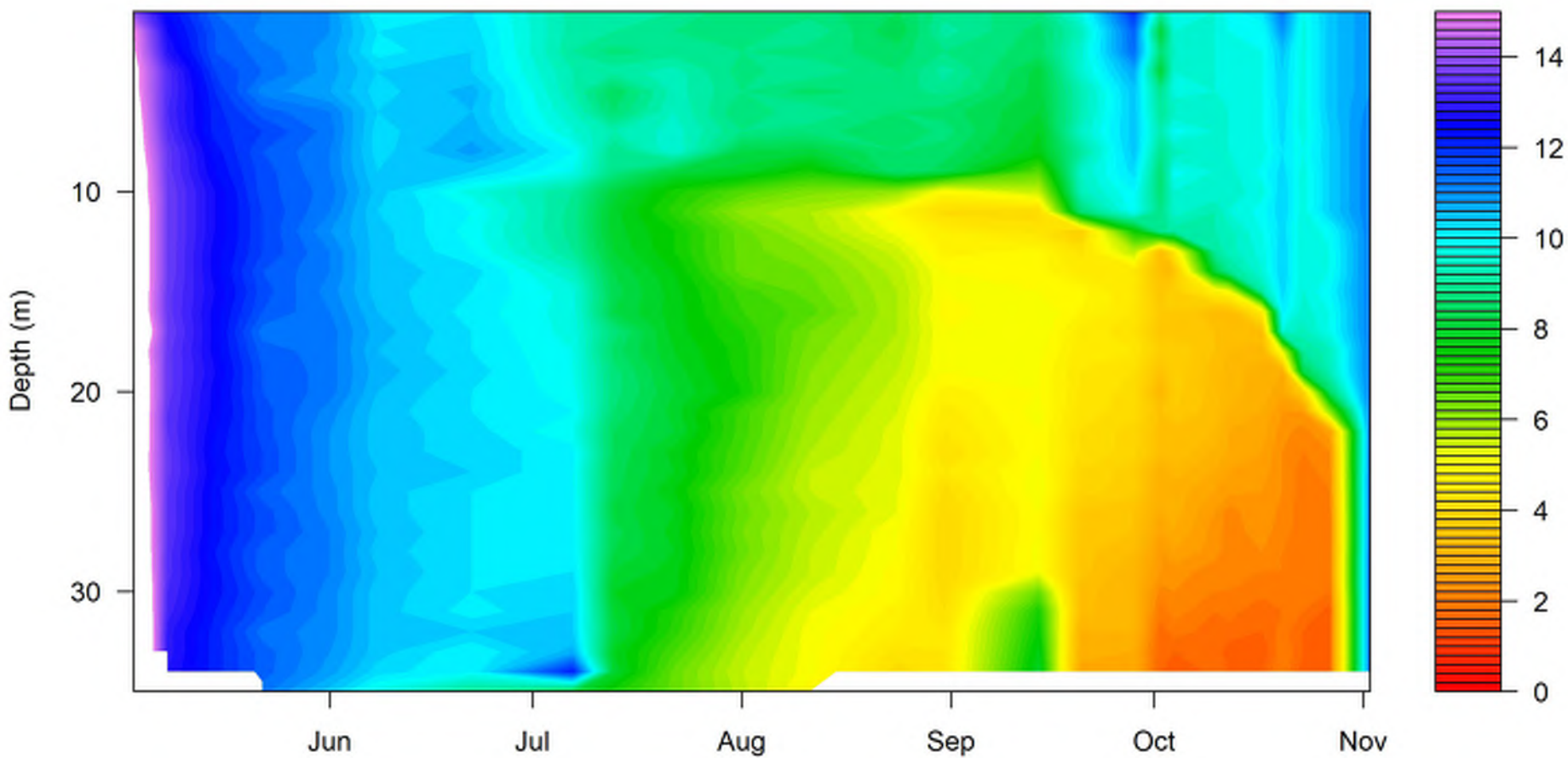
Station: 8 - DO - 1999

DO (mg/L)



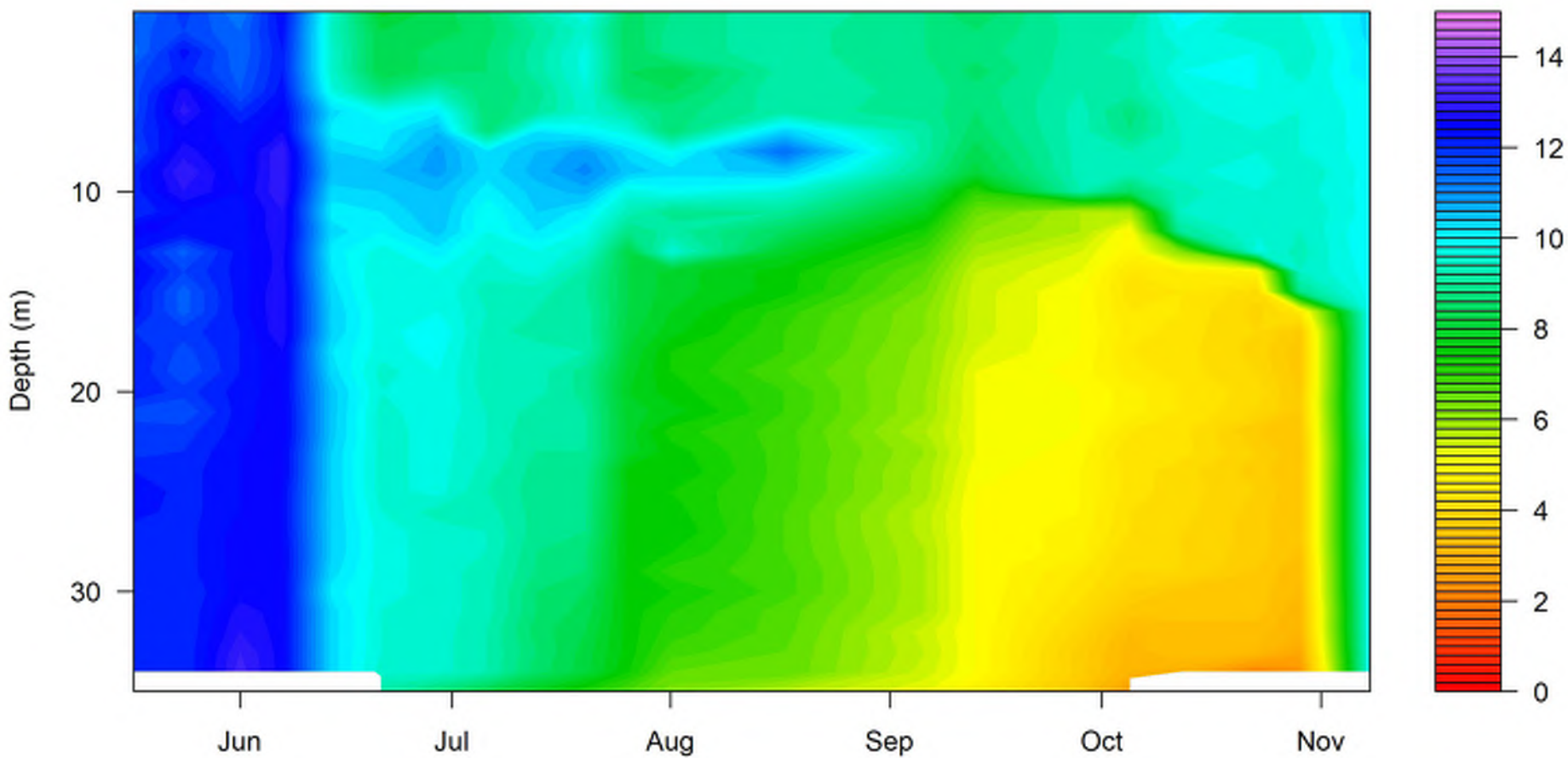
Station: 8 - DO - 2000

DO (mg/L)



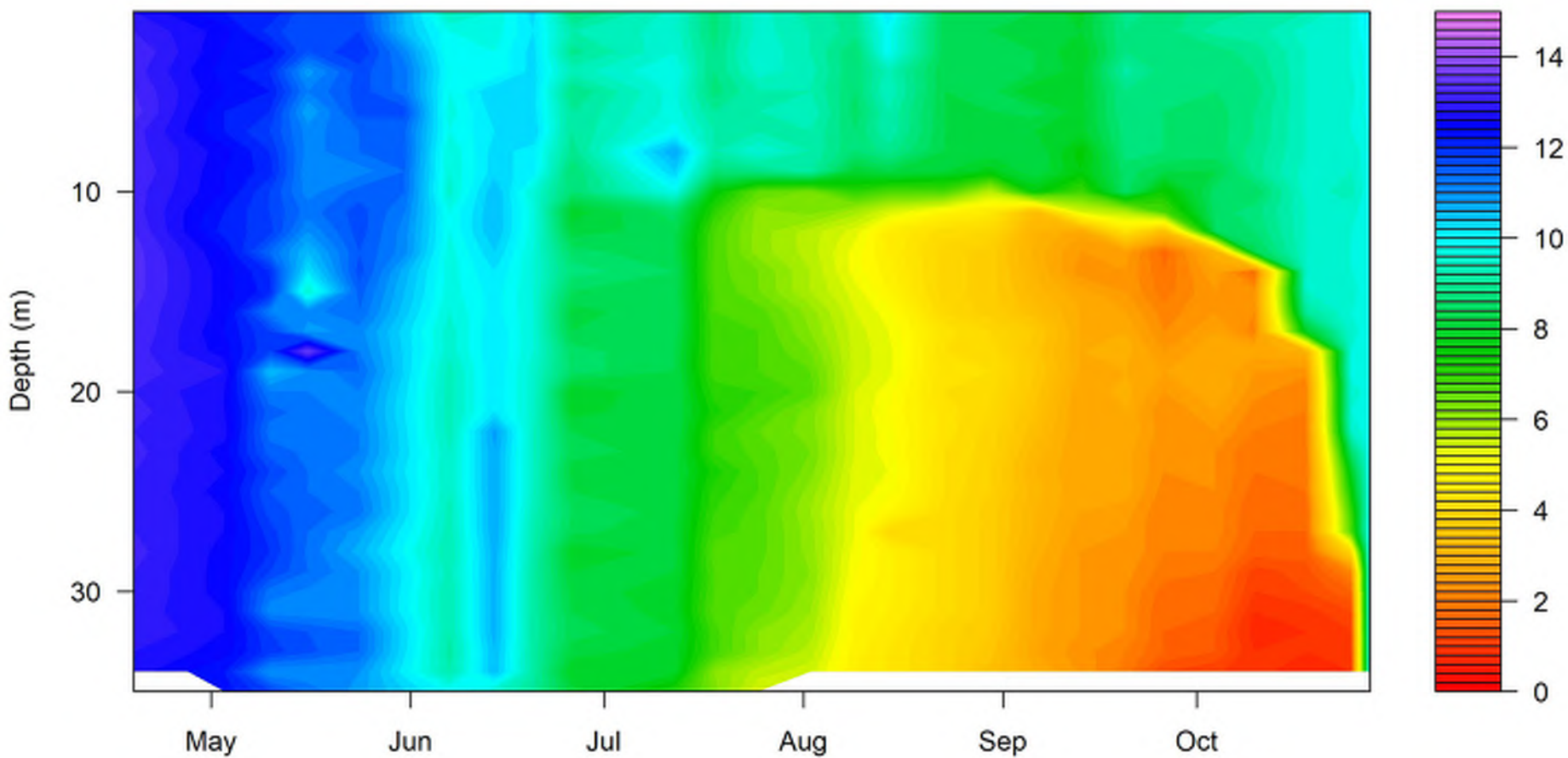
Station: 8 - DO - 2001

DO (mg/L)



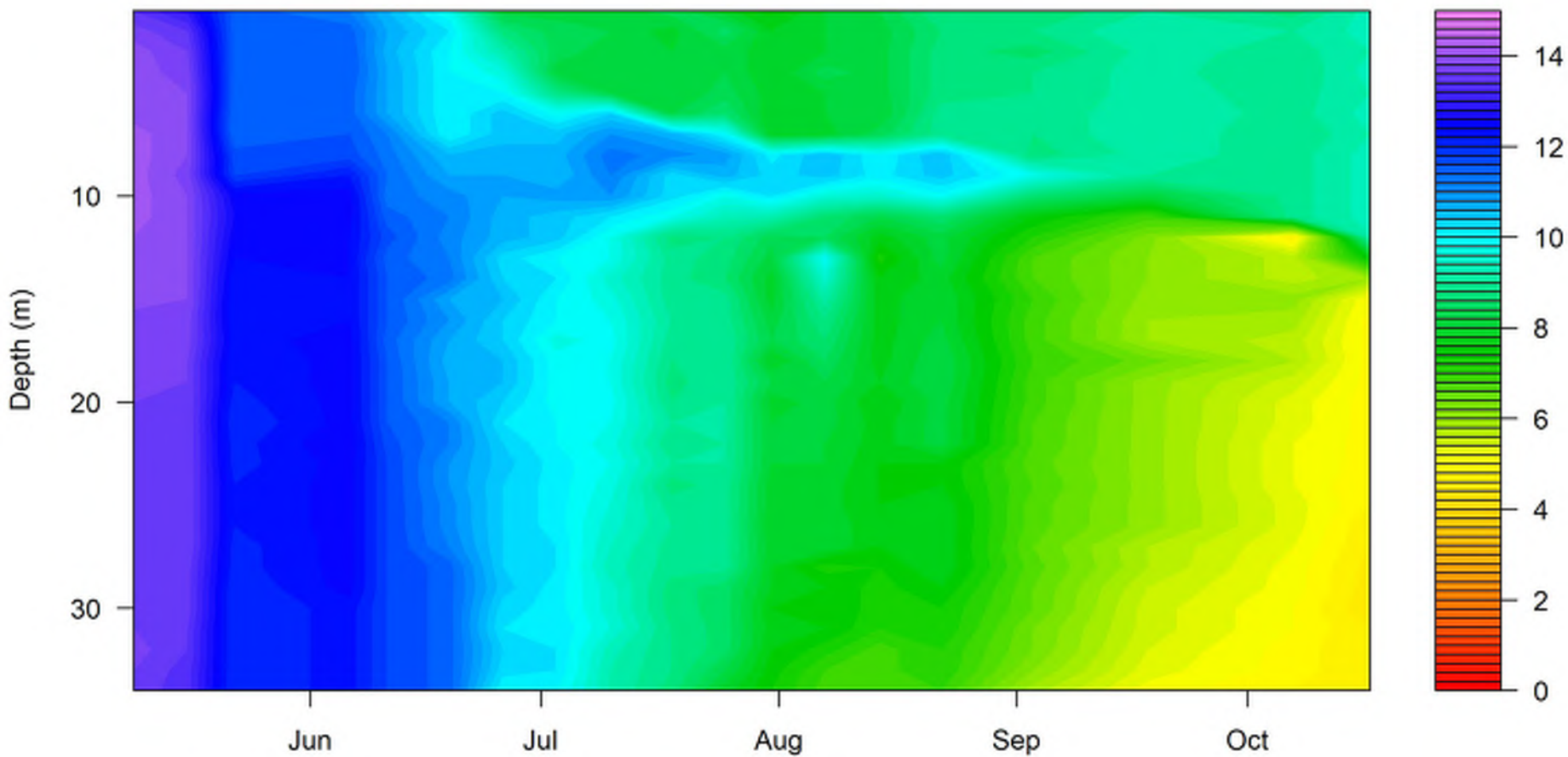
Station: 8 - DO - 2002

DO (mg/L)



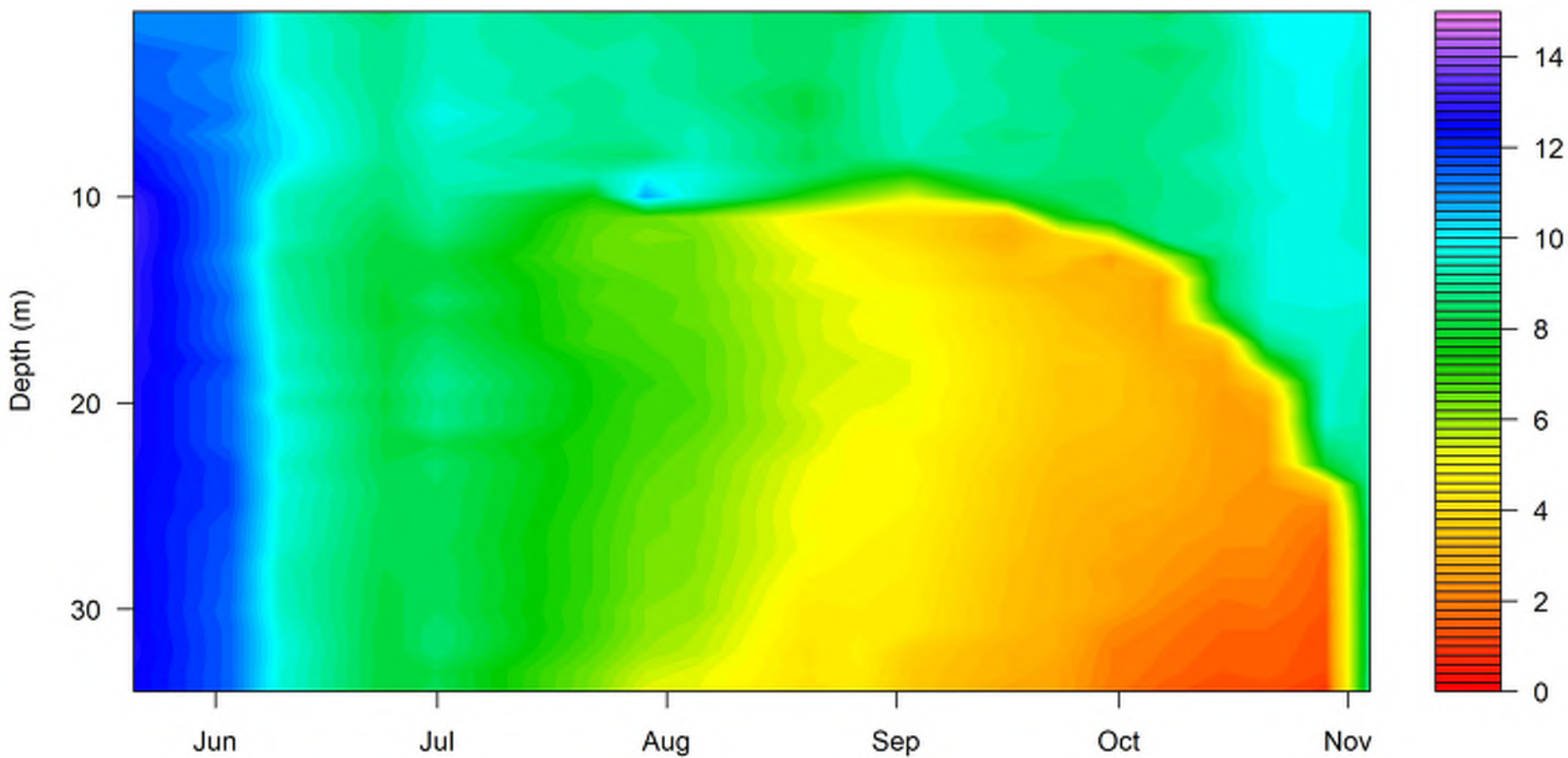
Station: 8 - DO - 2003

DO (mg/L)



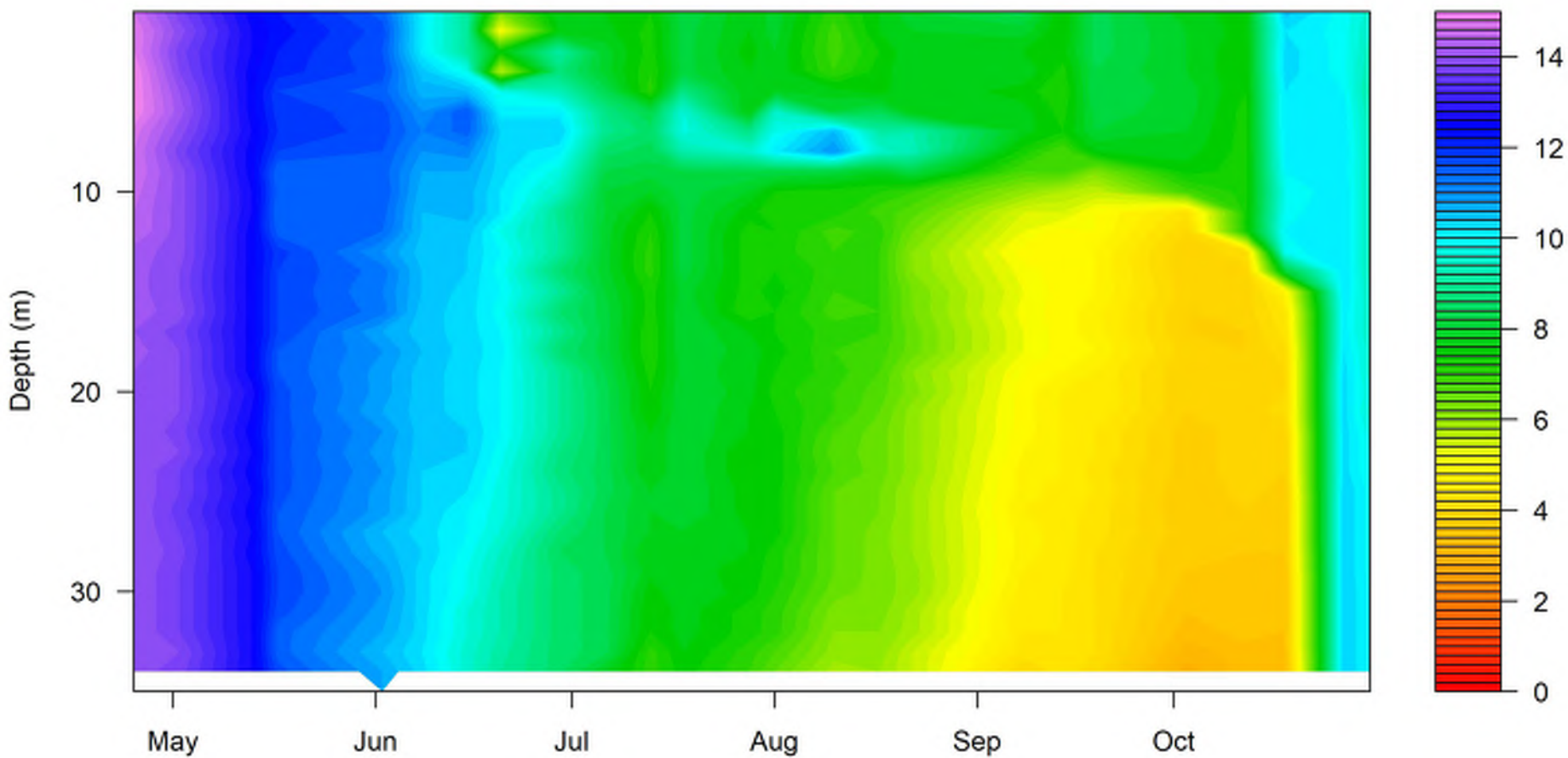
Station: 8 - DO - 2004

DO (mg/L)



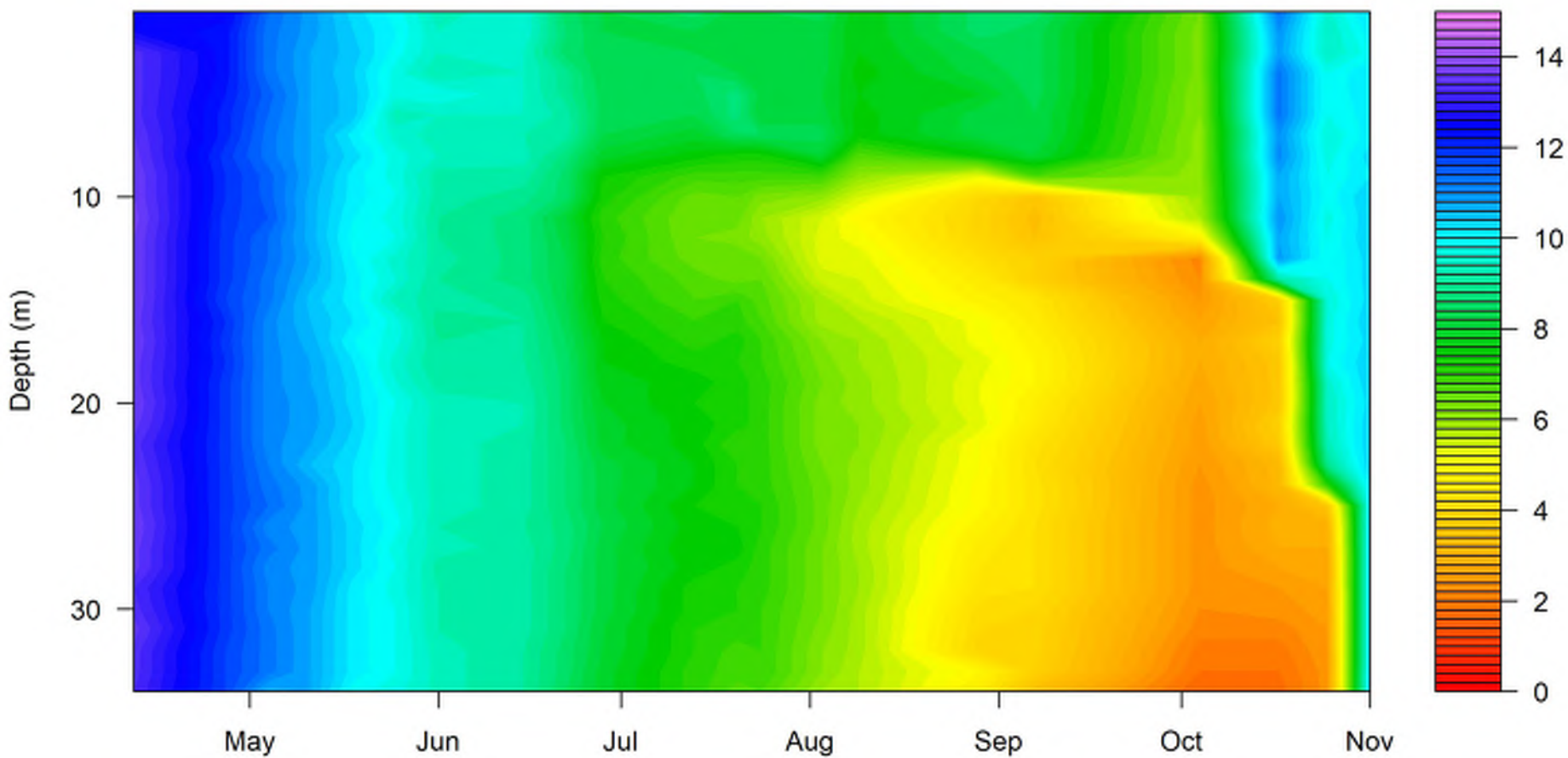
Station: 8 - DO - 2005

DO (mg/L)



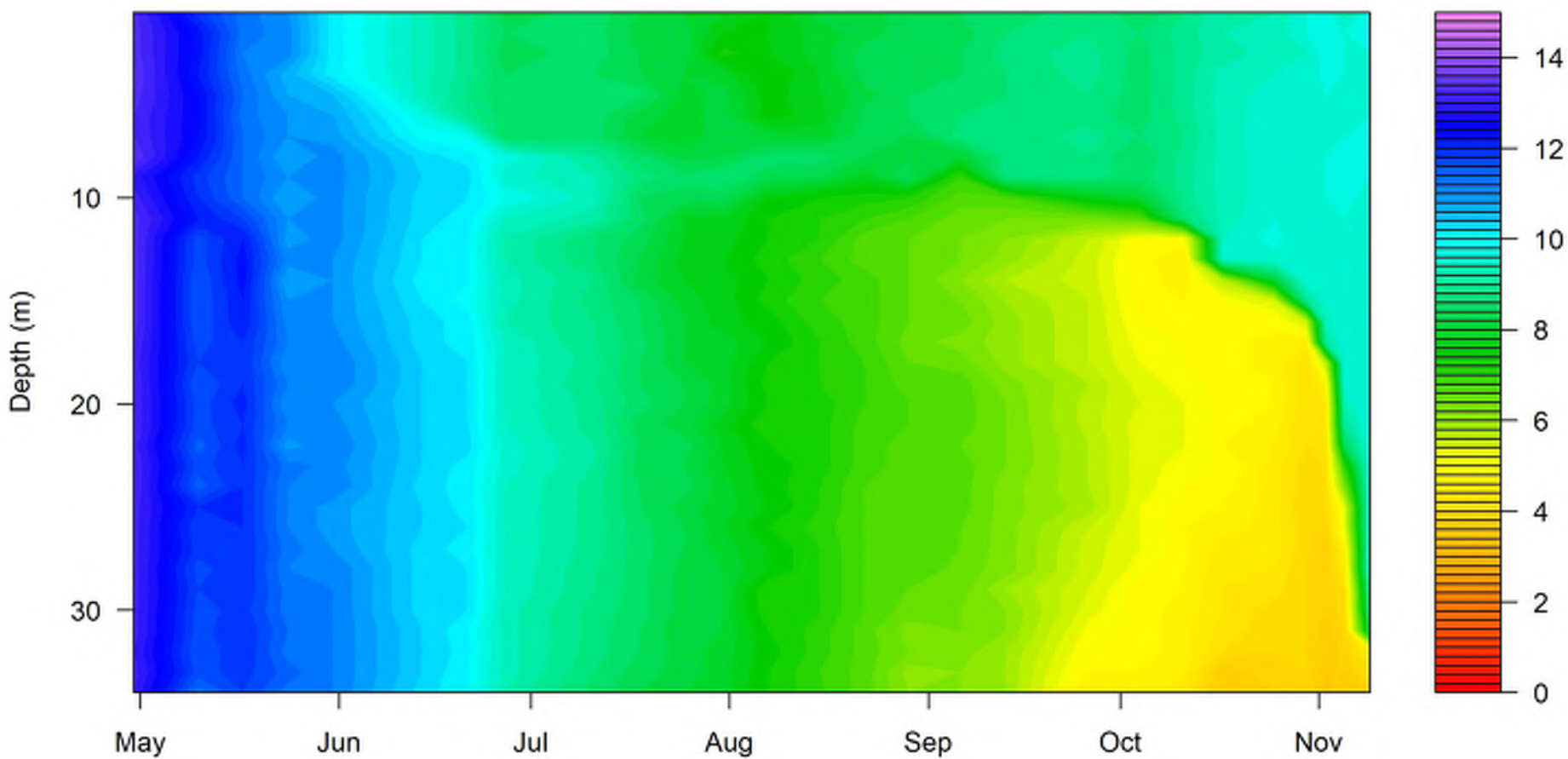
Station: 8 - DO - 2006

DO (mg/L)



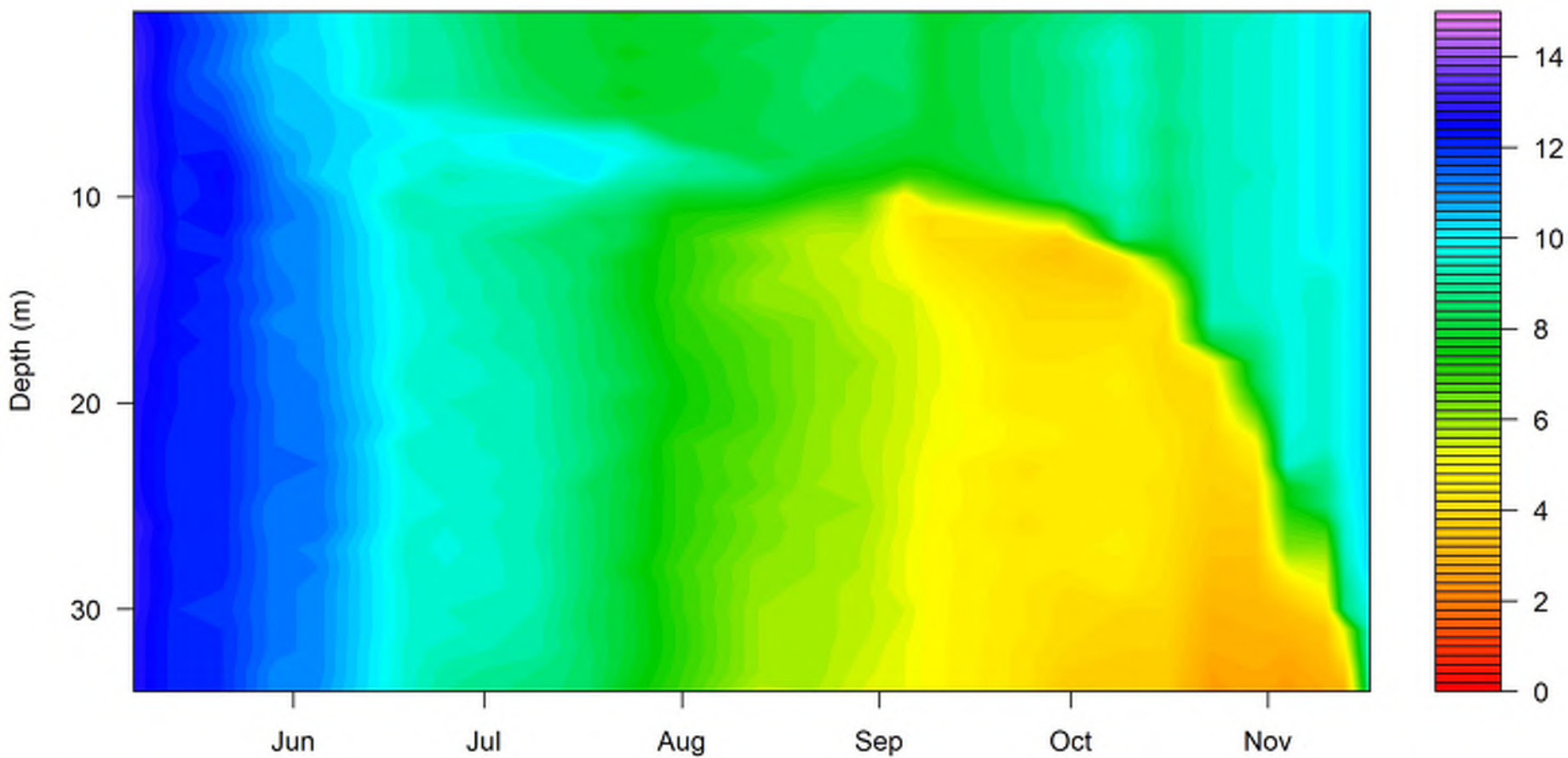
Station: 8 - DO - 2007

DO (mg/L)



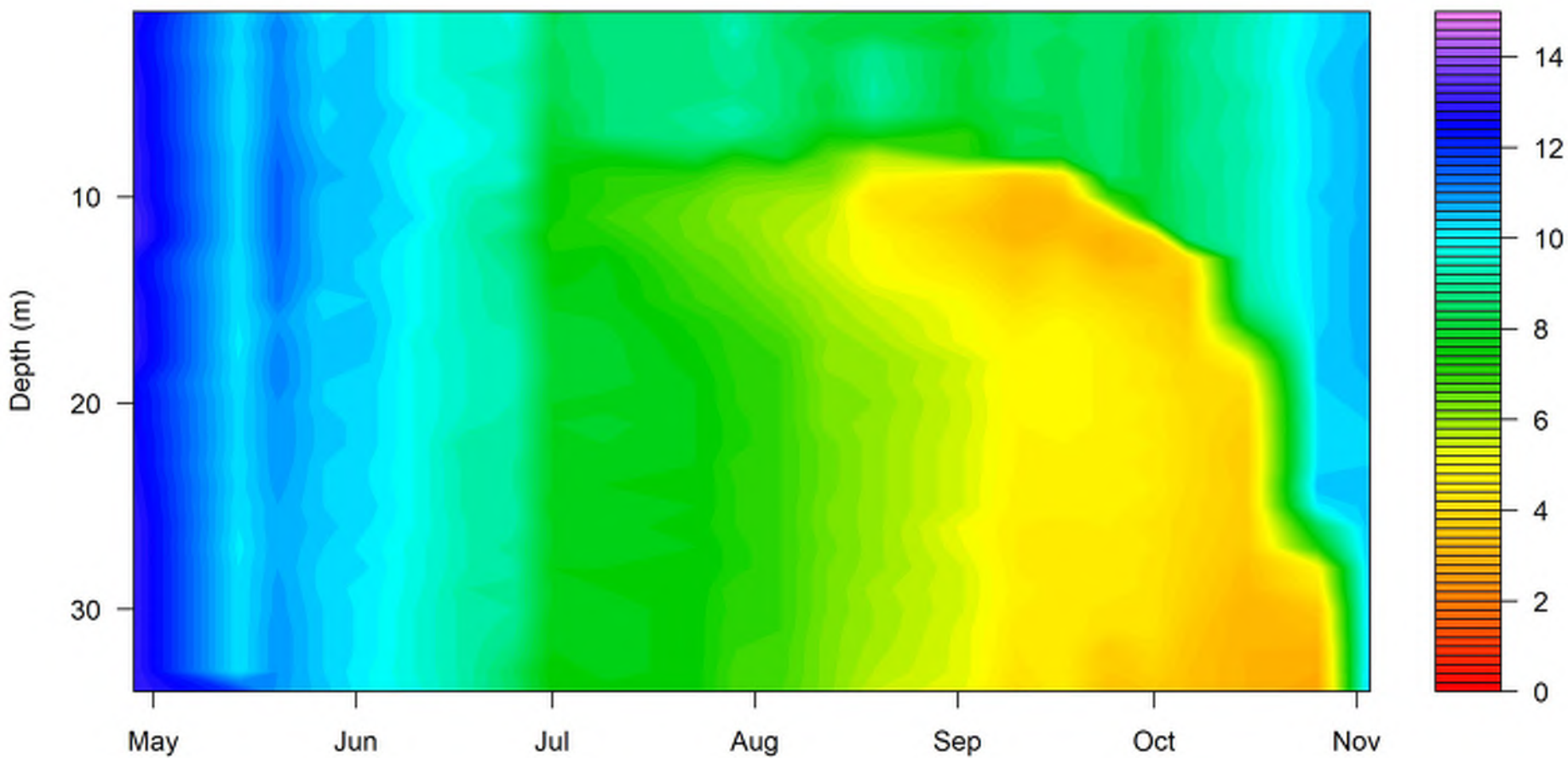
Station: 8 - DO - 2008

DO (mg/L)



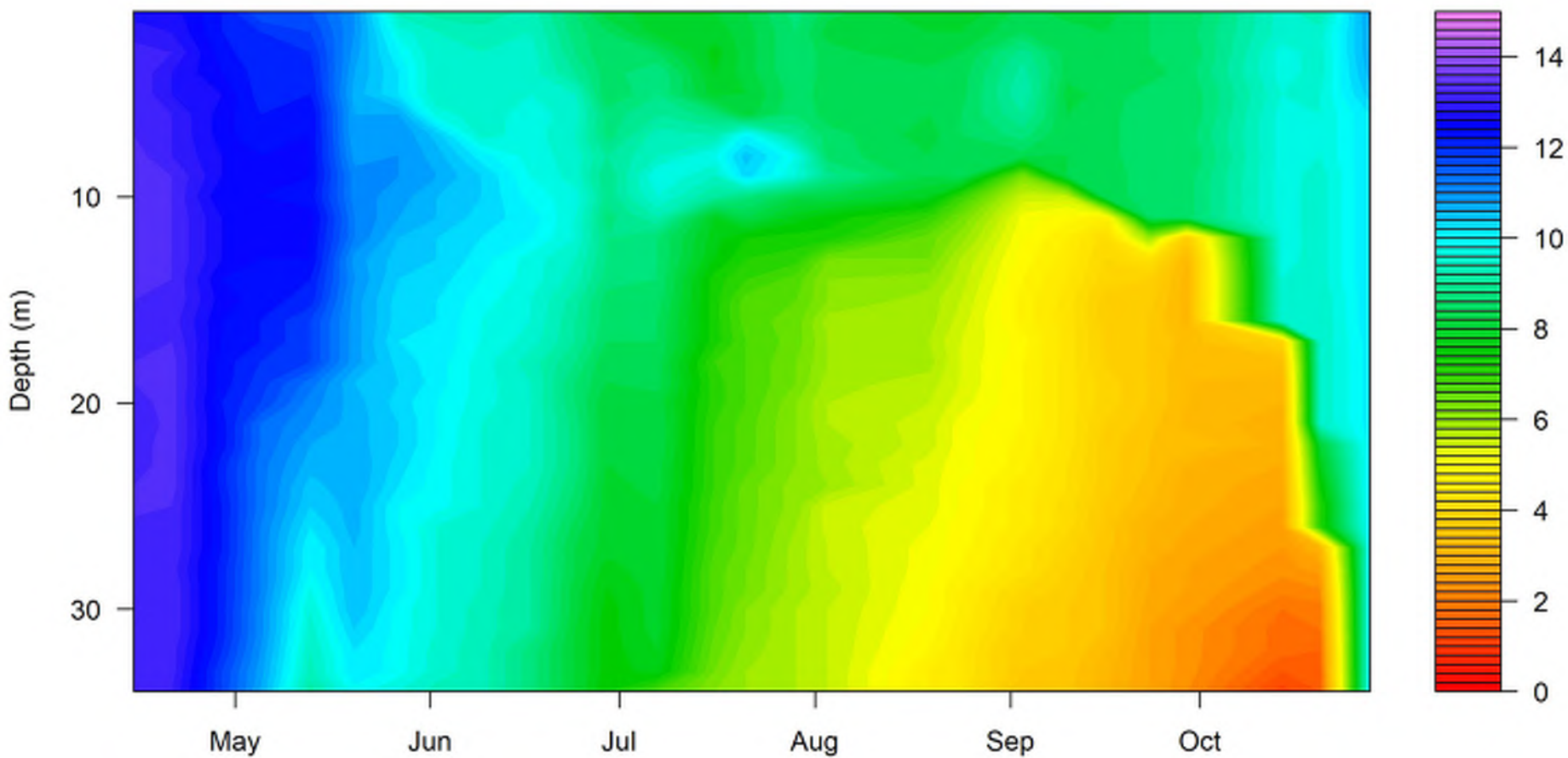
Station: 8 - DO - 2009

DO (mg/L)



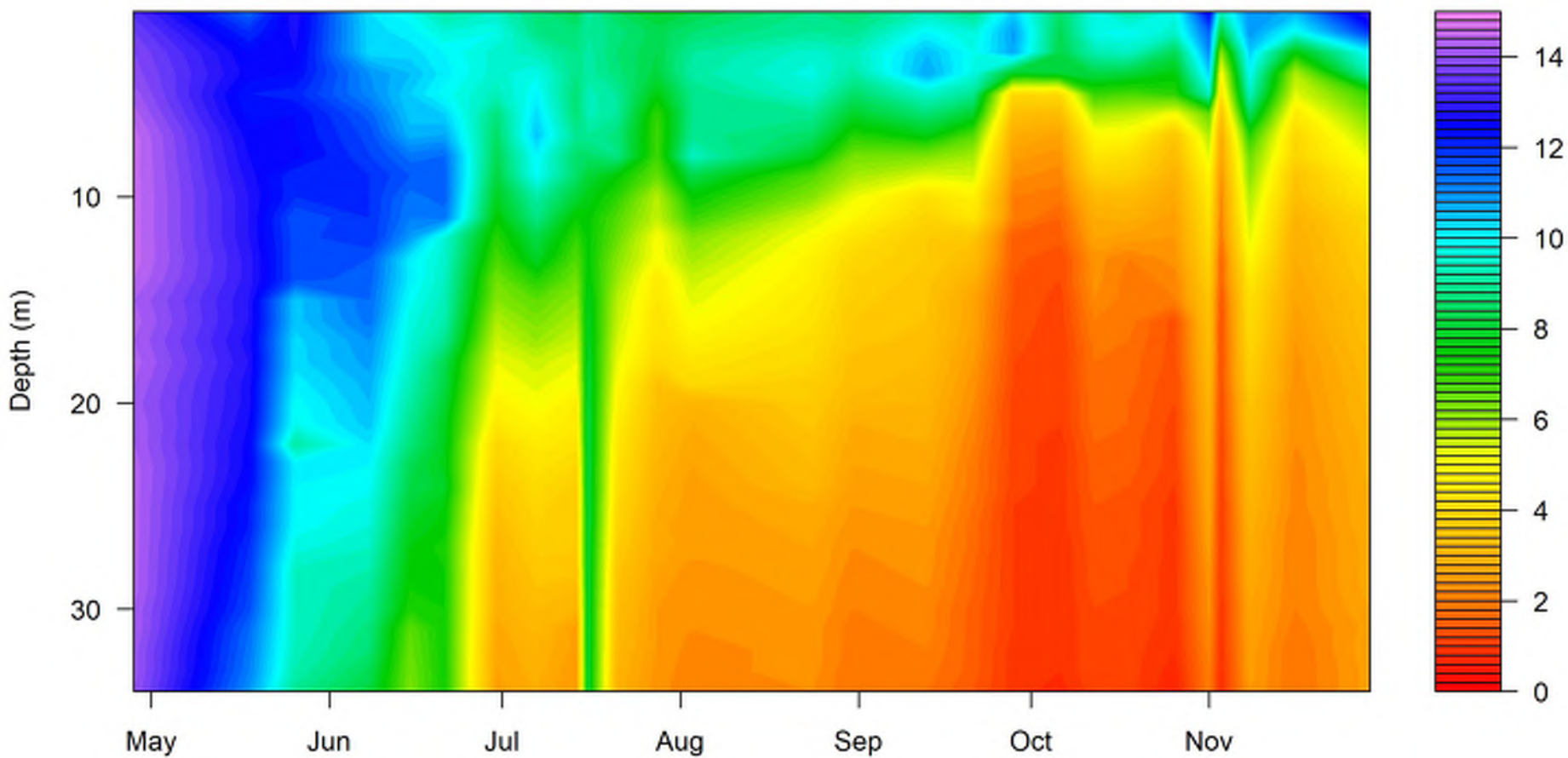
Station: 8 - DO - 2010

DO (mg/L)



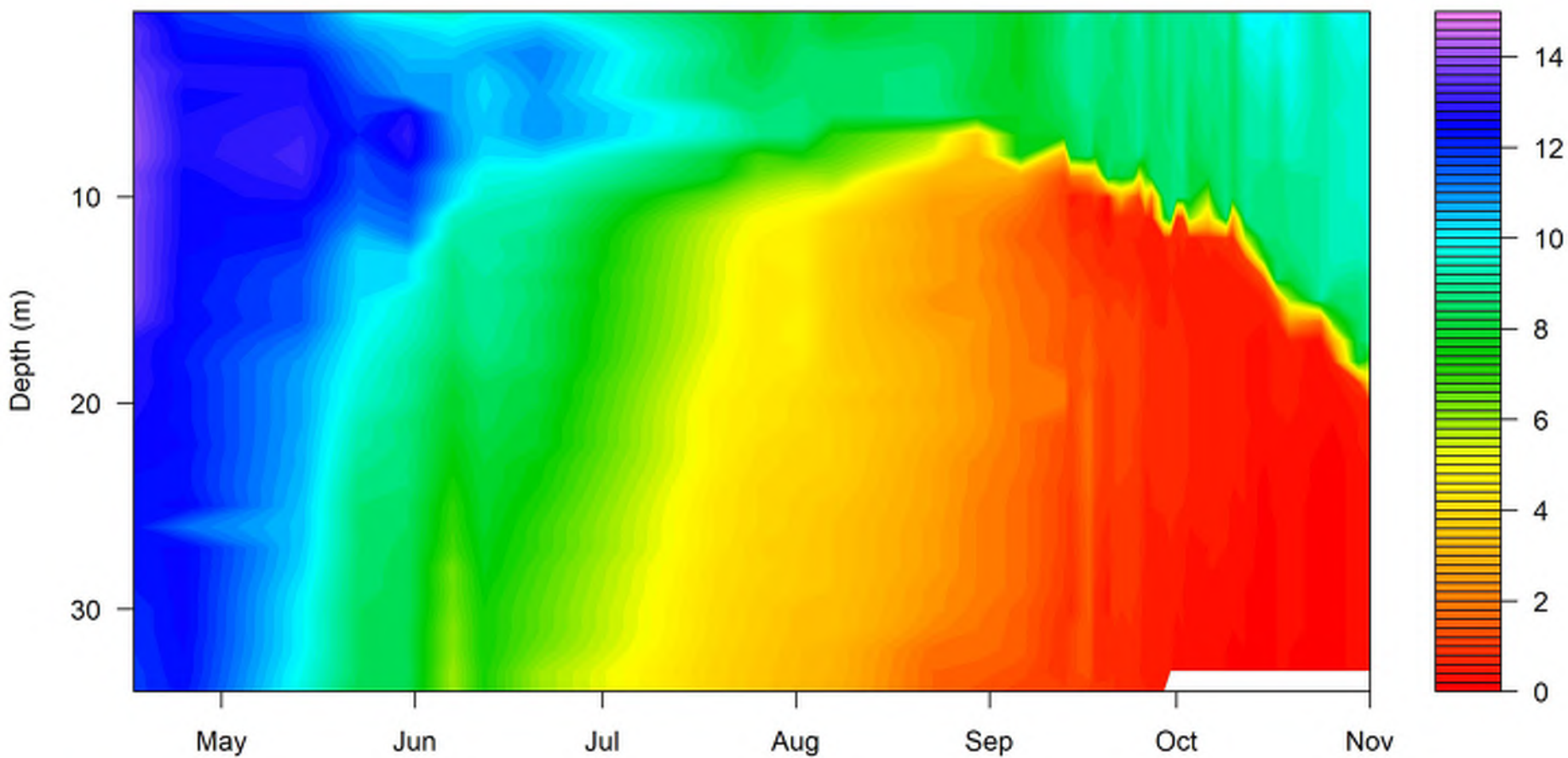
Station: 8 - DO - 2011

DO (mg/L)



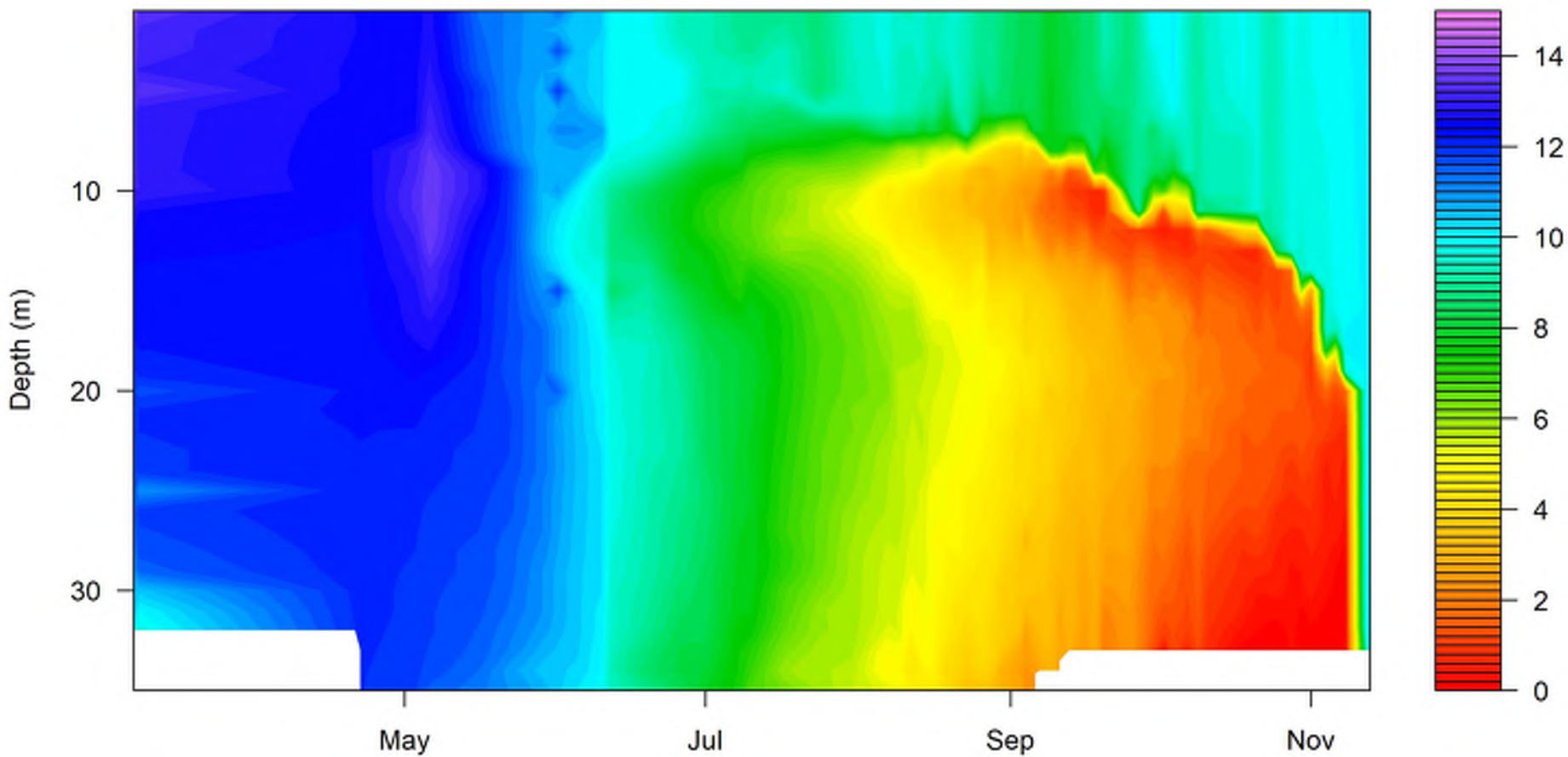
Station: 8 - DO - 2012

DO (mg/L)



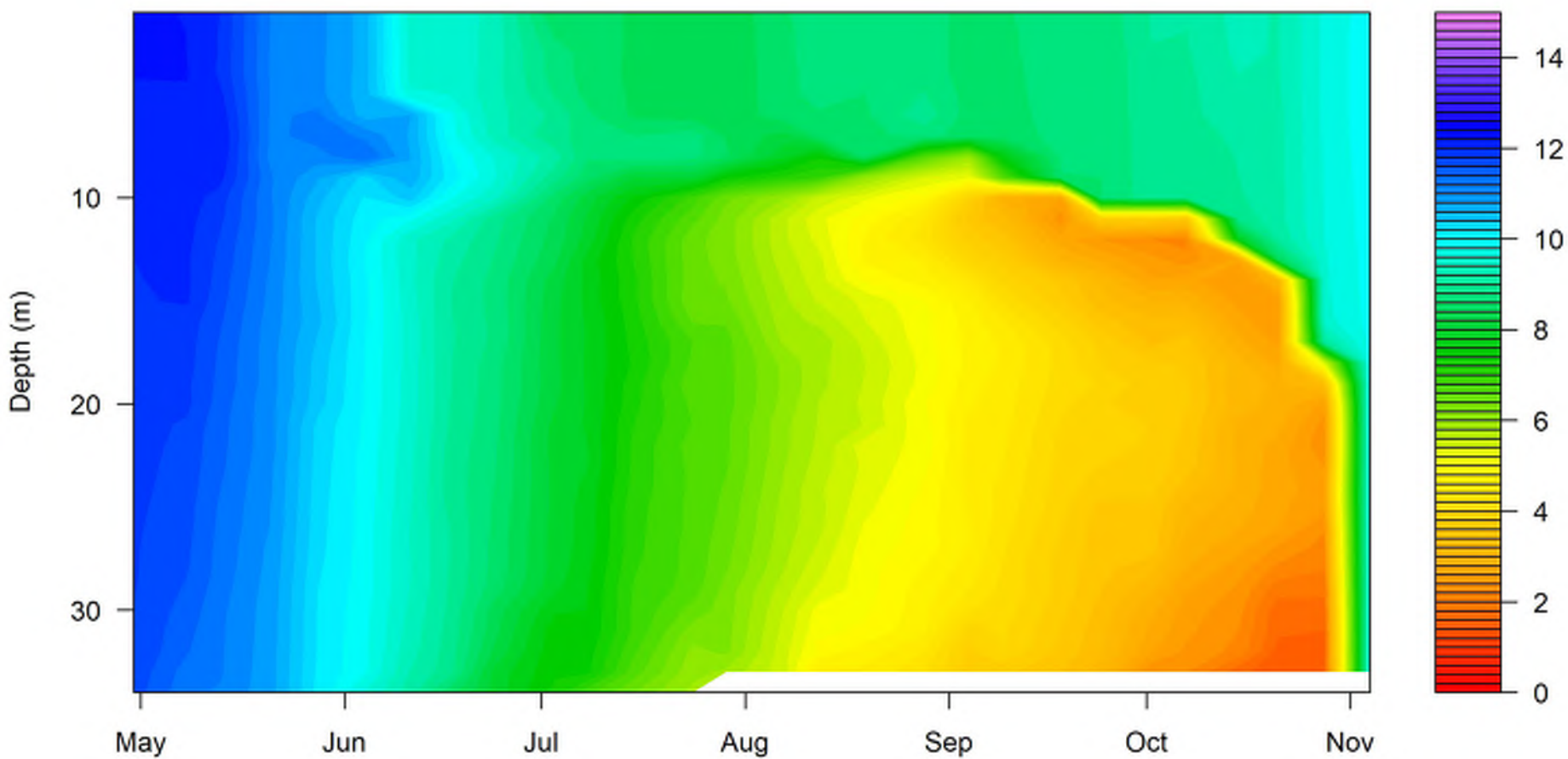
Station: 8 - DO - 2013

DO (mg/L)



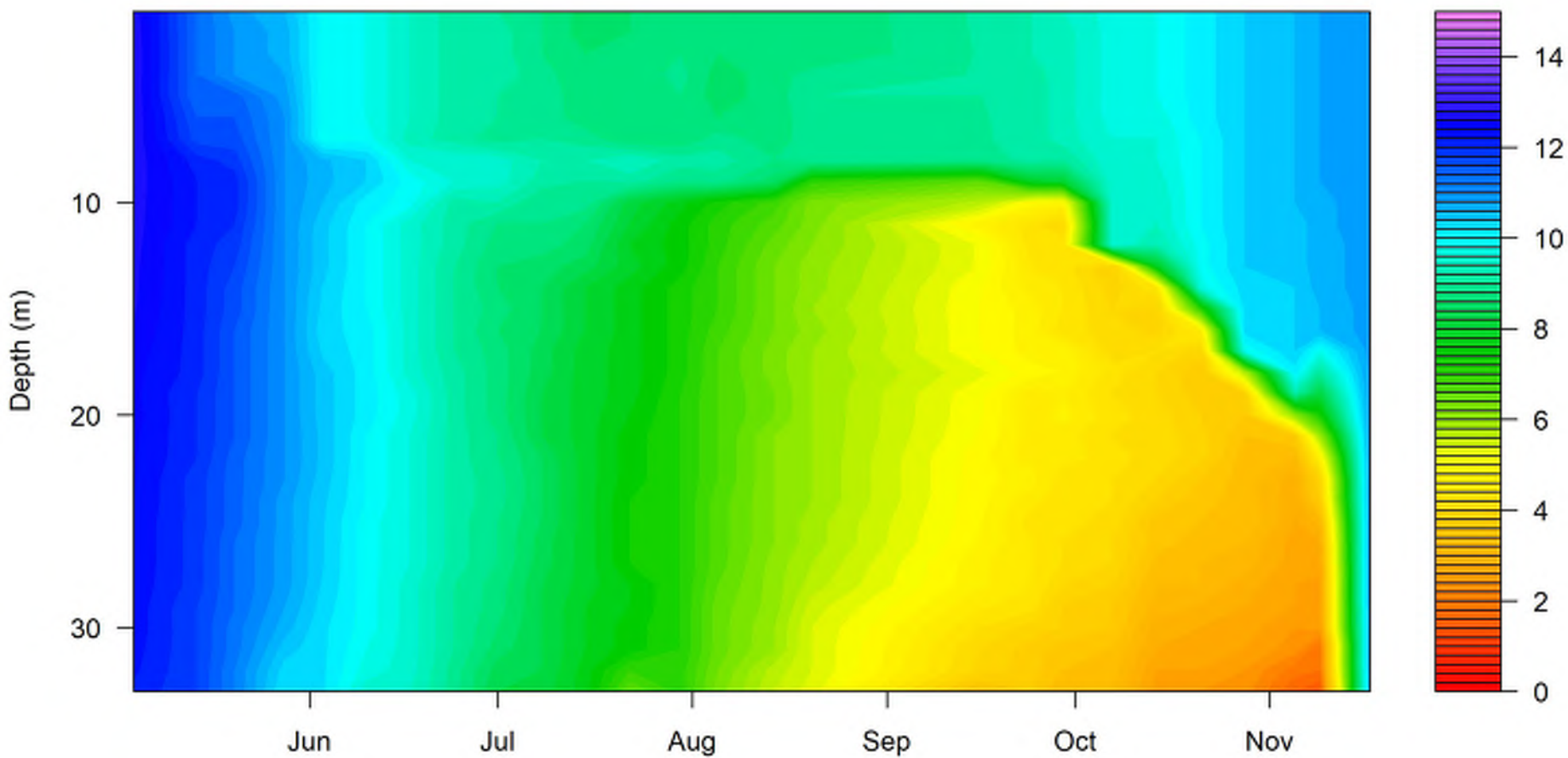
Station: 8 - DO - 2014

DO (mg/L)



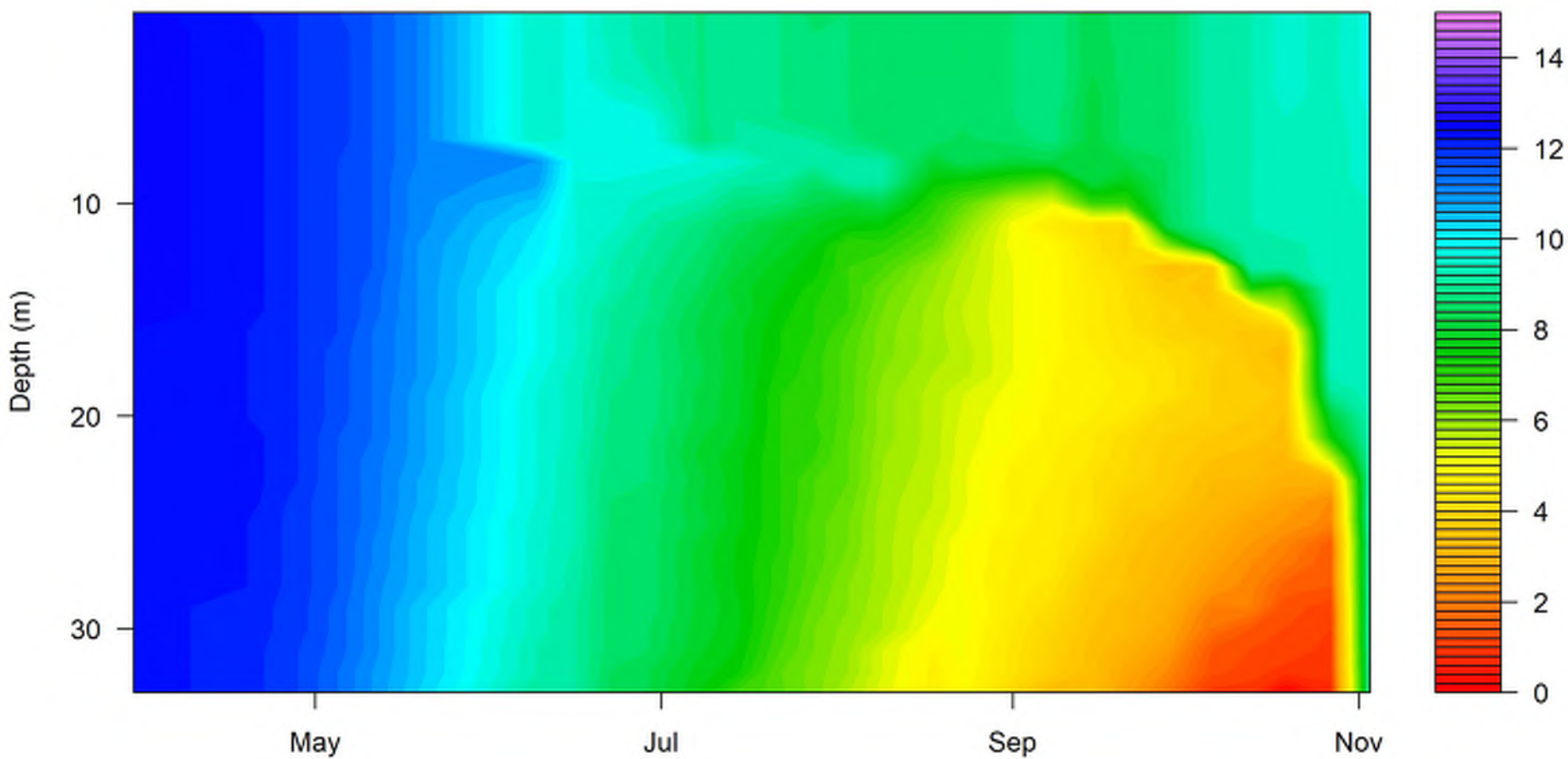
Station: 8 - DO - 2015

DO (mg/L)



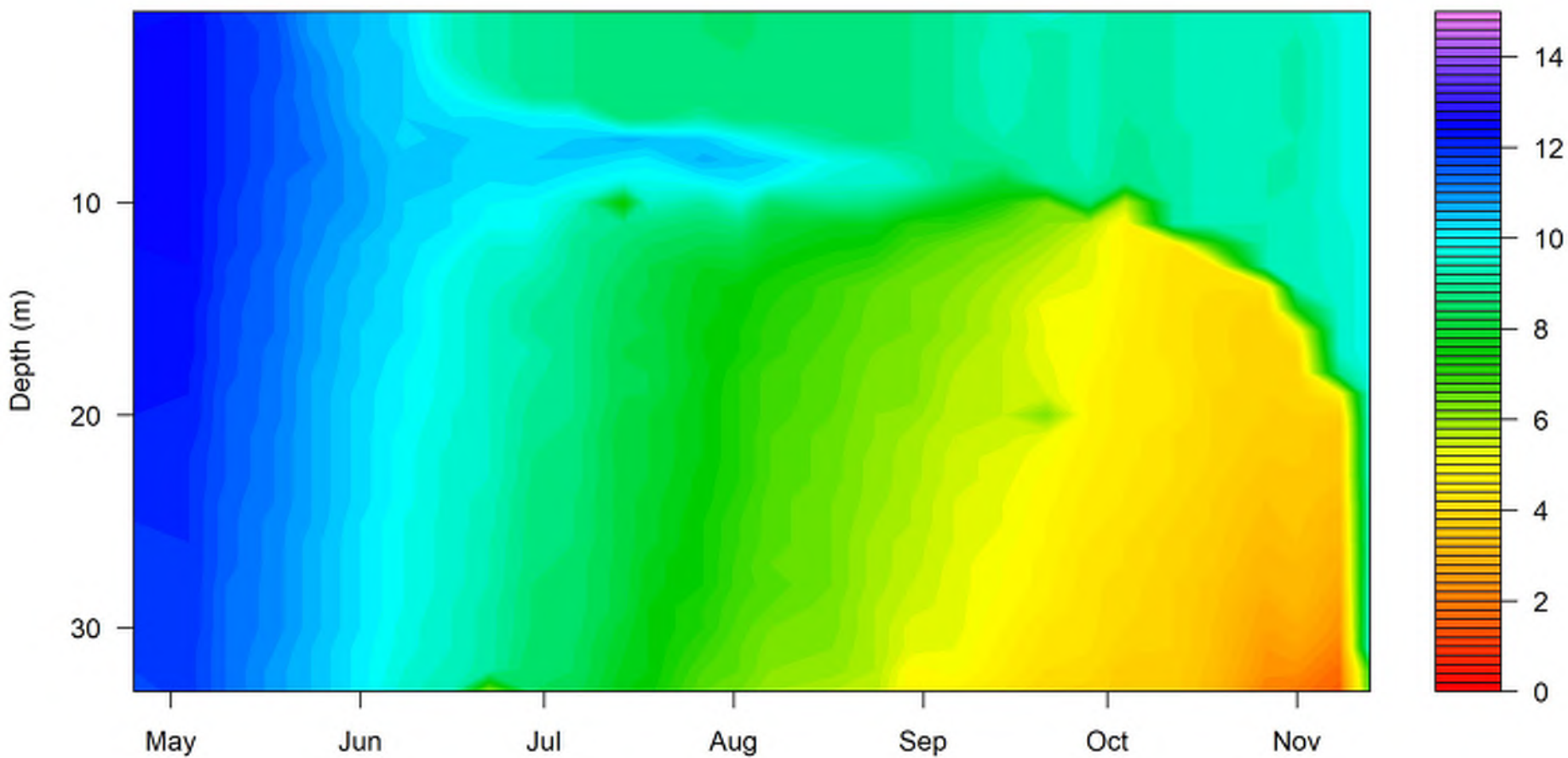
Station: 8 - DO - 2016

DO (mg/L)



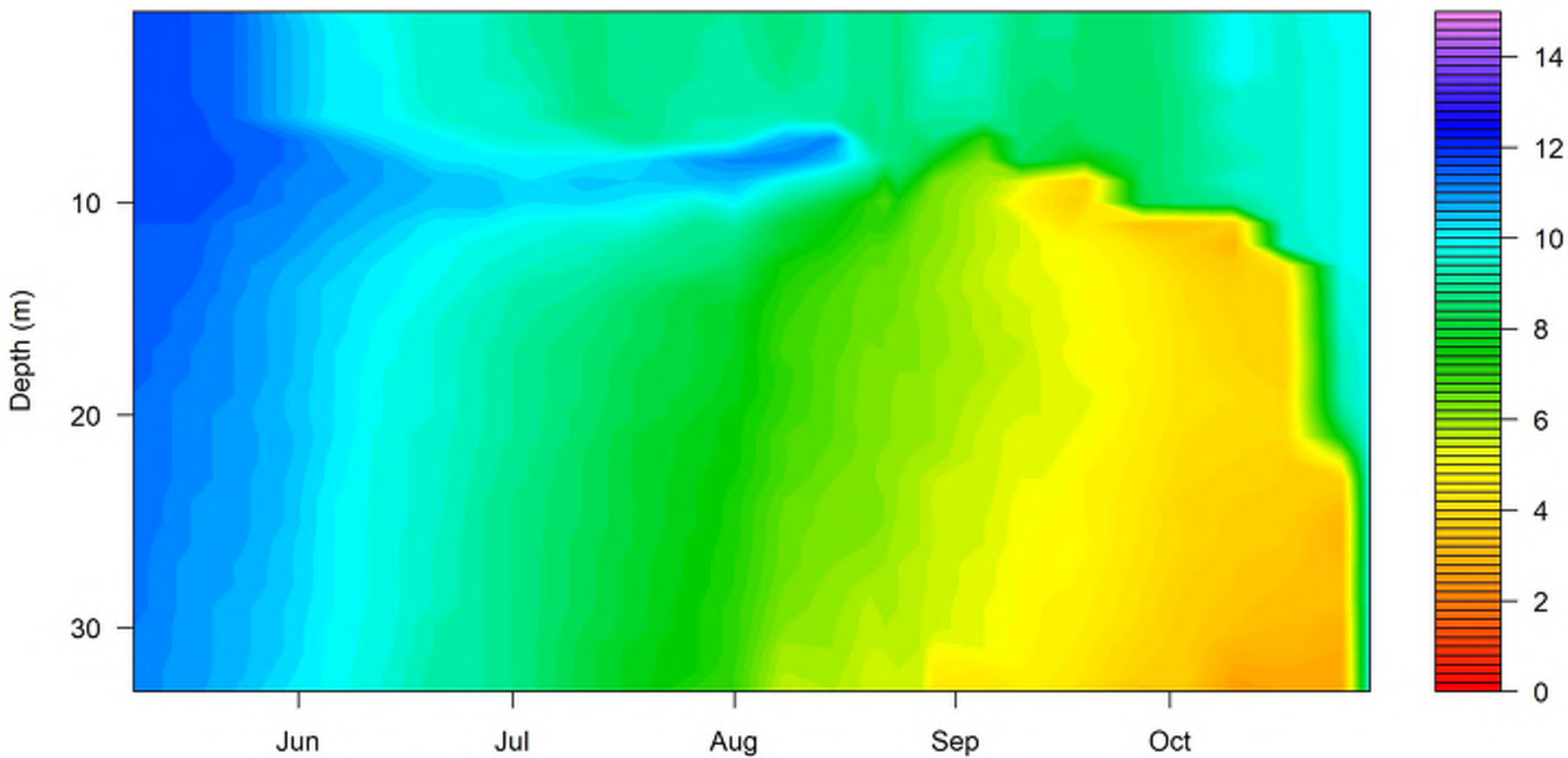
Station: 8 - DO - 2017

DO (mg/L)



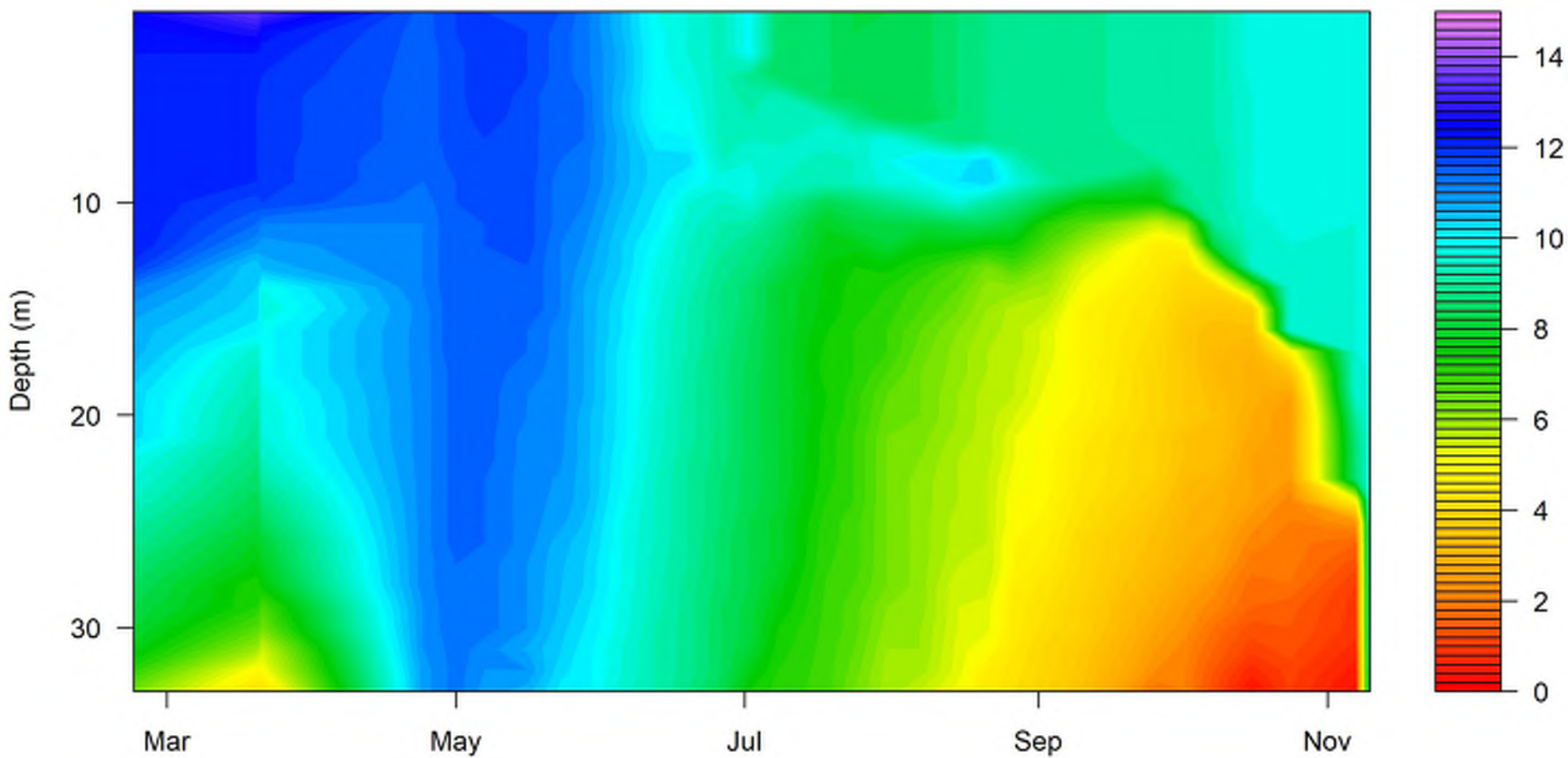
Station: 8 - DO - 2018

DO (mg/L)



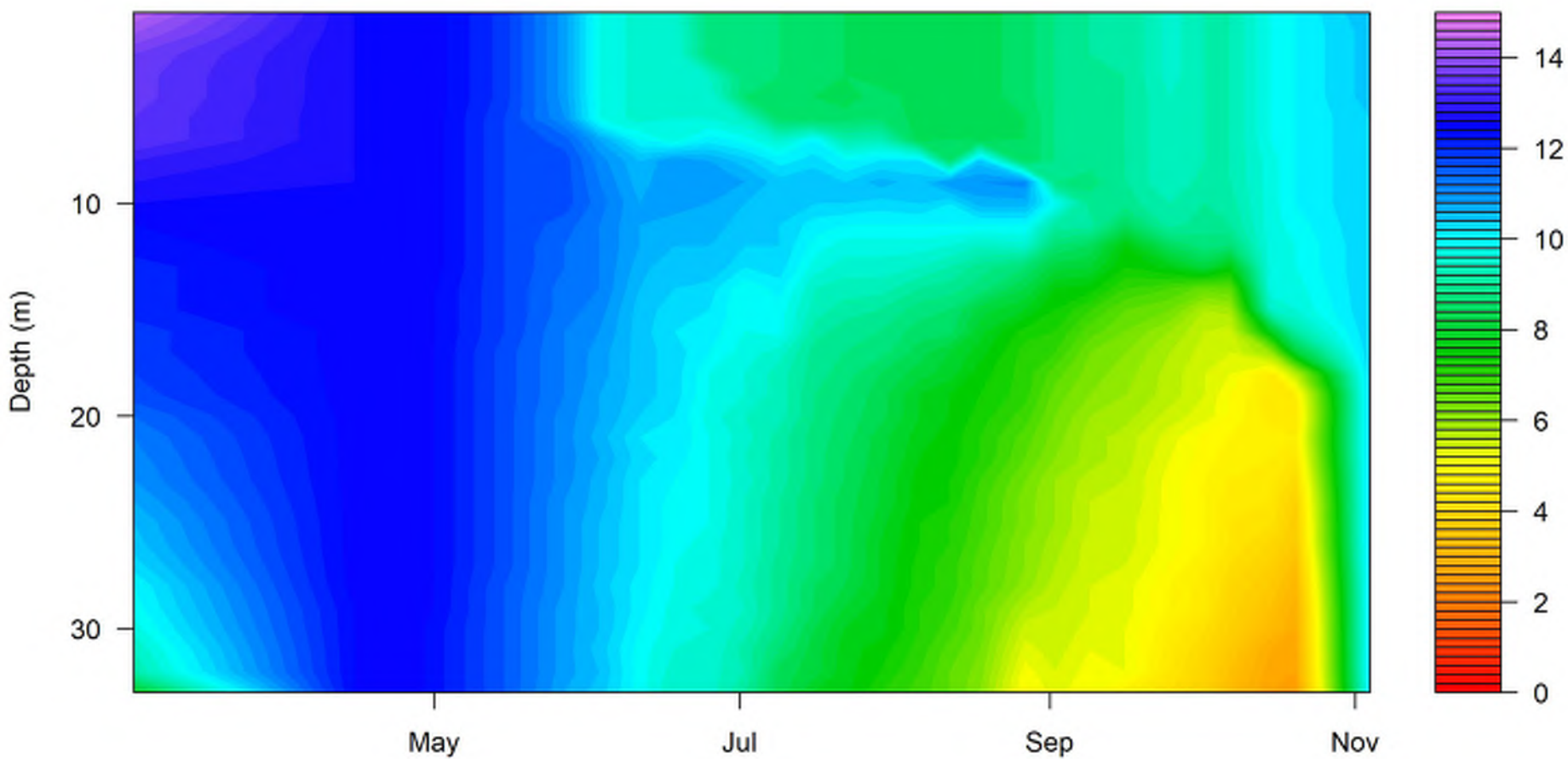
Station: 8 - DO - 2019

DO (mg/L)



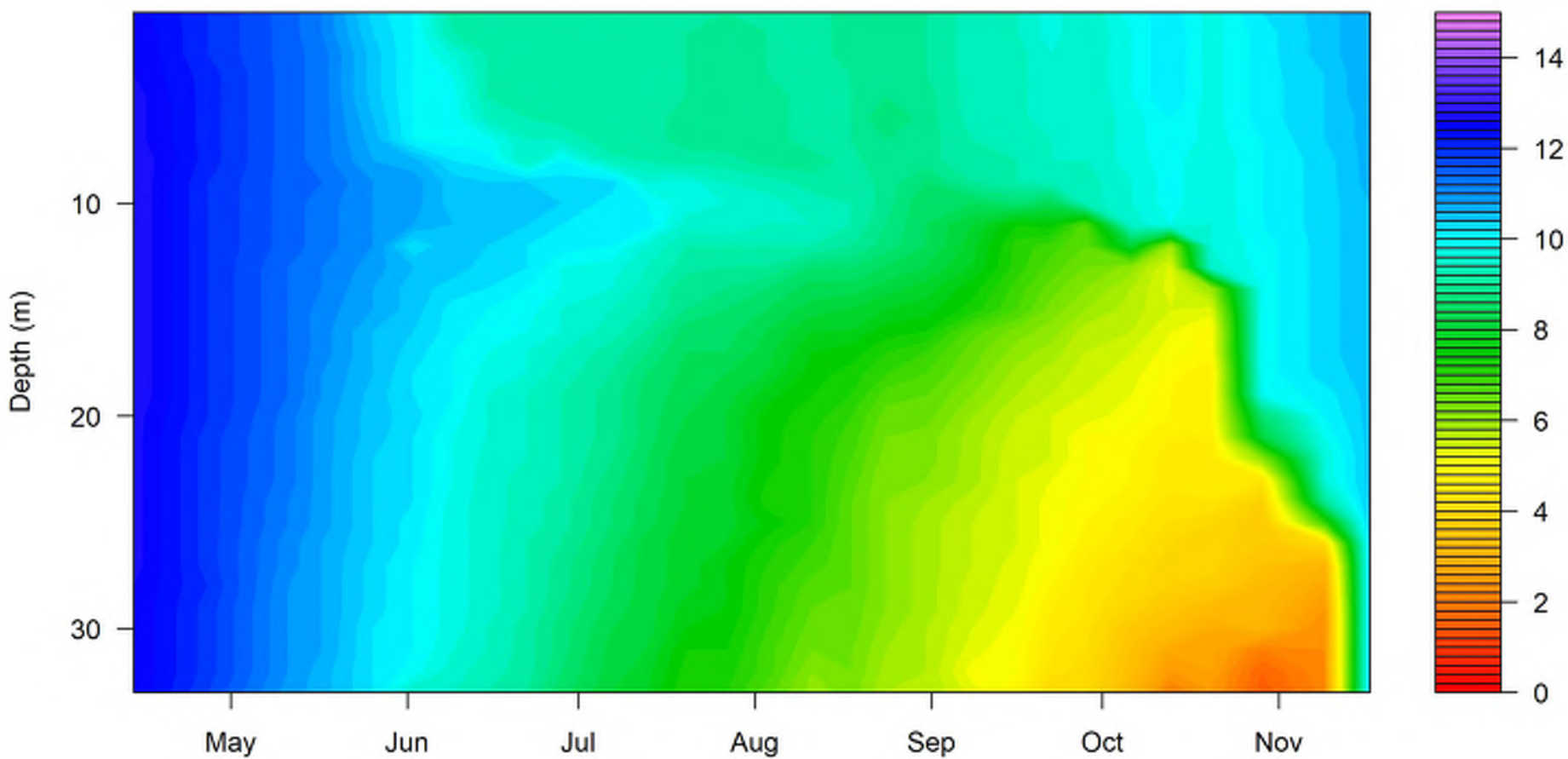
Station: 8 - DO - 2020

DO (mg/L)



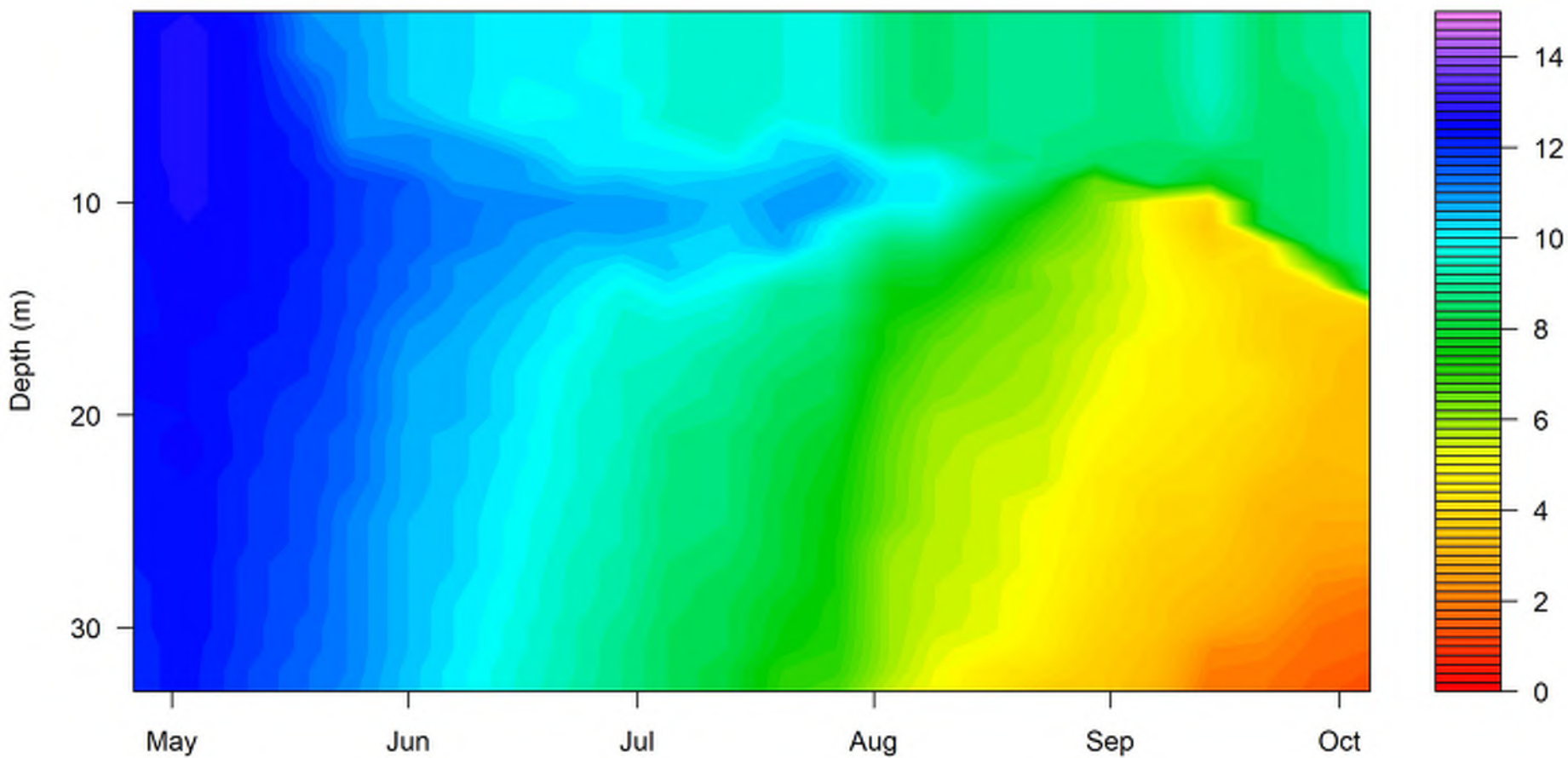
Station: 8 - DO - 2021

DO (mg/L)



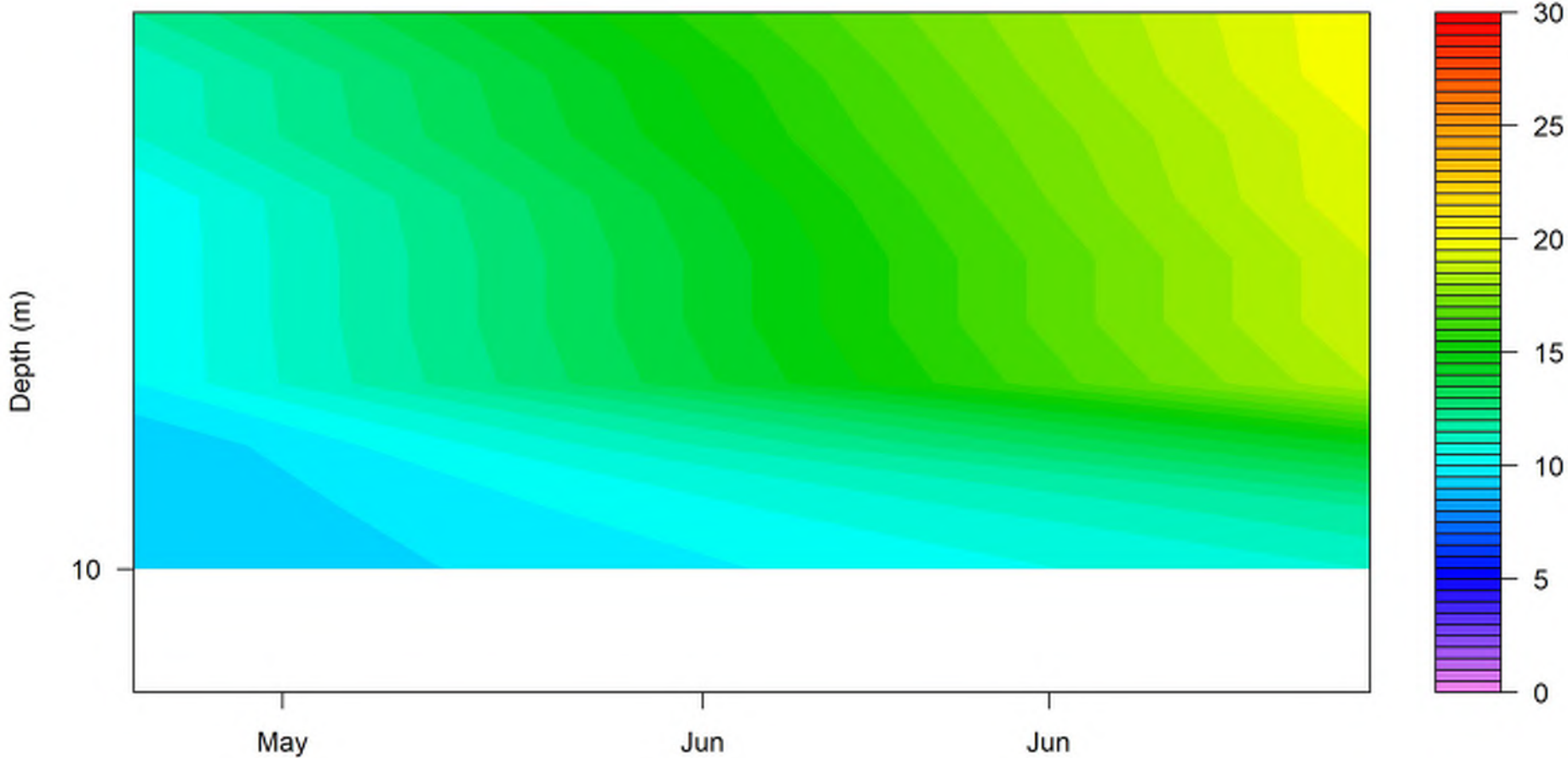
Station: 8 - DO - 2022

DO (mg/L)



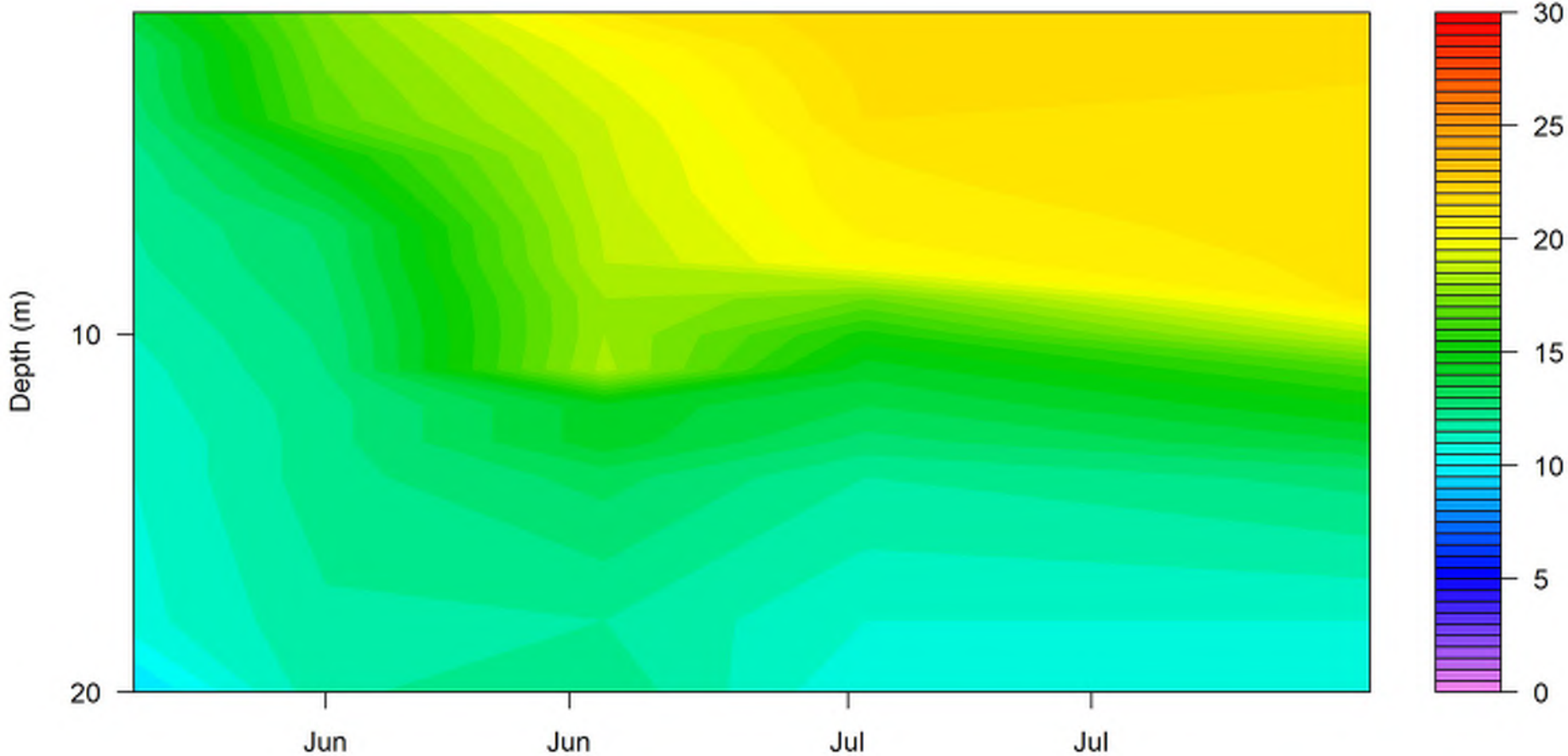
Station: 8 - T - 1979

Temp (Deg. C)



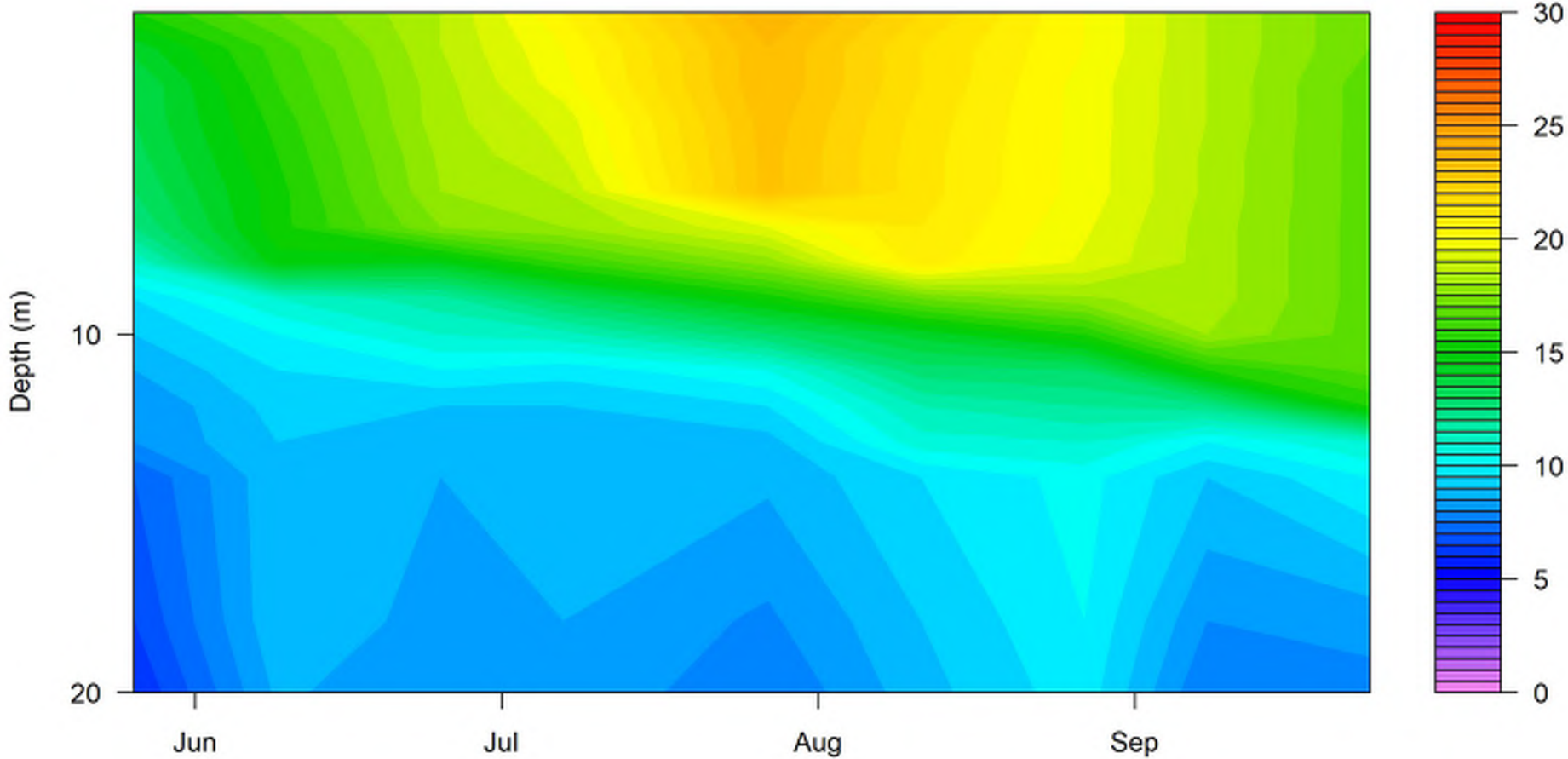
Station: 8 - T - 1981

Temp (Deg. C)



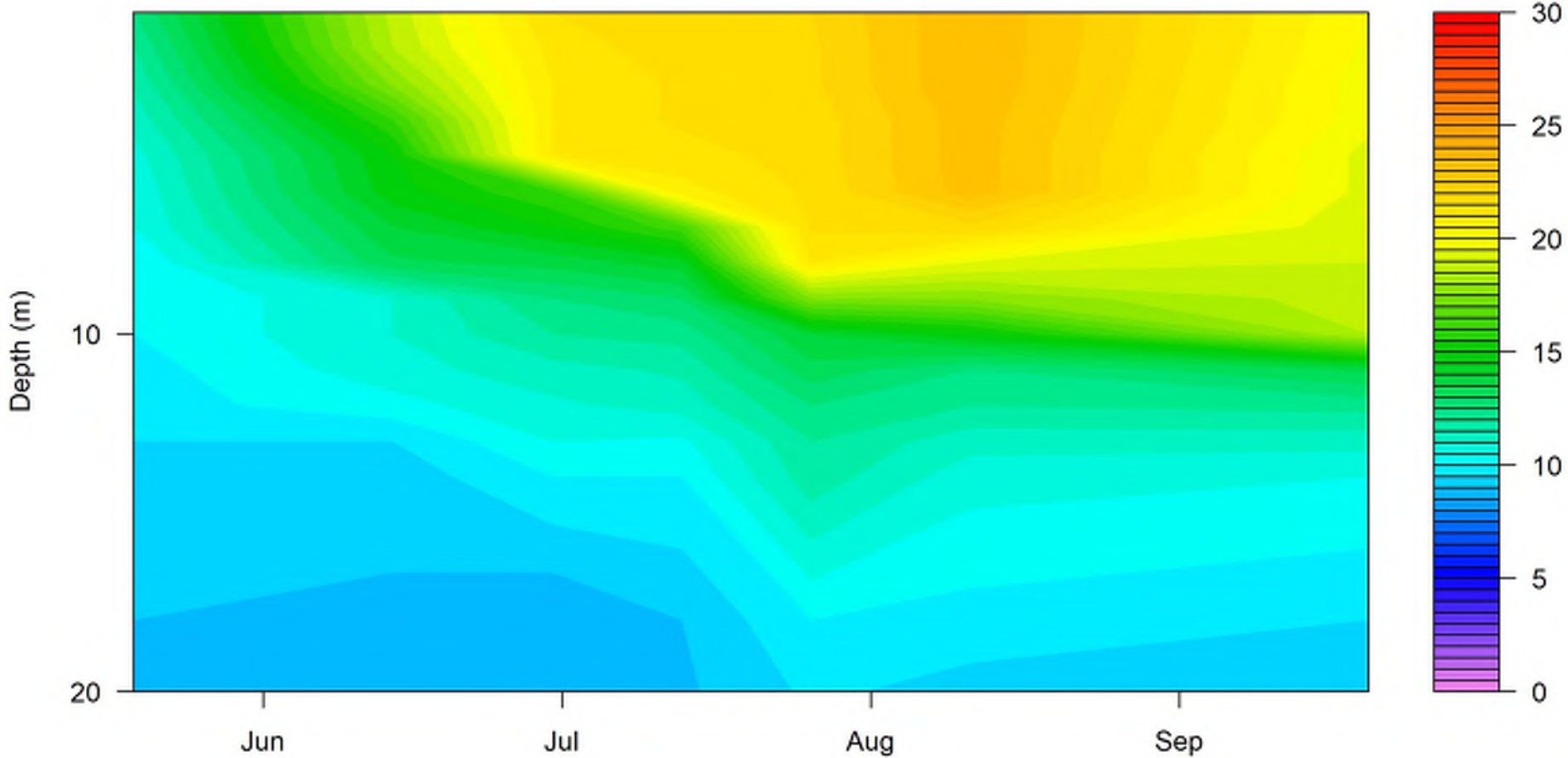
Station: 8 - T - 1982

Temp (Deg. C)



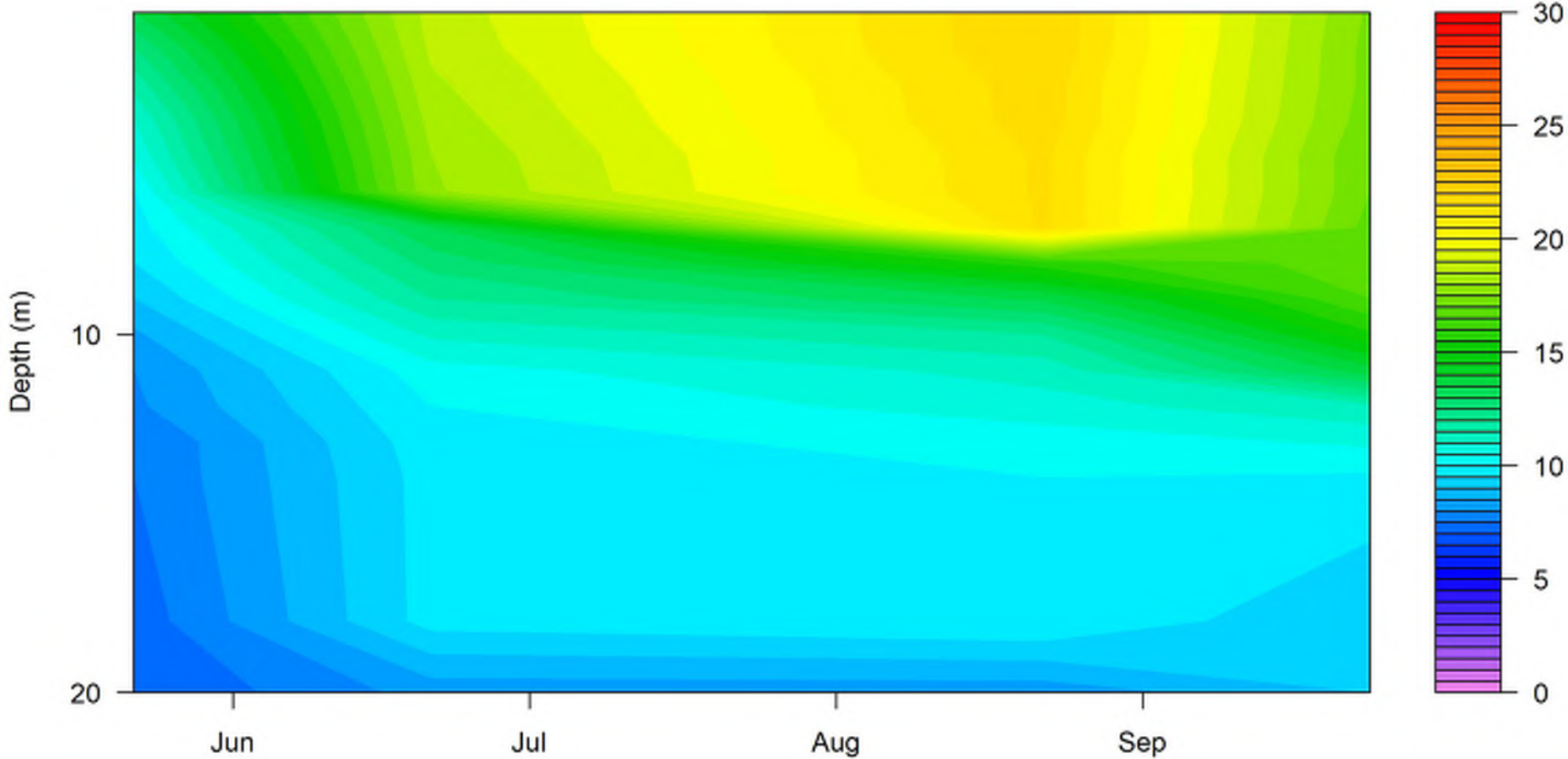
Station: 8 - T - 1983

Temp (Deg. C)



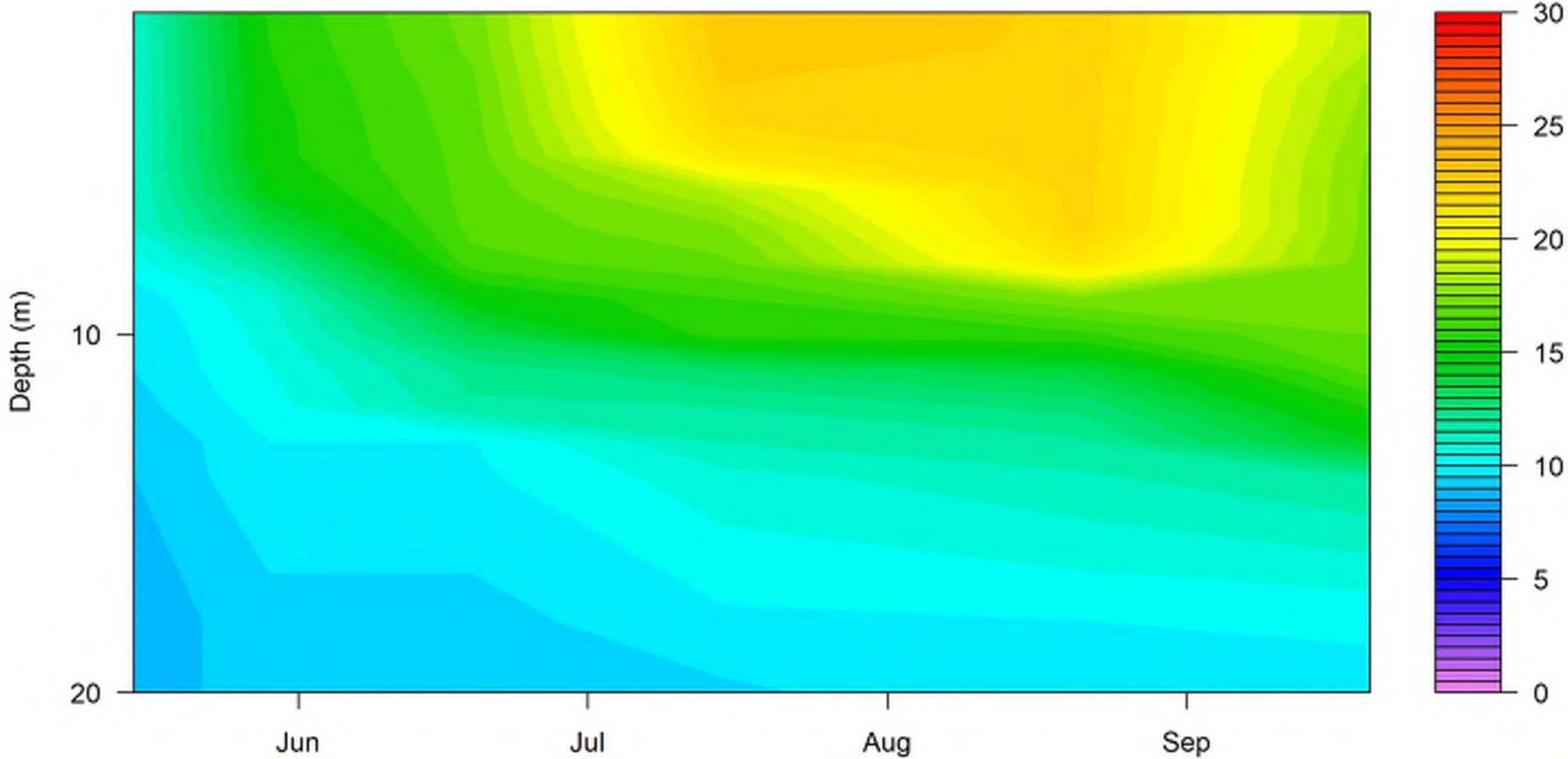
Station: 8 - T - 1984

Temp (Deg. C)



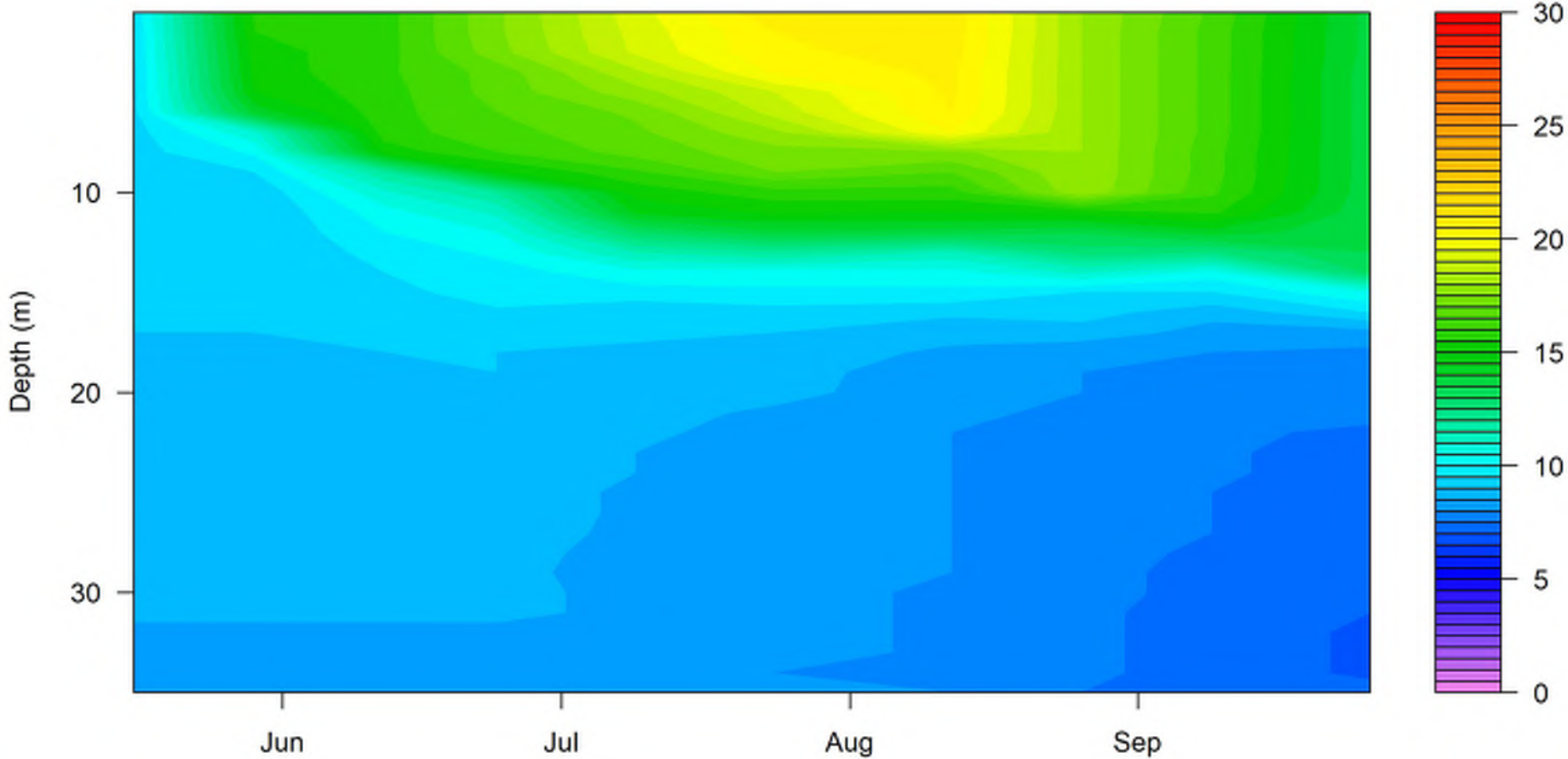
Station: 8 - T - 1985

Temp (Deg. C)



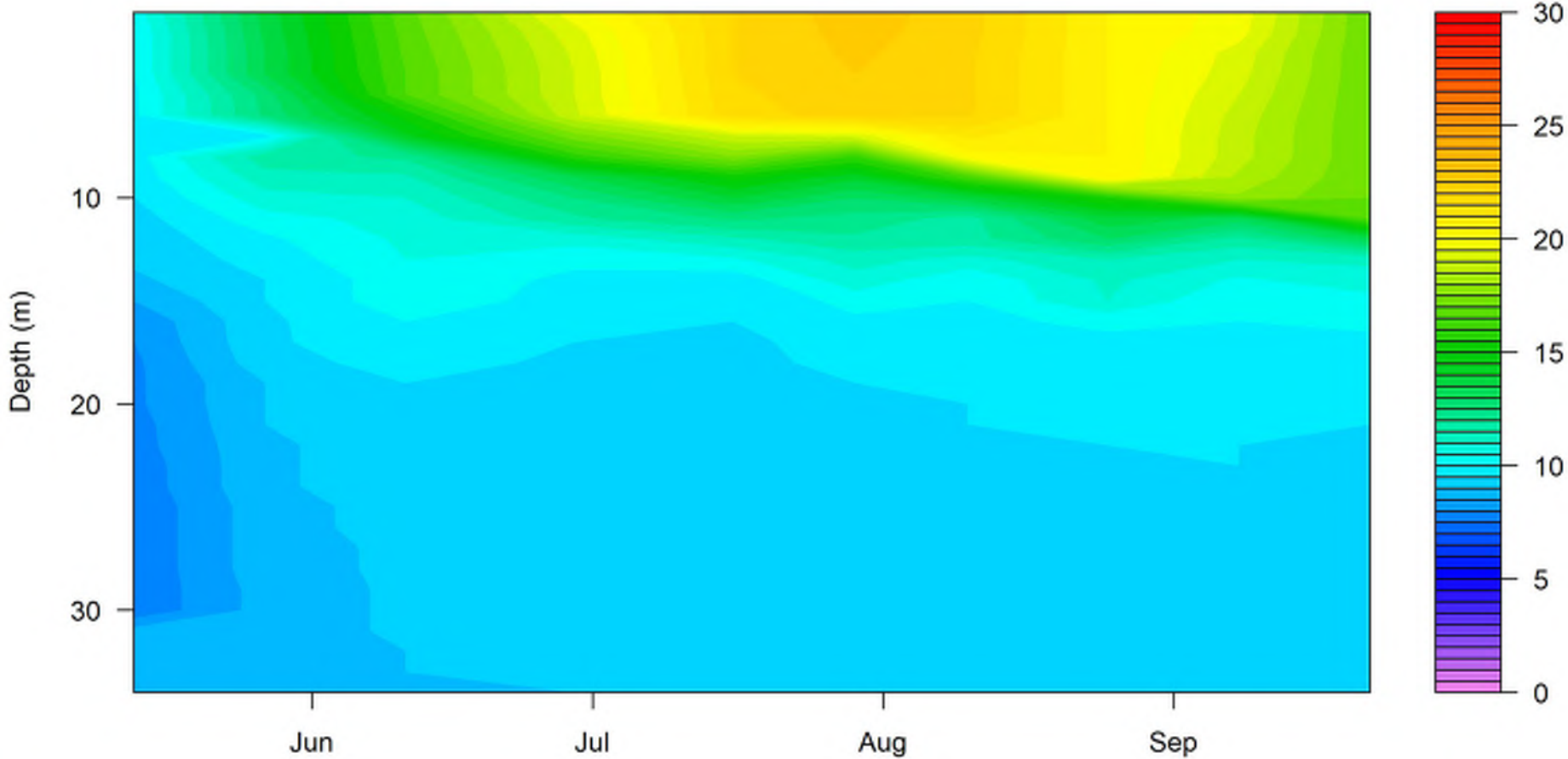
Station: 8 - T - 1986

Temp (Deg. C)



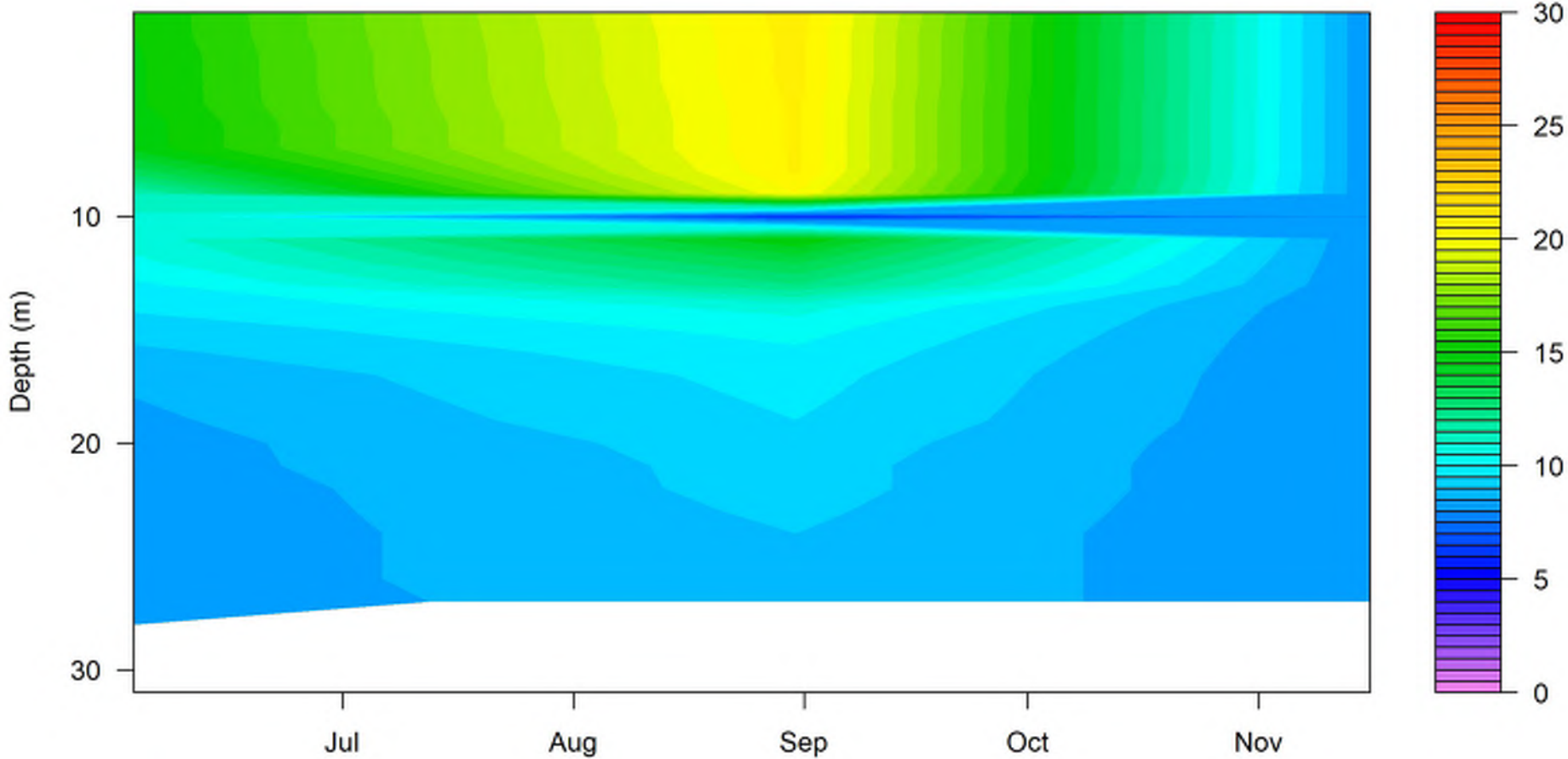
Station: 8 - T - 1987

Temp (Deg. C)



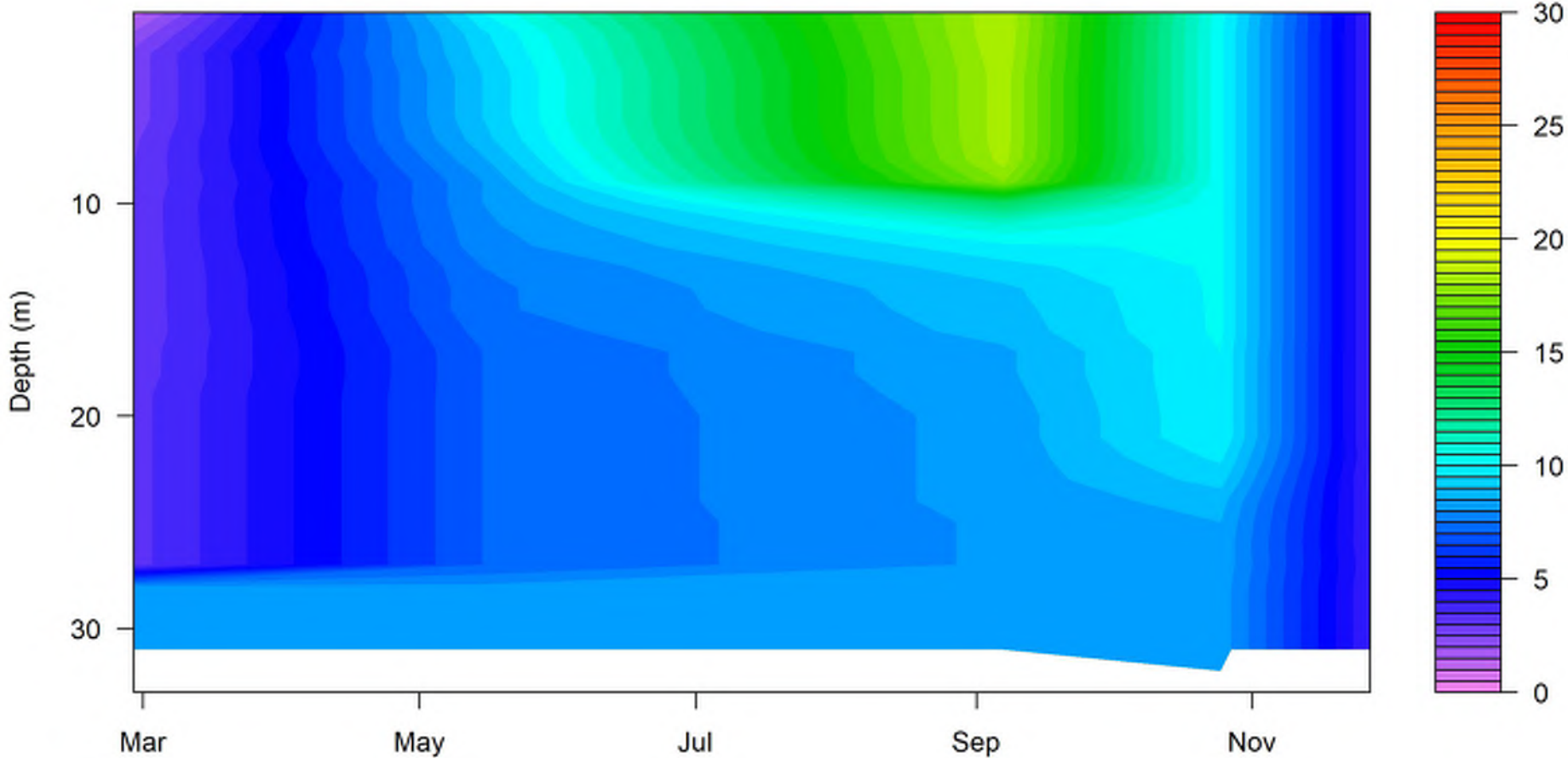
Station: 8 - T - 1988

Temp (Deg. C)



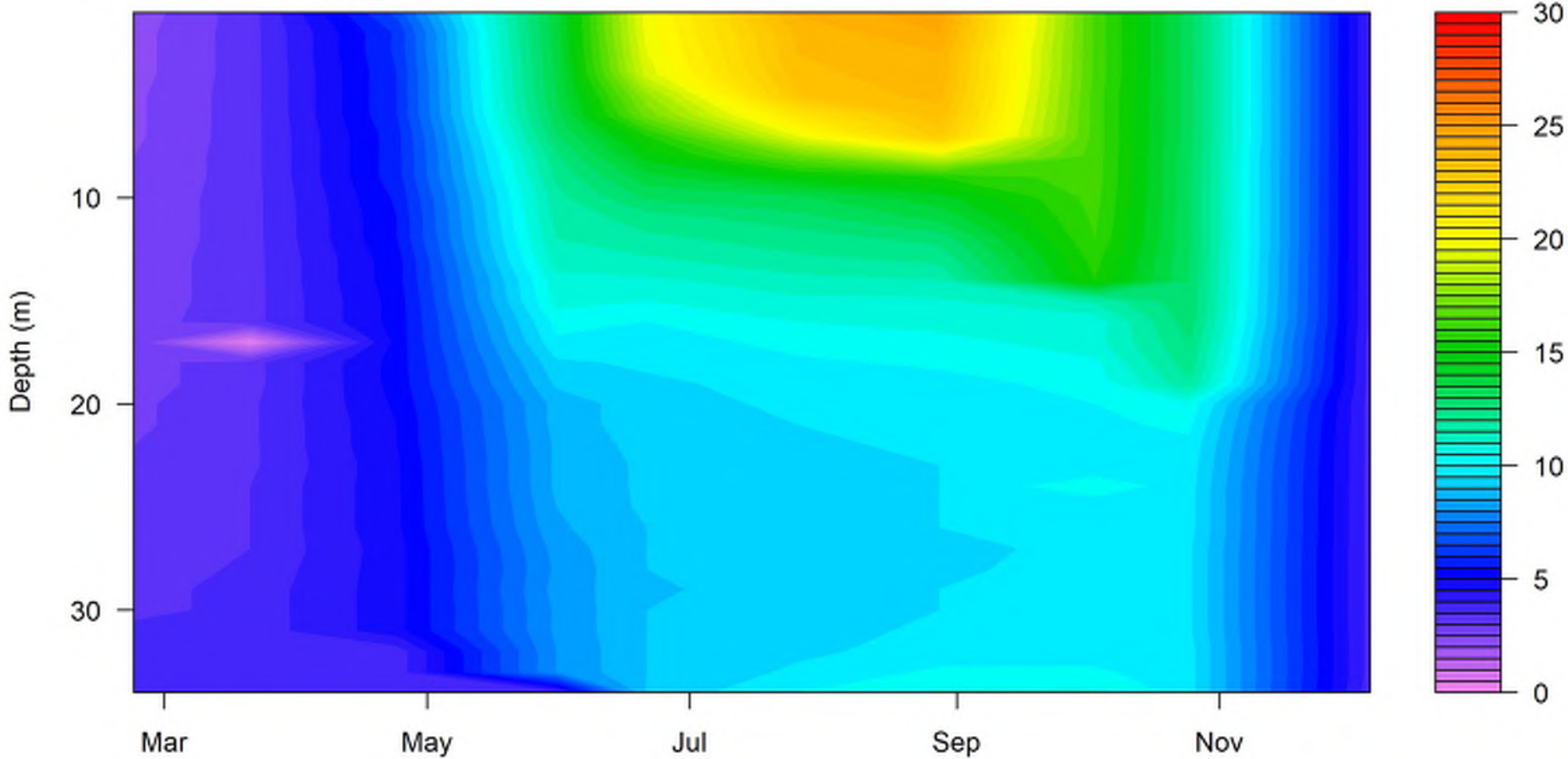
Station: 8 - T - 1989

Temp (Deg. C)



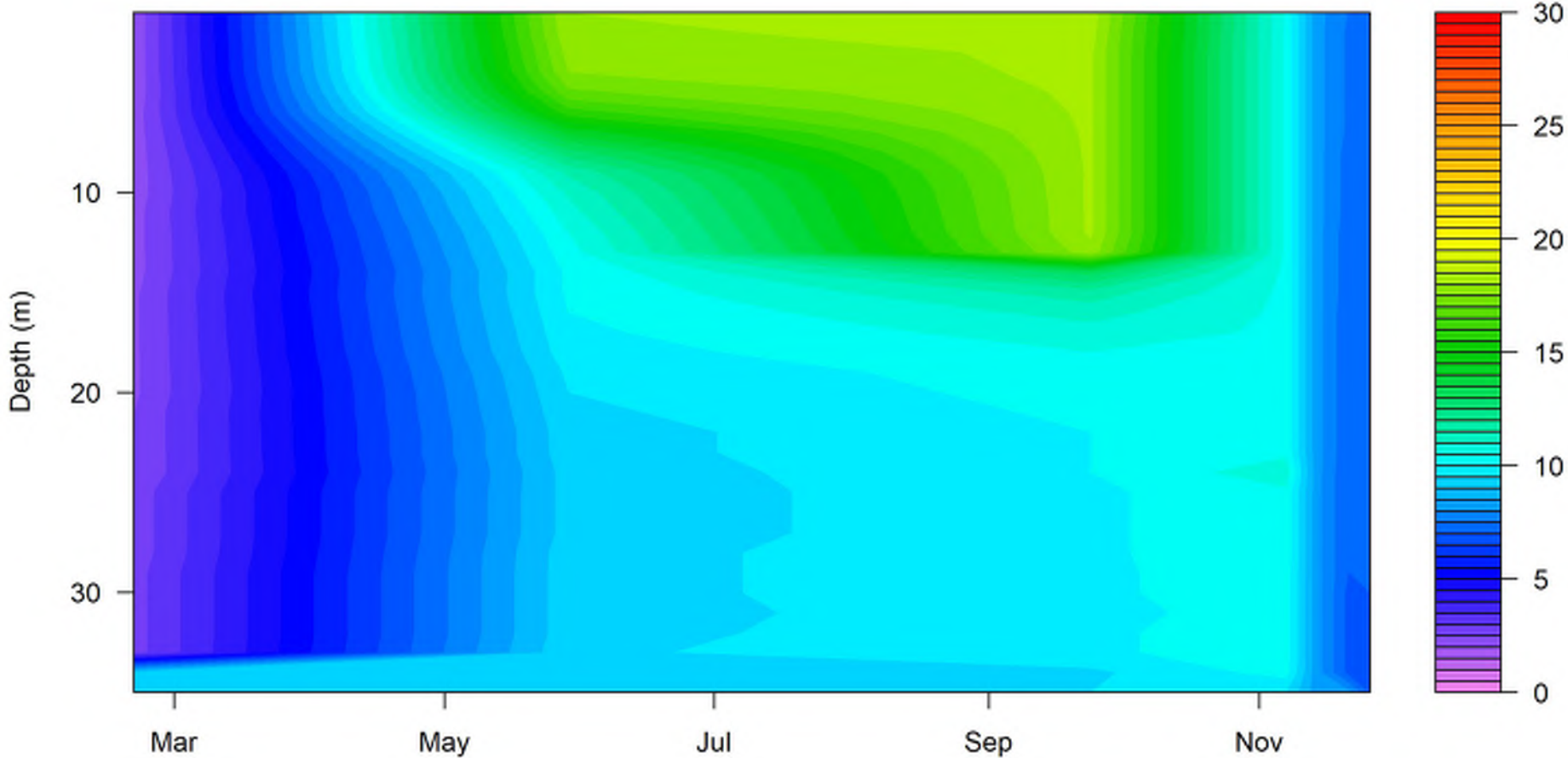
Station: 8 - T - 1990

Temp (Deg. C)



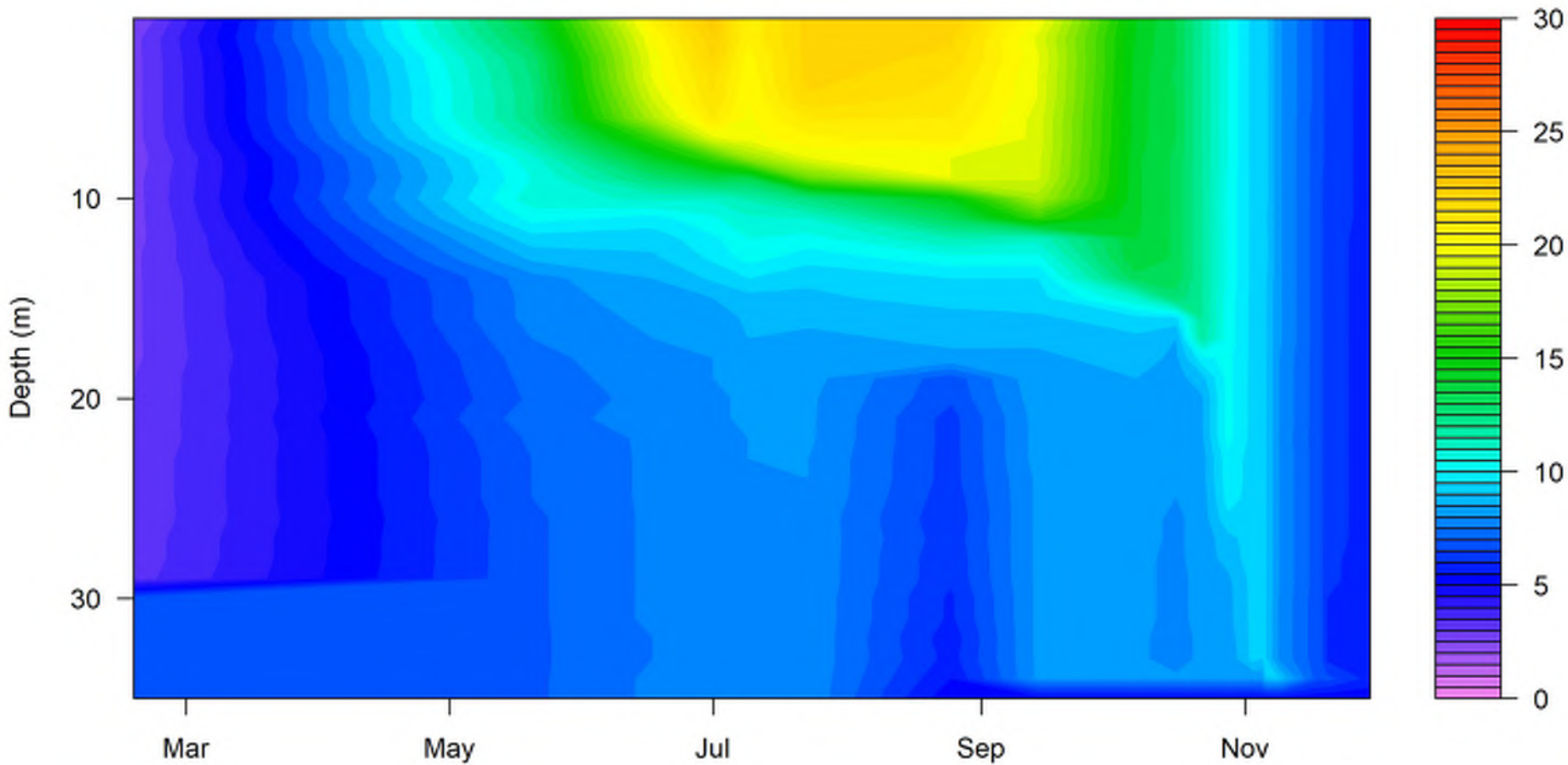
Station: 8 - T - 1991

Temp (Deg. C)



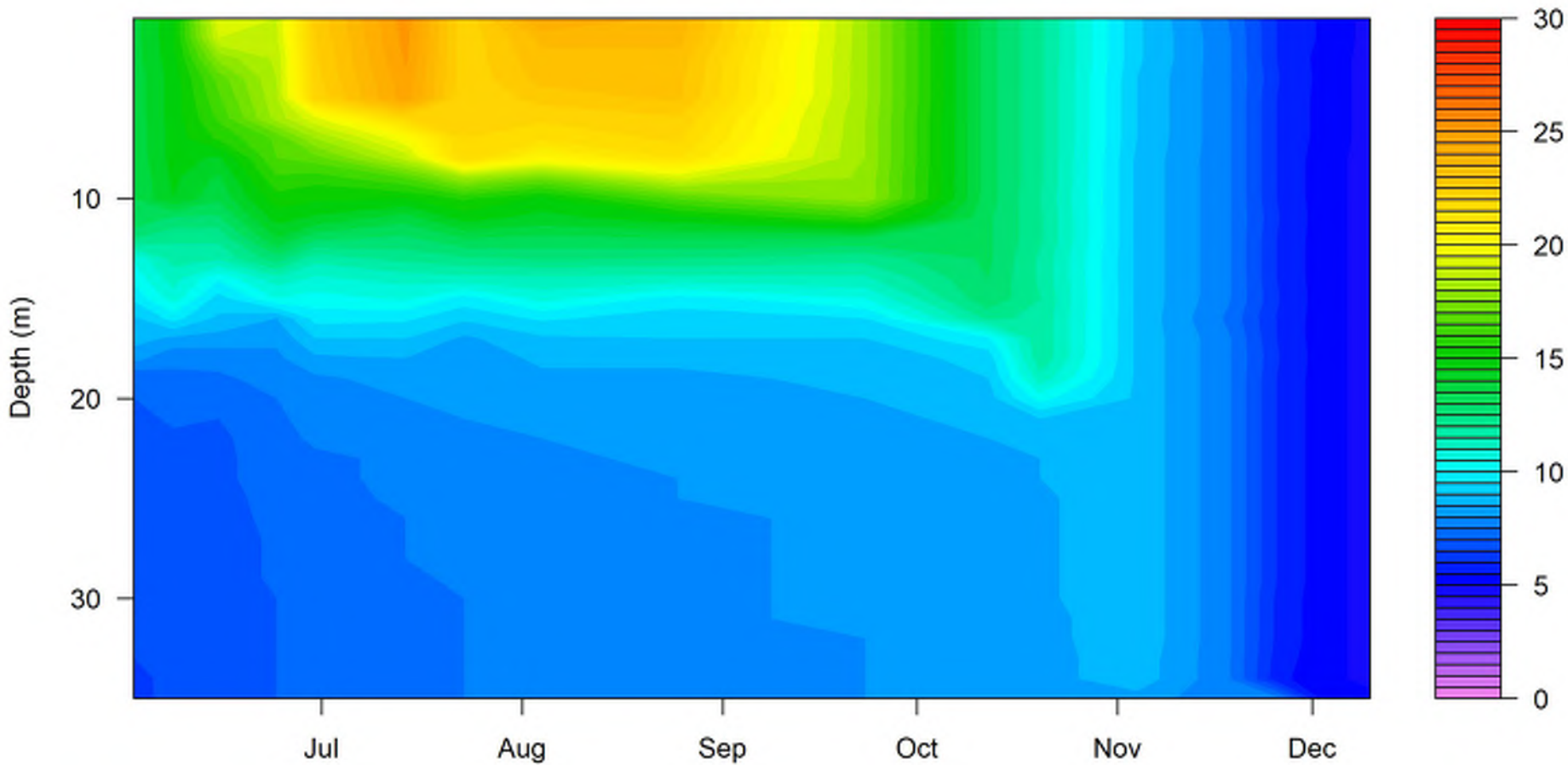
Station: 8 - T - 1992

Temp (Deg. C)



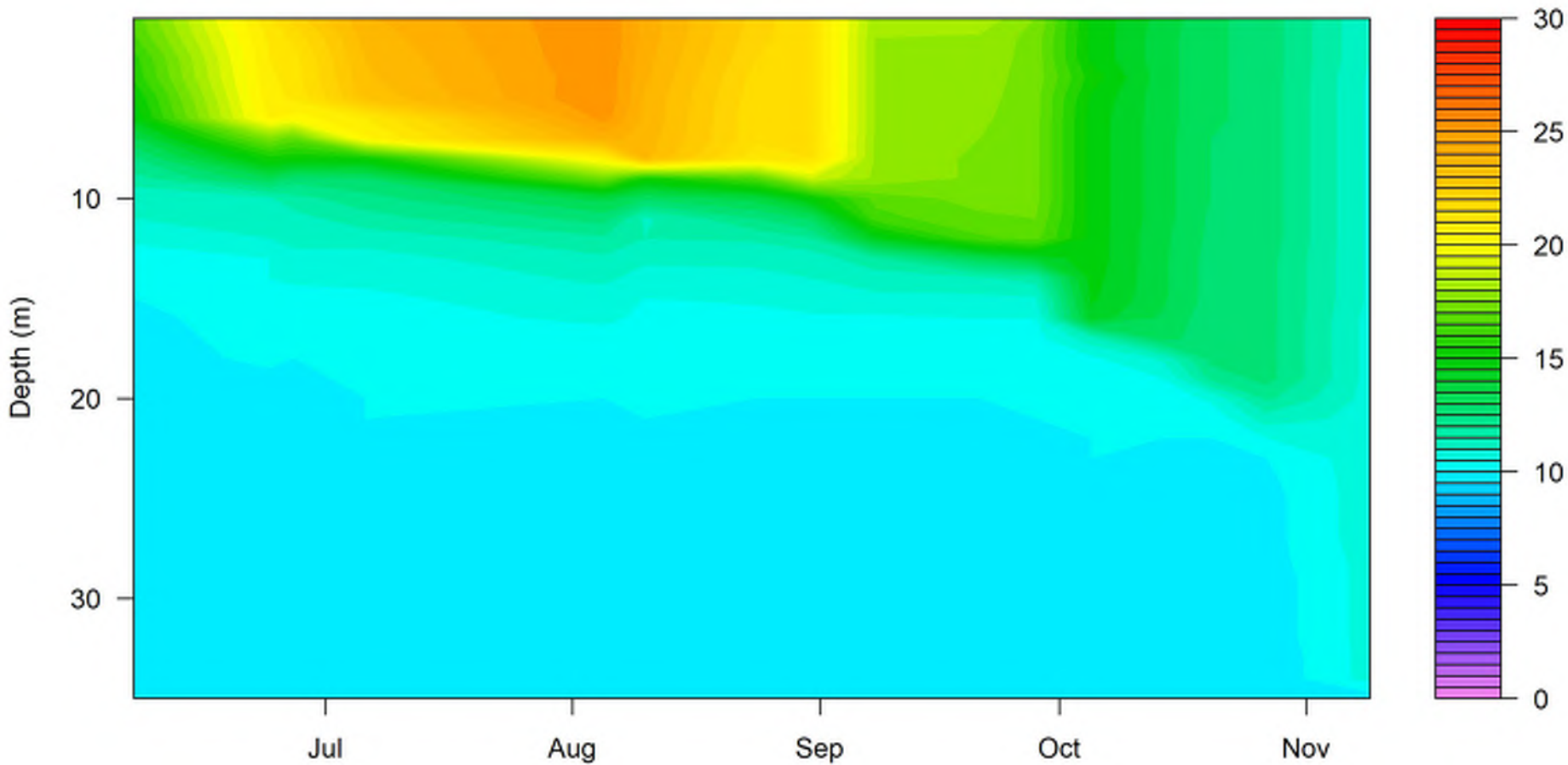
Station: 8 - T - 1993

Temp (Deg. C)



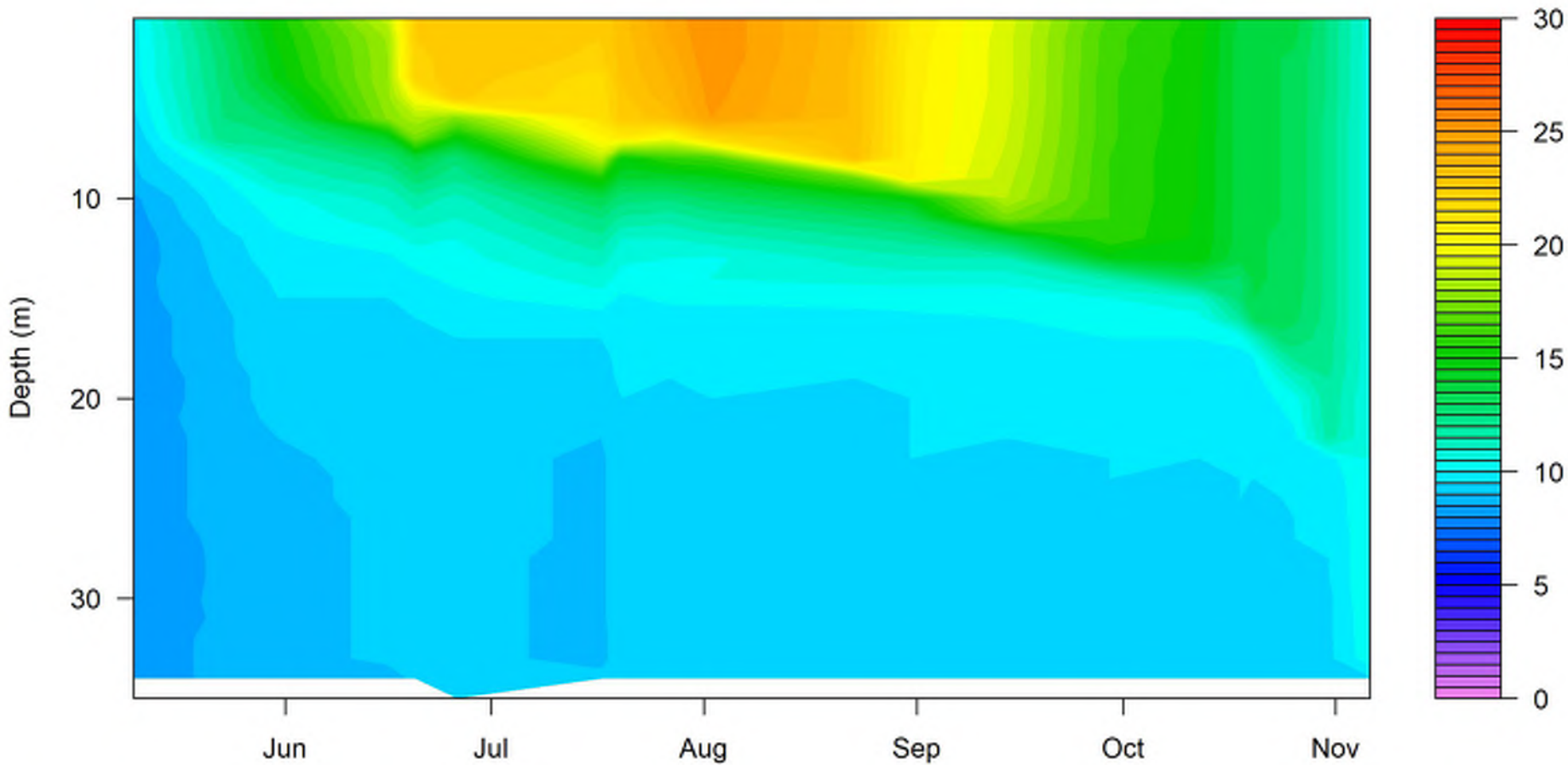
Station: 8 - T - 1994

Temp (Deg. C)



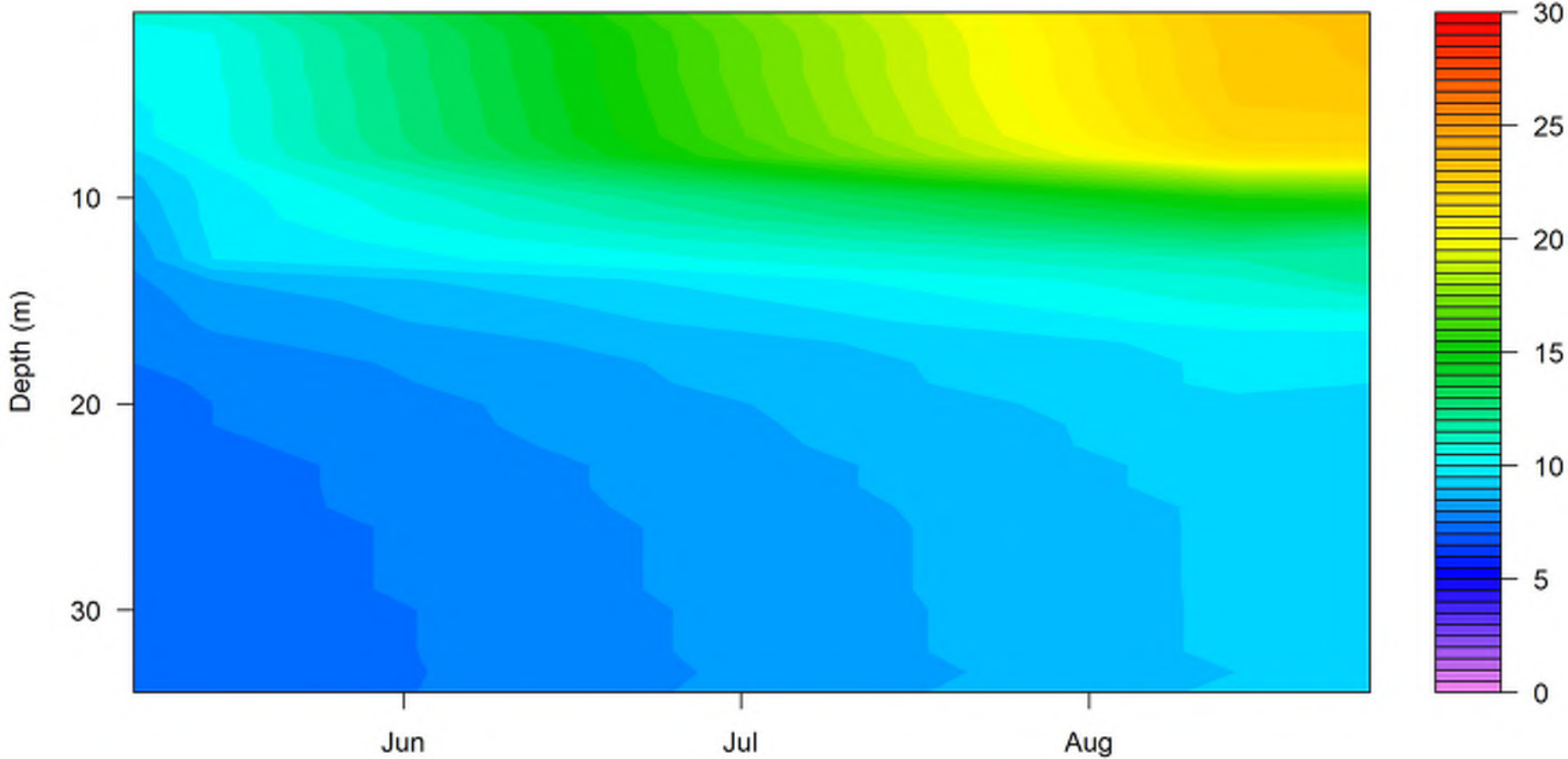
Station: 8 - T - 1995

Temp (Deg. C)



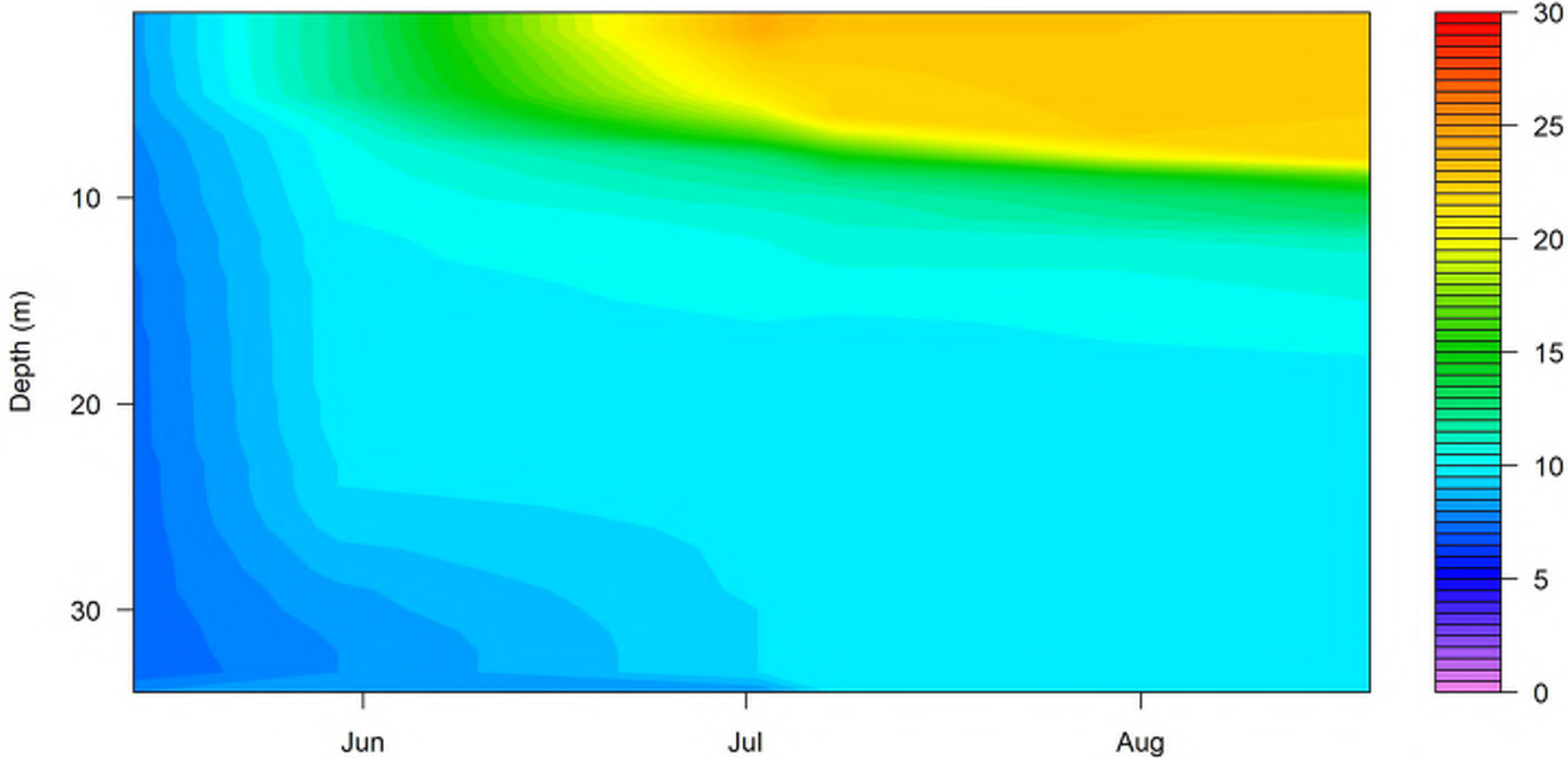
Station: 8 - T - 1996

Temp (Deg. C)



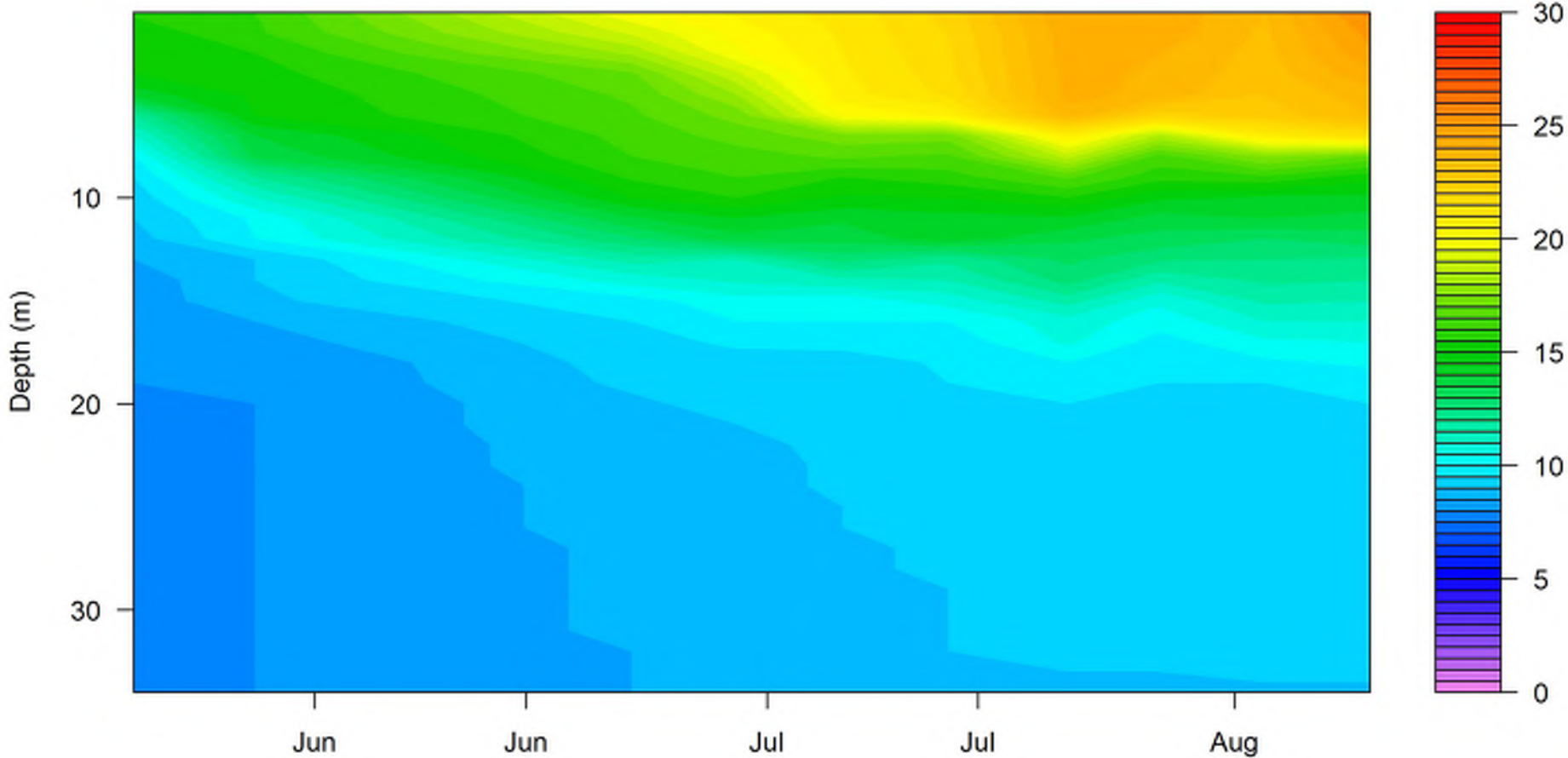
Station: 8 - T - 1997

Temp (Deg. C)



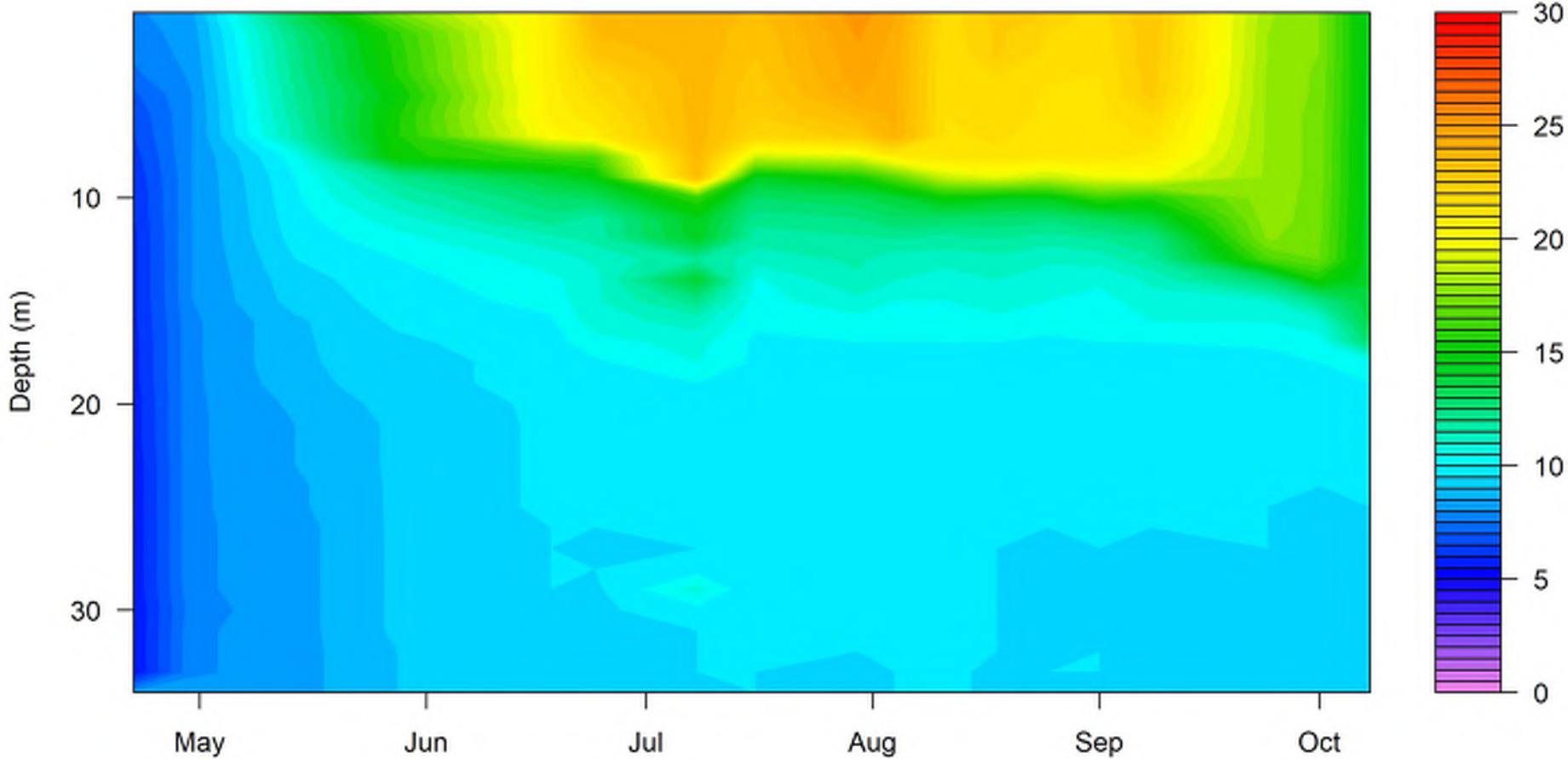
Station: 8 - T - 1998

Temp (Deg. C)



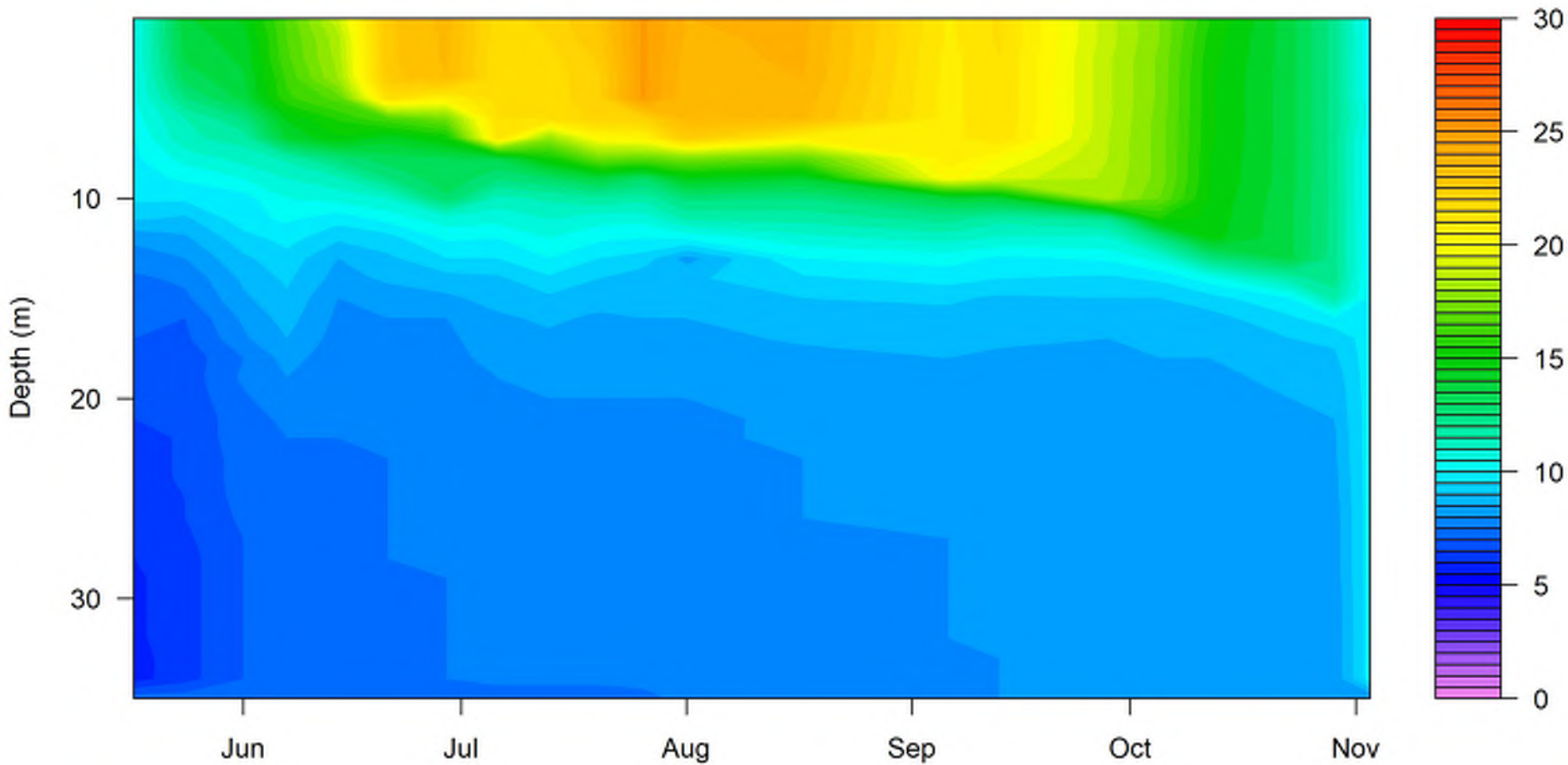
Station: 8 - T - 1999

Temp (Deg. C)



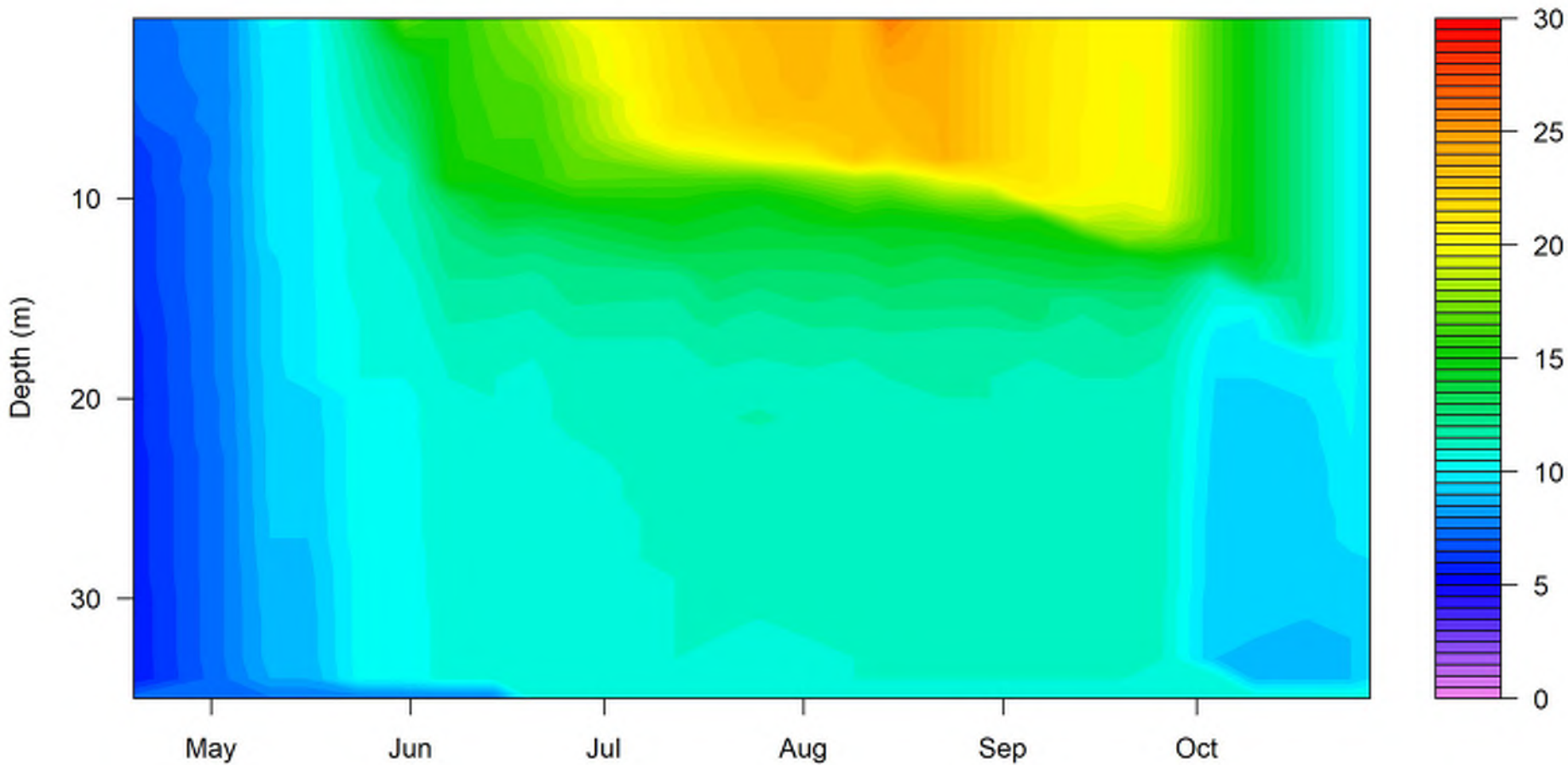
Station: 8 - T - 2001

Temp (Deg. C)



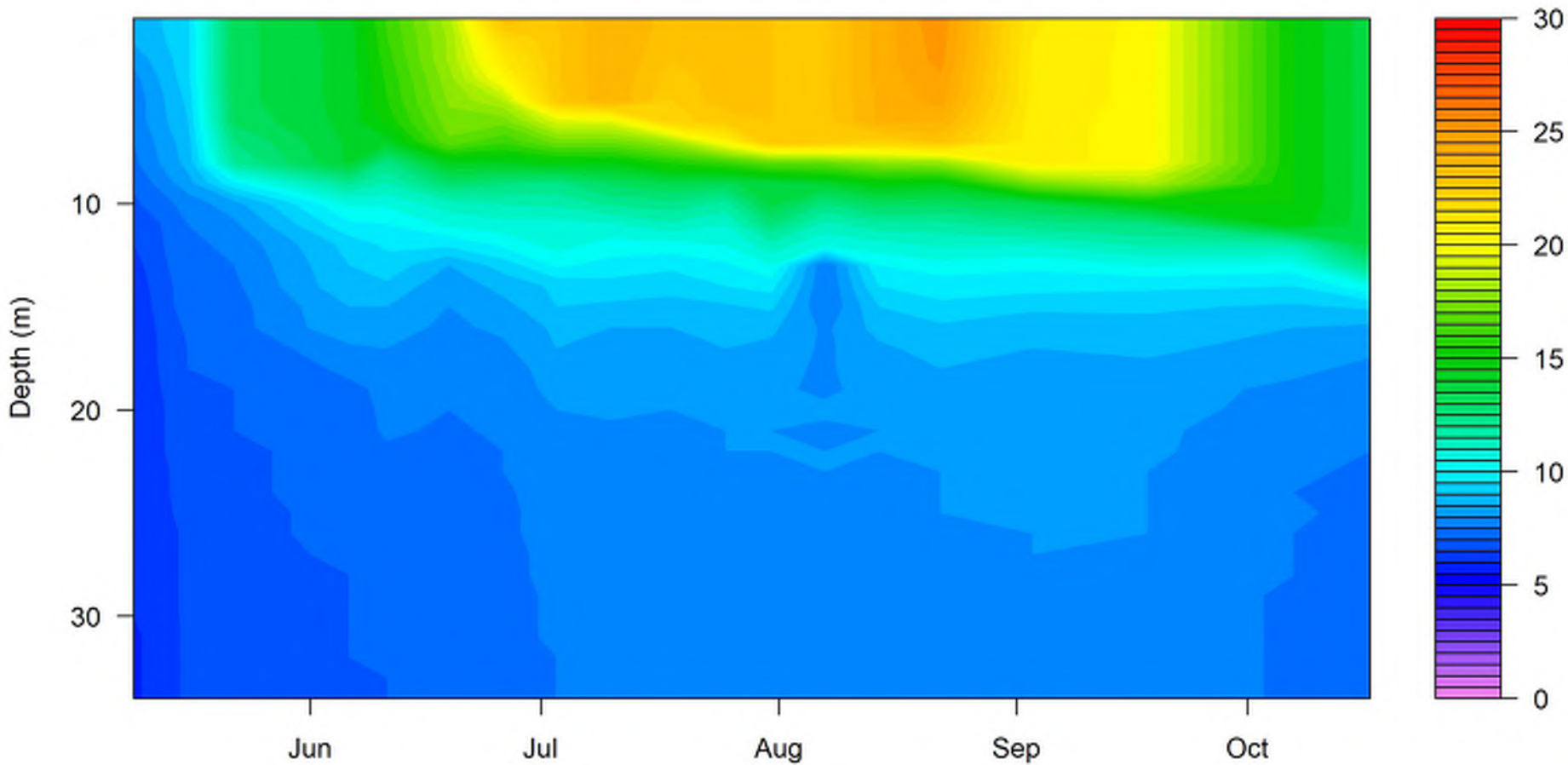
Station: 8 - T - 2002

Temp (Deg. C)



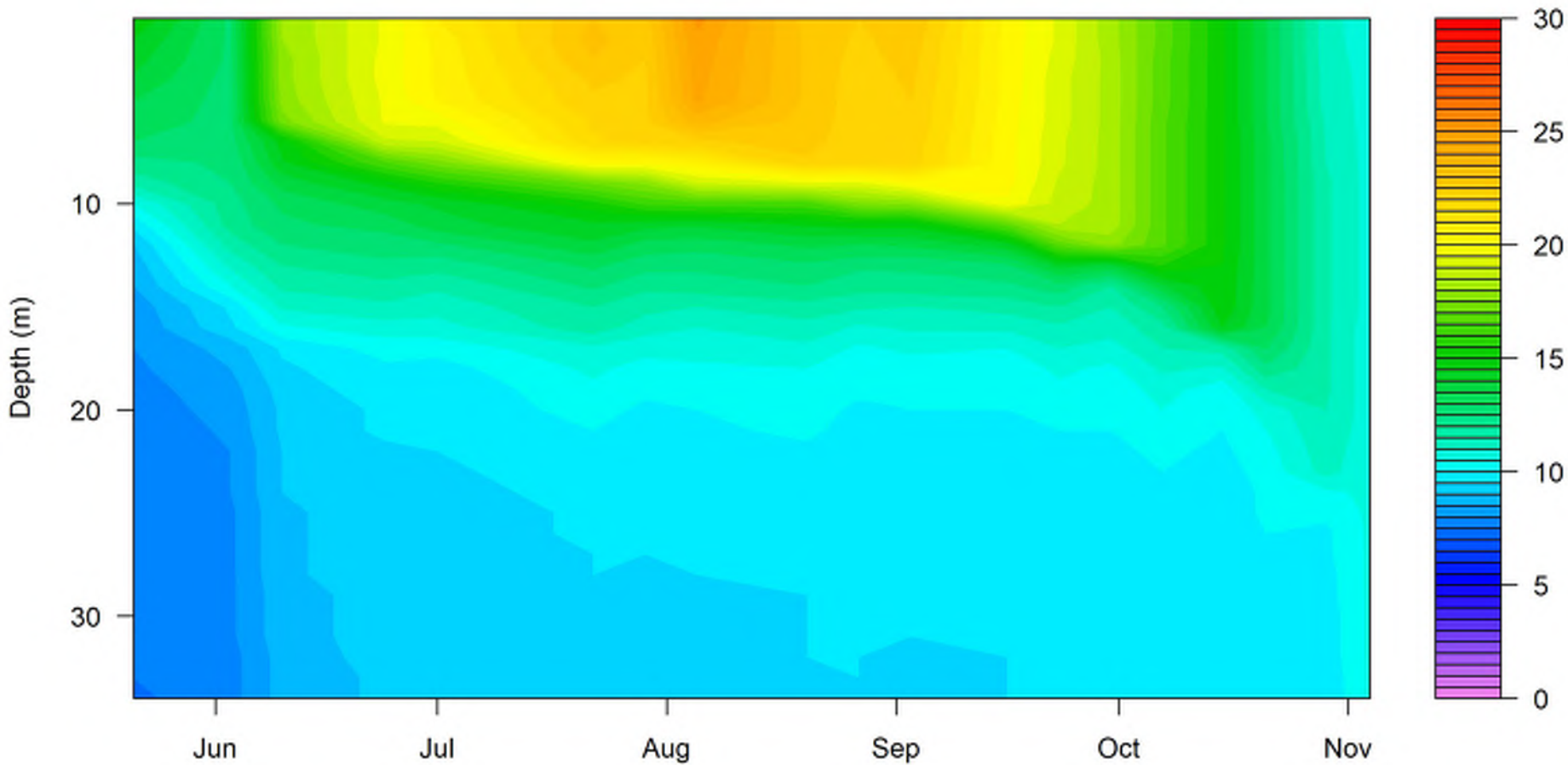
Station: 8 - T - 2003

Temp (Deg. C)



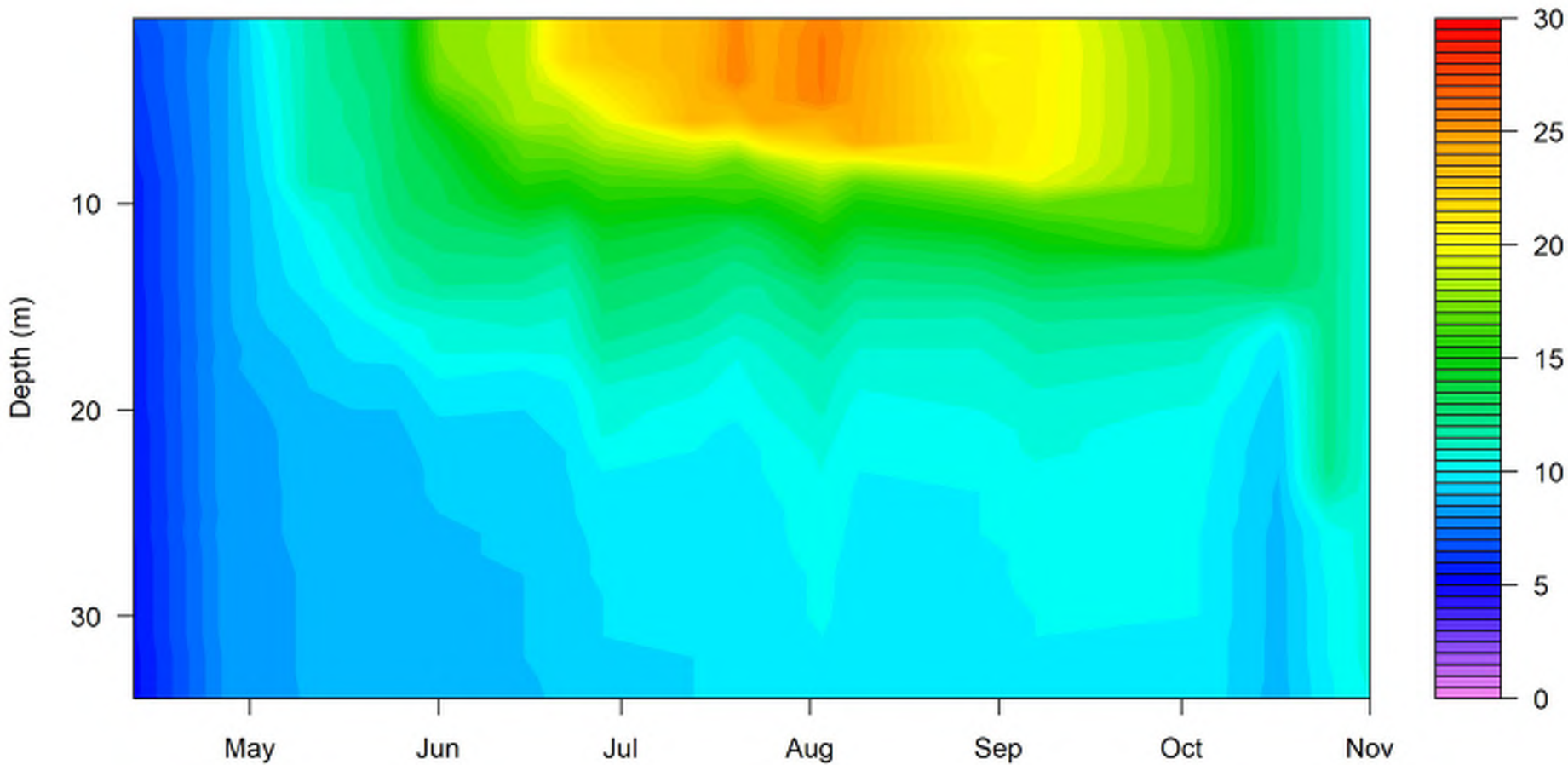
Station: 8 - T - 2004

Temp (Deg. C)



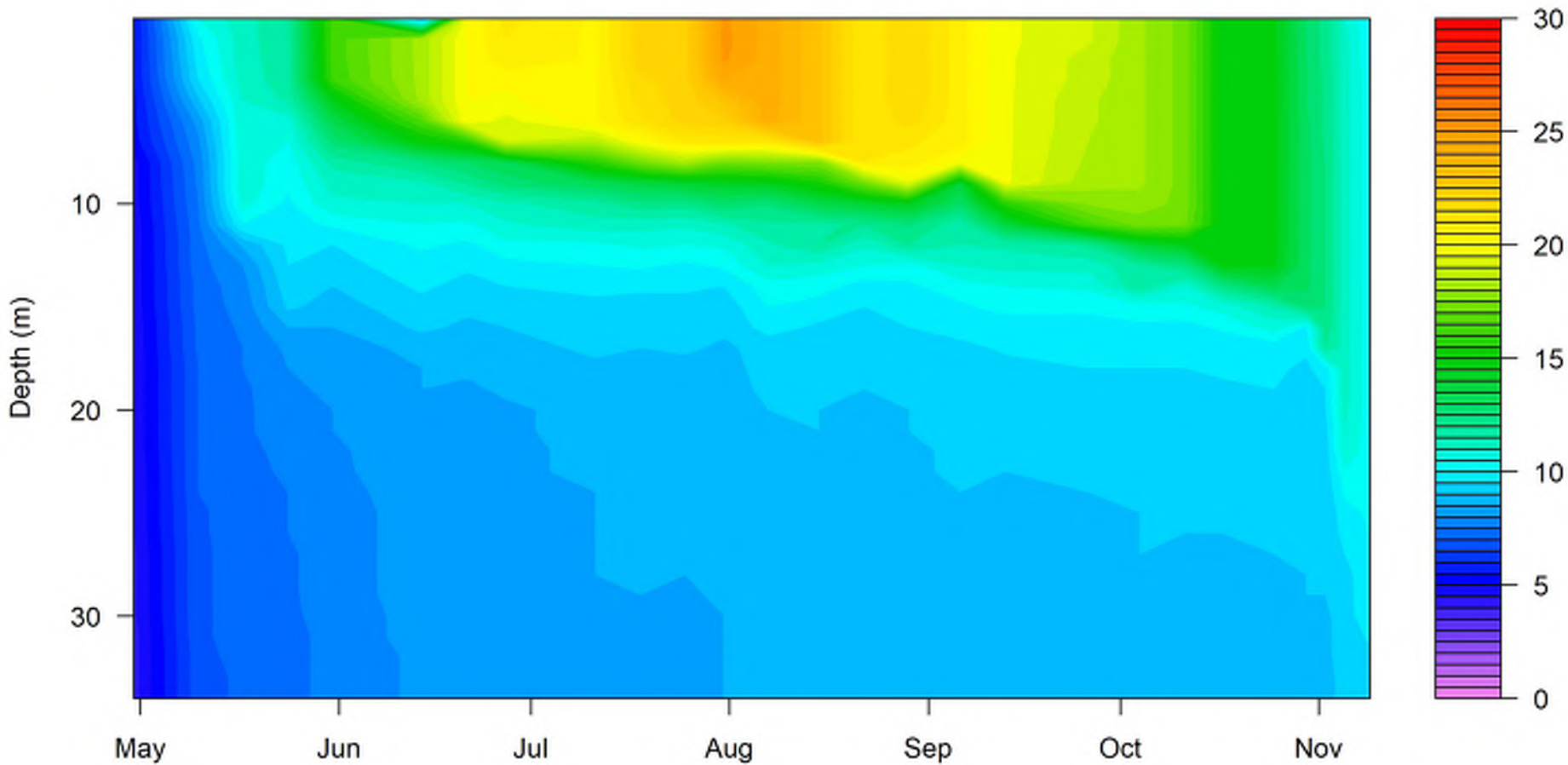
Station: 8 - T - 2006

Temp (Deg. C)



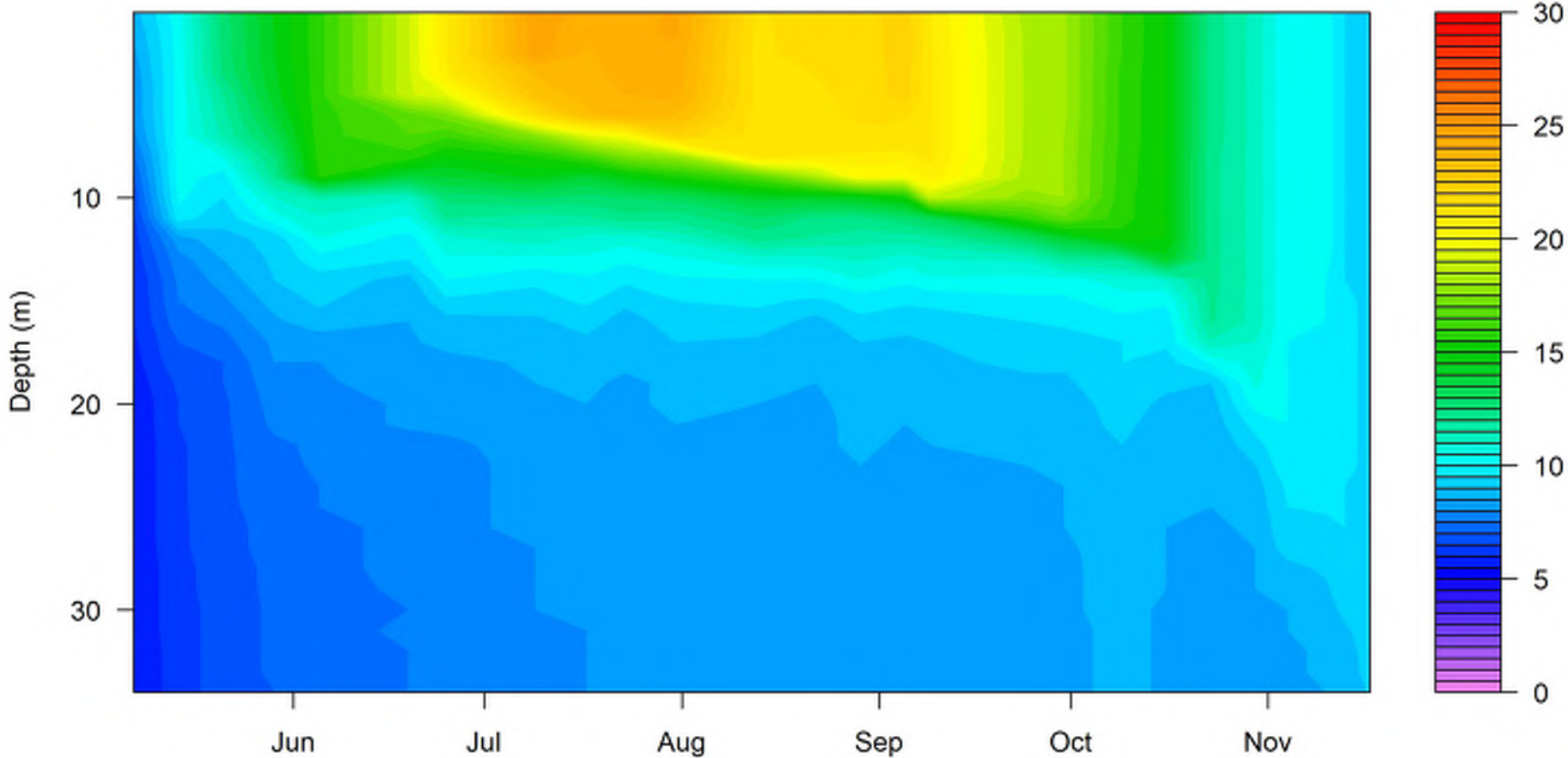
Station: 8 - T - 2007

Temp (Deg. C)



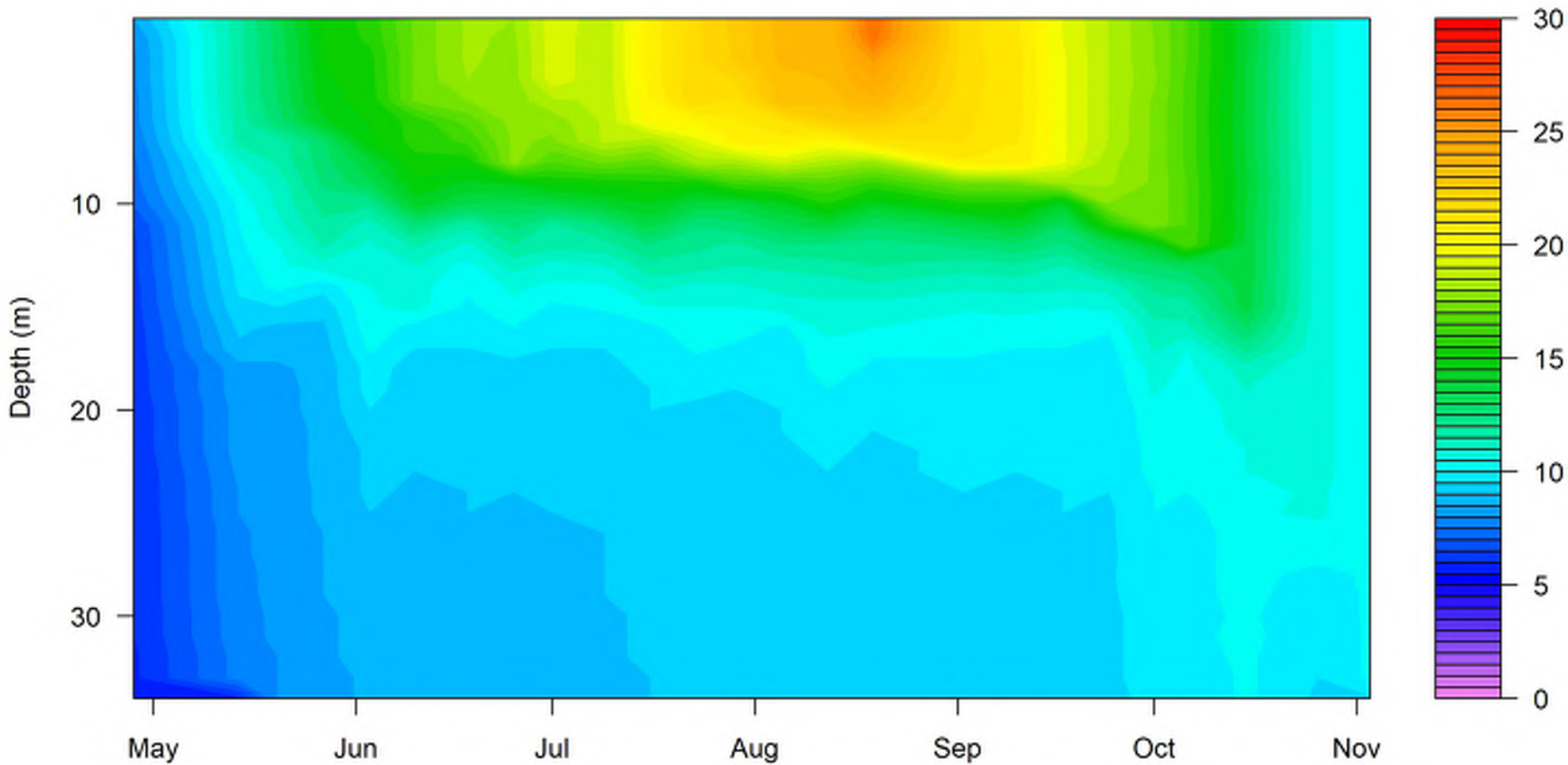
Station: 8 - T - 2008

Temp (Deg. C)



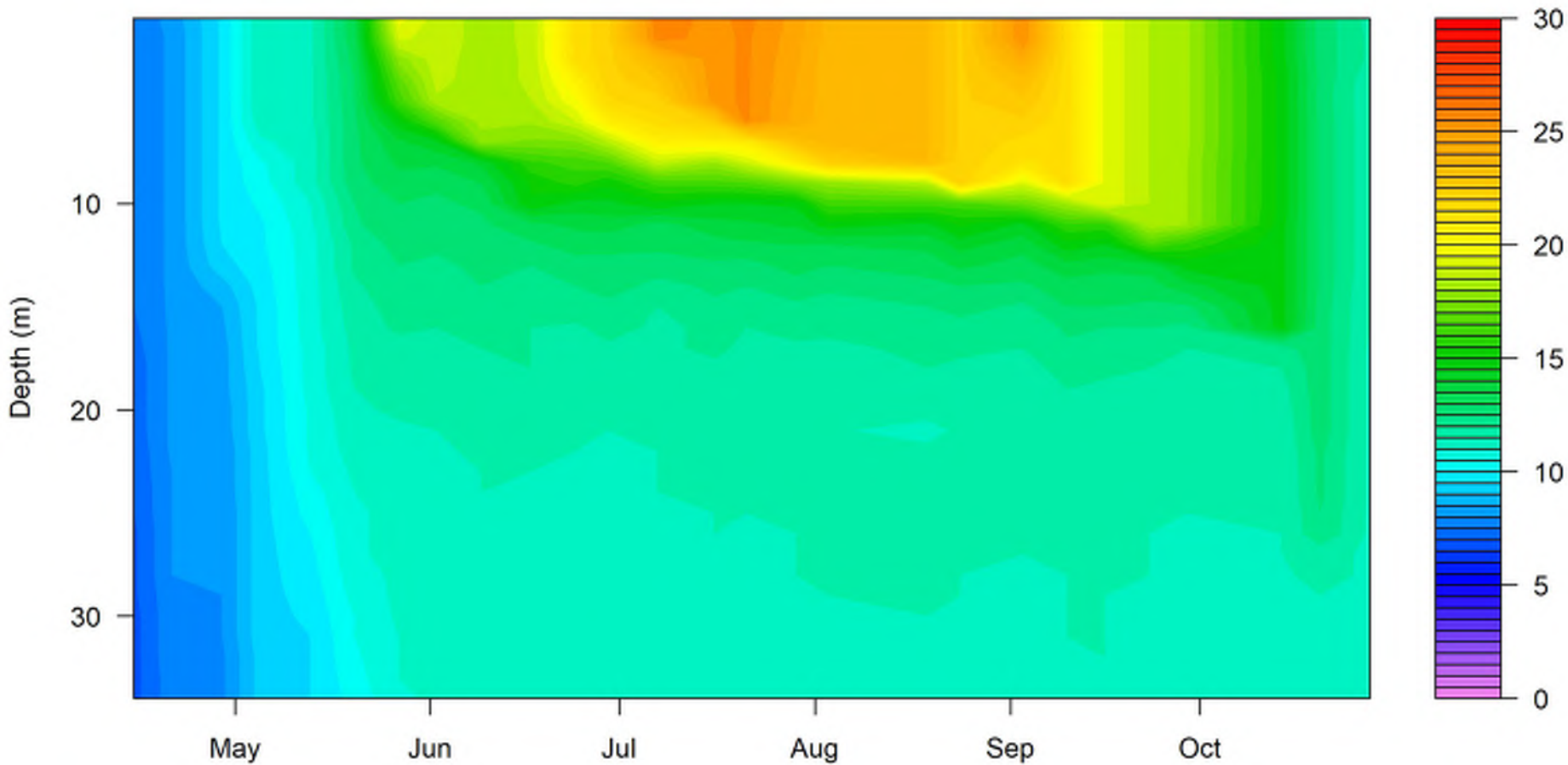
Station: 8 - T - 2009

Temp (Deg. C)



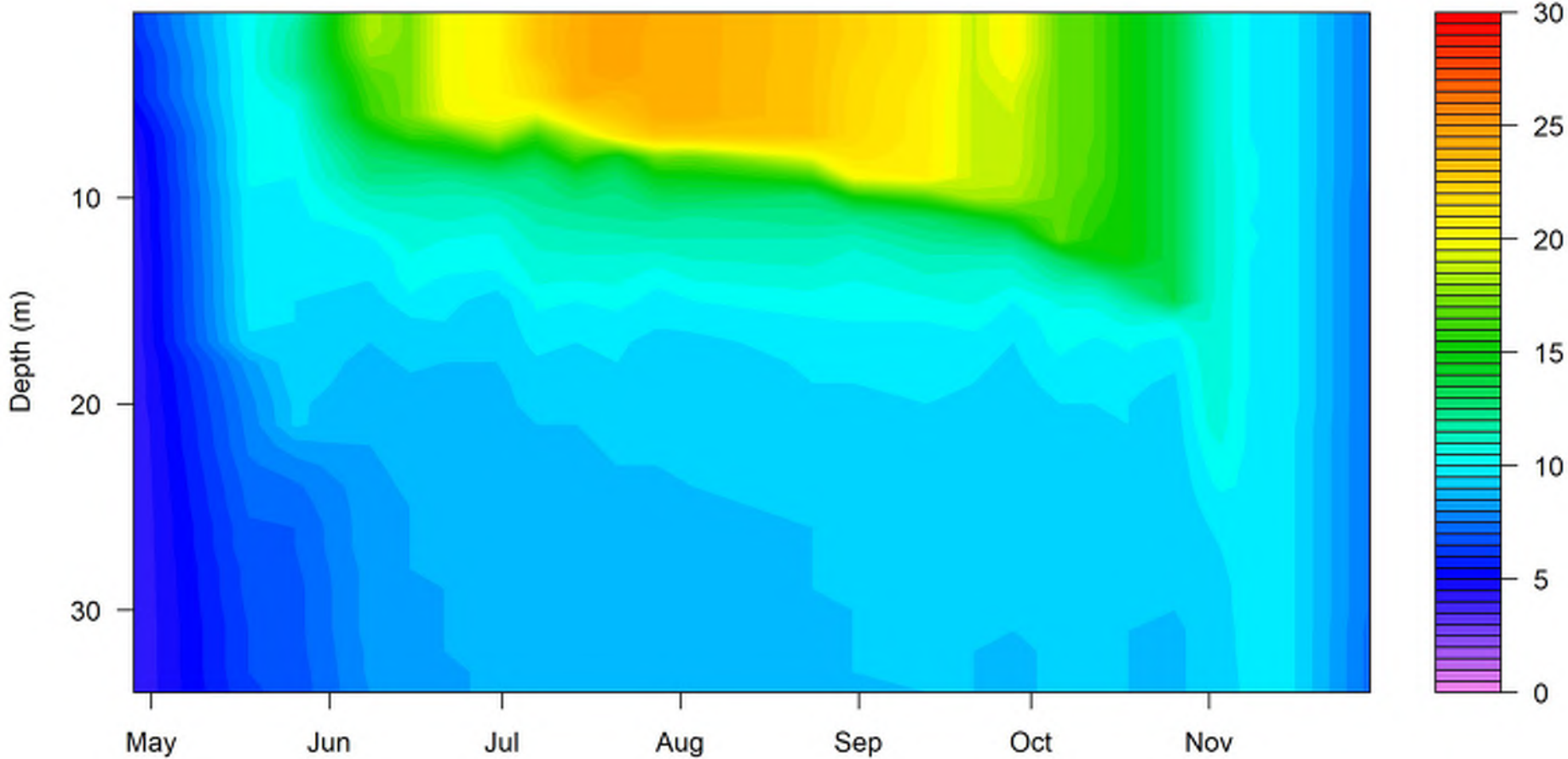
Station: 8 - T - 2010

Temp (Deg. C)



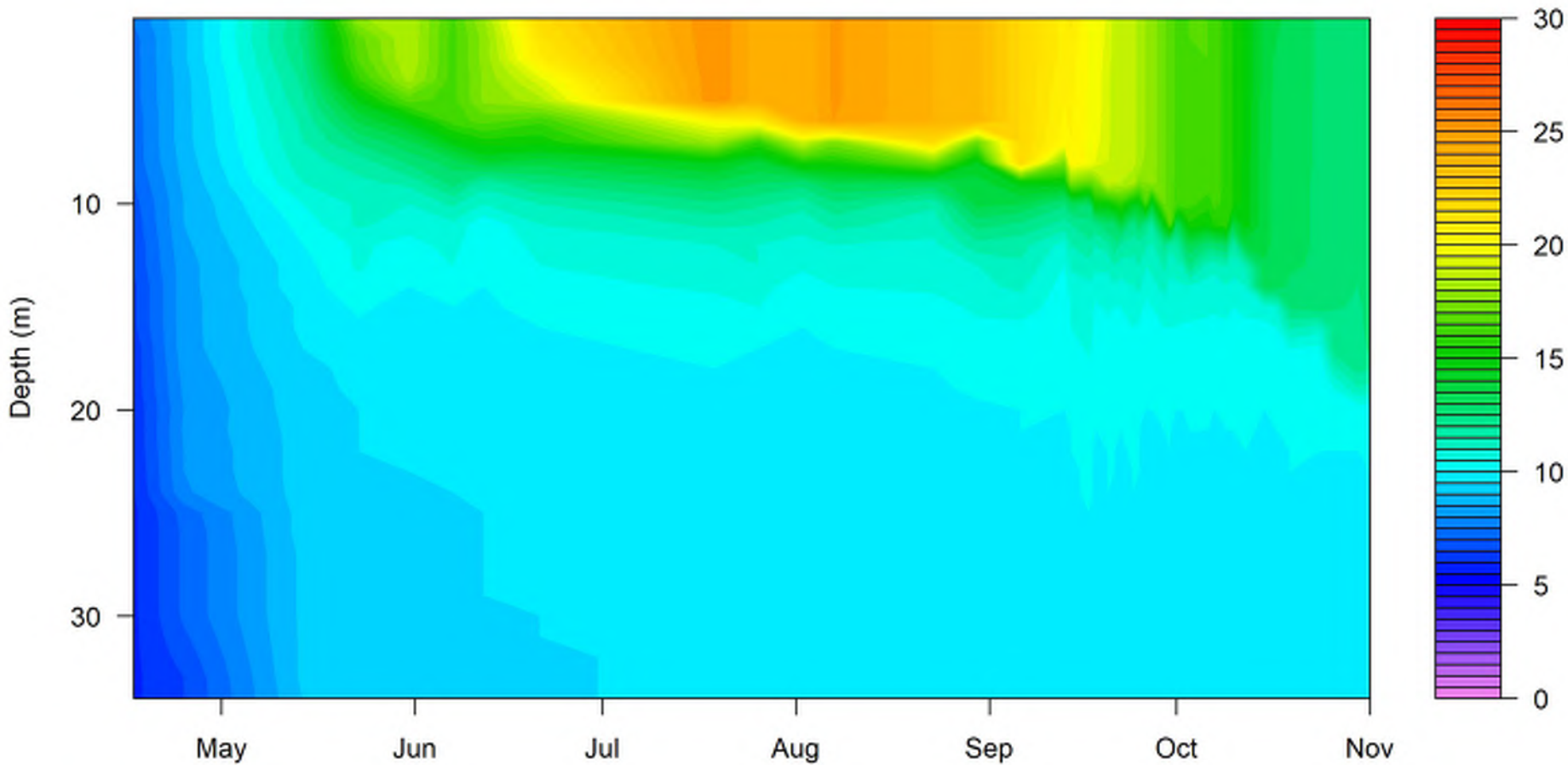
Station: 8 - T - 2011

Temp (Deg. C)



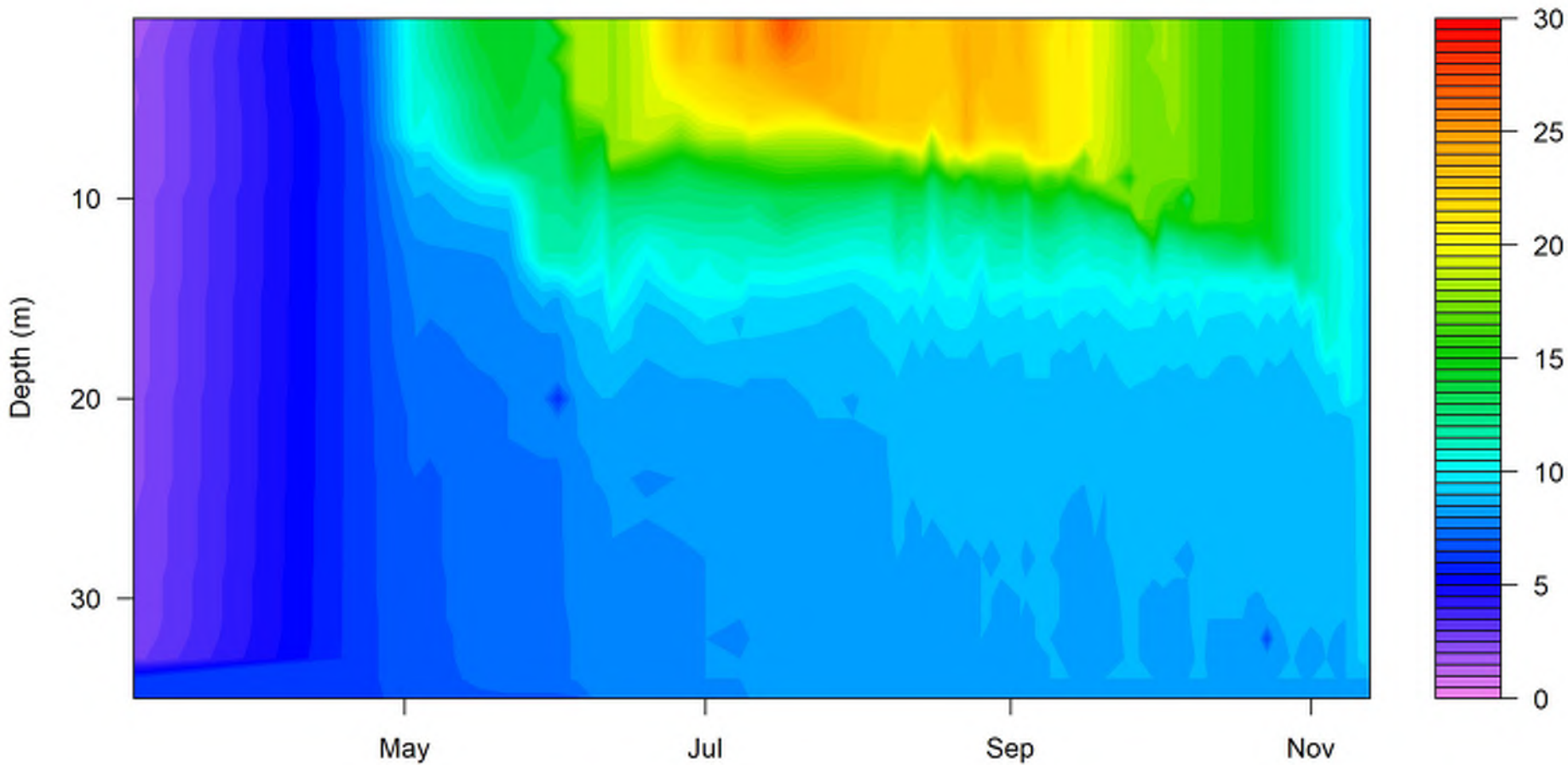
Station: 8 - T - 2012

Temp (Deg. C)



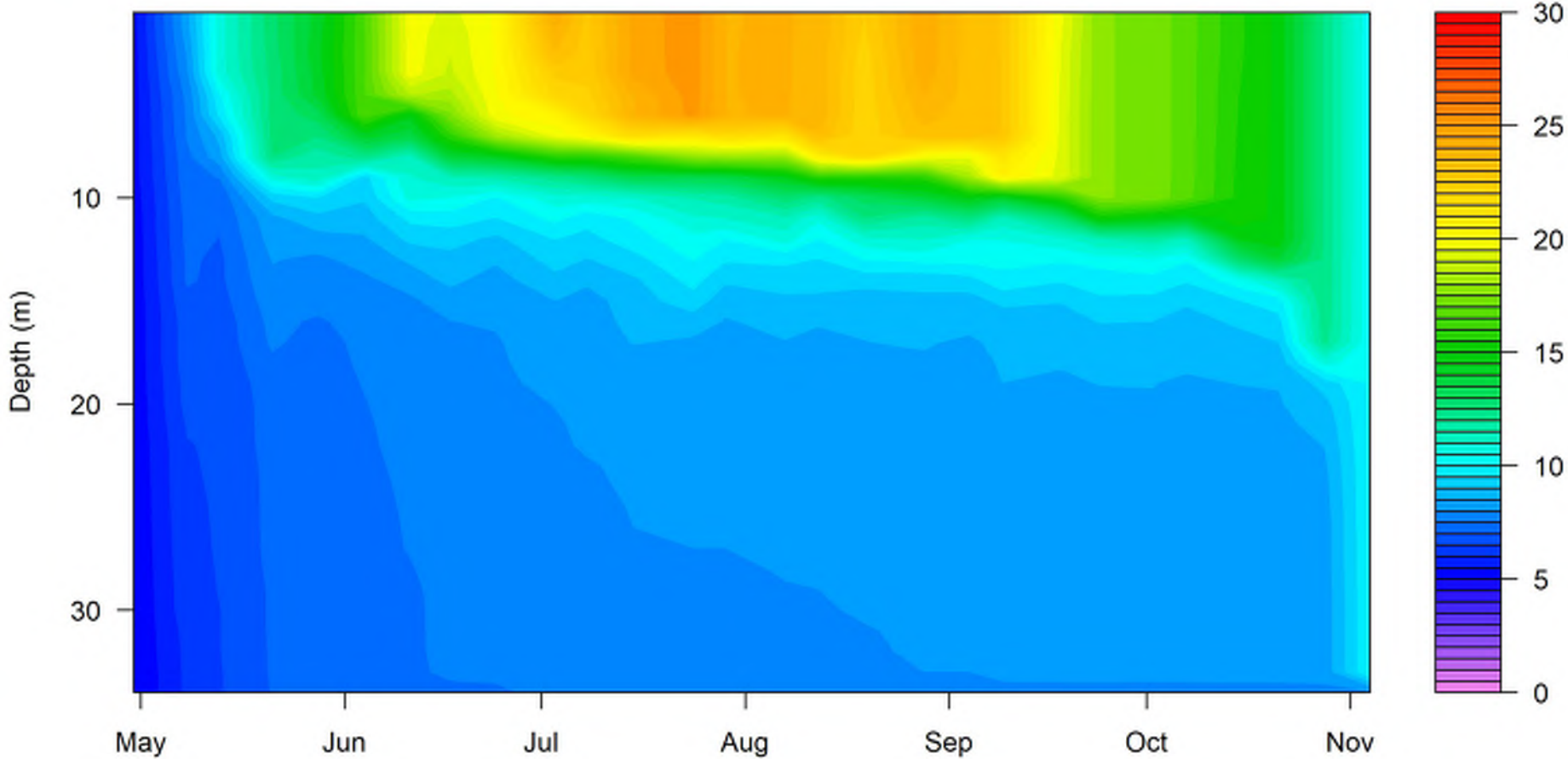
Station: 8 - T - 2013

Temp (Deg. C)



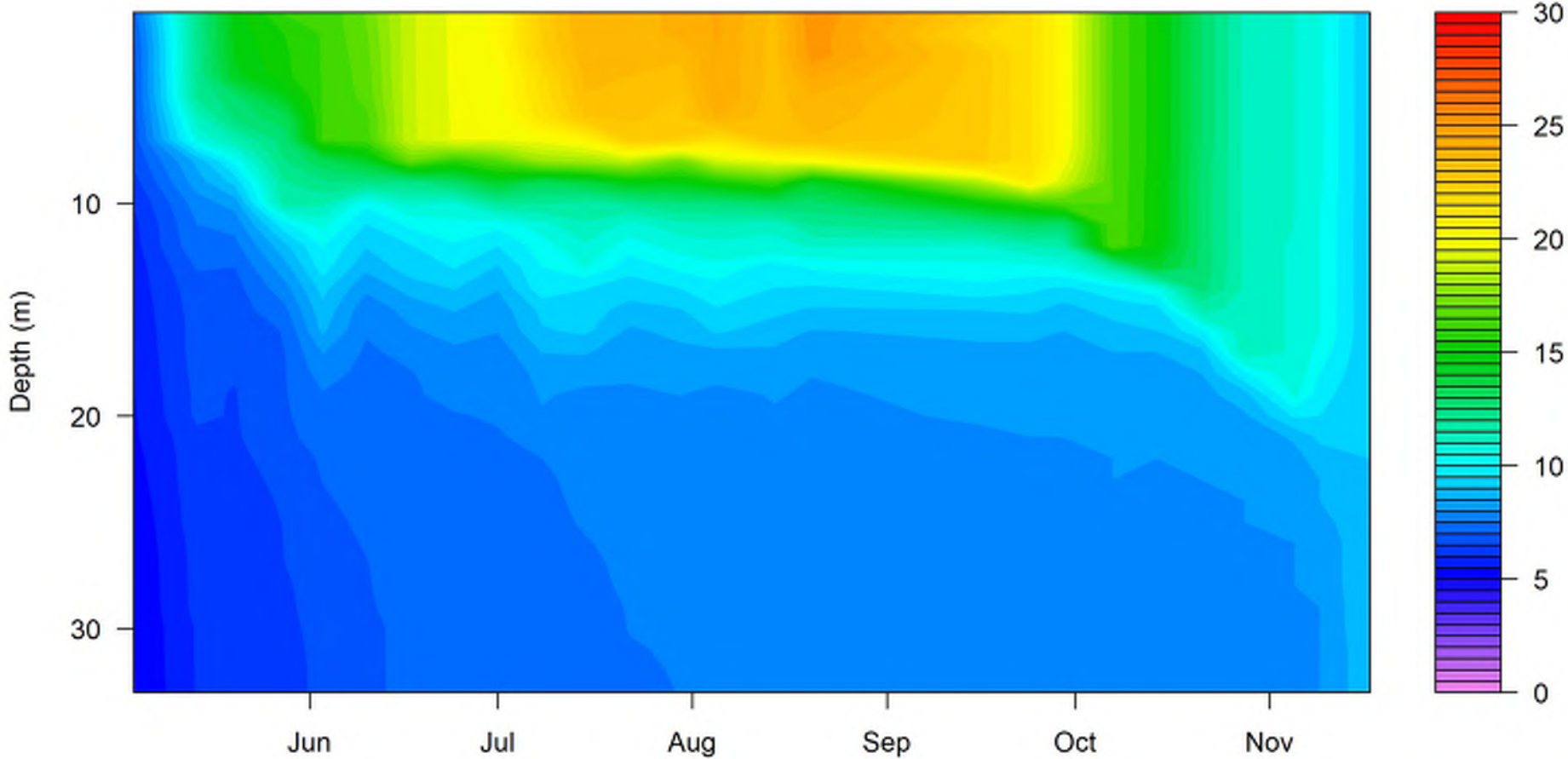
Station: 8 - T - 2014

Temp (Deg. C)



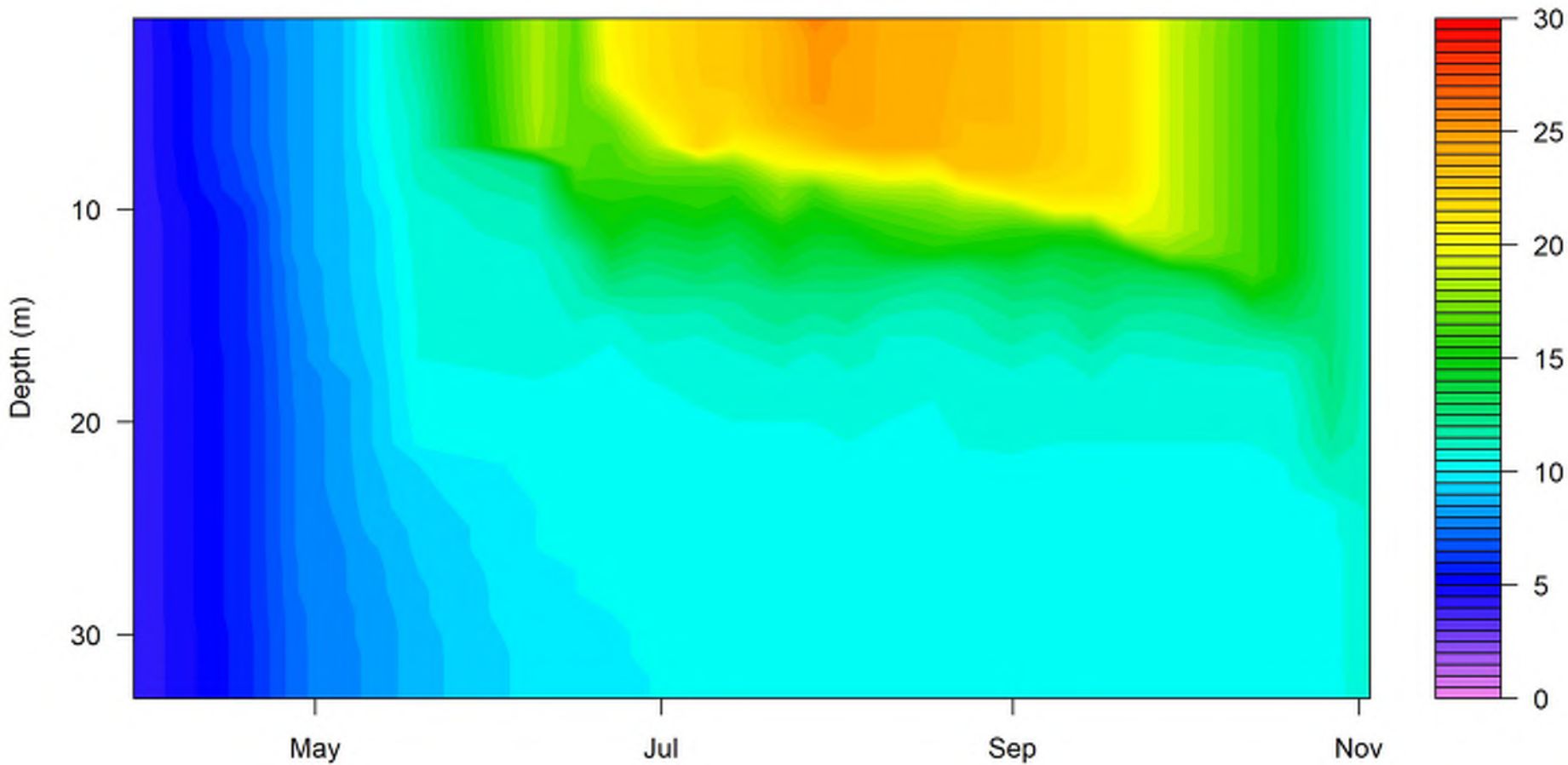
Station: 8 - T - 2015

Temp (Deg. C)



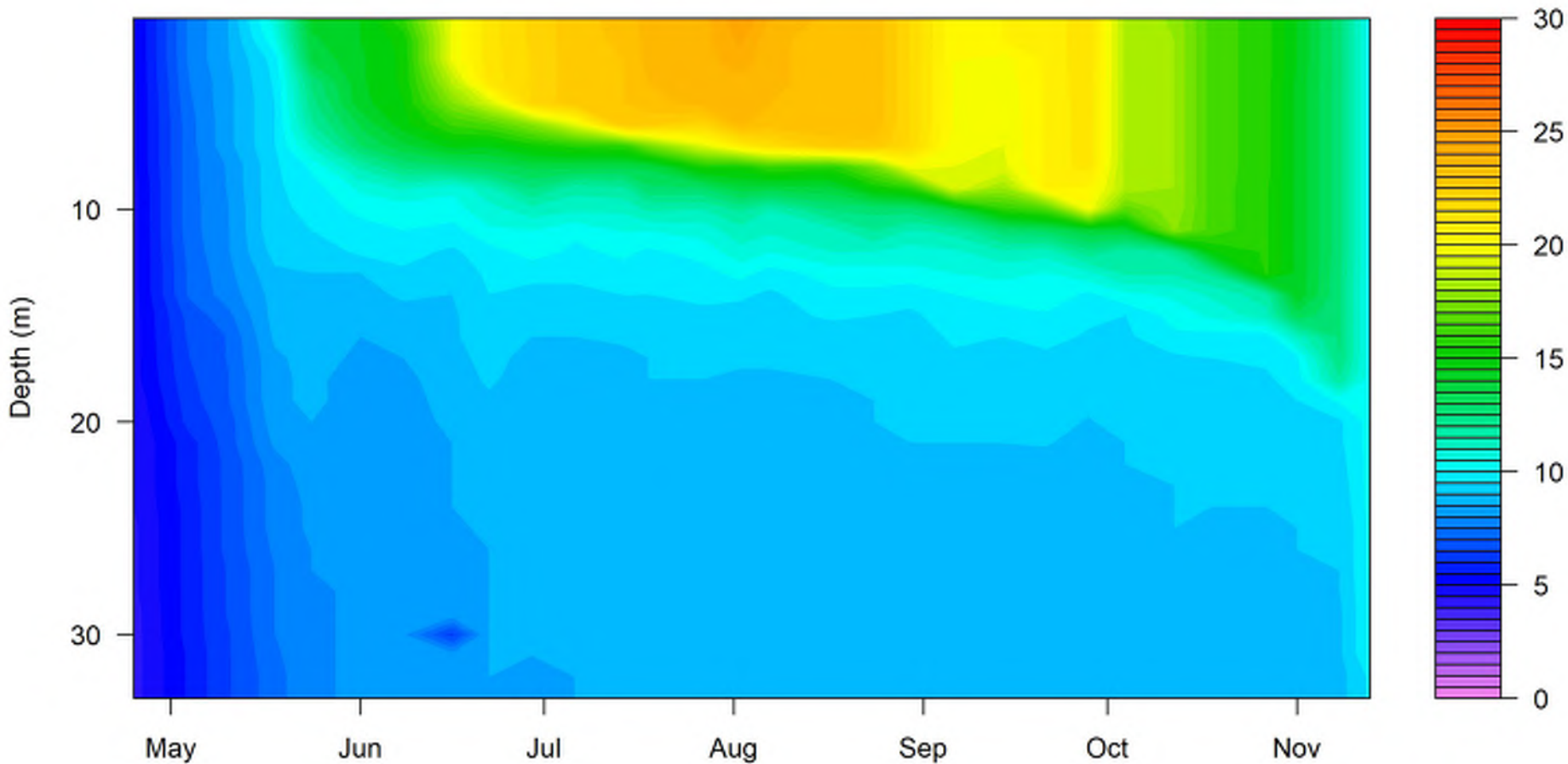
Station: 8 - T - 2016

Temp (Deg. C)



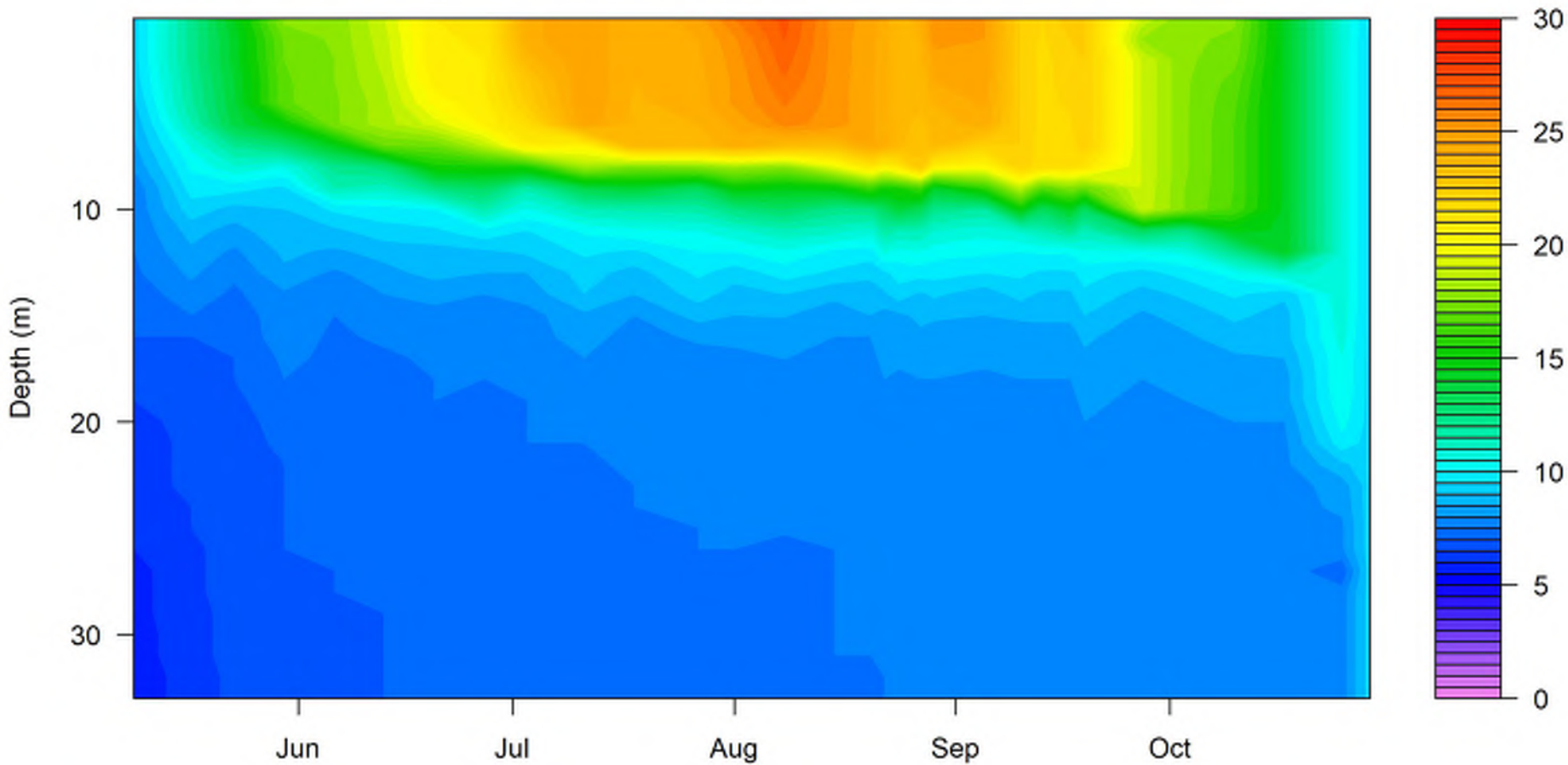
Station: 8 - T - 2017

Temp (Deg. C)



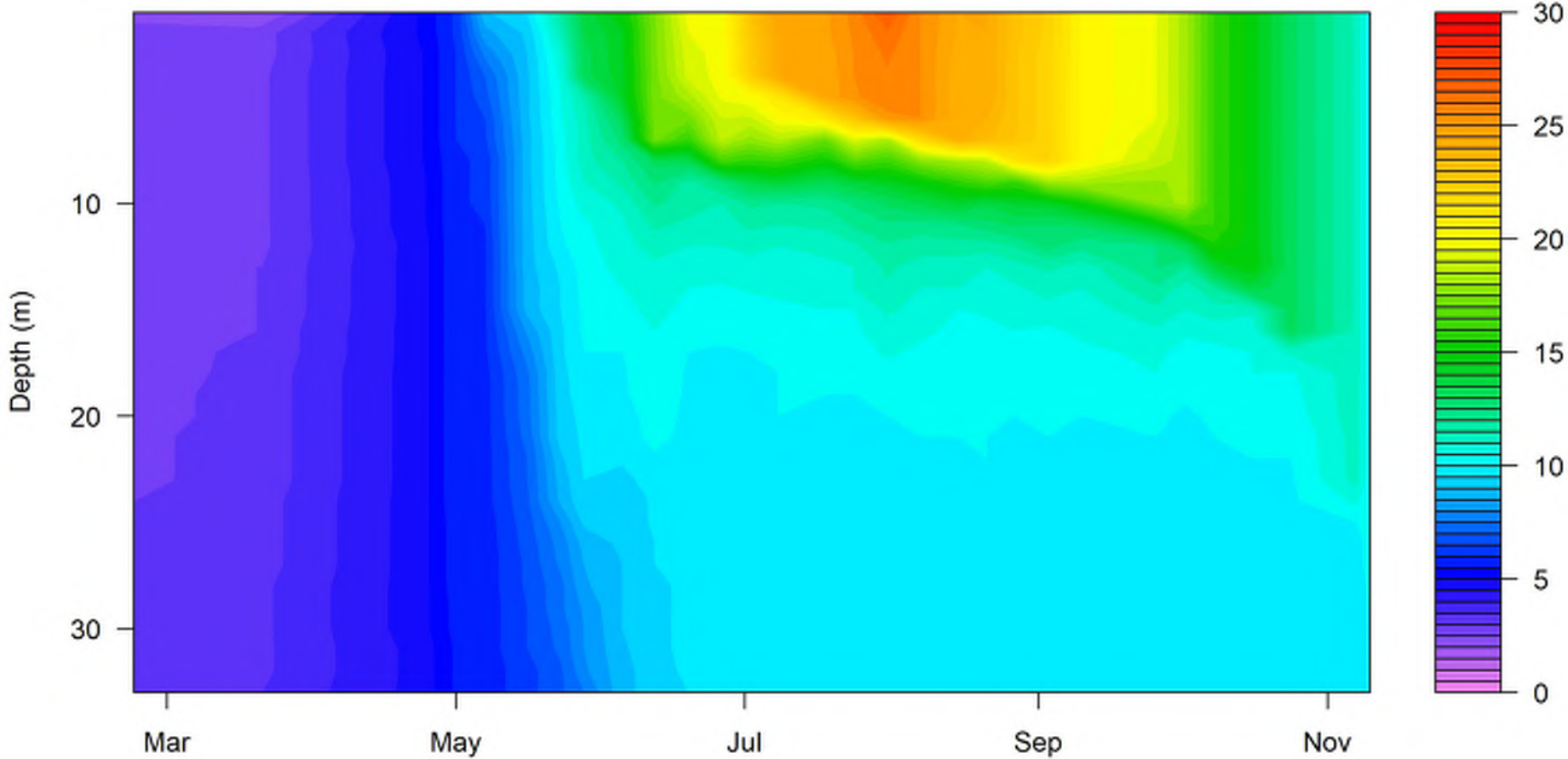
Station: 8 - T - 2018

Temp (Deg. C)



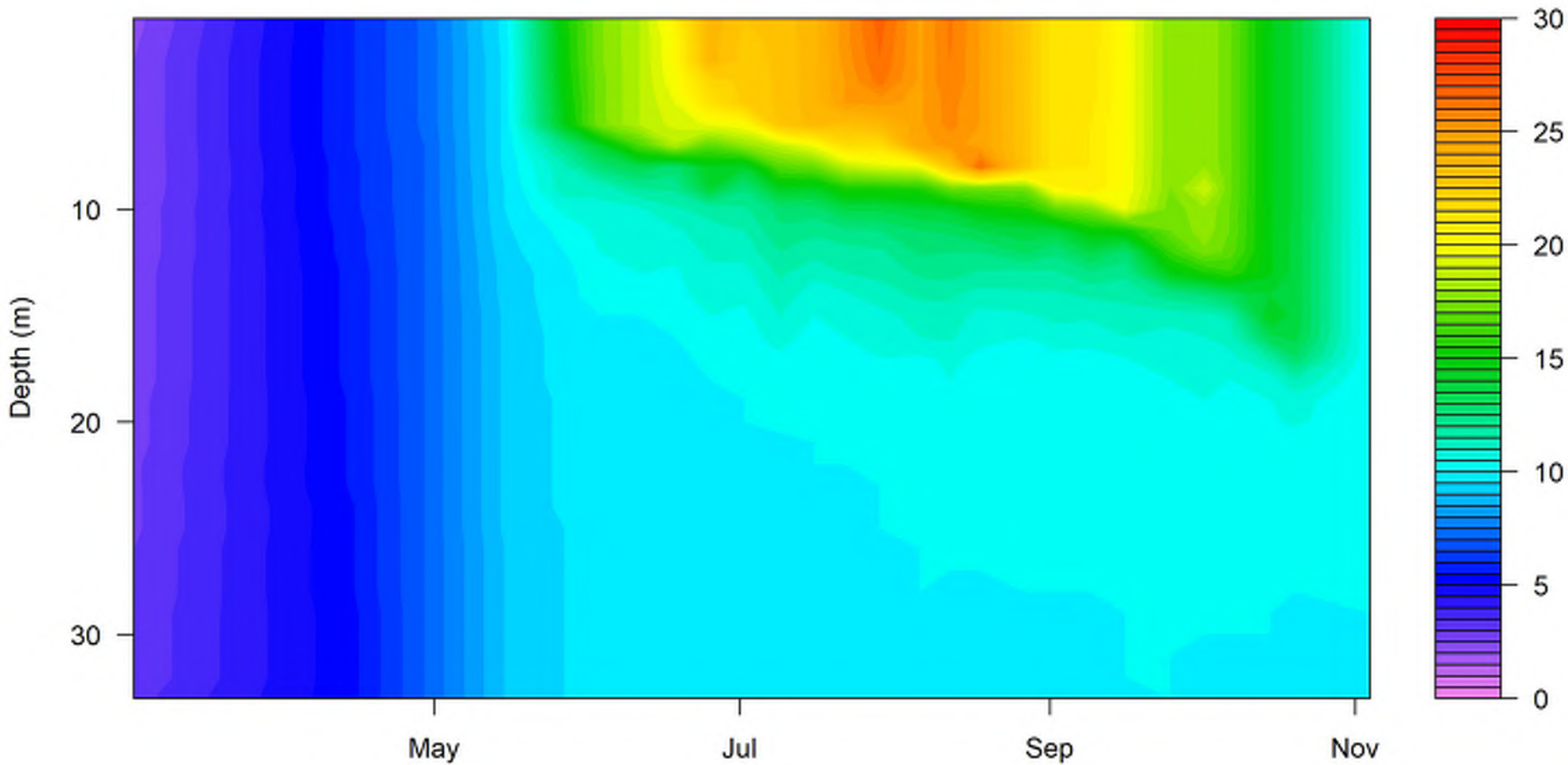
Station: 8 - T - 2019

Temp (Deg. C)



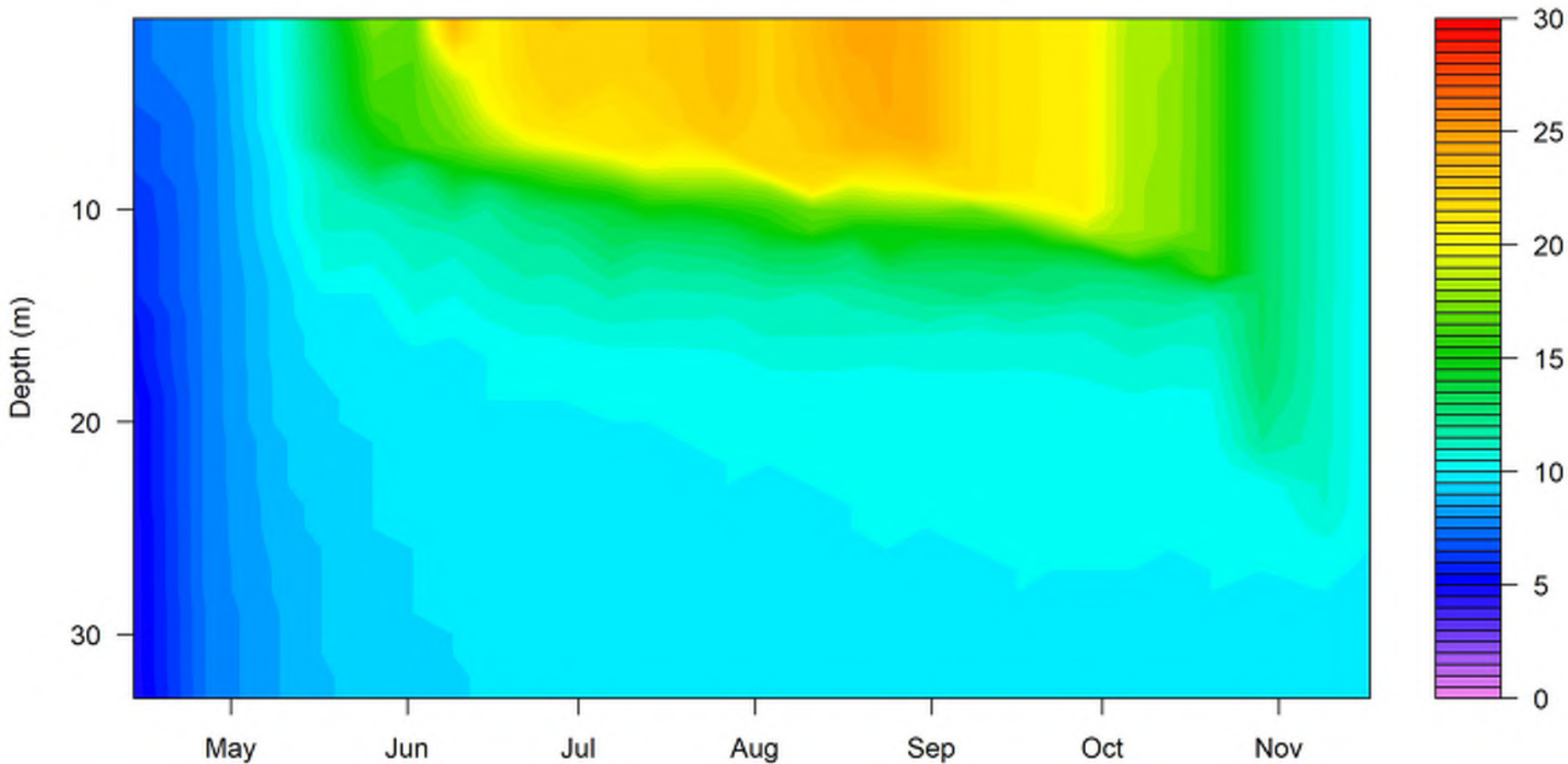
Station: 8 - T - 2020

Temp (Deg. C)



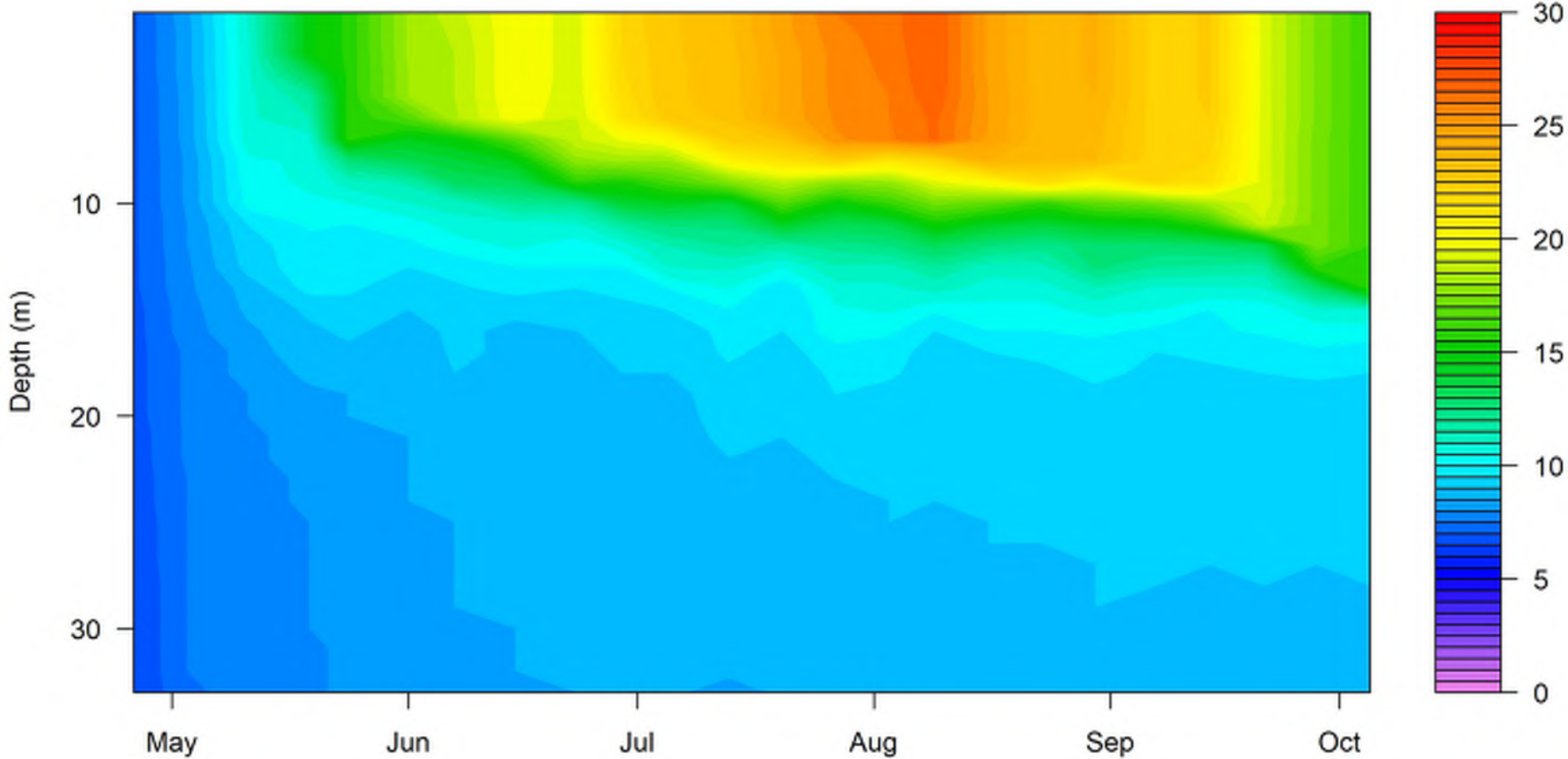
Station: 8 - T - 2021

Temp (Deg. C)



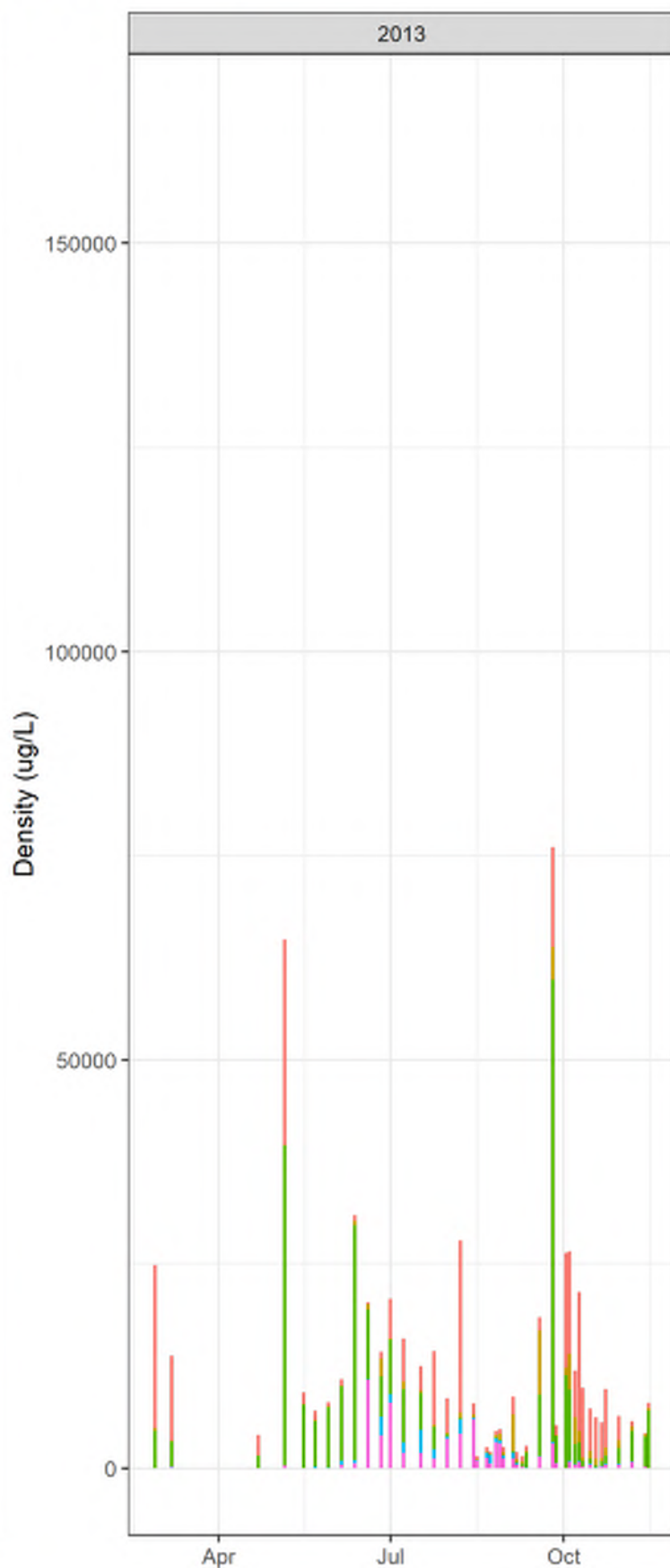
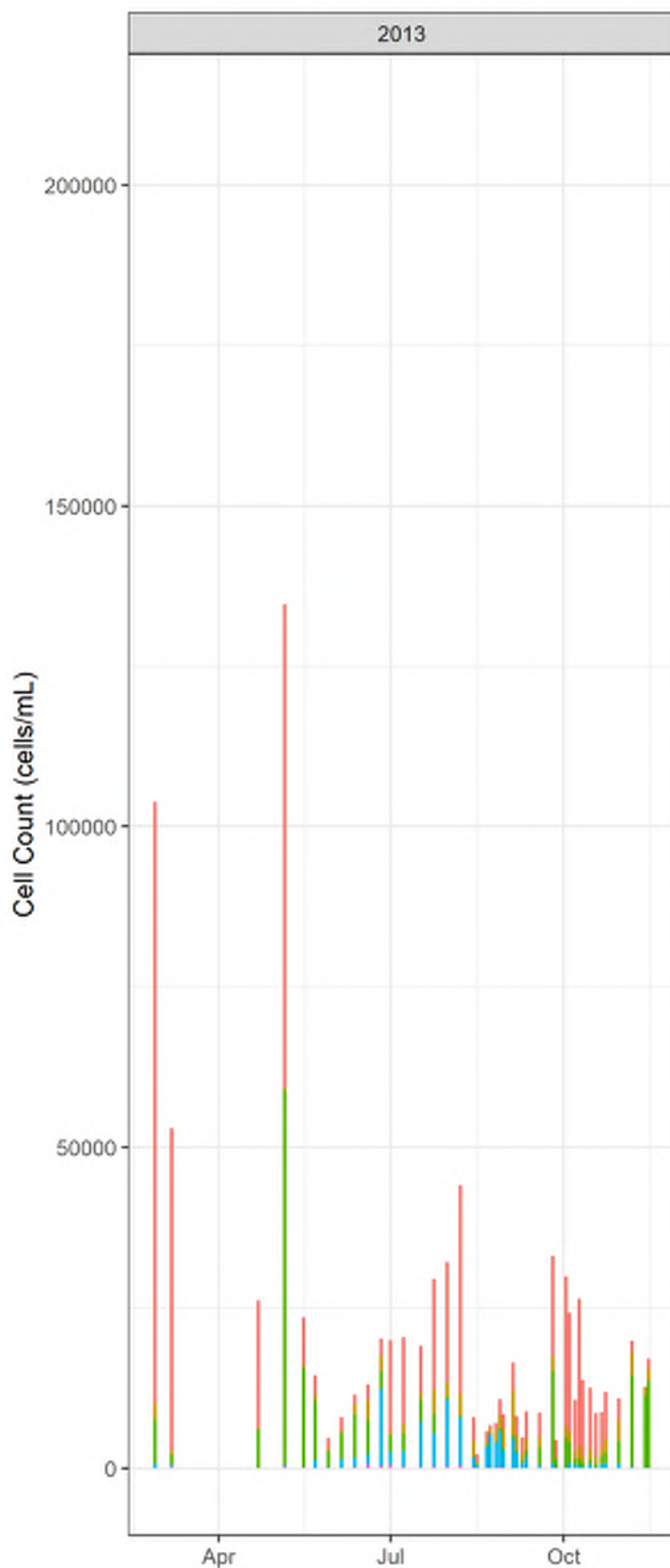
Station: 8 - T - 2022

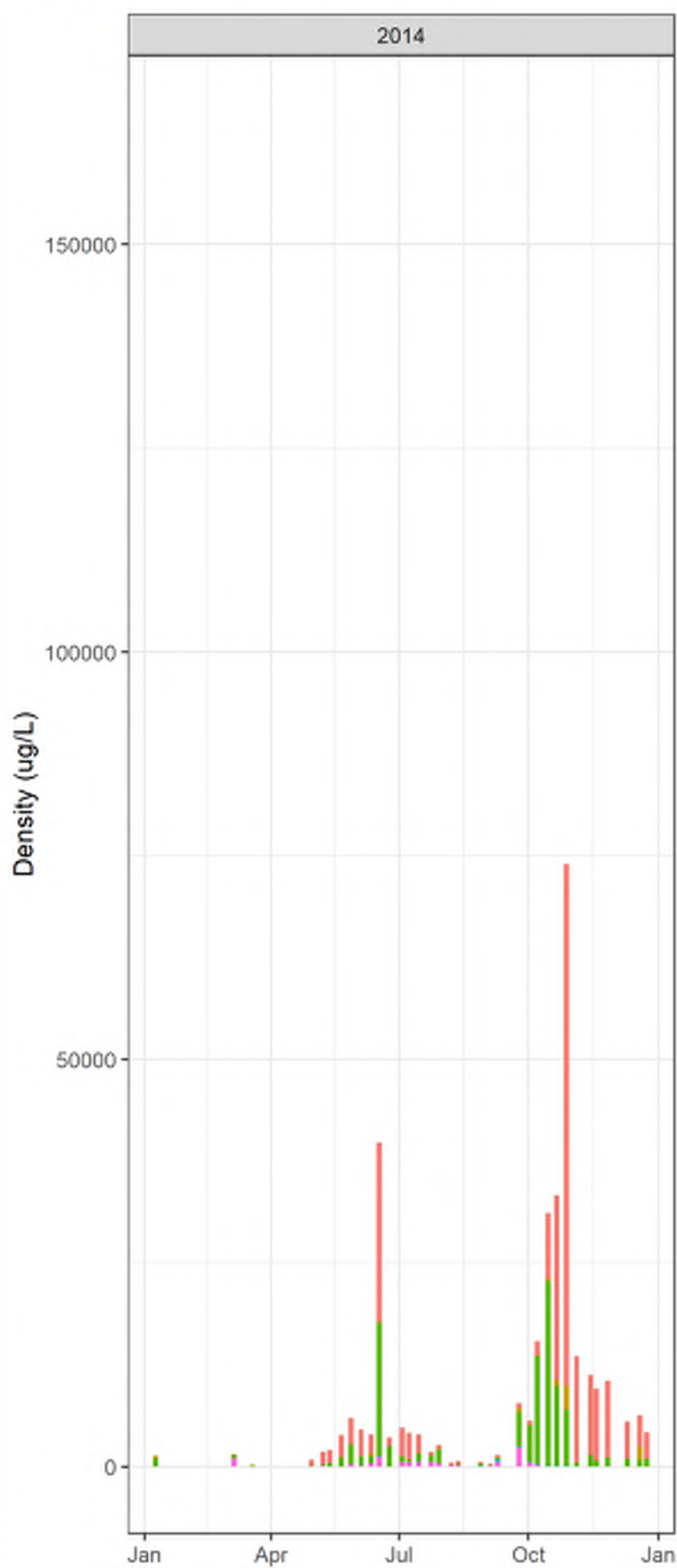
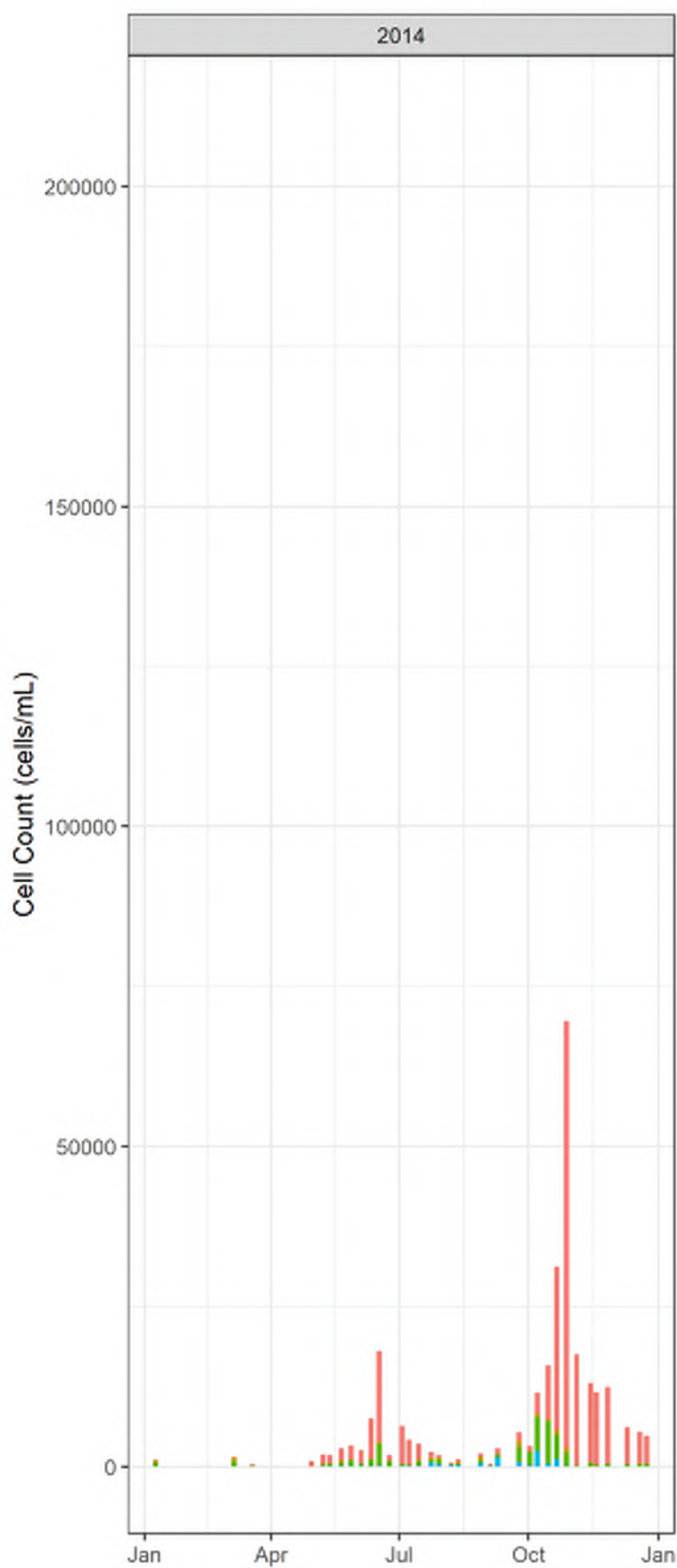
Temp (Deg. C)

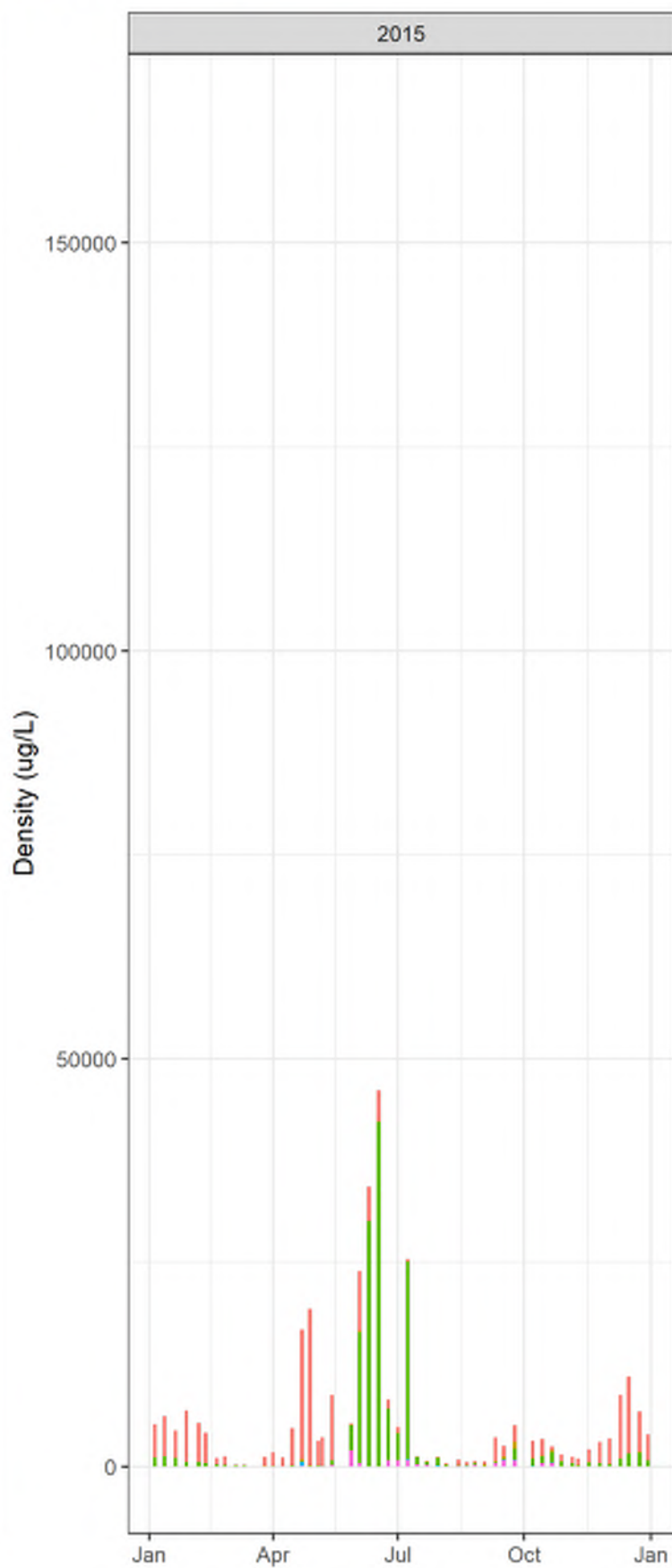
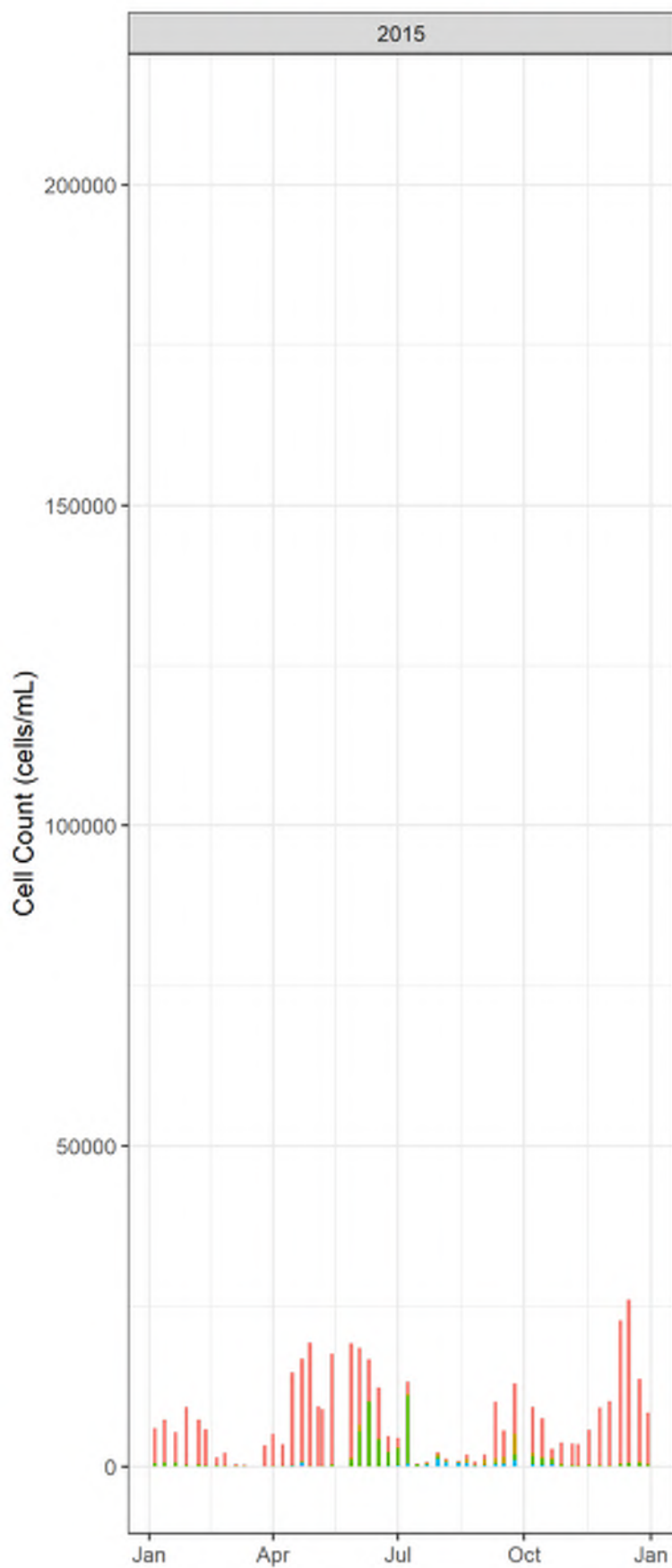


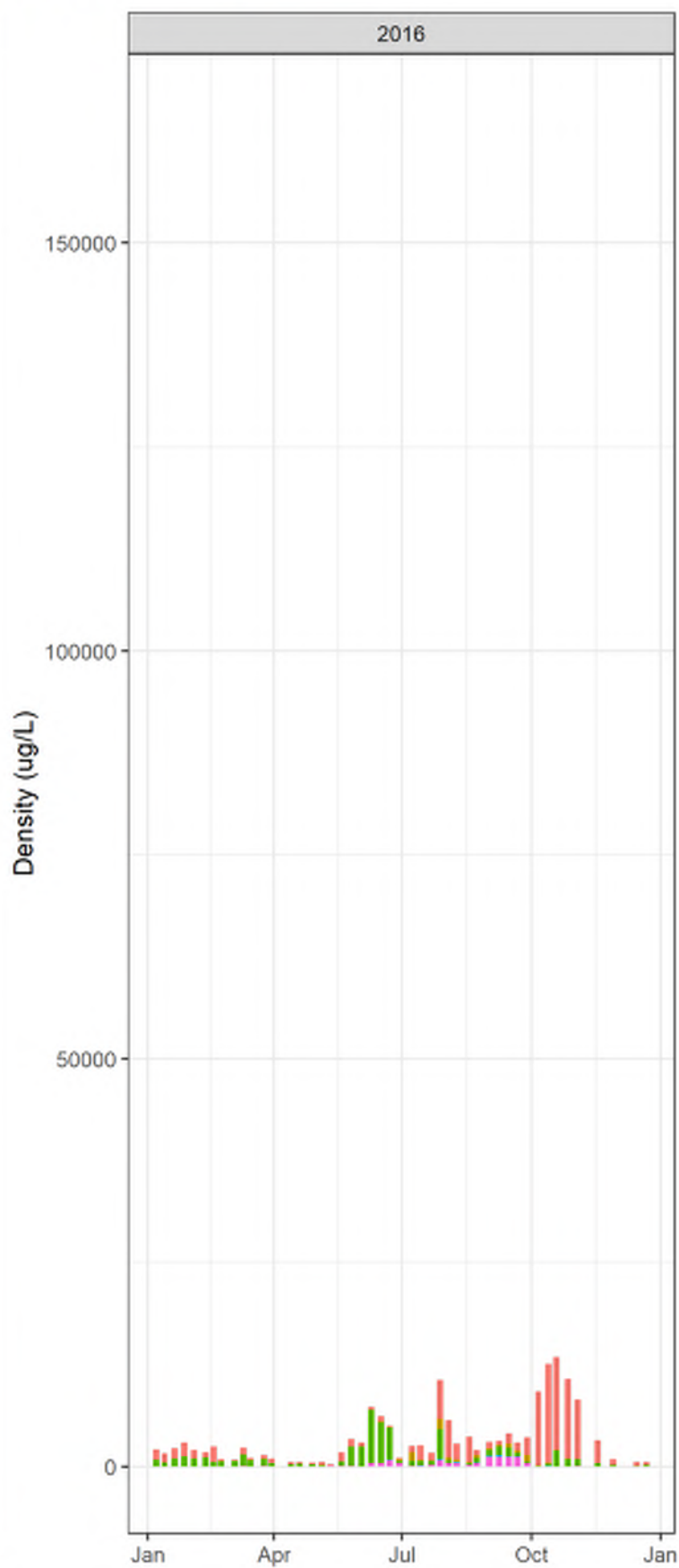
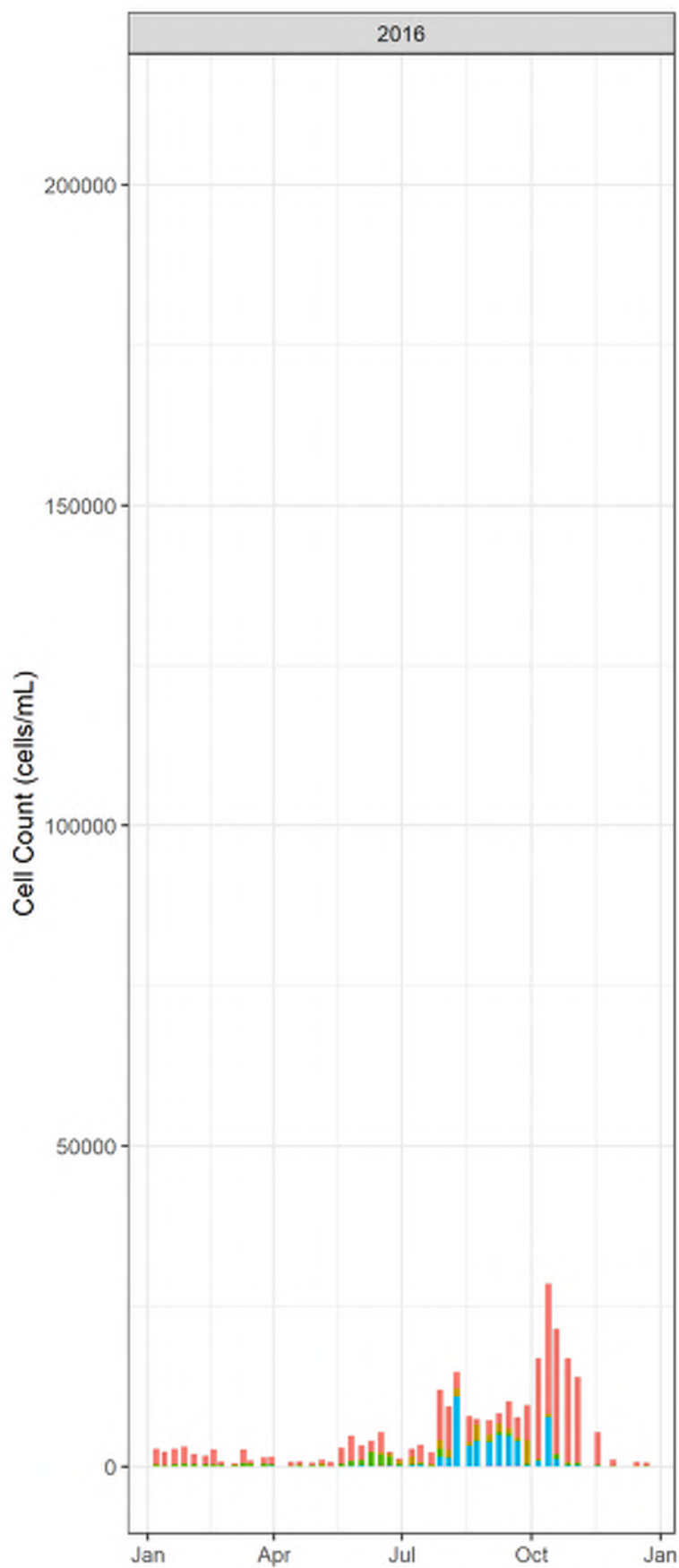
Appendix E

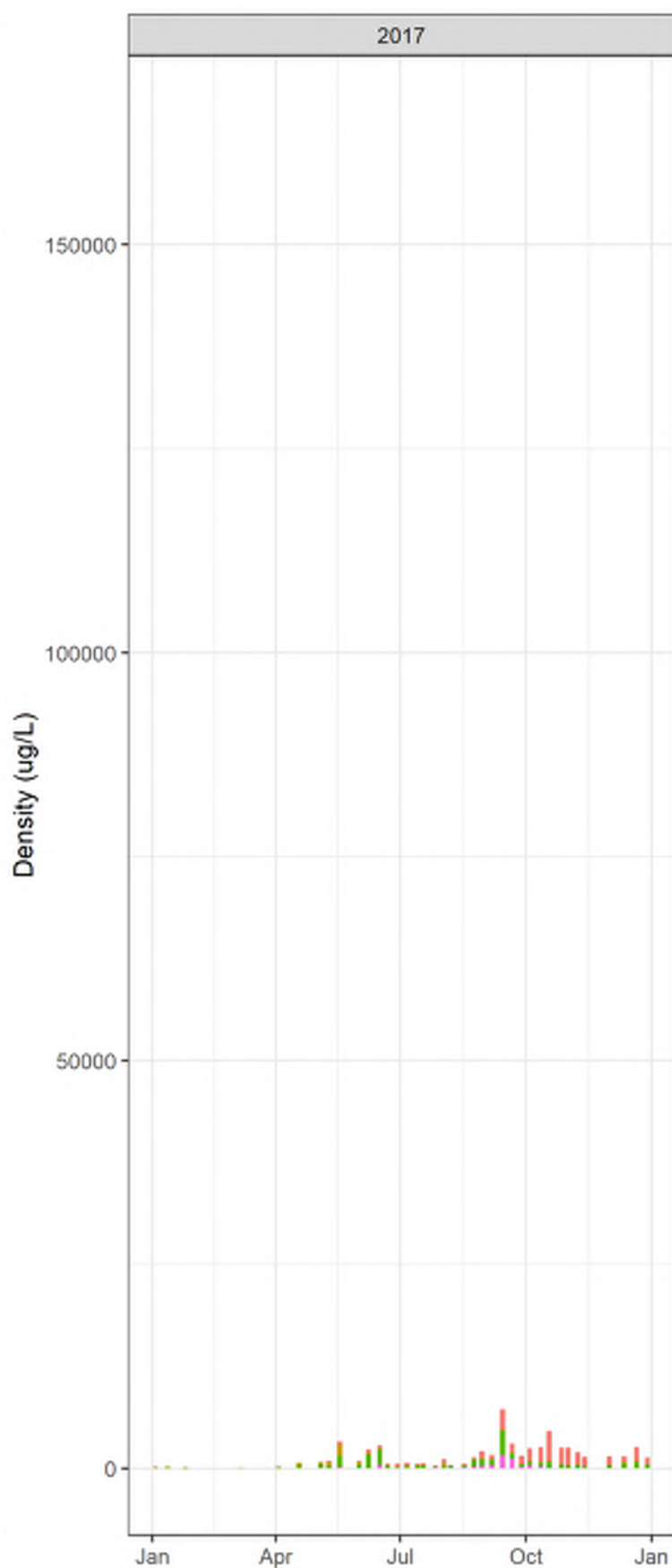
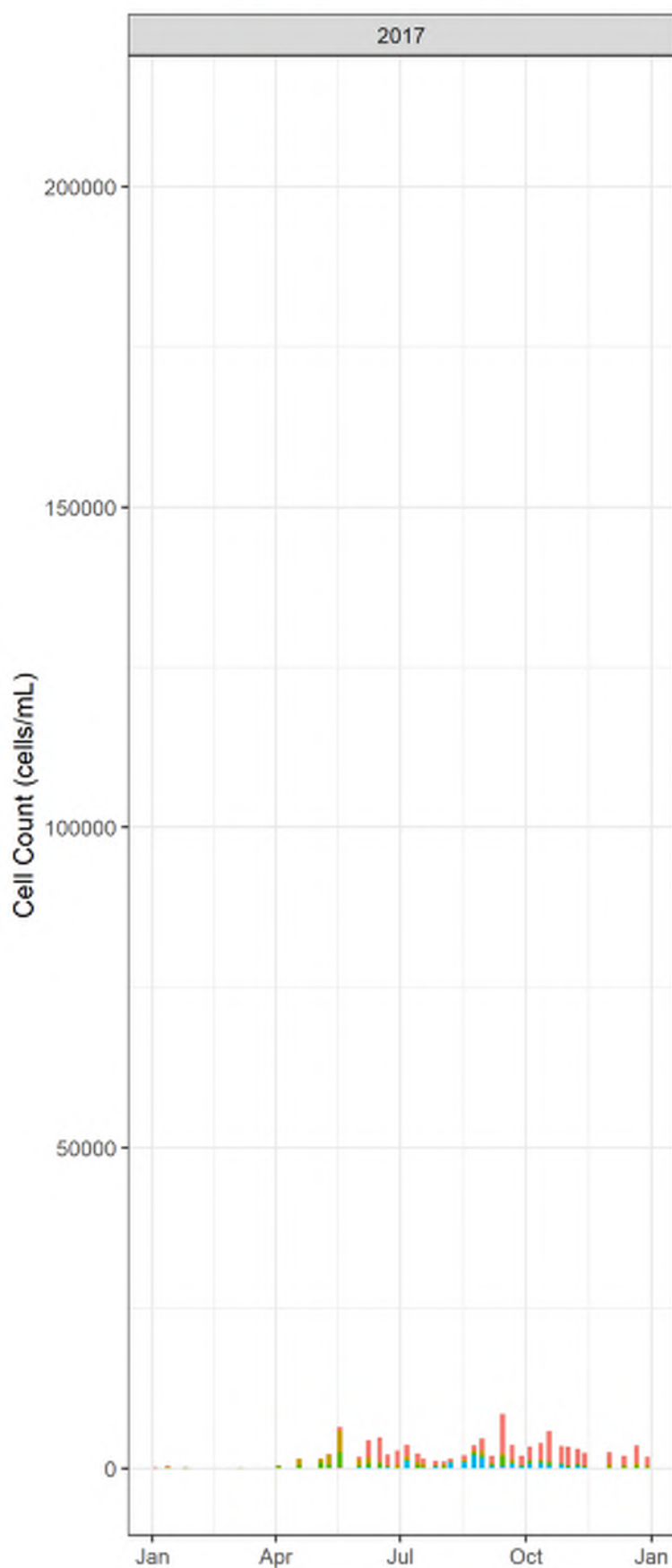
Algal Count and Biovolume Plots











■ BACILLARIOPHYTA
 ■ CHRYSOPHYTA
 ■ CYANOPHYTA
 ■ PYRRHOPHYTA
■ CHLOROPHYTA
 ■ CRYPTOPHYTA
 ■ EUGLENOPHYTA

