Cyanobacteria Stressor Analysis

for Cedar Lake and Lake Nokomis

Prepared for
Minneapolis Park and Recreation Board

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1 Introduction

Lake Nokomis and Cedar Lake are heavily used recreational lakes in the City of Minneapolis including swimming beaches and open-water swimming. Both lakes are classified as deep lakes with relatively large littoral areas (50 percent and 38 percent respectively) and long residence times (>2.5 years). Recent water quality in the lakes show the presence of Harmful Algae Blooms (HABs), including species that produce the toxins microcystin and cylindrospermopsin. Some toxin-producing species found in the lakes include Planktothrix agardhii, other Planktothrix sp., Aphanizomenon flos-aquae and Raphidopsis (Cylindrospermopsis) rasciborksii. Planktothrix and Aphanizomenon were not only present in the summer, but the winter as well. Microcystin concentrations were measured at levels higher than the Minnesota Pollution Control Agency's cyanotoxin levels for swimming advisories in Lake Nokomis and Cedar Lake. Cylindrospermopsin was detected in both lakes, however concentrations were below the MPCA's limit for swimming advisories.

Based on the current presence of toxin-producing blue-green algae and the presence of cyanotoxins that can exceed the MPCA's swimming advisory levels, the Minneapolis Park and Recreation Board (MPRB) contracted with Barr Engineering Co. (Barr) to develop specific blue-green algae (cyanobacteria) mitigation strategies for Lake Nokomis and Cedar Lake in Minneapolis to address ongoing concerns about toxic cyanobacteria blooms in these lakes.

The objectives of the project are to:

1. Identify the specific stressors causing beach season and off-season cyanobacteria blooms in the lakes, and
2. Identify structural and nonstructural mitigation strategies to address the stressors resulting in cyanobacteria blooms.

This memo focuses on the first objective and identifies stressors likely causing beach season and off-season cyanobacteria blooms in the lakes.

2 Lake Characteristics

Cedar Lake is a small, deep lake in the City of Minneapolis with a maximum depth of 51 feet and a mean depth of 20 feet (Table 1, Figure 1). Because the lake is deep and relatively sheltered, it strongly stratifies throughout the summer. In contrast, Lake Nokomis is relatively shallow with 50% of the lake shallow enough to support aquatic vegetation (Table 1; Figure 2). However, the submerged vegetation population is currently limited in the lake. With a maximum depth of only 33 feet and large portion of the lake in the 15- to 20-foot depth zone, the lake only weakly stratifies and is prone to periodic mixing events.

Table 1 Physical characteristics of Cedar Lake and Lake Nokomis

Parameter	Cedar Lake	Lake Nokomis
Surface Area (acres)	164	201
Mean Depth (feet)	20	14
Max Depth (feet)	51	33
Littoral Area (%)	38%	50%
Volume (acre-feet)	3,222	2,799
Watershed Area (acres)	1,956	869
Watershed:Lake Area ratio	11.5	4.3
Residence Time (years)	2.7	4.0

Both lakes have highly developed, urban watersheds including a mix of residential and commercial areas. Being highly developed, both lake watersheds have limited wetland areas and highly modified drainage including storm sewer networks, ditches, and stormwater ponds. Even with highly modified watersheds, both lakes have relatively small watershed:lake area ratios and have long residence times suggesting they capture and retain a high proportion of pollutants entering the lakes.

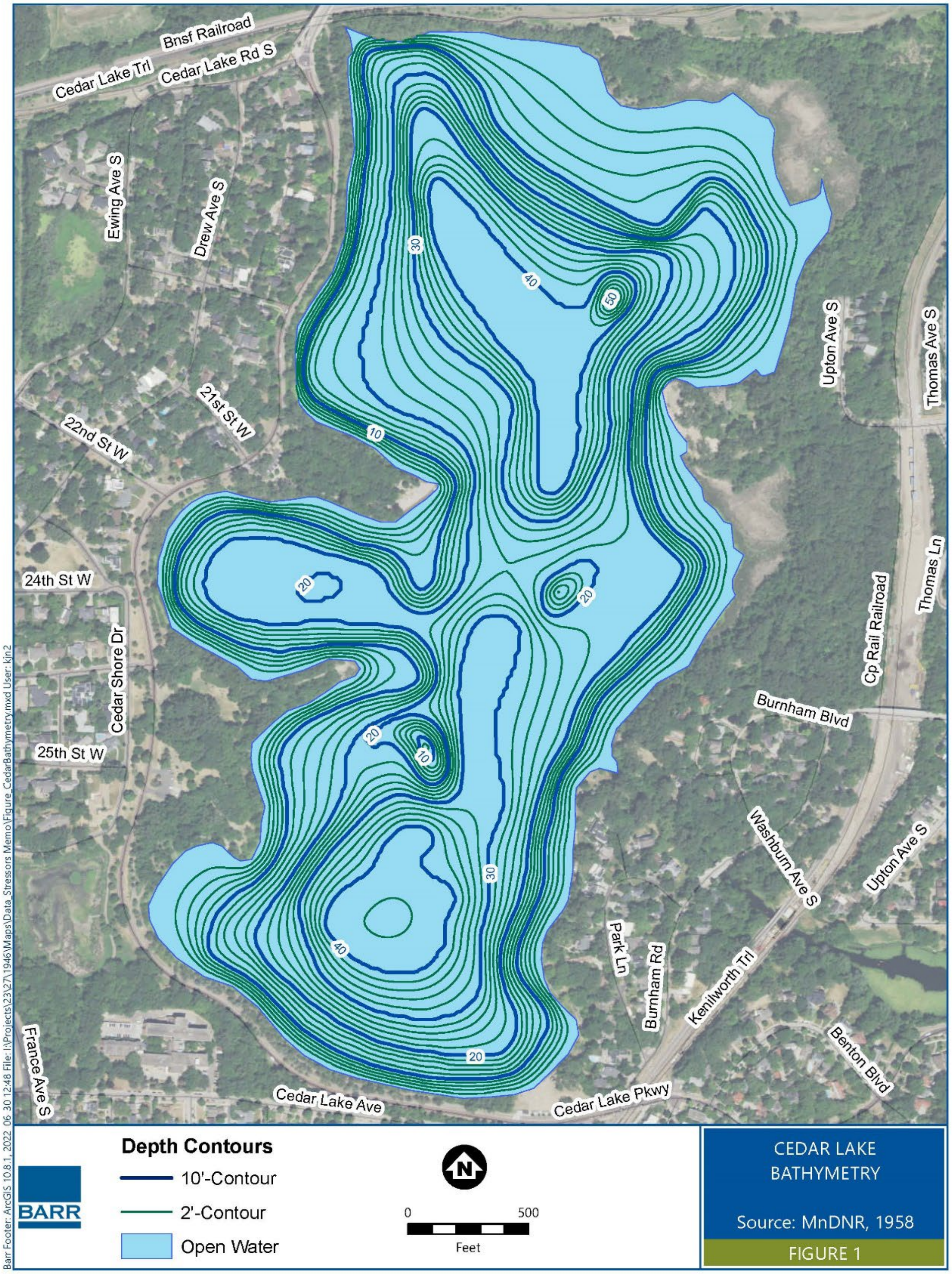


Figure 1 Cedar Lake Bathymetry

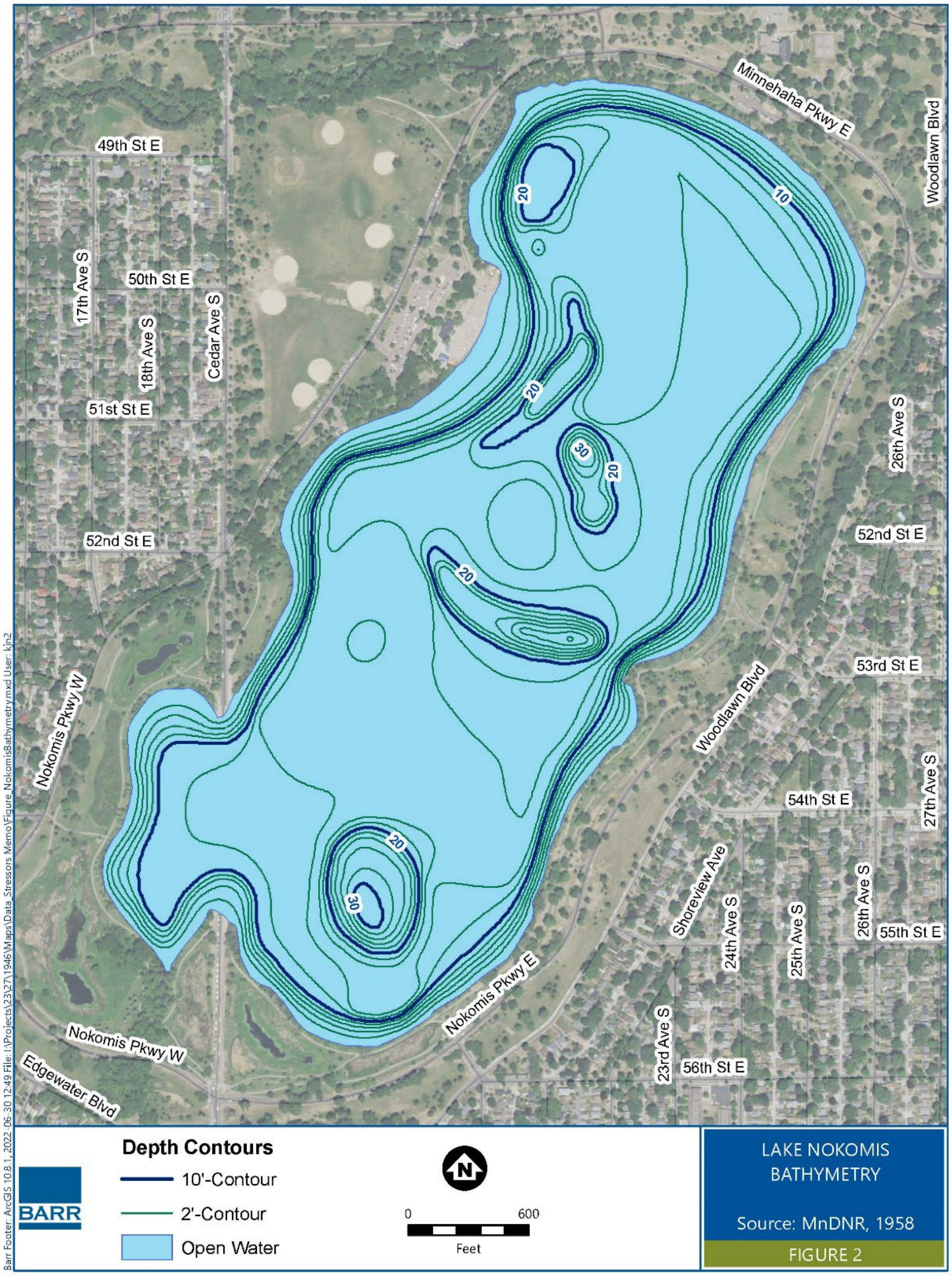


Figure 2 Lake Nokomis Bathymetry

3 Phytoplankton Community

Phytoplankton community data has been collected from both lakes dating back as far as the early 2000s using a relative abundance assay. For this study, data collected in 2012 or later was used to assess modern phytoplankton communities. While these data provide a description of the phytoplankton community, it does not provide an understanding of the magnitude of any phytoplankton bloom or community over time. While a certain species may dominate the community at any given time, the relative magnitude of the bloom may be small. Cyanobacteria dominate the phytoplankton community in most years in both lakes often representing between 50% and 75% of the phytoplankton in the lake (see Attachment 1).

Prior to 2015 in Cedar Lake, cyanobacteria appear to be restricted to summer blooms that often carried into the fall. Since 2015, cyanobacteria have dominated the phytoplankton community through the year including all four seasons. Since 2015, there are four primary phases in the cyanobacteria community throughout the year including (Figure 3):

1. Winter dominance by either Planktothrix or Aphanizomenon with more recent years being mostly Planktothrix
2. Early spring into early summer demonstrating a shift to dominance by Aphanizomenon presumably as water temperatures increase in the surface and the lake is still weakly stratified
3. A late summer shift to Cylindrospermopsis (Raphidiopsis) presumably as the lake is depleted of nitrate and surface water hits peak temperatures and
4. A fall transition back to dominance by Planktothrix as the water temperatures decrease, the thermocline is degraded, and the lake becomes destratified.

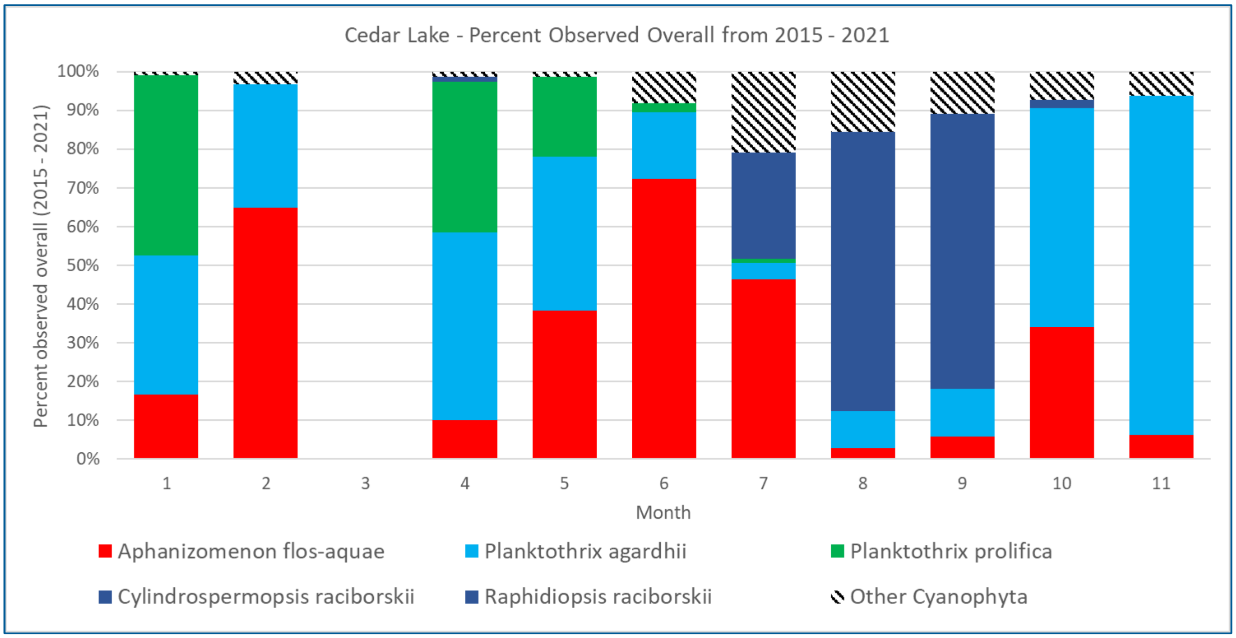


Figure 3 **Average relative abundance within the cyanobacteria community from 2015 through 2021 in Cedar Lake. 2012 through 2014 were excluded since the pattern changed in 2015 and has been more consistent since this time.**

Lake Nokomis follows a similar pattern with four primary phases including (Figure 4):

1. Winter dominance by primarily Planktothrix
2. Early spring into early summer demonstrating a shift to dominance by Aphanizomenon presumably as water temperatures increase in the surface and the lake is weakly stratified
3. While Planktothrix remains common in the lake, a late summer shift to Cylindrospermopsis (Raphidiopsis) occurs presumably as the lake is depleted of nitrate and surface water hits peak temperatures and
4. A fall transition back to dominance by Planktothrix as the water temperatures decrease and the lake fully mixes.

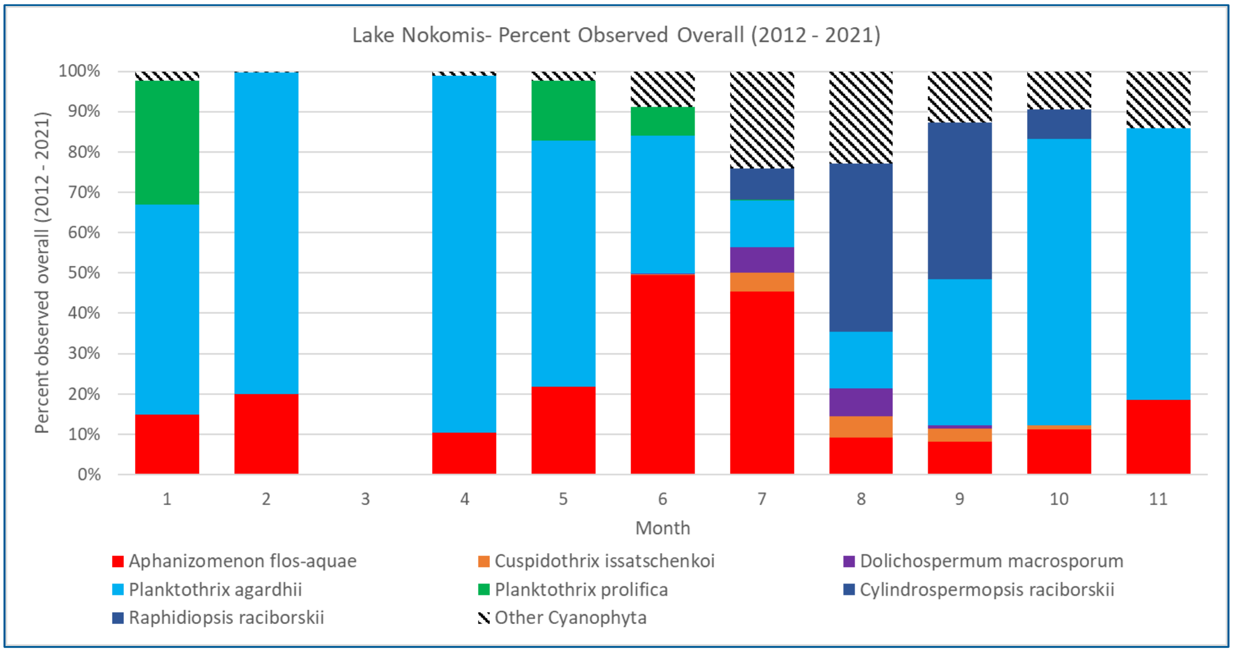


Figure 4 Average relative abundance within the cyanobacteria community from 2012 through 2021 in Lake Nokomis.

While the cyanobacteria in both lakes are typically dominated by Aphanizomenon, Planktothrix, Raphidiopsis (Cylindrospermopsis), and Dolichospermum, other toxin producing species were also found in the lakes. Numerous species of Anabaena, Lyngbya, and Microcystis were also found in both lakes but were never the dominant proportion of the cyanobacteria community. This is important when considering management options that may change the phytoplankton community structure. For example, artificial circulation to control cyanobacteria may just result in a shift from one toxin producing species to another minimizing the effectiveness of the approach. While this is very difficult to predict, some understanding of the species present can help guide the evaluation of this approach. The biological and ecological characteristics of common cyanobacteria found in Cedar Lake and Lake Nokomis are provided in Table 2 for reference.

Table 2 Phytoplankton characteristics of common cyanobacteria found in Cedar Lake and Lake Nokomis

Cyanophyta	Nitrogen Fixer?	Scum Forming?	Low Light Advantage	Buoyancy Regulator	Reproduction
Aphanizomenon flos-aquae	Y	Y	Y	Y	heterocysts and akinetes**
Cuspidothrix issatschenkoi	Y	--	--	Y	trichome fragmentation and akinetes**
Dolichospermum macrosporum	Y	--	--	Y	By heterocysts and akinetes**
Planktothrix agardhii	Y*	Y	Y	Y	hormogonia

Cyanophyta	Nitrogen Fixer?	Scum Forming?	Low Light Advantage	Buoyancy Regulator	Reproduction
Planktothrix prolifica (Planktothrix agardhii subspecies rubescens)	Y*	Y	Y	Y	hormogonia
Raphidiopsis (Cylindrospermopsis) raciborskii	Y	--	--	Y	binary fission, budding, or fragmentation
Microcystis aeruginosa	N	Y	Y	Y	By cell division and colony fragmentation
Microcystis wesenbergii	N	Y	Y	Y	By cell division and colony fragmentation
Planktolynbya limnetica	Y	Y	--	N	hormogonia
Lyngbya birgei (Limnoraphis birgei)	Y	Y	--	Y	hormogonia
Anabaena spp. (Dolichospermum spp.)	Y	Y	--	Y	heterocysts and akinetes**

*Although nitrogen fixation is generally limited to taxa with heterocysts, nitrogen fixation also occurs among mat-forming species of Oscillatoria (recent name changes have changed Oscillatoria to Plantothrix), but only during darkness when there is no photosynthetic oxygen generation. However, this particular species was not mentioned (1).

**Akinetes may persist as spores in sediments for long periods of time. Akinete formation may be triggered by cold temperatures or large temperature fluctuations (2).

The MPRB monitored several cyanobacteria bloom events in 2021 for toxin production to determine the risk for harmful cyanobacteria blooms. Many of the predominant cyanobacteria species found in the lakes can produce multiple toxins (Table 3). MPRB measured for microcystin and cylindrospermopsin anywhere scums were present including at the Cedar Lake and Lake Nokomis beaches where scum forming blooms are more prevalent. Monitoring for microcystin and cylindrospermopsin was conducted during a severe bloom at the Lake Nokomis boat launch. It should be noted that a phytoplankton analysis was not conducted at these locations during these events. Rather, phytoplankton samples were collected at the routine monitoring stations on the same day providing an overall assessment of the lake's phytoplankton community.

Table 3 Toxin production by cyanobacteria commonly found in Cedar Lake and Lake Nokomis.

Cyanophyta	Anabaenopeptins	Anatoxin a	Cylindrospermopsin	Microcystins	Saxitoxins
Aphanizomenon flos-aquae	X	X	X	X	X
Cuspidothrix issatschenkoi		X			X
Dolichospermum macrosporum		X			
Planktothrix agardhii	X	X		X	X
Planktothrix prolifica (Planktothrix agardhii subspecies rubescens)				X	
Raphidiopsis (Cylindrospermopsis) raciborskii	X	X	X	X	X
Microcystis aeruginosa				X	
Microcystis wesenbergii		X		X	
Planktolynbya limnetica					X
Lyngbya birgei (Limnoraphis birgei)	X				X
Anabaena spp. (Dolichospermum spp.)	X			X	

At the Cedar Lake monitored beaches, microcystin exceeded the MPCA Advisory Level of 6 µg/L in July 2021 (Figure 5). Monitored cylindrospermopsin concentrations did not exceed the MPCA Advisory Level of 15 µg/L during spring and summer 2021 (Figure 6). High microcystin levels followed a period of dominance by Aphanizomenon suggesting that much of the toxin came from this species (Figure 5). The highest cylindrospermopsin concentrations occurred in the late Fall following late summer dominance by Raphidiopsis (Cylindrospermopsis) raciborskii presumably as a result of senescence of the phytoplankton community and shift back to Planktothrix dominance (Figure 6).

Similar patterns were observed in Lake Nokomis with high microcystin concentrations in spring to early summer, which exceeded the MPCA Advisory Level of 6 µg/L (Figure 7). However, the early summer phytoplankton community was dominated by Planktothrix followed by a shift to Aphanizomenon suggesting that both species may be producing microcystin. Cylindrospermopsin reached its peak in late October following late summer dominance by Raphidiopsis (Cylindrospermopsis) raciborskii (Figure 8). Lake Nokomis also exceeded MPCA advisory level in winter and fall at locations other than the beaches.

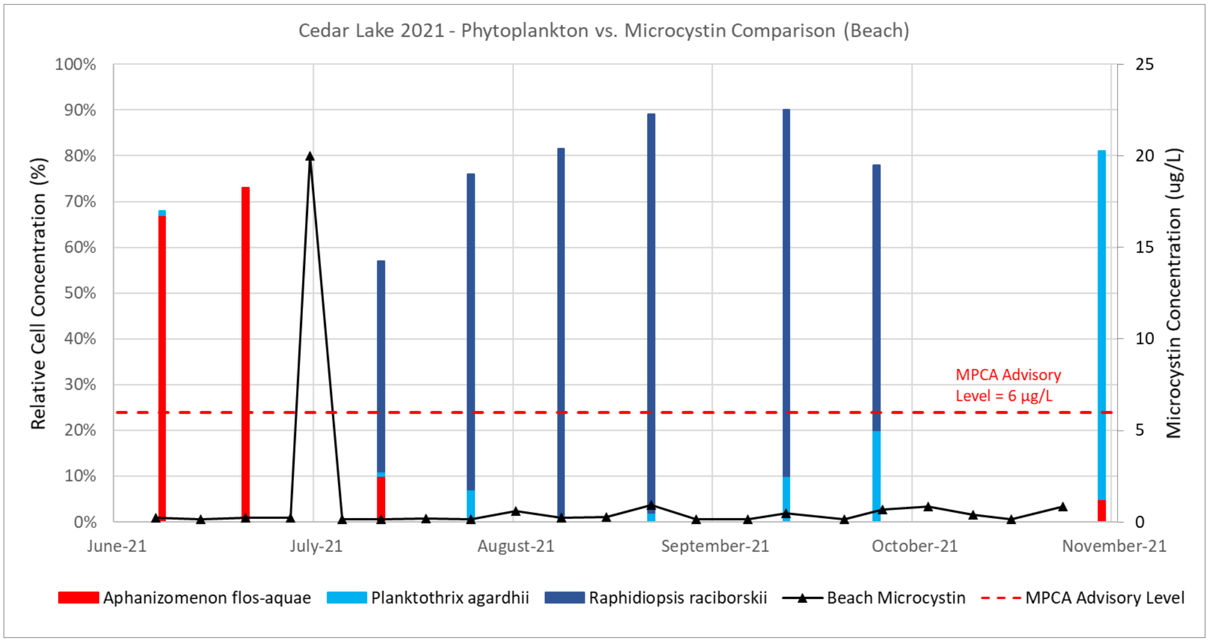


Figure 5 Dominant cyanobacteria species and average microcystin concentrations at the beach on Cedar Lake

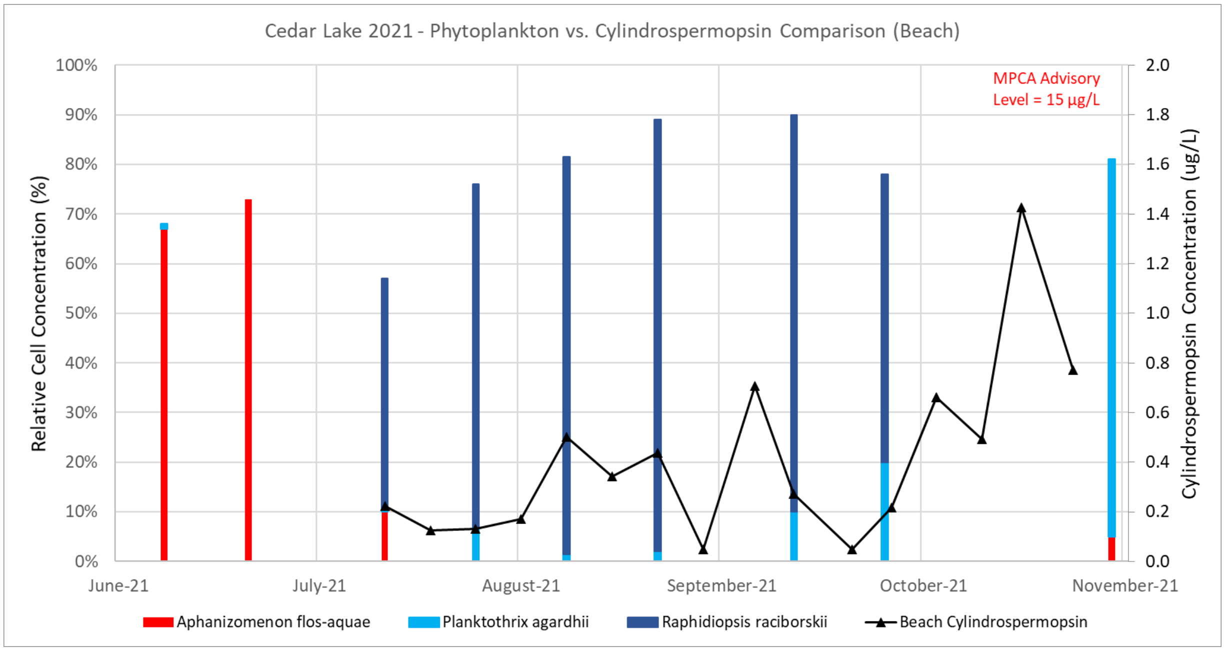


Figure 6 Dominant cyanobacteria species and average cylindrospermopsin concentrations at the beach on Cedar Lake.

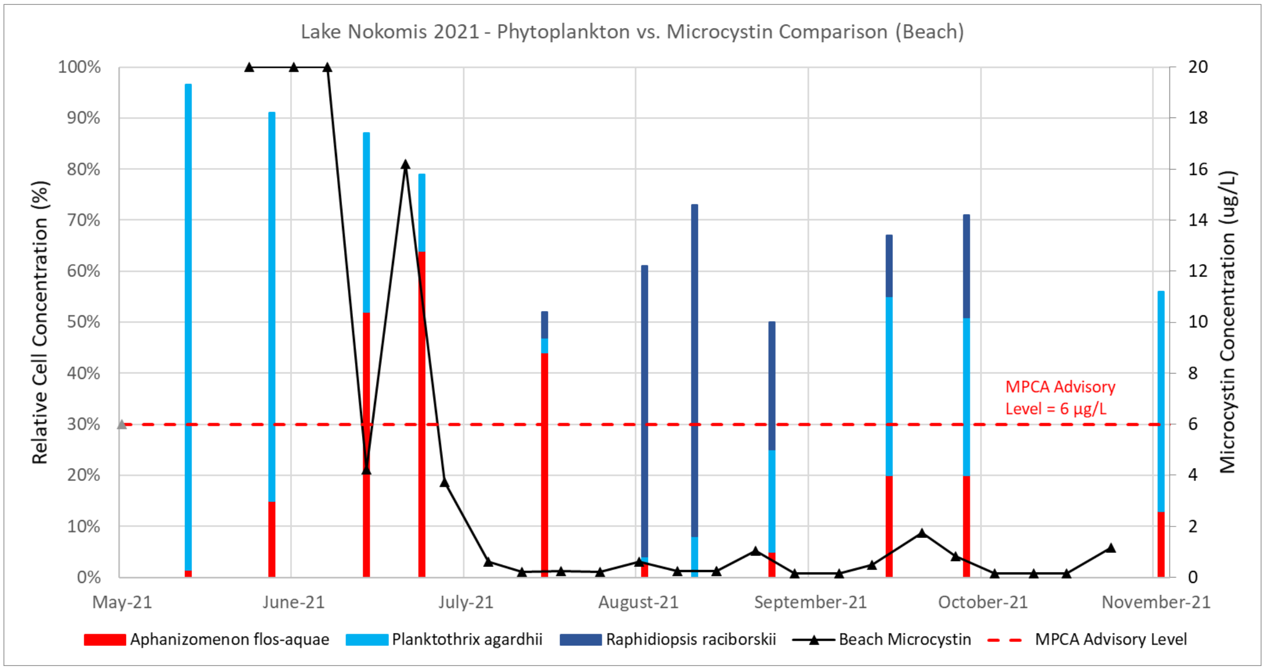


Figure 7 **Dominant cyanobacteria species and microcystin average concentrations at the beach on Lake Nokomis.**

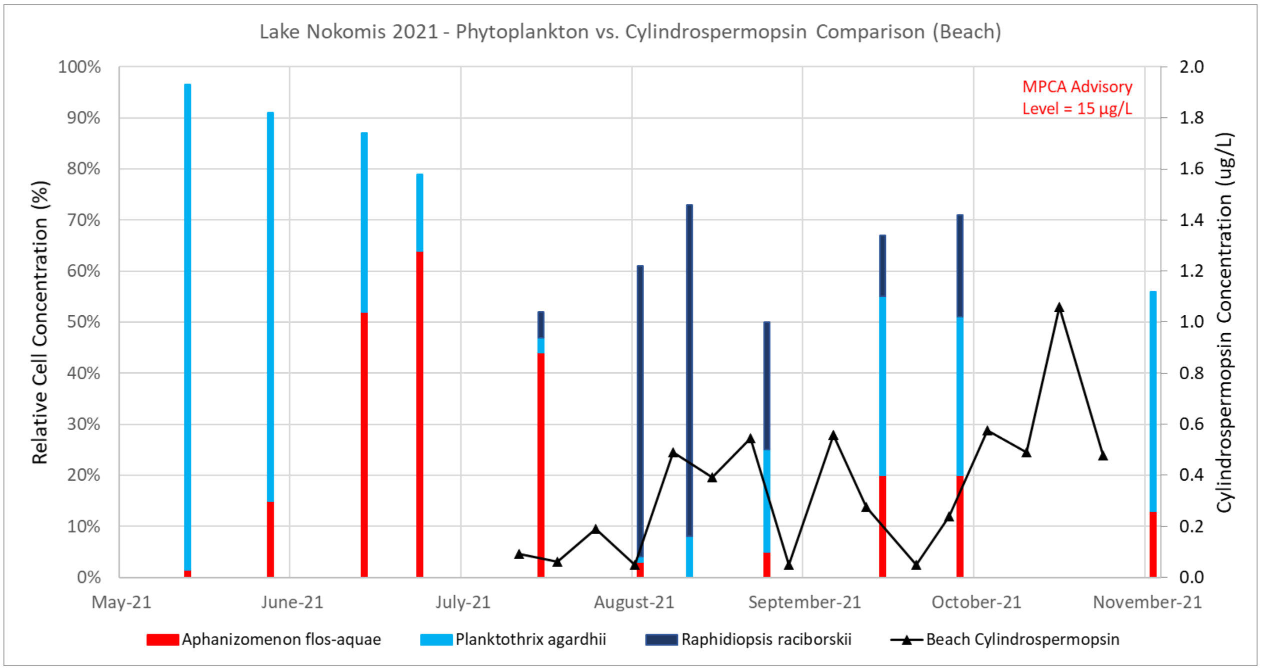


Figure 8 **Dominant cyanobacteria species and cylindrospermopsin average concentrations at the beach on Lake Nokomis.**

A severe bloom was observed at the Lake Nokomis boat launch in late September 2021 (Figure 9) and early November 2021. Microcystin concentrations were extremely high for these events exceeding the MPCA Advisory Level (Figure 10). In fact, the November algal scum sample reached 500 µg/L microcystin. Cylindrospermopsin was detected but well below the MPCA advisory of 15 µg/L. During both of these events the phytoplankton community was dominated by Planktothrix which is capable of producing microcystin. It should be noted that Aphanizomenon was also present in a relatively high proportion (10 to 20%) of the community and was a likely producer of microcystin in the early summer of 2021. Either Planktothrix or Aphanizomenon could be the source of microcystin. However, since only relative abundance is available for the phytoplankton community and not cell density, it’s difficult to determine the most likely toxin producers.

Figure 9 September 2021 cyanobacteria bloom athe Lake Nokomis boat launch.

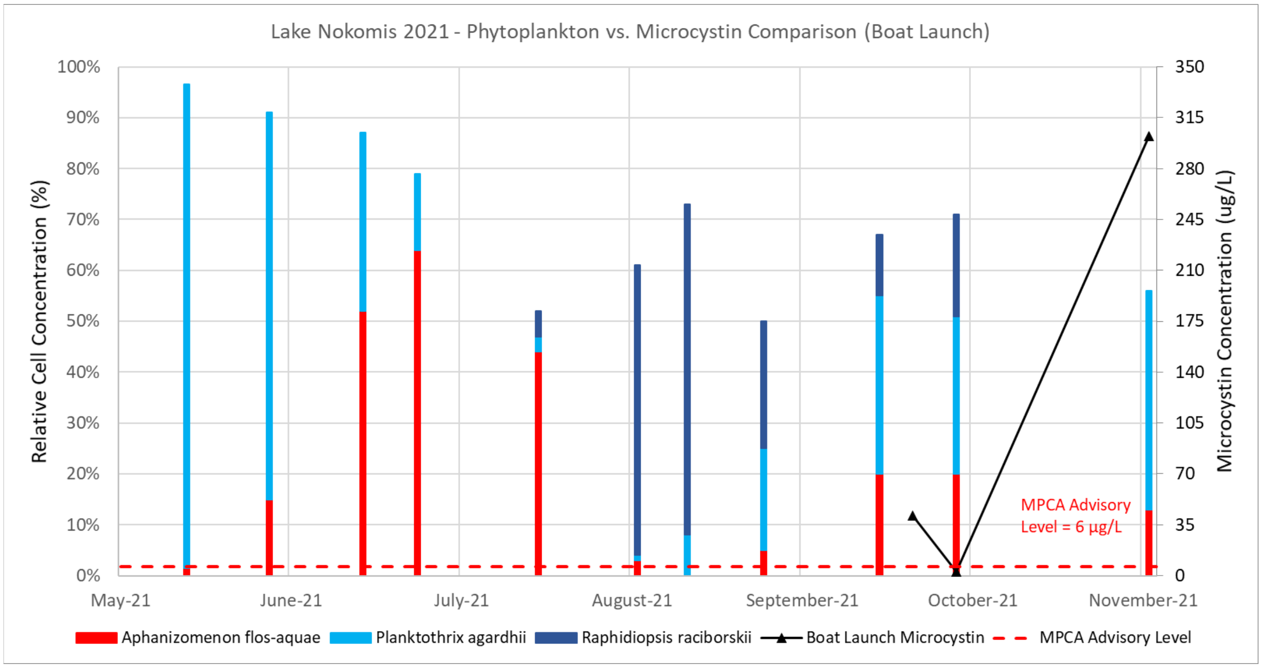


Figure 10 Average Microcystin levels at the Lake Nokomis boat launch during cyanobacteria blooms in late Fall 2021. Note that cylindrospermopsin was detected but well below the MPRB advisory of 1 µg/L.

Winter microcystin samples were collected in Cedar and Nokomis to assess toxic blooms under the ice (Table 4). While Cedar Lake was well below the MPCA Advisory level, Lake Nokomis was relatively high in microcystin. It should be noted that there was an upper reporting limit of 20 ug/L so the actual microcystin level is uncertain.

Table 4 Winter toxin samples from Cedar Lake and Lake Nokomis

Lake	Monitoring Date	Monitoring Location	Dominant Cyanophyta	Microcystin Concentration (µg/L)	MPCA Advisory Level (µg/L)
Cedar	2/2/2021	Lake	Aphanizomenon flos-aquae (77%) Planktothrix agardhii (20%)	0.3	6
Nokomis	1/29/2021	Lake	Planktothrix agardhii (90%)	>20	

4 Candidate Causes

To determine the probable drivers of the cyanobacteria Harmful Algal Blooms (CyanoHABs) in Cedar Lake and Lake Nokomis, a causal analysis was developed for the lakes. A list of candidate causes was developed based on a literature review focused on drivers of CyanoHABs and cyanobacteria blooms. Seven potential CyanoHAB drivers were identified that may be applicable to Cedar Lake and Lake Nokomis (Table 5). The list of candidate causes was developed considering remediation actions to help identify management options for reducing or eliminating CyanoHABs in the lakes. For example, nutrients were evaluated for both the potential impact on the phytoplankton community and sources (where possible) to determine the most appropriate remediation actions for the CyanoHABs. Results of the literature review are presented in Table 5.

Table 5 Candidate causes for cyanobacteria blooms in Cedar Lake and Lake Nokomis

Water Quality Parameter	Impacts/Cyanobacteria Response	Reference
Nutrient Enrichment - Phosphorus	• Phosphorus correlated with increased cyanobacteria biomass and taxa found in lakes • High sediment P release can favor buoyancy regulating cyanobacteria	(3), (4), (5), (6), (7)
Nutrient Enrichment - Nitrogen	• Nitrogen correlated with increased biomass and cyanobacteria taxa found in lakes • N_2 fixation at low N:P ratios which may lead to cyanobacteria dominance • In freshwater ecosystems, P concentration typically sets bloom growth rate; N also impacts growth rate, but has a larger influence on toxin production • Nitrogen deficiency, relative to other resources, limits toxin production • Toxin production demands high ratio of N:C compared to Redfield Ratio • Studies show that there are N concentration reduction thresholds at which bloom microcystin levels will decrease, leading to further evidence that N limitation may play a role in controlling cyanotoxin production	(3), (5), (6), (8), (9), (10), (11)
Warming Air/Water Temperature	• Increased lake stability • Prolonged growing season and stratification • Increased potential for hypolimnetic anoxia and subsequent sediment nutrient release • Buoyancy regulation to access P from hypolimnion • Cyanobacteria have a higher temperature optimum for growth than eukaryotes	(3), (5), (8), (12), (13)
Light	• Planktothrix can thrive over a broader temperature range and maintain high growth rate at lower light intensities (e.g., growth under the ice) • Cyanobacteria become competitively more dominant than other algal groups in enriched waters, due to their tolerance of the associated low CO2 and light environments and associated shifts in the availability of nitrogen.	(4), (14)
Micronutrients (Iron, cobalt, copper, manganese, molybdenum, zinc)	• Research indicates that high cyanobacteria biomass corresponds to lakes with low ferric ion concentrations • Cyanobacteria may be capable of supporting biomass levels across a gradient in ferric ion concentration by overcoming low ferric ion conditions through more efficient uptake strategies and (or) the activation of Fe-scavenging strategies. • Increased iron bound in TOC may lead to more intensive cyanobacteria blooms	(15), (16), (17)
Zooplankton Predation	• Zooplankton select green algae over cyanobacteria • Grazer avoidance or mortality associated with large colonies and/or toxic forms have also been reported.	(3), (18)
Hydrology/Detention Time	• Bloom forming cyanobacteria are typically slower-growing than other classes of phytoplankton and do best where resources (nutrients) are plentiful and loss rates to flushing are minimal.	(4)

5 Causal Analysis

To complete the causal analysis for Cedar Lake and Lake Nokomis, each candidate cause was evaluated to develop a weight of evidence for its impact on the cyanobacteria community. The analysis includes seasonal and temporal effects, analytical analyses, and literature support for the cause.

5.1 Eliminated Candidate Causes

Several of the candidate causes were ruled out based on geography, lake characteristics, or limited scientific understanding of the potential driver resulting in high uncertainty of the outcomes of management efforts. Following is a description of the eliminated candidate causes.

5.1.1 Micronutrients

The role of micronutrients in controlling toxic cyanobacteria blooms is gaining attention as a controlling factor. However, the scientific understanding is still limited, and most studies demonstrate the higher importance of macronutrients (phosphorus and nitrogen) in limiting cyanobacteria blooms. Particular attention is being paid to iron where studies in Alberta, CA have demonstrated linkages between iron and cyanobacteria biomass in shallow lakes (15). However, lakes in the Twin Cities Metropolitan Area do not tend to be low in iron and it remains an unlikely driver of cyanobacteria blooms. Because data is limited on micronutrients in these lakes and there are no known case studies where reducing micronutrients have resulted in decreased cyanobacteria biomass in eutrophic lakes, micronutrients were eliminated from this analysis.

5.1.2 Zooplankton Predation

Another factor that may influence cyanobacteria dominance in freshwater lakes is the interaction of zooplankton grazing. In shallow lakes, zooplankton grazing can play a significant role in controlling overall algal biomass. However, the extent to which zooplankton grazing impacts cyanobacteria dominance is unclear. It is possible that selective grazing could limit green algae in the lake through selective grazing opening a niche for cyanobacteria. Cedar Lake and Lake Nokomis are eutrophic with highly impacted aquatic vegetation communities. These conditions likely limit zooplankton grazing efficiency. Because this interaction is poorly understood and manipulating the zooplankton community is not likely to be an effective strategy for mitigating cyanobacteria blooms, it was eliminated from this analysis. It should be noted that establishing a healthy aquatic vegetation community and balanced fishery will support a healthy zooplankton population and ultimately a health lake.

5.1.3 Hydrology and Detention Time

Cyanobacteria blooms tend to do best in lakes with high nutrients, clear water and moderate alkalinity (4). While the role of detention time has not been extensively studied, lakes with short detention times tend to favor small phytoplankton with relatively high reproductive rates (high wash-out) while large, bloom-forming cyanobacteria are recognized for their slower reproductive rates and dominate in longer retention times. Since both lakes have very long detention times (>2.7 years), the lakes favor bloom forming cyanobacteria and altering detention times will not impact cyanobacteria blooms. Therefore, detention time was eliminated from consideration in this study.

There have also been reports of dewatering in the area to support local development activities. However, it is highly unlikely that these efforts have resulted in cyanobacteria blooms in Cedar Lake. While shallower water may be warmer, temperature differences in the surface water are unlikely to change significantly with dewatering. Other drivers in this report are clear factors and are not affected by dewatering.

5.2 Temperature and Stratification

The extent and magnitude of anoxia and stratification in a lake is widely believed to be a factor in selecting for cyanobacteria in north temperate lakes. However, its widely recognized that most stratified lakes are not dominated by cyanobacteria. Rather, the impacts are more lake specific and likely a result of mixing dynamics, impacts on sediment P and N release, and the timing of cyanobacteria blooms.

To evaluate stratification in Cedar Lake, temperature and dissolved oxygen profiles were plotted for all years. In 2021, Cedar Lake was strongly stratified for the majority of the growing season, setting up in early June (Figure 11). Deepening, or erosion of, the thermocline started in September with stratification holding until November. Stratification starts as shallow as 4 meters suggesting this is a relatively sheltered lake. Low dissolved oxygen follows the same pattern with anoxic conditions as shallow as 4 meters in 2021 (Figure 12). Strongly stratified lakes with high nutrients in the hypolimnion can favor cyanobacteria that can regulate their buoyancy. For example, Planktothrix are adapted to low light conditions and can move to the thermocline to access high nutrients at or below the thermocline. This process gives them a competitive advantage over other algae types.

In contrast, Lake Nokomis only weakly stratifies, setting up in mid-June and almost fully mixing in early September (Figure 13). The weak stratification allows for increased mixing events that may bring up nutrients from the sediments. Lake Nokomis also demonstrates long periods of anoxia with anoxic conditions often shallower than temperature stratification (Figure 14). These nutrients are then easily mixed into the water column and photic zone. While this favors all algae and not just cyanobacteria, the weak stratification over a large area of the lake provides a nutrient source for buoyancy regulators and can favor cyanobacteria. Weakly stratified lakes with high oxygen demand are often heavily impacted by sediment phosphorus release.

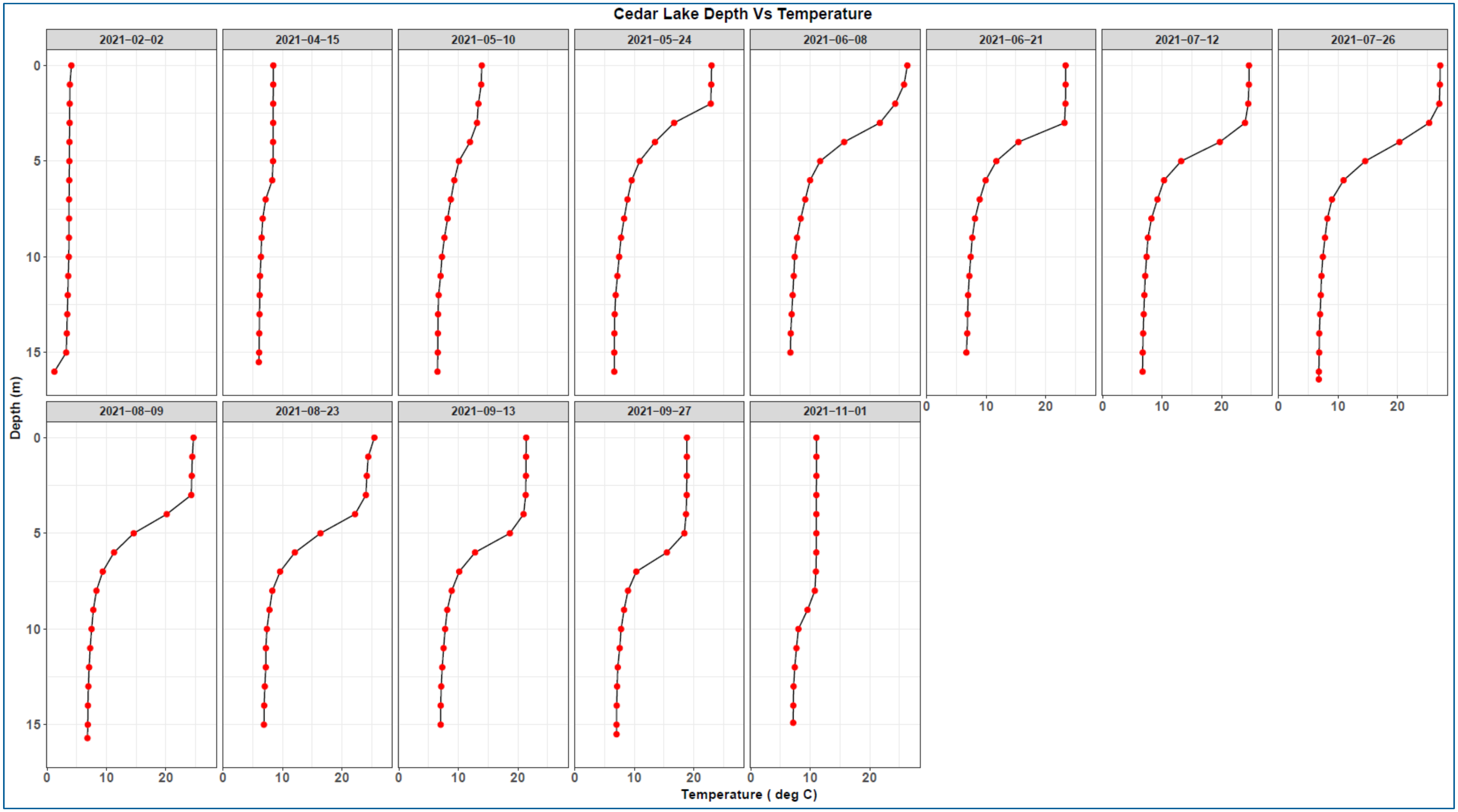


Figure 11 Temperature profiles in Cedar Lake in 2021.

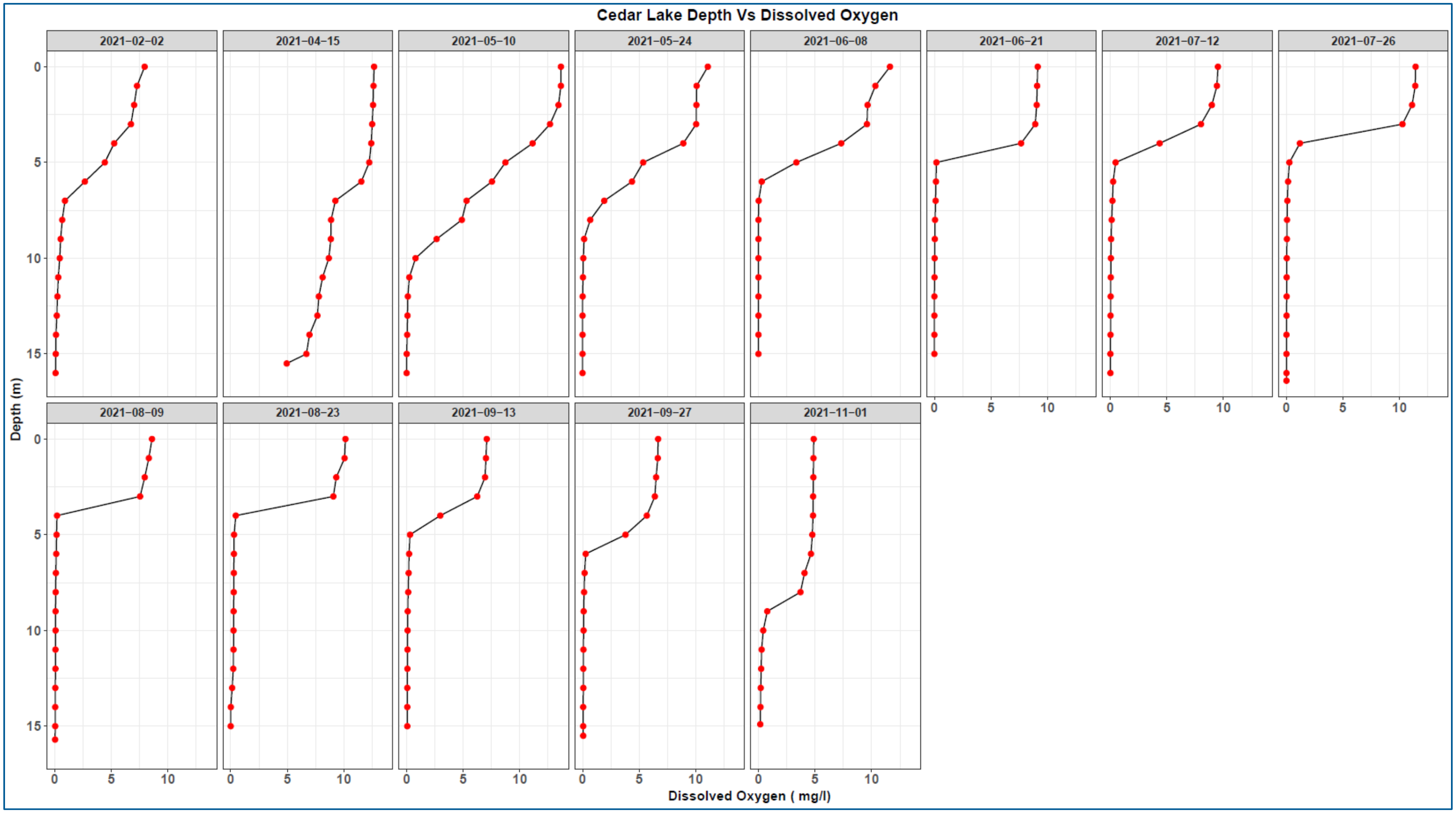


Figure 12 Dissolved oxygen profiles in Cedar Lake in 2021.

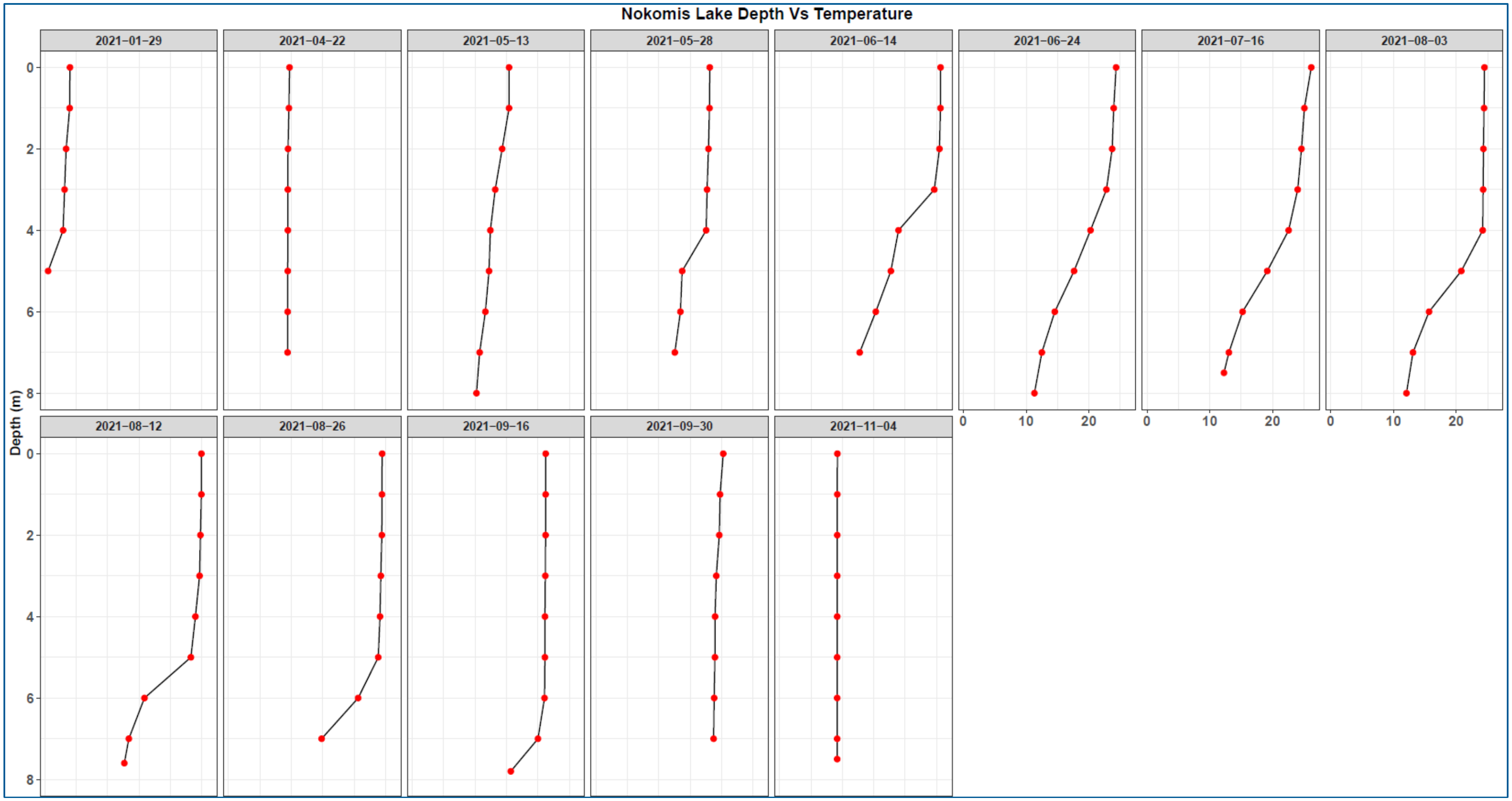


Figure 13 Temperature profiles in Lake Nokomis in 2021.

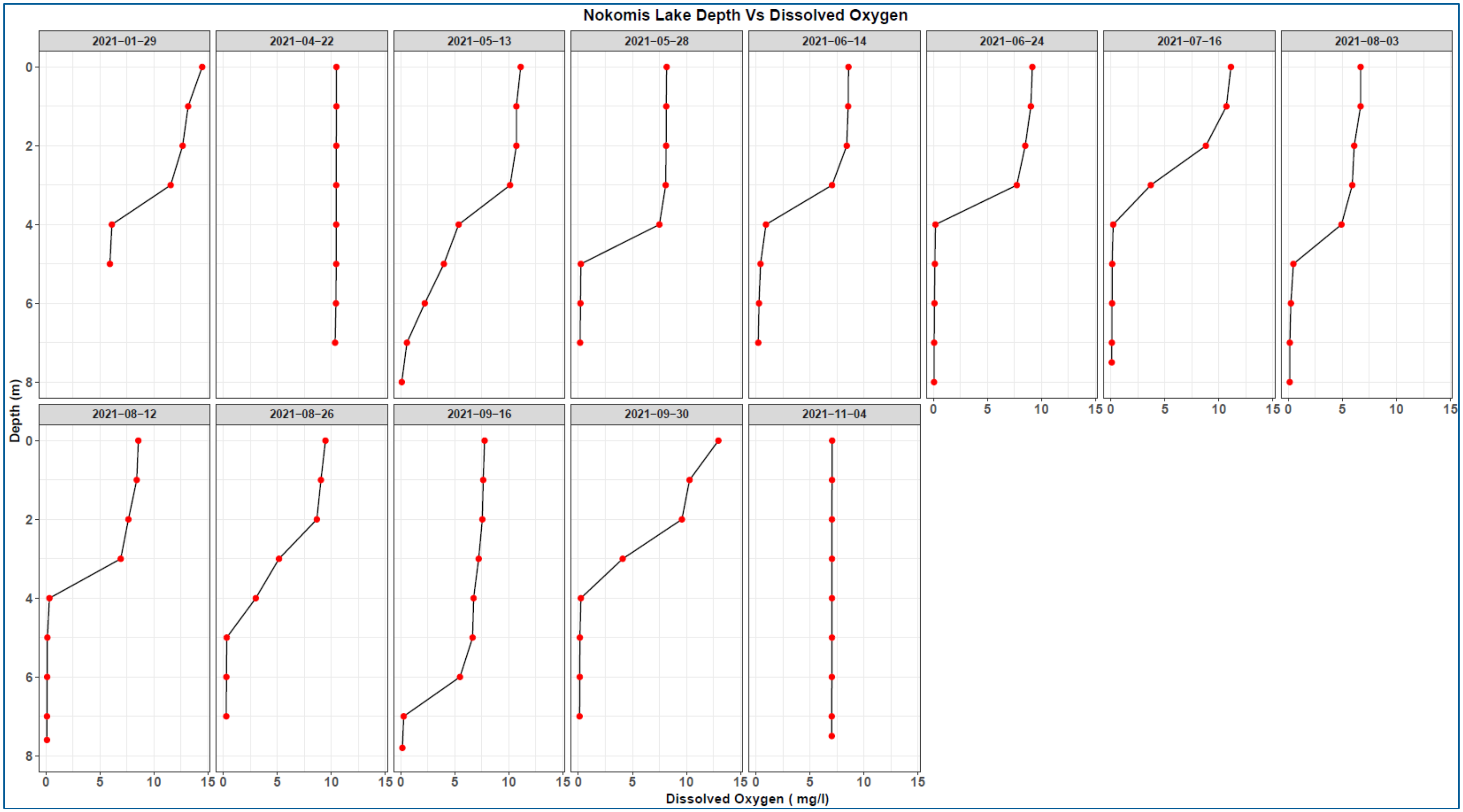


Figure 14 Dissolved oxygen profiles in Lake Nokomis in 2021.

To further assess the role of anoxia in the lakes, anoxic factors were calculated for the summer growing season and winter months. It should be noted that winter dissolved oxygen data are limited suggesting we may be underestimating the duration of anoxia. An anoxic factor is reported in days and is the number of days an area equal to the lake area is anoxic. For example, if 50% of the lake area is anoxic for half the growing season (122 days), the anoxic factor is 50% of 122 or 61 days. This approach allows for comparison among lakes of different sizes.

Cedar Lake demonstrates consistent anoxia throughout the growing season and in the winter, which can lead to sediment P release and conditions that favor cyanobacteria that regulate buoyancy (Figure 15). Because Lake Nokomis is shallower and more weakly stratified, anoxia is much more variable from year to year (Figure 16). The past 4 years have had very high anoxia coinciding with poorer water quality. Mapped areas of anoxia are provided in Figure 17 and Figure 18.

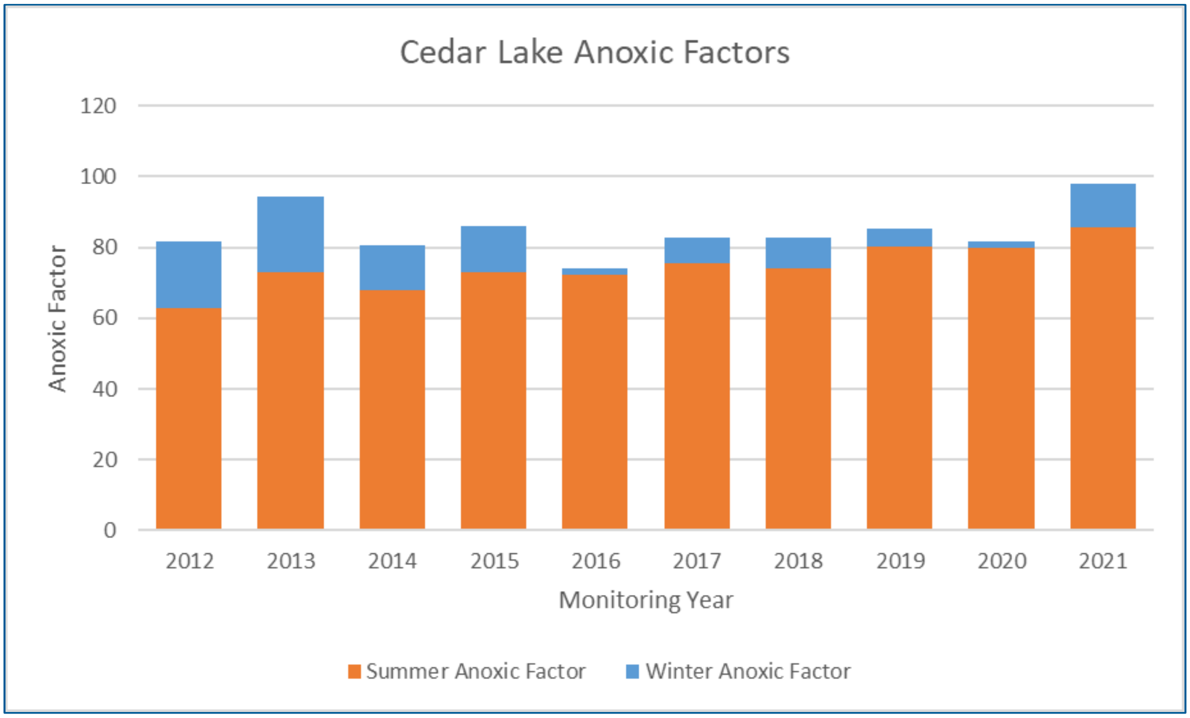


Figure 15 Anoxic factors for Cedar Lake.

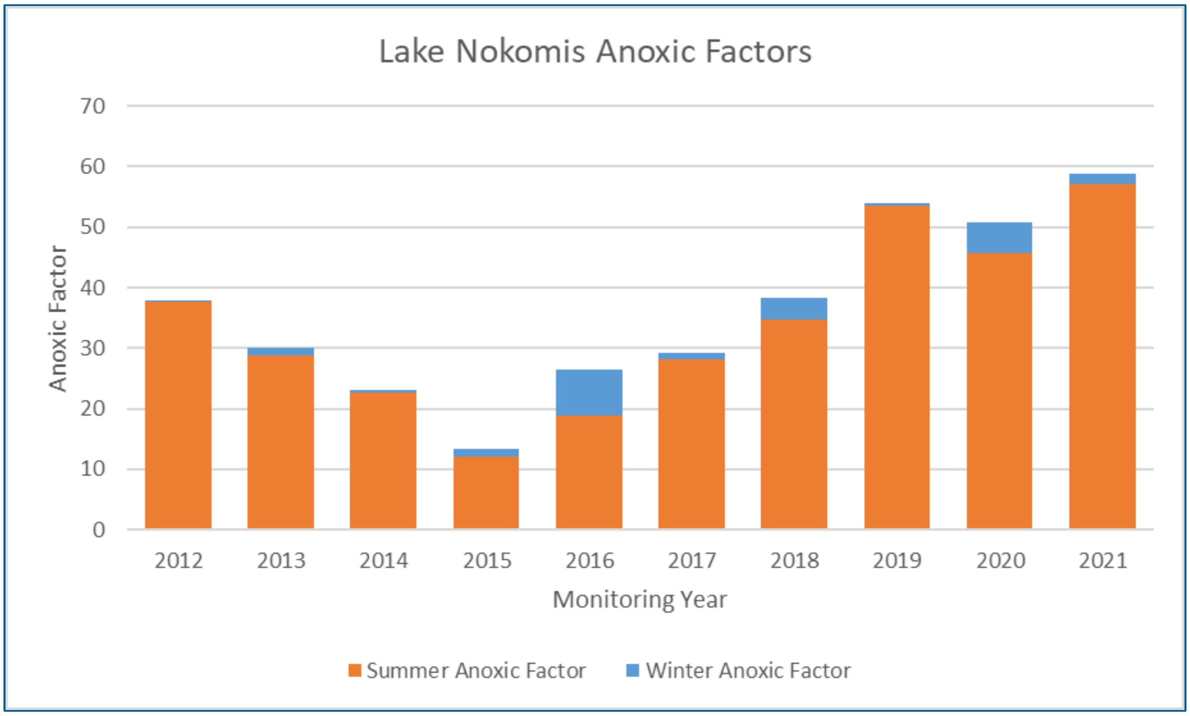
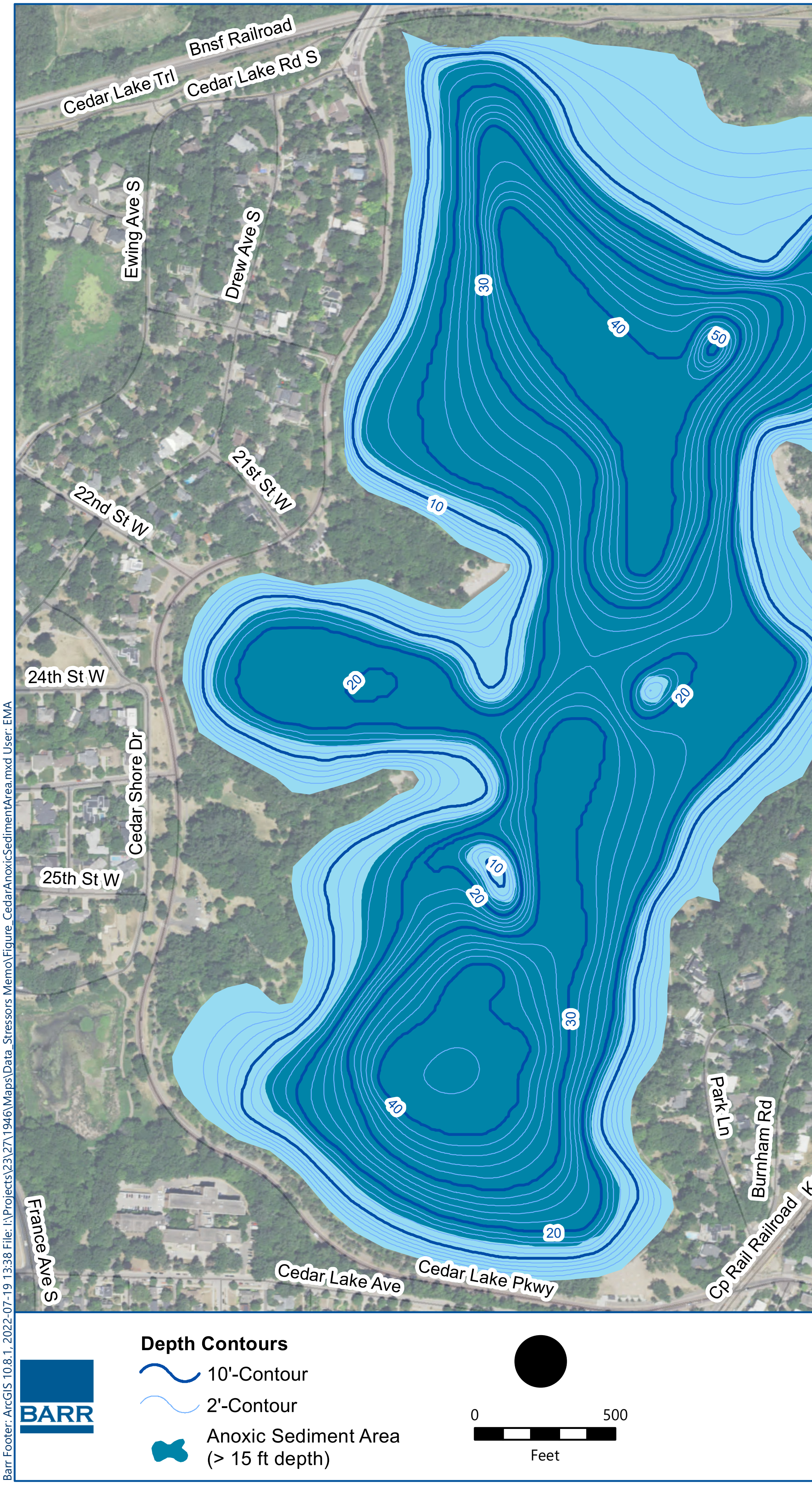


Figure 16 Anoxic factors for Lake Nokomis.

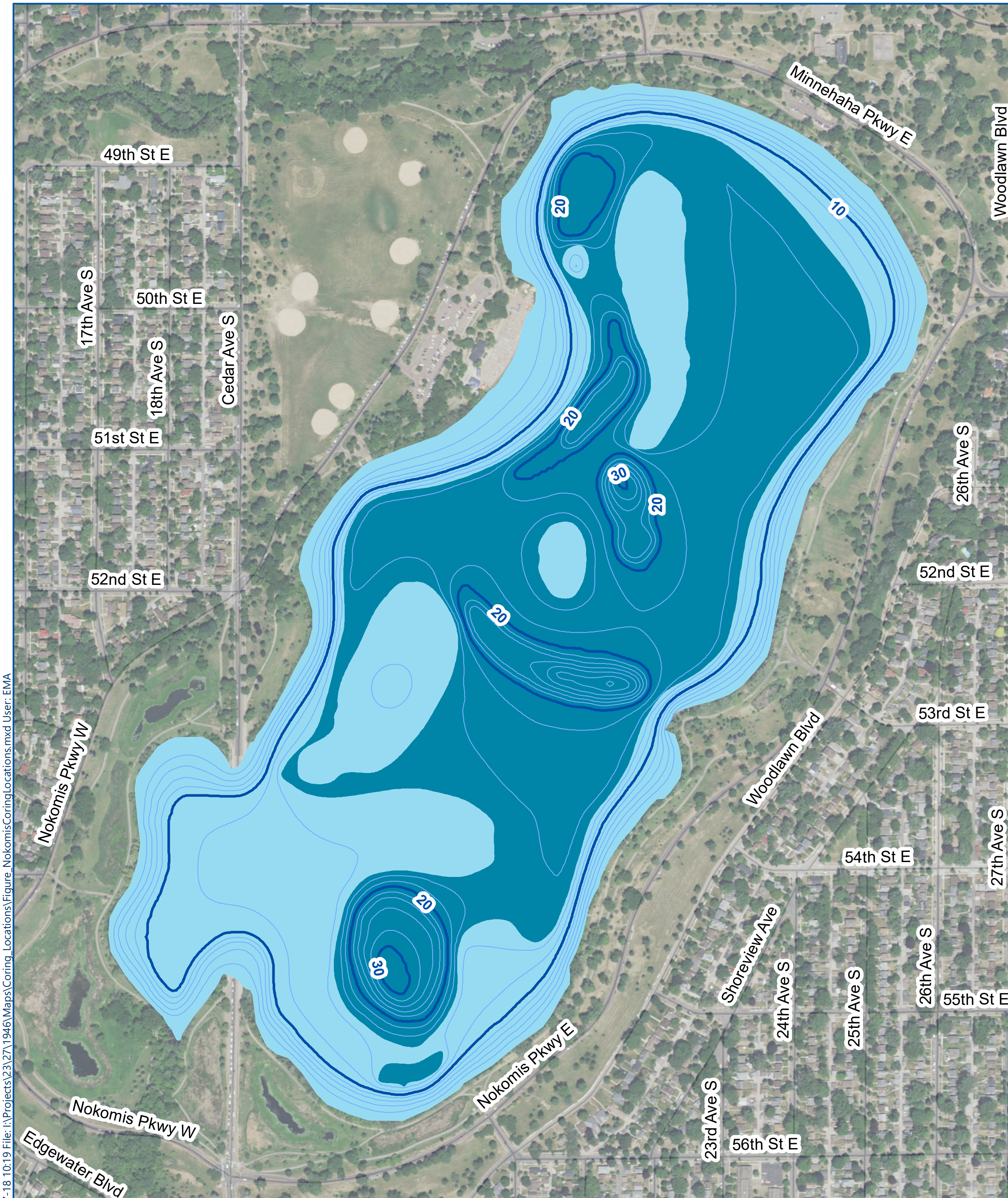


CEDAR LAKE

Anoxic Sediment Area
(>15 feet depth)

FIGURE 17

Barr Footer: ArcGIS 10.8.1, 2022-07-19 13:38 File: I:\Projects\23\27\1946\Maps\Data_Stressors Memo\Figure_CedarAnoxicSedimentArea.mxd User: EMA



Depth Contours

10'-Contour

2'-Contour

Anoxic Sediment Area (> 15 ft depth)

0 600

Feet

BARR

LAKE NOKOMIS

Anoxic Sediment Area (>15 feet depth)

FIGURE 18

Both lakes have strong evidence that stratification and anoxia are drivers of cyanobacteria although the impacts are slightly different. Cedar Lake maintains strongly stratified conditions through the summer with a strong nutrient gradient that favors cyanobacteria that can regulate buoyancy. In contrast, Lake Nokomis is weakly stratified but still has large anoxic areas that can promote nutrient release. Large areas of the lake are anoxic and temperature stratified creating pockets of high nutrient water that can favor cyanobacteria.

5.3 Nutrient Enrichment –Phosphorus

While other nutrients such as nitrogen play a role in cyanobacteria production, phosphorus remains one of the primary drivers of both cyanobacteria biomass and taxa present. Phosphorus can come from numerous sources including watershed runoff, mineralization of organic P in the water column, or sediment P release. The form and relative abundance of phosphorus, in relation to other nutrients such as nitrogen, influence the competitive success of cyanobacteria in lakes. How these nutrients affect the competitive success of CyanoHABs depends on uptake kinetics and physiological needs of various species. However, these relationships are not sufficiently understood to predict the response of CyanoHAB species versus non-HAB species. Further, these uptake kinetics and needs may be altered by changes in pH or temperature further complicating the response. However, the primary paradigms of phosphorus and nitrogen limitation and community response are critical in determining management steps for freshwater lakes.

5.3.1 Watershed and Sediment Phosphorus Loading

Cedar Lake Phosphorus Dynamics

Phytoplankton biomass, including cyanobacteria, are most often driven by nutrient enrichment in lakes. Surface concentrations of phosphorus is the most commonly used approach for assessing eutrophication in lakes. Water quality standards for lakes most commonly include total phosphorus and response variable such as chlorophyll-a to assess primary production in lakes. However, surface concentrations only tell part of the nutrient story in lakes especially lakes that stratify. Nutrients trapped in the hypolimnion can create a strong nutrient gradient that can be advantageous to cyanobacteria.

Total phosphorus concentrations in the surface (epilimnion) of Cedar Lake typically meet state water quality standards (<40 µg/L TP as a summer average) with median values between 20 and 40 µg/L (Figure 19). However, severe or moderate cyanobacteria blooms continue to occur in some years. While cyanobacteria blooms occur in similar lakes with surface concentrations as low as 20 ug/L. Mid-depth (metalimnion) and bottom (hypolimnetic) TP concentrations are five to twenty times greater than surface concentrations creating a strong nutrient gradient in the lake. Internal phosphorus loading because of sediment P release has long been considered an issue in Cedar Lake. In 1996, an aluminum sulfate treatment was conducted on the lake with a dose of 27 g Al/m^2 to bind sediment P and reduce hypolimnetic phosphorus. It should be noted that the alum dose was determined using lake alkalinity where modern dosing techniques evaluate sediment phosphorus concentrations to determine the required aluminum dose. In comparison to more recent alum treatments, 27 g Al/m^2 is a low dose. Recent alum treatments range between 100 and 150 g Al/m^2. As a result of applying a lower dose, the treatment was effective for about 5 years; after which, the hypolimnetic TP began steadily increasing. Since 2016, a strong nutrient gradient has occurred in the lake each year. This type of gradient favors cyanobacteria that can regulate their buoyancy to access phosphorus diffusing across the thermocline. This strong nutrient gradient coincides with a shift on the cyanobacteria community moving toward a dominance by Planktothrix, Aphanizomenon, and Raphidiopsis (Cylindrospermopsis).

Figure 19 Box plot of total phosphorus concentrations in the surface, mid-depth and bottom of Cedar Lake.

Another factor that can contribute to sediment P loading is the presence of common carp in the lake. While Cedar Lake is a deep lake, it does have a large littoral area where high carp activity can lead to sediment P release as the carp uproot vegetation and stir up sediments. While it's difficult to quantify the effects of carp, water quality does not suggest that carp are a major player in Cedar Lake. High P concentrations exist in the hypolimnion which is below where carp activity would impact P concentrations. Further, surface water quality is relatively good. If carp were impacting water quality, surface water quality would be higher in phosphorus and turbidity.

While data clearly demonstrate that internal phosphorus loading is critical in Cedar Lake, watershed phosphorus loading should not be discounted. However, if watershed phosphorus loading is high, surface concentrations would be expected to be higher than observed concentrations. Watershed runoff during the stratified periods would mix primarily with the surface waters of the lake due to temperature increasing the surface P concentrations. As the temperature of water changes, so does its density and runoff will be similar in density to surface lake water, preventing mixing deeper in the lake. Since surface concentrations typically meet state standards (Figure 19), it is likely that surface runoff is not the dominant P source in the lake. However, watershed runoff likely contributes P to the lake episodically throughout the year which reports to the lake sediments through sedimentation of particulates or algae following senescence.

Lake Nokomis Phosphorus Dynamics

Lake Nokomis demonstrates similar patterns in lake phosphorus dynamics with relatively low surface phosphorus concentrations (median values between 30 and 40 µg/L) and high phosphorus concentrations in the bottom of the lake. However, because Lake Nokomis is much shallower and only weakly stratifies, high bottom phosphorus concentrations don't occur every year. Further, mid-depth phosphorus concentrations are more similar to surface concentrations likely as a result of mixing the water column. Lake Nokomis does stratify enough to create a zone of anoxia and high phosphorus concentrations that may favor cyanobacteria that can access the bottom phosphorus. In the most recent five years, bottom phosphorus concentrations have reached almost 800 µg/L. Considering the large anoxic area that occurs in Lake Nokomis, sediment P release is likely a strong driver of cyanobacteria blooms in Lake Nokomis.

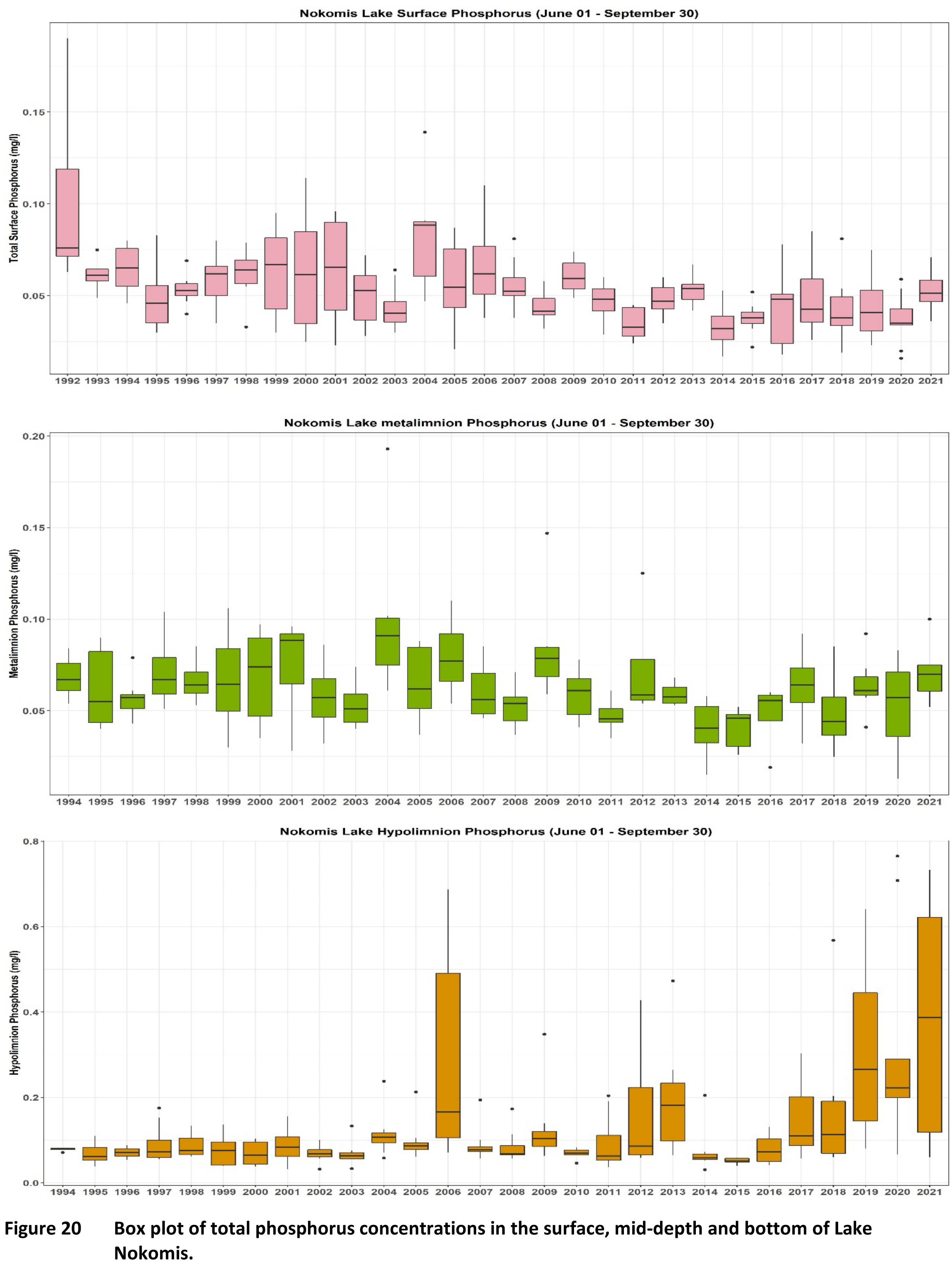


Figure 20 **Box plot of total phosphorus concentrations in the surface, mid-depth and bottom of Lake Nokomis.**

Carp may be impacting phosphorus concentrations in Lake Nokomis where high population biomass was reported in the lake (WSB 2019). While it is difficult to determine the amount P loading resulting from carp activity, carp management should be pursued to ensure future management actions are effective.

5.3.2 Seasonal Phosphorus Loading

One of the more interesting aspects of the cyanobacteria blooms in Cedar Lake and Lake Nokomis is the early season blooms of cyanobacteria such as Planktothrix and Aphanizomenon even under winter ice.

In Cedar Lake, high phosphorus concentrations exist in the hypolimnion throughout the year including under winter ice. Bottom phosphorus increases through the summer growing season presumably as a result of sediment P release. Because the lake stratifies so strongly, these high concentrations are maintained well into the late Fall. Interestingly, winter bottom phosphorus concentrations decrease as the lake finally mixes and some of the released P likely precipitates back to the sediments. However, surface P increases following the mixing event. These conditions provide a robust environment for cyanobacteria adapted to low light conditions. Since little surface runoff occurs in the winter, under the ice and early season cyanobacteria blooms are likely driven by high internal loading throughout the growing season that maintains high phosphorus concentrations to fuel cyanobacteria growth (Figure 21).

Lake Nokomis follows a more typical pattern where hypolimnetic P concentrations are high throughout the stratified growing season but decrease following fall turnover. While winter concentrations are relatively low, phosphorus concentrations greater than 20 µg/L can maintain a cyanobacteria bloom. Since the phytoplankton data only provide a relative abundance and not a biovolume or biomass estimate, it's difficult to determine on an annual basis if the cyanobacteria are low but surviving to seed a spring bloom or if the bloom is large enough to be concerned about toxin production. In 2021, microcystin data collected in Lake Nokomis in late January showed that the phosphorus concentrations were sufficient enough to cause a significant Planktothrix bloom event. Microcystin concentrations were measured greater than 20 µg/L, which is well above the MPCA warning threshold of 6 µg/L. However, since toxin data is only available for one winter it is difficult to determine a trend in winter blooms. Either way, current data demonstrates that enough phosphorus persists under the ice to support cyanobacteria adapted to low light conditions (Figure 22).

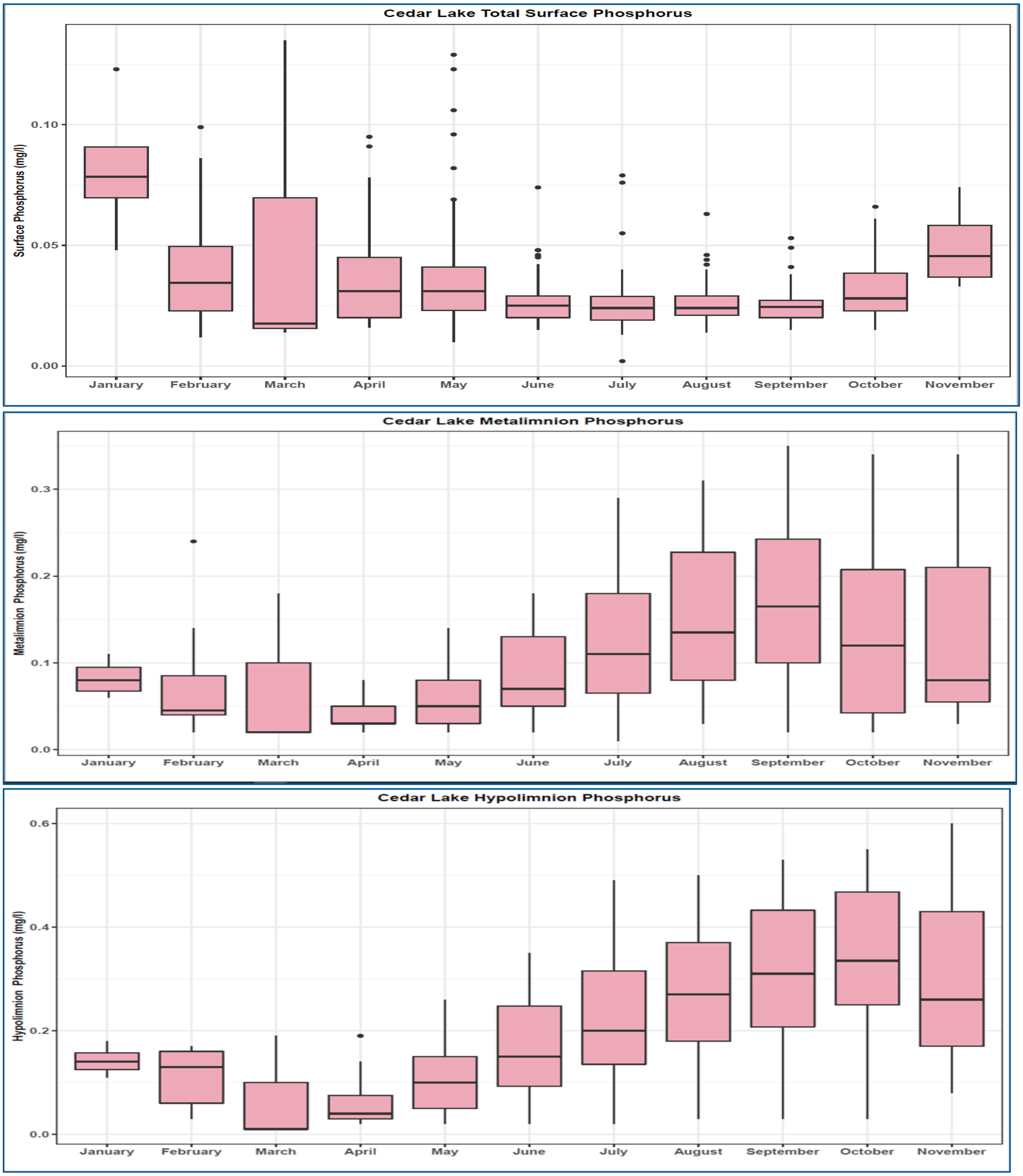


Figure 21 **Box plot of monthly total phosphorus concentrations in the surface, mid-depth and bottom of Cedar Lake from 1991 to 2021.**

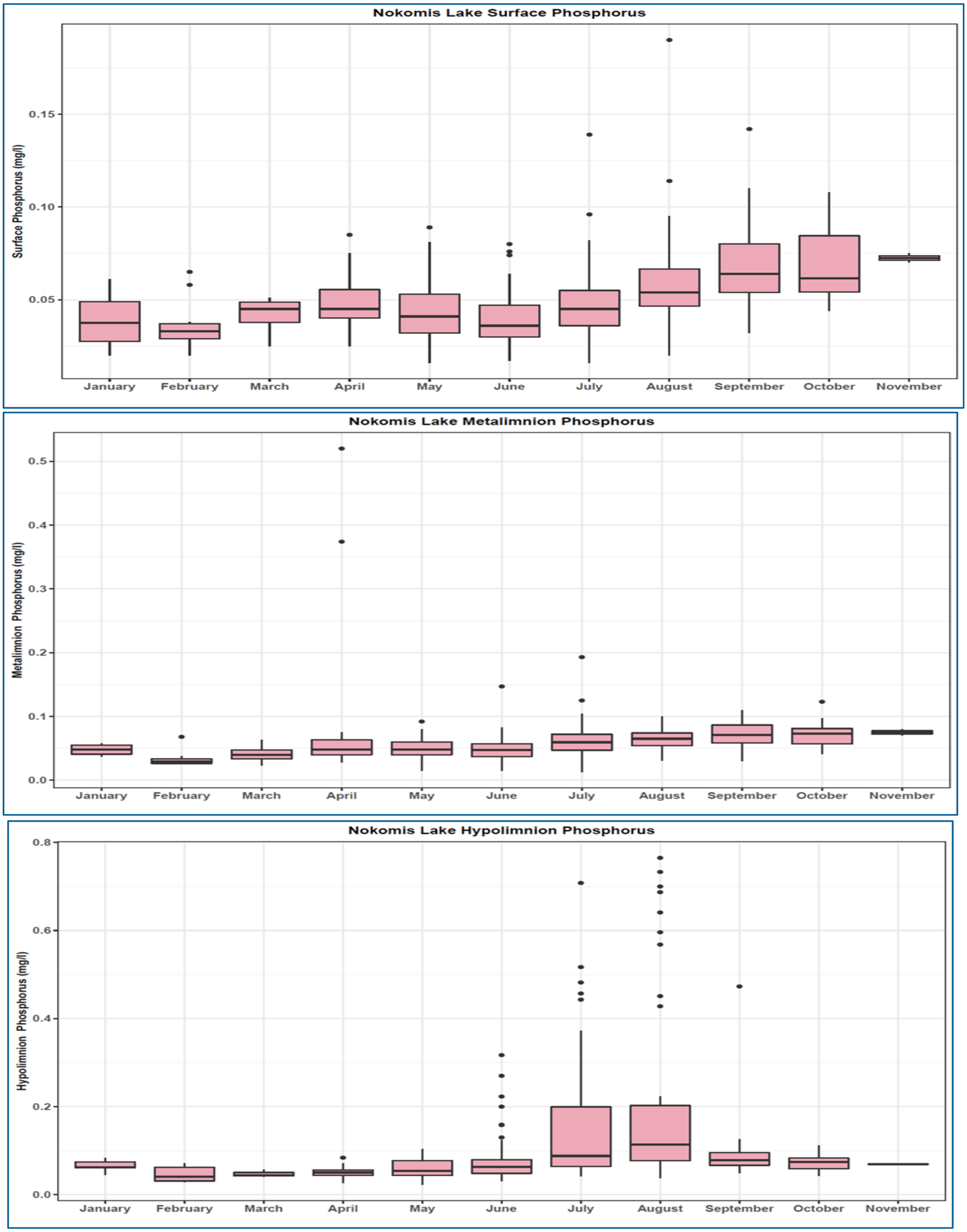


Figure 22 **Box plot of monthly total phosphorus concentrations in the surface, mid-depth and bottom of Lake Nokomis from 1991 to 2021.**

5.4 Nutrient Enrichment – Nitrogen

While phosphorus is typically the primary driver for algae and cyanobacteria blooms, nitrogen can impact both the biomass and taxa of cyanobacteria blooms. Further, changes in nitrogen and phosphorus ratios can select for cyanobacteria dominance where low N:P ratios favor cyanobacteria. Many cyanobacteria are nitrogen fixers and do well in nitrogen limited environments where they can fix their own nitrogen. Consequently, mitigation strategies that target nitrogen reductions can result in a change in the cyanobacteria community that does not always result in better water quality. Lowering N concentrations may just shift the community to N fixing cyanobacteria, trading one problem for the next. However, long term reductions in N concurrently with P is demonstrated to be an effective strategy for reducing cyanobacteria. While lowering N loading should be pursued, there are few studies that demonstrate this approach results in immediate water quality changes.

Total nitrogen concentrations in both lakes are near the 50% percentile for lakes in the Northern Hardwood Forest ecoregion suggesting the lakes are not overloaded with nitrogen (Figure 23 and Figure 24). Lake Nokomis demonstrated higher annual variability in total nitrogen whereas Cedar Lake was fairly consistent year to year.

To determine if the lakes demonstrate nitrogen limitation, molar N:P ratios were calculated for both lakes and plotted monthly. N:P ratios less than 16:1, the Redfield ratio, are expected to be nitrogen limited. Total nitrogen and nitrate/nitrite were also plotted.

N:P ratios were typically above the Redfield ratio thought the year in Cedar Lake suggesting N limitation in the lake is not critical (Figure 25). However, total N tends to decrease until midsummer and then increase following a shift in the cyanobacteria community. Nitrate in surface waters tend to deplete to zero by mid-July and remain low into the Fall. This depletion is followed by the increase in total nitrogen from July to November. These nitrogen dynamics suggest that the lake reaches N limitation in mid- to late summer driving a shift in the cyanobacteria community to nitrogen fixers. Total nitrogen increases in the lake as cyanobacteria fix nitrogen for growth. High phosphorus concentrations combined with N limitation effectively selects for N fixing cyanobacteria in late summer and into the Fall (such as the shift to Raphidiopsis (Cylindrospermopsis) raciborskii observed in the data).

A similar, but much more pronounced, pattern is seen in Lake Nokomis where nitrate/nitrite is depleted shifting the cyanobacteria community to N fixers (such as the shift to Raphidiopsis (Cylindrospermopsis) raciborskii observed in the data). However, nitrate depletion occurs much sooner (June) followed by a much steeper increase in total nitrogen in the lake (Figure 26). Again, high phosphorus concentrations combined with low nitrate/nitrate and N:P ratios suggest that nutrient conditions provide an environment where cyanobacteria have a strong competitive advantage.

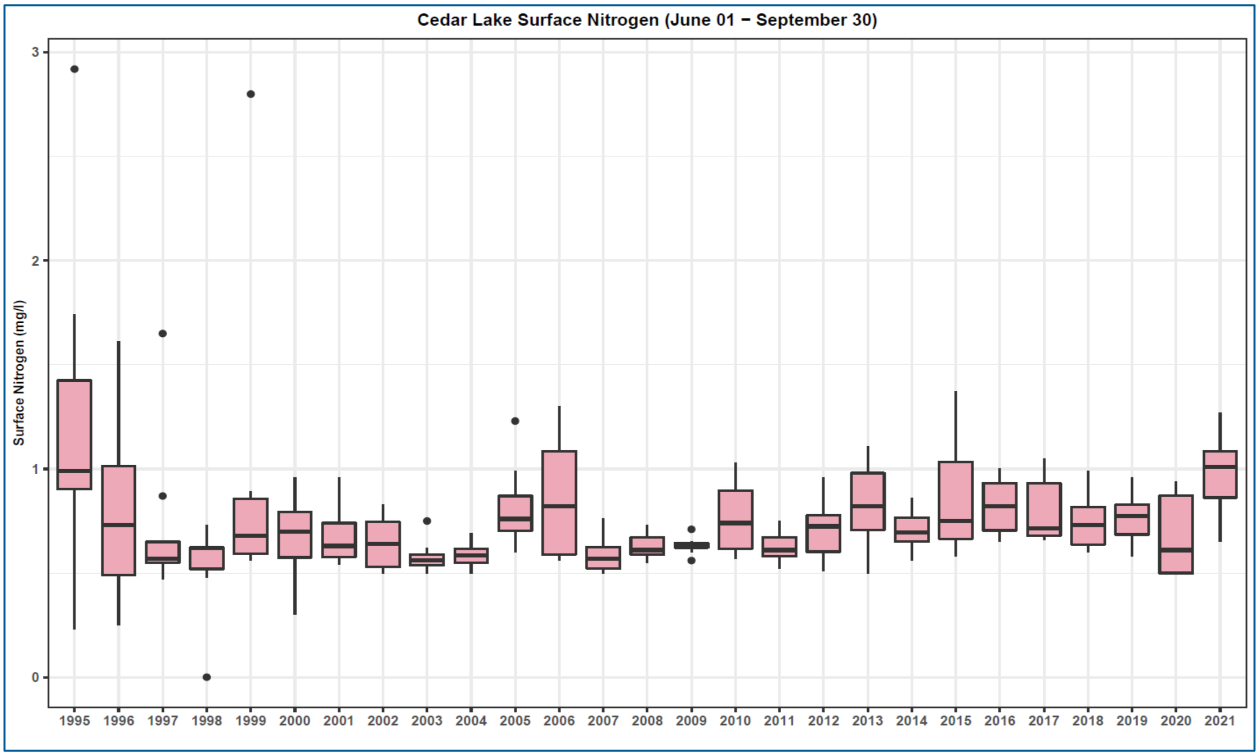


Figure 23 Box plot of surface total nitrogen in Cedar Lake.

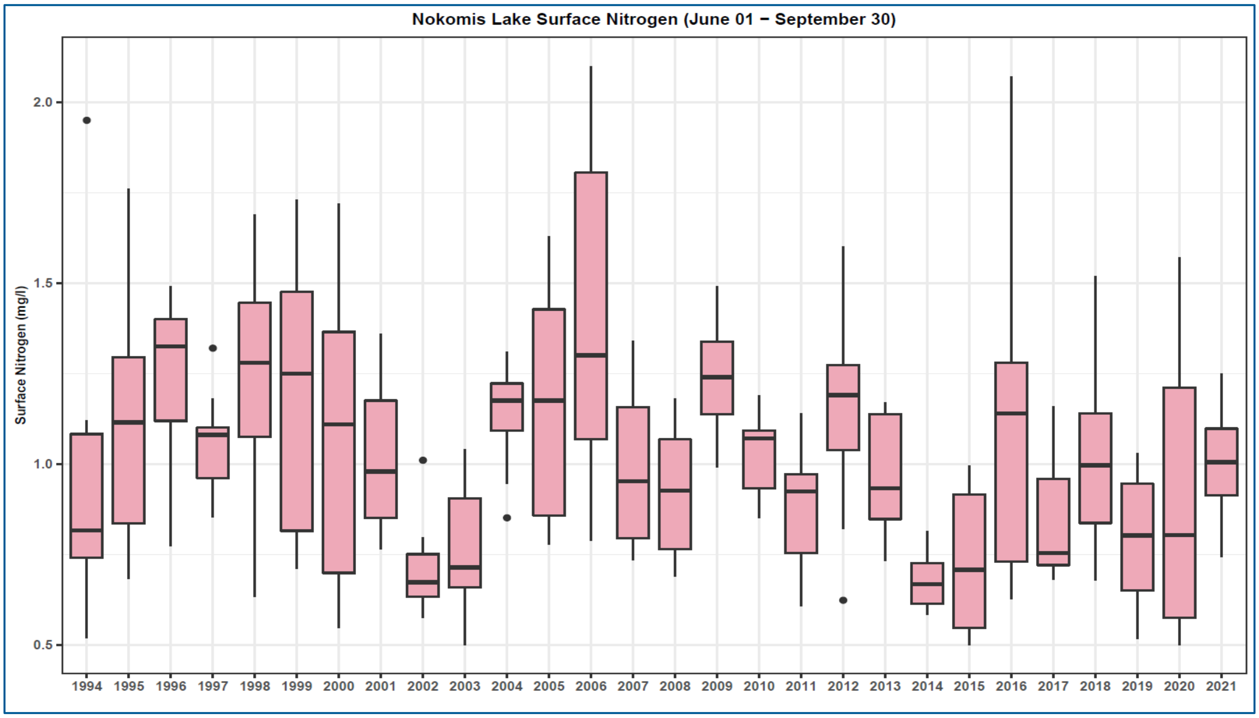
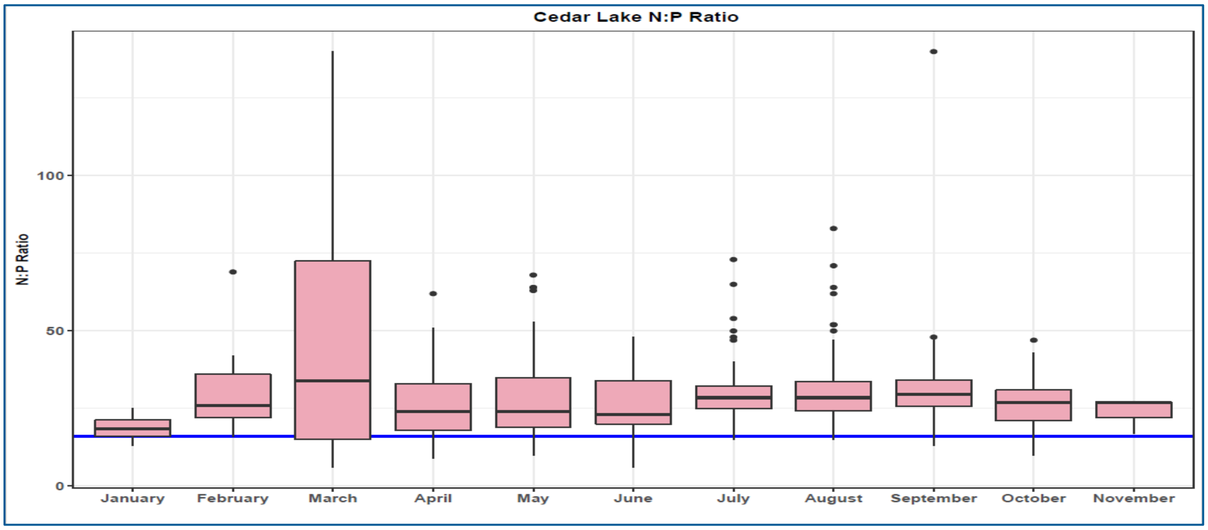
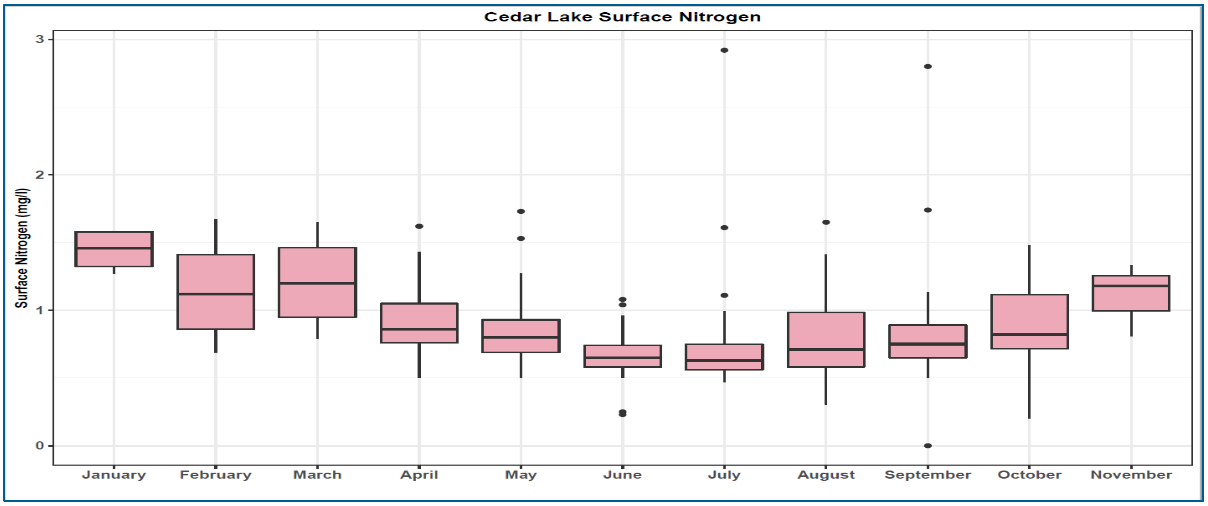


Figure 24 Box plot of surface total nitrogen in Lake Nokomis.





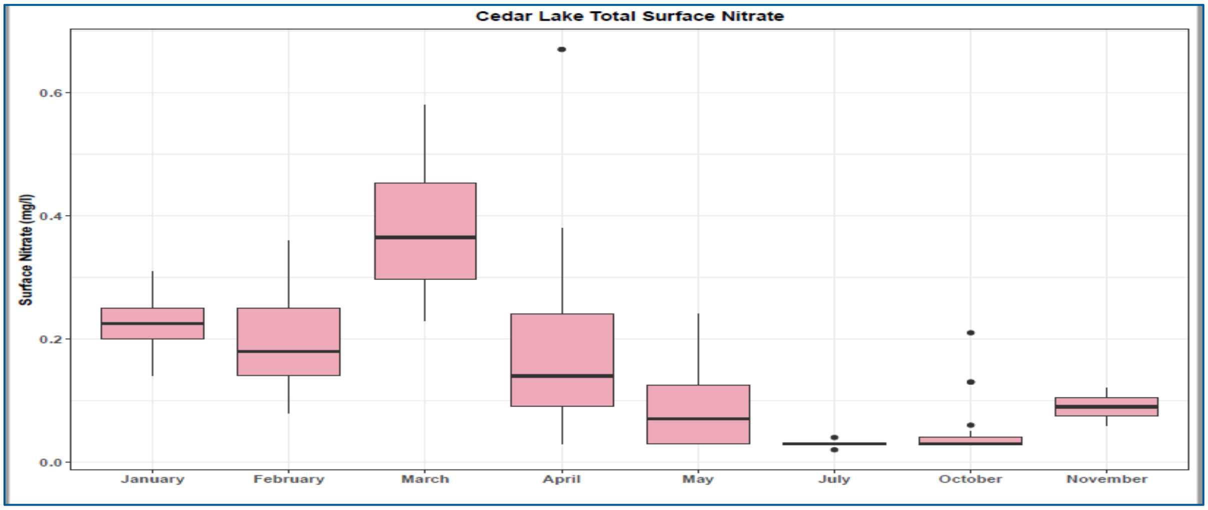


Figure 25 Box plot of monthly N:P ratios, total nitrogen and nitrate/nitrite in Cedar Lake from 1991 to 2021.

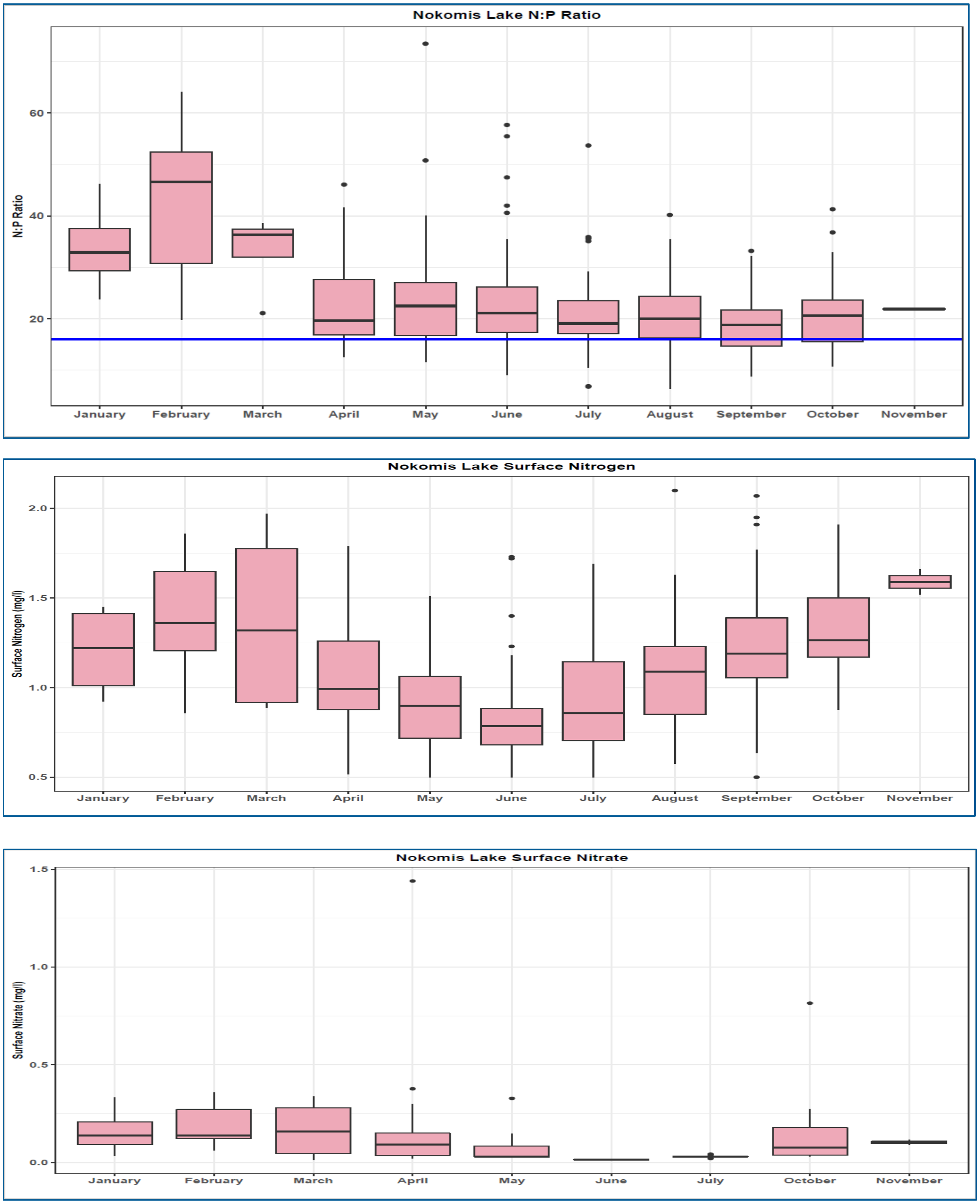


Figure 26 Box plot of monthly N:P ratios, total nitrogen and nitrate/nitrite in Lake Nokomis from 1991 to 2021.

5.5 Light

Cedar Lake and Lake Nokomis have cyanobacteria growth under the ice dominated by Planktothrix and Aphanizomenon. While Cedar lake maintains high phosphorus concentrations throughout the winter, Lake Nokomis phosphorus is more moderate. If enough light is present, these conditions can result in cyanobacteria blooms under the ice leading into spring turnover. Many cyanobacteria species are adapted to low light and low temperature conditions allowing them to grow under the ice in winter. While the size of the cyanobacteria blooms in the winter in Cedar Lake and Lake Nokomis are unknown, it is clear cyanobacteria are present under low light conditions. Presumably, years with greater snow cover on the ice will limit the amount of light available for cyanobacteria growth whereas years with low snow cover and clear ice will result in more light and greater cyanobacteria biomass.

Snow cover on both lakes is managed and may contribute to cyanobacteria growth under the ice. On Cedar lake, snow is plowed to help maintain local cross country ski trails. No records of when this occurs or what area of the lake is plowed are currently available. On Lake Nokomis, approximately 22 acres are cleared every winter to support pond hockey activities. The clearing of snow off the ice will increase the amount of light available for winter cyanobacteria production. Since both lakes have high phosphorus environments, the additional light could fuel cyanobacteria growth in the lakes and contribute to spring dominance by cyanobacteria.

6 Summary and Conclusions

6.1 Stressor identification Summary

Cedar lake and Lake Nokomis experience cyanobacteria blooms that include toxin producing species (CyanoHABs) throughout the year. High toxins have been measured in the Spring, Summer, and Fall in the lakes and cyanobacteria are known to grow under the ice. In 2021, microcystin concentrations in January were measured greater than 20 µg/L, which is well above the MPCA advisory level of 6 µg/L. However, since toxin data is only available for one winter it is difficult to determine a trend in winter blooms.

A weight of evidence approach was used to assess the drivers of cyanobacteria dominance and blooms in the lakes. Primary drivers are defined as drivers that have a direct impact on the biomass and selection for cyanobacteria. Secondary drivers may impact cyanobacteria biomass and dominance indirectly by creating conditions supporting primary drivers.

Cedar Lake

There are four primary phases in the cyanobacteria community throughout the year in Cedar Lake including:

1. Winter dominance by either Planktothrix or Aphanizomenon with more recent years in Cedar Lake being mostly Planktothrix
2. Early Spring into early Summer demonstrating a shift to dominance by Aphanizomenon presumably as water temperatures increase in the surface and the lake is still weakly stratified
3. A late summer shift to Cylindrospermopsis (Raphidiopsis) presumably as the lake is depleted of nitrate and surface water hits peak temperatures and
4. A Fall transition back to dominance by Planktothrix as the water temperatures decrease and the thermocline is degraded and the lake becomes destratified.

For Cedar Lake the primary drivers include:

1. High nutrient concentrations in the hypolimnion because of shallow anoxia and sediment P release
2. Strongly stratified conditions with high nutrient concentrations at the thermocline selecting for cyanobacteria that regulate buoyancy in the Summer and into the Fall
3. High phosphorus concentrations under winter ice as result of high internal P loading resulting in conditions that favor cyanobacteria adapted to cold temperatures and low light conditions
4. Nitrogen limitation in late summer that favors nitrogen fixing cyanobacteria
5. Increased light availability during the winter as a result of snow plowing and removal to maintain local cross country ski trails.

The evaluated stressors and evidence are summarized in Table 6.

Lake Nokomis

Lake Nokomis follows a similar pattern as Cedar Lake with the four primary phases listed above except:

1. Winter dominance is primarily Planktothrix and
2. Planktothrix remains common in the lake during the late summer shift to Cylindrospermopsis (Raphidiopsis)

For Lake Nokomis the primary drivers include:

1. Weakly stratified conditions with high nutrient concentrations near the lake bottom selecting for cyanobacteria that regulate buoyancy in the Summer and into the Fall
2. High nutrient concentrations in the hypolimnion because of large areas of anoxia and sediment P release
3. A large carp population that may be exacerbating internal phosphorus loading in the lake
4. While phosphorus concentrations under winter ice as result of internal P loading is moderate, conditions still favor cyanobacteria adapted to cold temperatures and low light conditions
5. Nitrogen limitation in late summer that favors nitrogen fixing cyanobacteria
6. Increased light availability during the winter because of snow plowing and removal to support local pond hockey activities.

The evaluated stressors and evidence are summarized in Table 7.

Table 6 Cyanobacteria stressor summary for Cedar Lake.

Water Quality Parameter	Stressor	Stressor Rating	Justification
Nutrient Enrichment - Phosphorus	Internal (sediment) Phosphorus Loading	Primary	• Hypolimnetic P concentrations are high throughout the year. • Summer P increases from Spring turnover to Fall turnover with peak concentrations over 500 µg/L. • Fall P concentrations remain high near the bottom and mid-depth suggesting that summer released P is available to drive algae blooms. • Winter P concentrations were typically over 150 µg/L suggesting internal release remains high in the winter or precipitation of summer released P is low.
	Nutrient gradient favoring buoyancy regulators	Primary	• Low epilimnetic P concentrations with high metalimnetic P concentration favors cyanobacteria that can regulate buoyancy to access P in the metalimnion
	Watershed Phosphorus Loading	Secondary	• Surface TP remains relatively low through the summer growing season with lowest concentrations during the growing season. • A more detailed assessment of external loading requires a one or two dimensional daily/weekly time step model.
Nutrient Enrichment or Limitation - Nitrogen	Nitrogen limitation favoring N fixing cyanobacteria	Secondary	• Late summer nitrate/nitrite depletion coincides with a shift in cyanobacteria community suggesting N fixation • Total N increases after midsummer nitrate/nitrite depletion suggesting N fixation • The role of nitrogen release from the sediments is inconclusive as no hypolimnetic N data are available. Long anoxic periods favor denitrification but may limit nitrification leading to high ammonia concentrations.

Water Quality Parameter	Stressor	Stressor Rating	Justification
	Nitrogen enrichment (watershed or sediment N release)	Inconclusive	• Total Nitrogen fairly typical for lakes in the North Central Hardwood Forest Ecoregion (50th percentile of 1,039 μg/L) • No data are available to assess potential impacts from sediment N release
Temperature	Strength and duration of stratification	Primary	• Stratification typically begins in early May and holds well into late Fall with the metalimnion beginning as shallow as 2.5 meters • Epilimnetic and hypolimnetic temperature gradients are strong often exceeding a 10 degrees C difference in temperature
	Sediment anoxia driving sediment P release	Primary	• Low DO (<2 mg/L) exist over large areas of the lake (as high as 30%) with low DO as shallow as 4 meters in the lake • No sediment data exist to evaluate primary sediment P release drivers, but literature and high hypolimnetic P concentrations suggest high redox sensitive P likely exist in the sediments
Light	Increased light during winter months favoring low light cyanobacteria	Secondary	• Nutrient rich conditions during low light winter (ice and snow cover) conditions may favor cyanobacteria adapted to low light conditions • Plowing activities on the lake may increase light favoring cyanobacteria already growing or adapted to cold water temperatures

Table 7 Cyanobacteria stressor summary for Lake Nokomis.

Water Quality Parameter	Stressor	Stressor Rating	Justification
Nutrient Enrichment - Phosphorus	Internal (sediment) Phosphorus Loading	Primary	• Hypolimnetic P concentrations are variable from year to year with high concentrations in the past five years (400 to 600 µg/L). • Summer P increases from midsummer into Fall turnover. • Winter P concentrations were typically low but high enough to support cyanobacteria (approximately 30 µg/L TP) • A large carp population in Lake Nokomis may be contributing the internal loading
	Nutrient gradient favoring buoyancy regulators	Primary	• The shallowness of Lake Nokomis and high bottom P concentrations supports cyanobacteria with buoyancy control to reach P laden bottom water.
	Watershed Phosphorus Loading	Secondary	• Surface TP remains relatively low through the summer growing season with lowest concentrations during the growing season. • More recent years demonstrate a greater spread in the data suggesting increased P loading, most likely from sediments. • A more detailed assessment of external loading requires a one or two dimensional daily/weekly time step model.
Nutrient Enrichment or Limitation - Nitrogen	Nitrogen limitation favoring N fixing cyanobacteria	Secondary	• Late summer nitrate/nitrite depletion and low N:P molar ratios coincide with a shift in cyanobacteria community suggesting N fixation • Total N increases after midsummer nitrate/nitrite depletion suggesting N fixation • The role of nitrogen release from the sediments is inconclusive as no hypolimnetic N data are available. Long anoxic periods favor denitrification but may limit nitrification leading to high ammonia concentrations.

Water Quality Parameter	Stressor	Stressor Rating	Justification
	Nitrogen enrichment (watershed or sediment N release)	Inconclusive	• Total Nitrogen fairly typical for lakes in the North Central Hardwood Forest Ecoregion (50th percentile of 1,039 µg/L) • No data are available to assess potential impacts from sediment N release
Temperature	Strength and duration of stratification	Primary	• Lake Nokomis is weakly stratified with thermocline deepening typically occurring in August rather than later in the summer. • Much of the lake is polymictic allowing for easy mixing bottom P into the water column. • The shallowness of Lake Nokomis combined with high anoxia/interna P loading favors cyanobacteria adapted to low light and buoyancy control.
	Sediment anoxia driving sediment P release	Primary	• Low DO (<2 mg/L) exist over large areas of the lake (as high as 60%) with low DO as shallow as 4 meters in the lake • No sediment data exist to evaluate primary sediment P release drivers, but literature and high hypolimnetic P concentrations suggest high redox sensitive P likely exist in the sediments
Light	Increased light during winter months favoring low light cyanobacteria	Secondary	• Low but sufficient nutrients during low light winter (ice and snow cover) conditions may favor cyanobacteria adapted to low light conditions • Plowing activities on the lake may increase light favoring cyanobacteria already growing or adapted to cold water temperatures

6.2 Data and Knowledge Gaps

While there is strong evidence that high phosphorus concentrations because of sediment P release (internal loading) are driving cyanobacteria blooms in both lakes, there are a number of data and knowledge gaps that limits our understanding of cyanobacteria production and CyanoHABS in Cedar Lake and Lake Nokomis. These gaps include:

1. Limited understanding of the size of the blooms for cyanobacteria. While chlorophyll-a data are available for the lakes, these data can be poor indicators for cyanobacteria because cyanobacteria use multiple pigments for photosynthesis. Cell counts or the addition of phycocyanin concentrations would improve our understanding of the blooms.

2. Phytoplankton and toxin samples were only collected at the surface, so there is limited understanding on the impact of buoyancy regulators or benthic cyanobacteria species on toxin production.

3. Limited data and understand of hypolimnetic nitrogen. High phosphorus concentrations in the hypolimnion clearly drive cyanobacteria blooms, however the role of nitrogen is unclear. Nitrate is expected to be low due to denitrification under anoxic conditions, however no data are available to evaluate nitrogen in the hypolimnion.

4. Light availability can impact cyanobacteria production, however light conditions under the ice are poorly understood.

5. There is limited water quality monitoring (usually just one sampling event) during the middle of the winter to adequately quantify internal phosphorus load.

6. The role of carp in internal loading is not well established in Lake Nokomis. While a common carp management plan was completed for Lake Nokomis in 2019 and found that carp biomass density was nearly 3 times the ecological tipping point of 100 kg/ha, the extent carp contribute to internal phosphorus loading compared to anoxic causes is still unclear. However, since carp can also negatively impact lake clarity (turbidity), plant growth, and effect the longevity of an alum treatment, additional studies and considerations for carp management should be considered.

7. There is limited understanding on the role of Brownie Lake impacts on Cedar lake. Brownie Lake is upstream of Cedar Lake and may be discharging high P water into Cedar Lake. This will be further evaluated in Phase 2 of this project.

6.3 Monitoring Recommendations

Following the review of the data, several data gaps were identified that could be filled during future monitoring efforts. Following is a number of general recommendations to help improve our understanding of the potential cyanobacteria drivers. More specific details on the monitoring approach (SOPs, frequencies, depth, etc.) should be developed based on funding, staff availability and other considerations.

6.3.1 Phytoplankton Monitoring

Previous phytoplankton monitoring included relative abundance and chlorophyll-a monitoring. We understand that the MPRB recently purchased a phycocyanin probe to better characterize phytoplankton communities. Some recommendations for monitoring the phytoplankton community using the probe along with water samples include:

1. A Standard Operating Procedure should be developed for the sampling including field protocols such as:
    - i. Sample depth and composting to ensure that cyanobacteria are well represented
    - ii. Scum sampling procedures to identify toxins, cyanobacteria species of concern, and phycocyanin/chlorophyll-a concentrations
2. Collecting phycocyanin profiles on a routine basis.
    - a. Routine phycocyanin concentration profiles will help determine vertical heterogeneity in the cyanobacteria population and determine sample collection protocols. Further, over time, phycocyanin thresholds can be developed as an early warning mechanism for CyanoHABs.
    - b. Relating the probe-measured phycocyanin concentrations to laboratory derived cell counts may allow for estimates of bloom severity by developing a regression. Any time a phytoplankton sample is collected, a phycocyanin and temperature profile should be conducted.
3. Cell concentrations or biomass. Current monitoring uses relative abundance index to evaluate the phytoplankton community since cell counts can be prohibitively expensive to do on a regular basis. However, MPRB's current contractor archives the slides used to determine relative abundance, so cell counts can be completed ad-hoc. One approach is to continue to collect relative abundance and do cell concentrations post hoc based on:
    - a. Known blooms or high cyanobacteria concentrations based on water clarity, scums, high phycocyanin concentrations, or toxin monitoring. The phycocyanin probe can be

used to determine bloom severity and heterogeneity. Collecting phytoplankton samples should occur every time a scum forming event occurs or an event is sampled for toxins. Samples should be collected at the scum or toxin testing site. Cell counts could be conducted post hoc based on toxin or phycocyanin results.

b. Selecting key samples throughout the season including winter, spring, late summer and fall. This will help characterize seasonal dynamics. Representative samples should be counted for each season.

6.3.2 Nutrient and Other Parameter Monitoring

Additional nutrient monitoring could help to better define nutrient dynamics in the lakes. While phosphorus is well described, nitrogen cycling in the lakes is poorly understood. Following are some recommendations to consider for improving our understanding of nutrient cycles in the lakes.

1. Additional hypolimnetic monitoring would help better describe nutrient cycling the lakes. Sampling should occur every time the deep areas of the lake are sampled either biweekly or, at a minimum, monthly. Parameters to be sample include (in priority order):

    a. Total iron
    b. Total nitrogen
    c. Nitrate+nitrite
    d. Ammonia

    These samples could be done on a profile to better describe nutrient gradients that may contribute to severe cyanobacteria blooms or cyanobacteria dominance.

2. Total suspended solids in Lake Nokomis every time surface samples, specifically chlorophyll-a, are collected. With a large carp population, determining the cause of turbidity can better describe water quality drivers.

3. Chloride profiles to determine if salinity gradients may be affecting lake mixing or sediment P release. These should be collected more frequently during spring turnover (weekly) to determine lake mixing.

7 References

1. **Bautista, M.F. and Paerl, H.W.** *Diel N2 fixation in an intertidal marine cyanobacterial mat community.* s.l. : Marine Chemistry, 1985. 16, 369-377.

2. **Wisconsin Department of Natural Resources.** *Wisconsin Department of Natural Resources - Aquatic Invasive Species Literature Review.* s.l. : dnr.wi.gov/topic/Invasives/documents/classification/Cylindrospermopsis%20raciborskii.pdf, 2022.

3. **MacKeigan, Paul.** Quantifying microcystin concentrations, their composition and drivers across over 400 north-temperate and boreal Canadian lakes. Toledo, OH : International Conference on Toxic Cyanobacteria, May 2022.

4. *Cyanobacterial blooms: statistical models describing risk factors for national-scale lake assessment and lake management.* **Carvalho, Laurence, et al.** 24, s.l. : Science of the Total Environment, 2011, Vol. 409. 5353-5358.

5. *Mitigating the Expansion of Harmful Algal Blooms Across the Freshwater-to-Marine Continuum.* **Paerl, Hans, Otten, Timothy and Kudela, Raphael.** s.l. : Environmental Science & Technology, 2018, Vol. 52.

6. **Scott, Thad.** Biogeochemical constraints on ecosystem stoichiometry and its influence on cyanotoxin hazards. Toledo, OH : International Conference on Toxic Cyanobacteria, May 2022.

7. **Reynolds, C.S.** *The Ecology of Phytoplankton.* s.l. : Cambridge University Press, 2007.

8. *Florida's Harmful Algal Bloom (HAB) Problem: Escalating Risks to Human, Environmental, and Economic Health with Climate Change.* **Heil, Cynthia and Muni-Morgan, Lorraine.** s.l. : Frontiers in Ecology and Evolution, 2021, Vol. 9.

9. **Natwora, Kaela.** The physiological and transcriptional responses of harmful algal blooms in nitrogen limited lakes. Toledo, OH : International Conference on Toxic Cyanobacteria , May 2022.

10. *Roles of Nutrient Limitation on Western Lake Erie CyanoHAB Toxin Production.* **Barnard, Malcolm and et al.** 47, s.l. : Toxins, 2021, Vol. 13.

11. *Cyanobacterial Dominance in Lakes.* **Dokulil, M.T. and Teubner, K.** s.l. : Hydrobiologia, 2000, Vol. 438.

12. *Harmful algal blooms and their eco-environmental indication.* **Sha, Jun, et al.** s.l. : Chemosphere, 2021, Vol. 274.

13. *Vertical heterogeneities of cyanobacteria and microcystin concentrations in lakes using a seasonal in situ monitoring station.* **Wilkinson, A, Hondzo, M and Guala, M.** s.l. : Global Ecology and Conservation, 2020, Vol. 21.

14. *Comparative effects of the quality and quantity of light and temperature on the growth of Planktothrix agardhii and P. rubescens.* **Oberhaus, L, et al.** 6, s.l. : Journal of Phycology, 2007, Vol. 43.

15. *Cyanobacteria biomass in shallow eutrophic lakes is linked to the presence of iron-binding ligands.* **Du, Xue, et al.** s.l. : Can. J. Fish. Aquat. Sci., 2018, Vol. 76.

16. *Evaluation of indicators for cyanobacterial risk in 108 temperate lakes using 23 years of environmental monitoring data.* **Li, J., Persson, K.M. and Pekar, H.** 54, s.l. : Environ Sci Eur , 2021, Vol. 33.

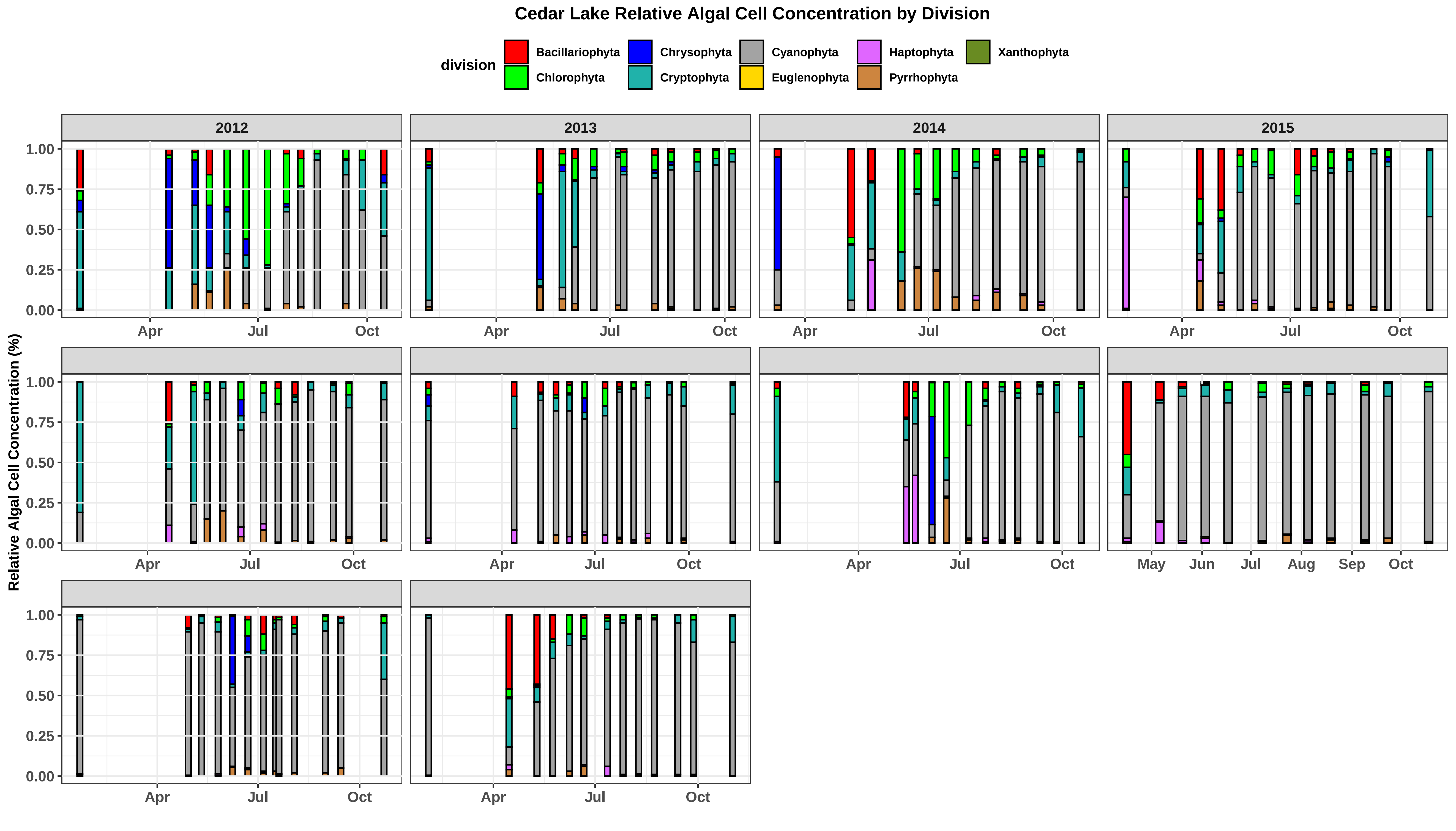
17. *Response of pelagic cyanobacteria to iron additions—enclosure experiments from Lake Erken.* **Hyenstrand, Per, Rydin, Emil and Gunnerhed, Malin.** 6, s.l. : Journal of Plankton Research, 2000, Vol. 22. 1113-1126.

18. *Nuisance phytoplankton blooms in coastal, estuarine, and inland waters* . **Paerl, Hans.** 4, s.l. : Limnology and Oceanography, 1988, Vol. 33.

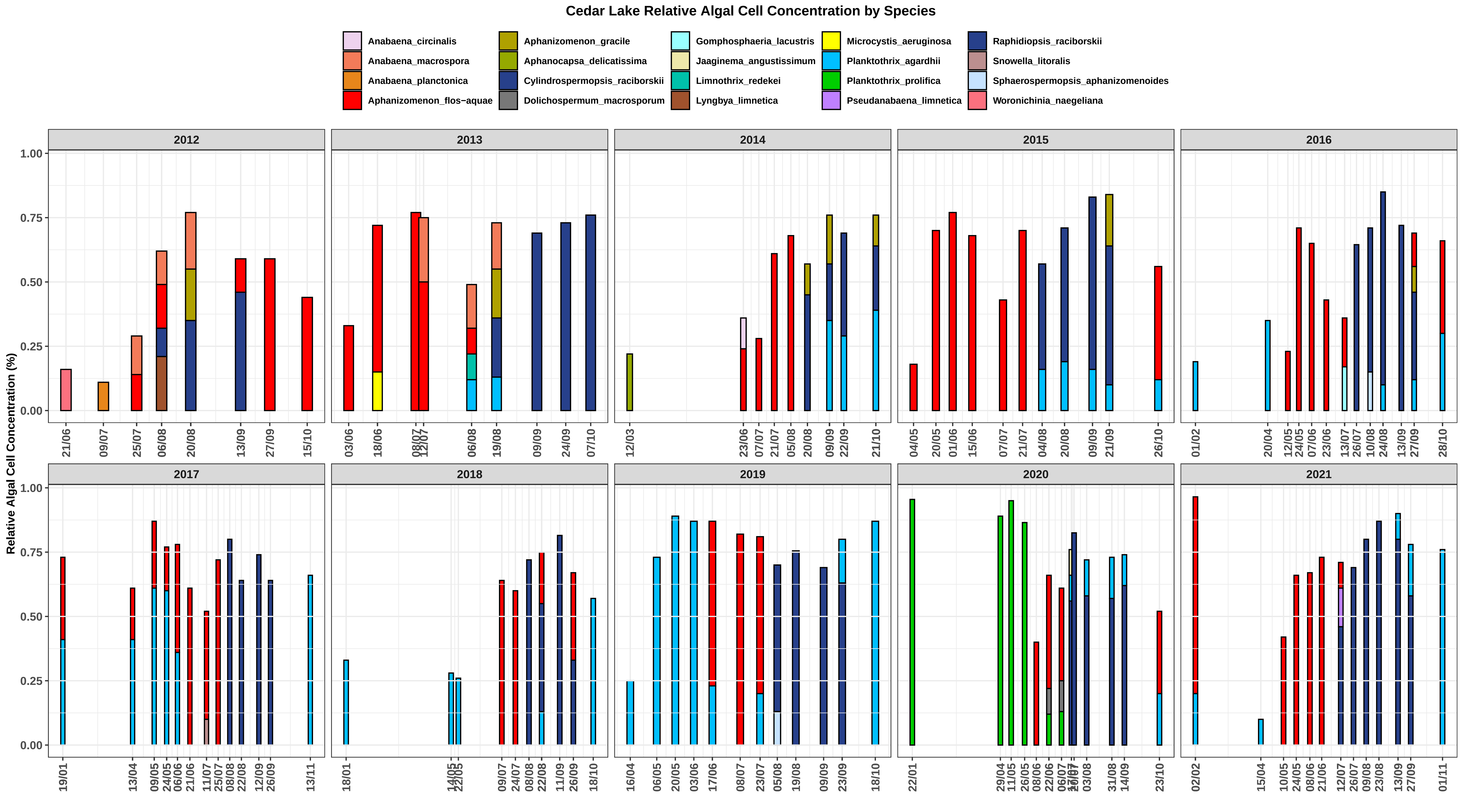
19. **WSB.** *2019 Invasive Common Carp Integrated Pest Management Plan (IPM) for the Lake Nokomis Subwatershed.* 2019. R-01165-900..

Attachment 1

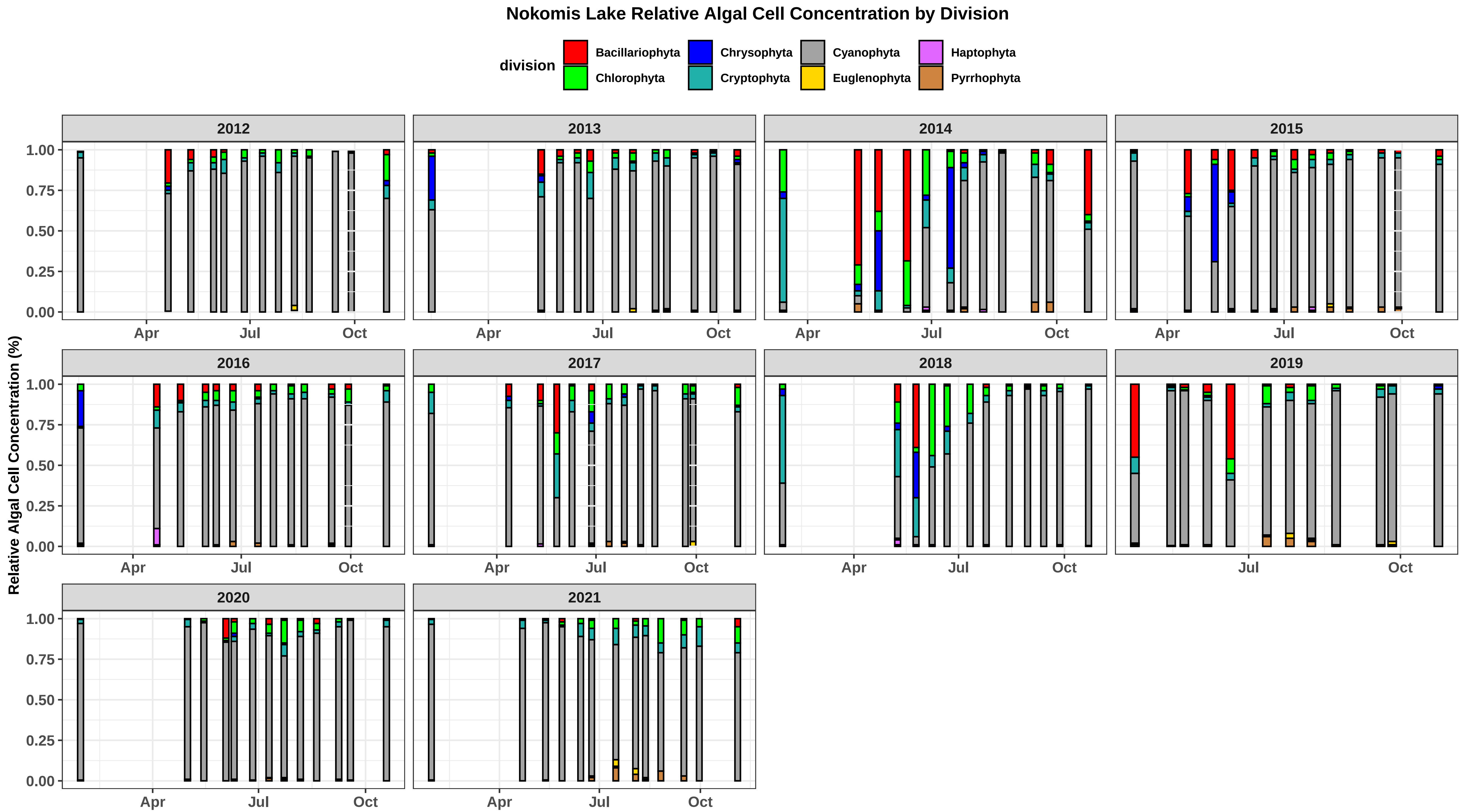
Annual Phytoplankton Community Structure

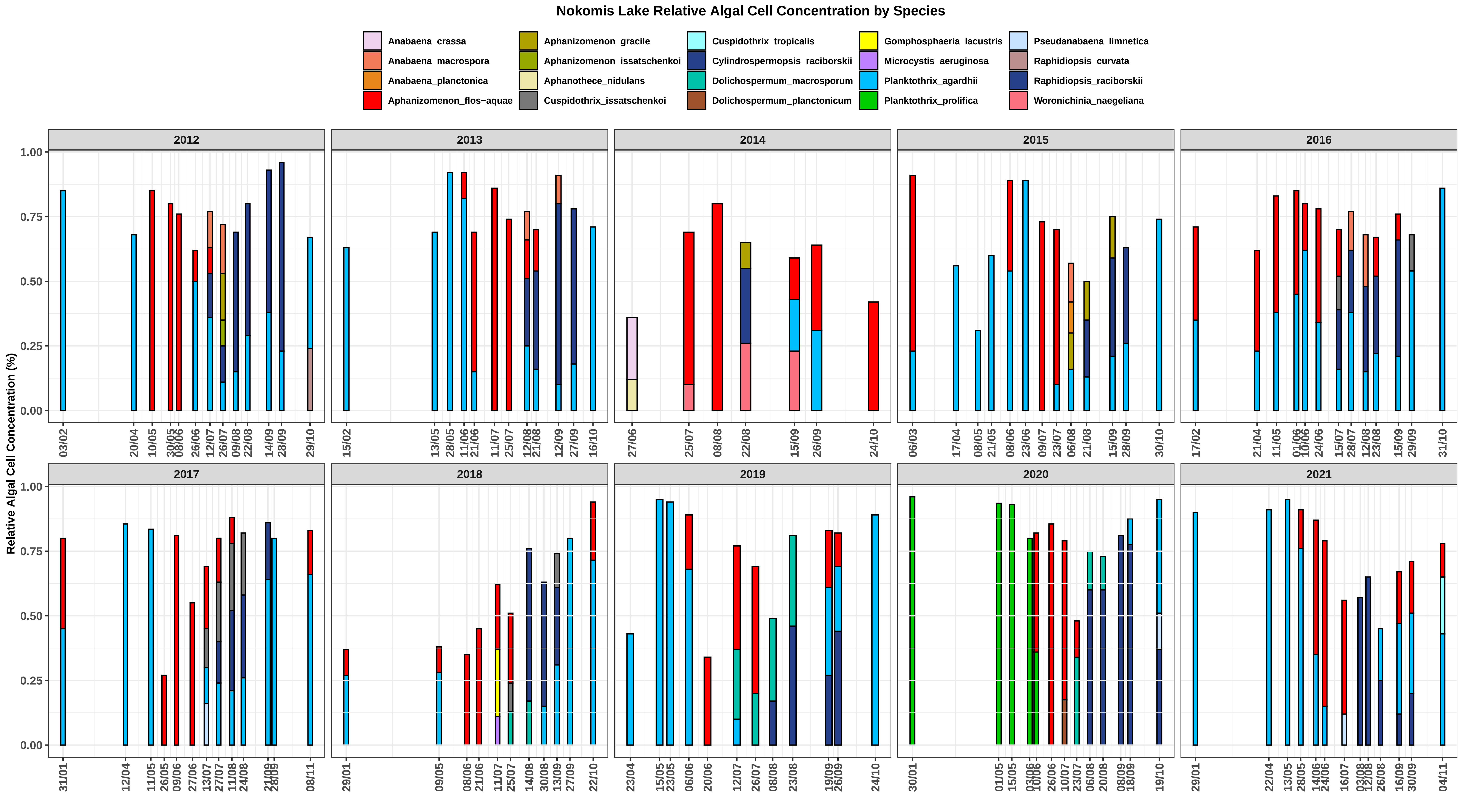


Cedar Lake Relative Algal Cell Concentration by Division
division
Bacillariophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta
Euglenophyta
Haptophyta
Pyrrhophyta
Xanthophyta
2012
2013
2014
2015
Relative Algal Cell Concentration (%)
1.00
0.75
0.50
0.25
0.00
Apr
Jul
Oct
May
Jun
Aug
Sep



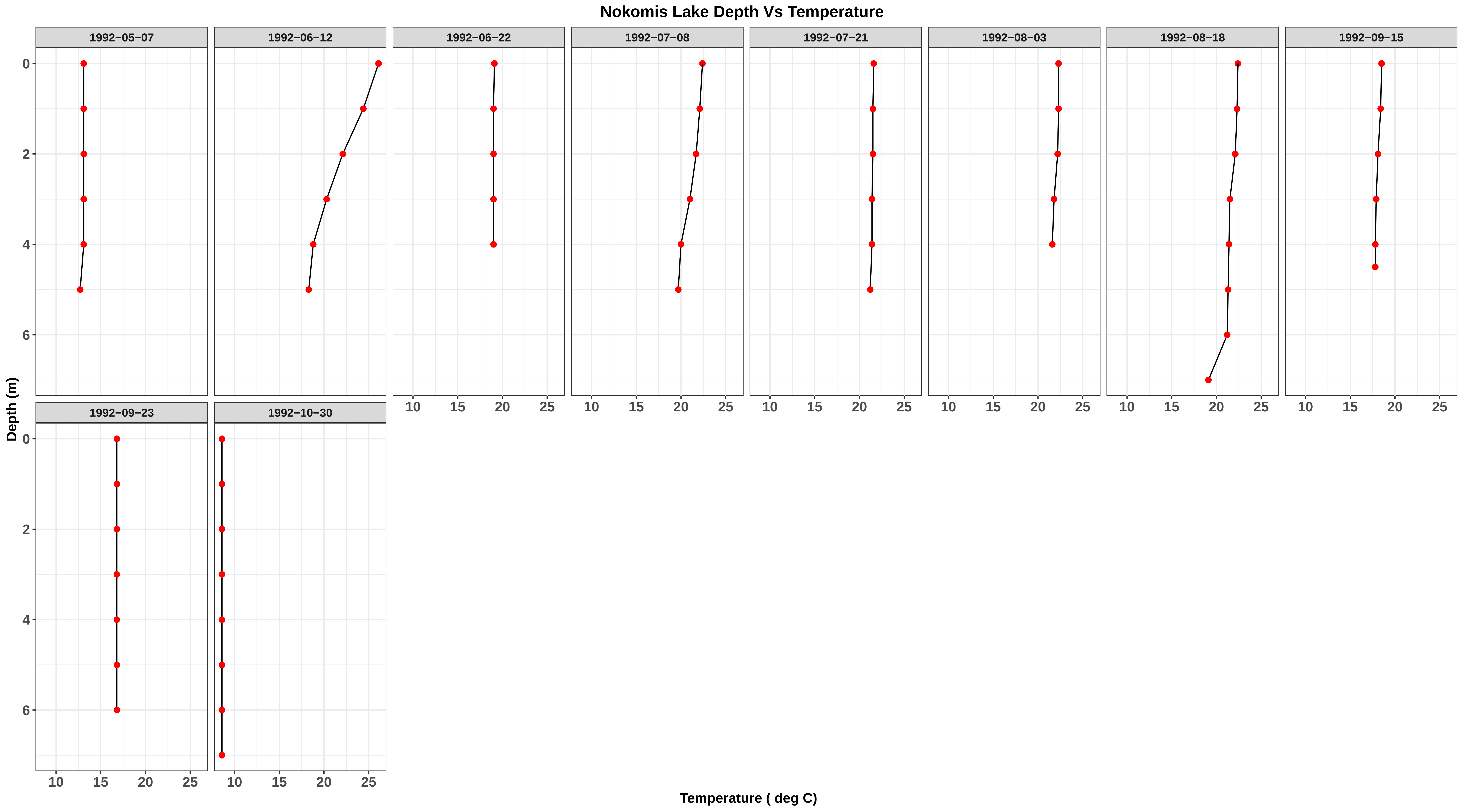
Cedar Lake Relative Algal Cell Concentration by Species
Anabaena_circinalis
Anabaena_macrospora
Anabaena_planctonica
Aphanizomenon_flos−aquae
Aphanizomenon_gracile
Aphanocapsa_delicatissima
Cylindrospermopsis_raciborskii
Dolichospermum_macrosporum
Gomphosphaeria_lacustris
Jaaginema_angustissimum
Limnothrix_redekei
Lyngbya_limnetica
Microcystis_aeruginosa
Planktothrix_agardhii
Planktothrix_prolifica
Pseudanabaena_limnetica
Raphidiopsis_raciborskii
Snowella_litoralis
Sphaerospermopsis_aphanizomenoides
Woronichinia_naegeliana
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Relative Algal Cell Concentration (%)
0.00
0.25
0.50
0.75
1.00


Nokomis Lake Relative Algal Cell Concentration by Division
division
Bacillariophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta
Euglenophyta
Haptophyta
Pyrrhophyta
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Relative Algal Cell Concentration (%)
0.00
0.25
0.50
0.75
1.00
Apr
Jul
Oct

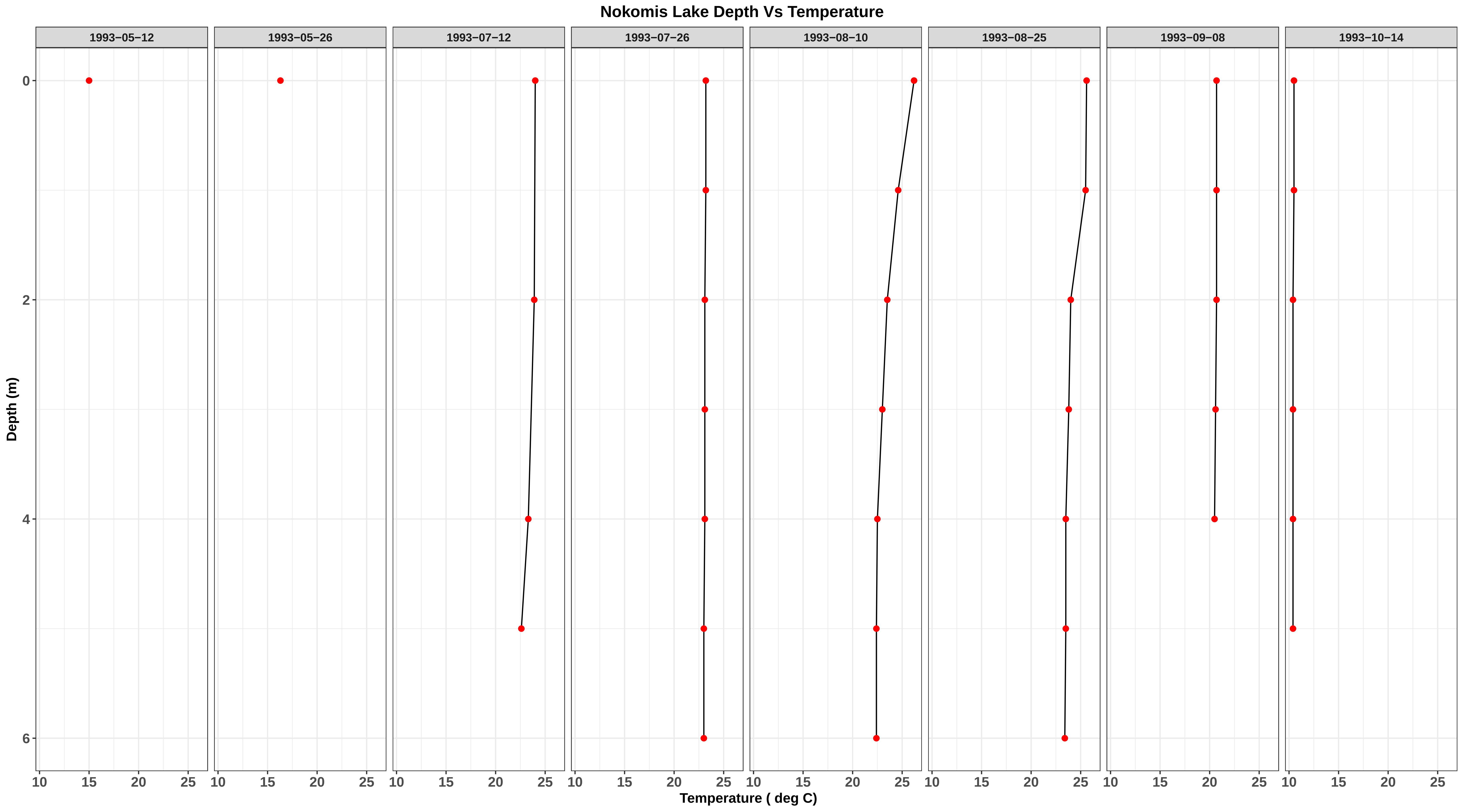

Nokomis Lake Relative Algal Cell Concentration by Species
Anabaena_crassa
Anabaena_macrospora
Anabaena_planctonica
Aphanizomenon_flos−aquae
Aphanizomenon_gracile
Aphanizomenon_issatschenkoi
Aphanothece_nidulans
Cuspidothrix_issatschenkoi
Cuspidothrix_tropicalis
Cylindrospermopsis_raciborskii
Dolichospermum_macrosporum
Dolichospermum_planctonicum
Gomphosphaeria_lacustris
Microcystis_aeruginosa
Planktothrix_agardhii
Planktothrix_prolifica
Pseudanabaena_limnetica
Raphidiopsis_curvata
Raphidiopsis_raciborskii
Woronichinia_naegeliana
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Relative Algal Cell Concentration (%)

Attachment 2

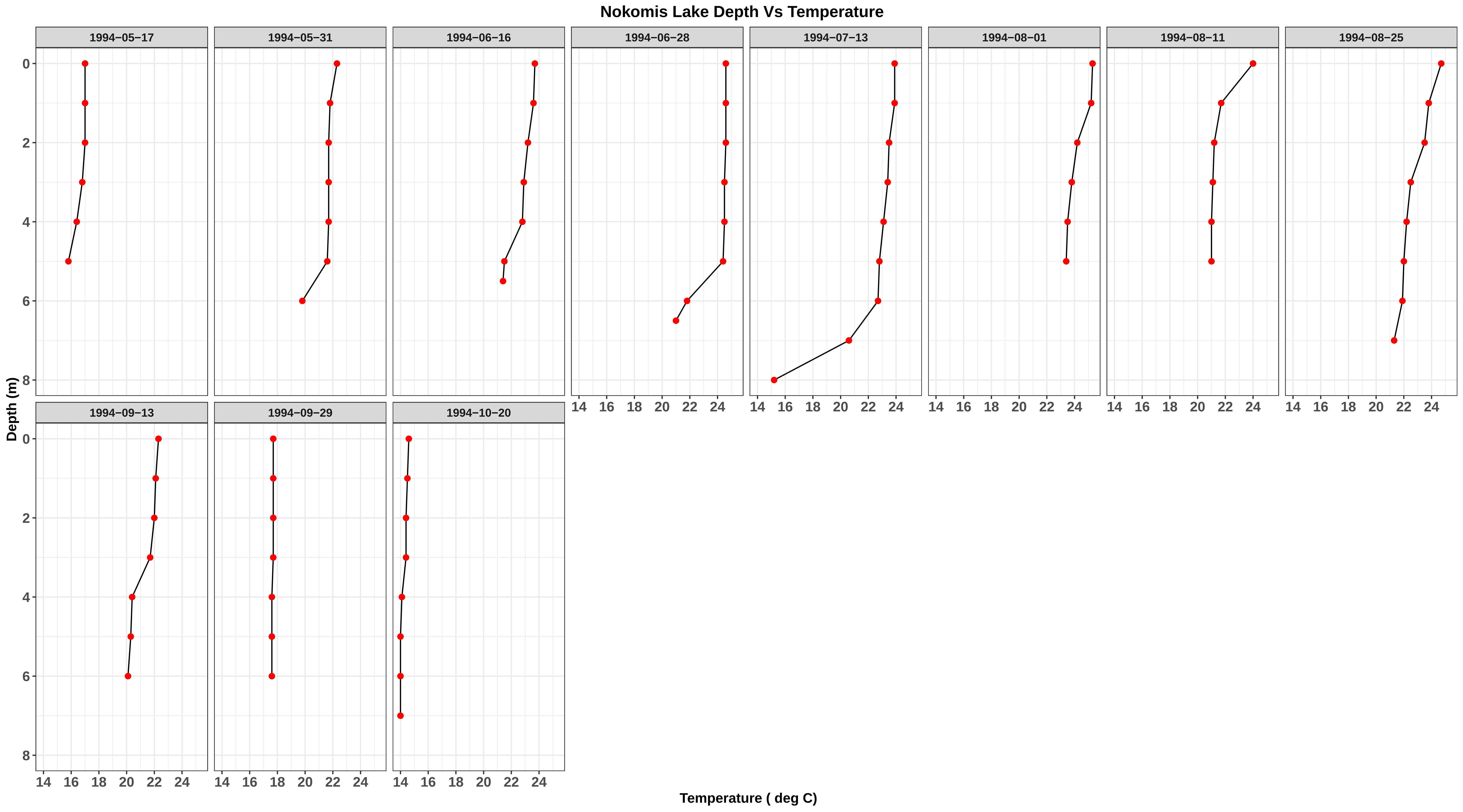
Temperature and Dissolved Oxygen Profiles



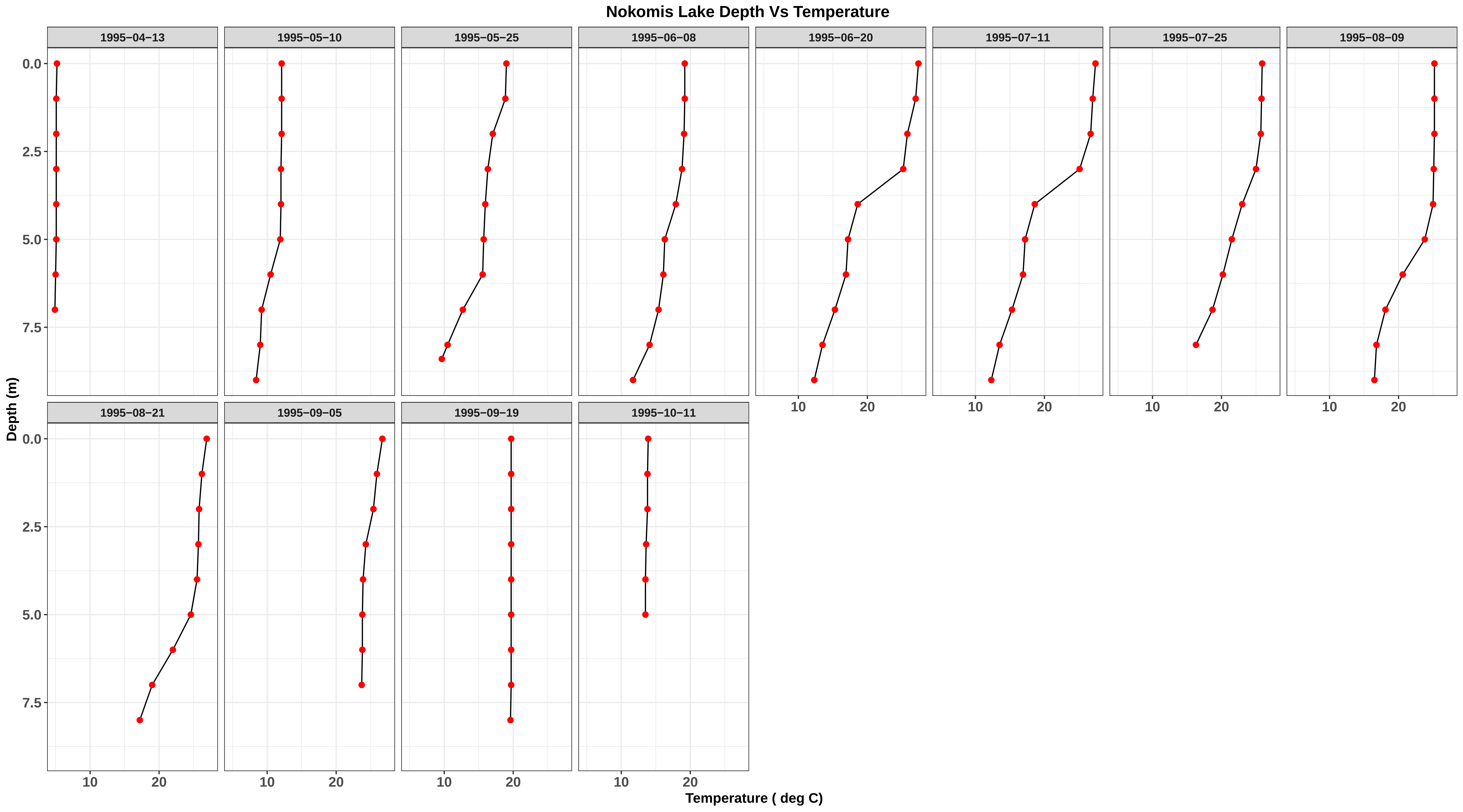
Nokomis Lake Depth Vs Temperature
1992−05−07
1992−06−12
1992−06−22
1992−07−08
1992−07−21
1992−08−03
1992−08−18
1992−09−15
1992−09−23
1992−10−30
Depth (m)
0
2
4
6
10
15
20
25
Temperature (deg C)



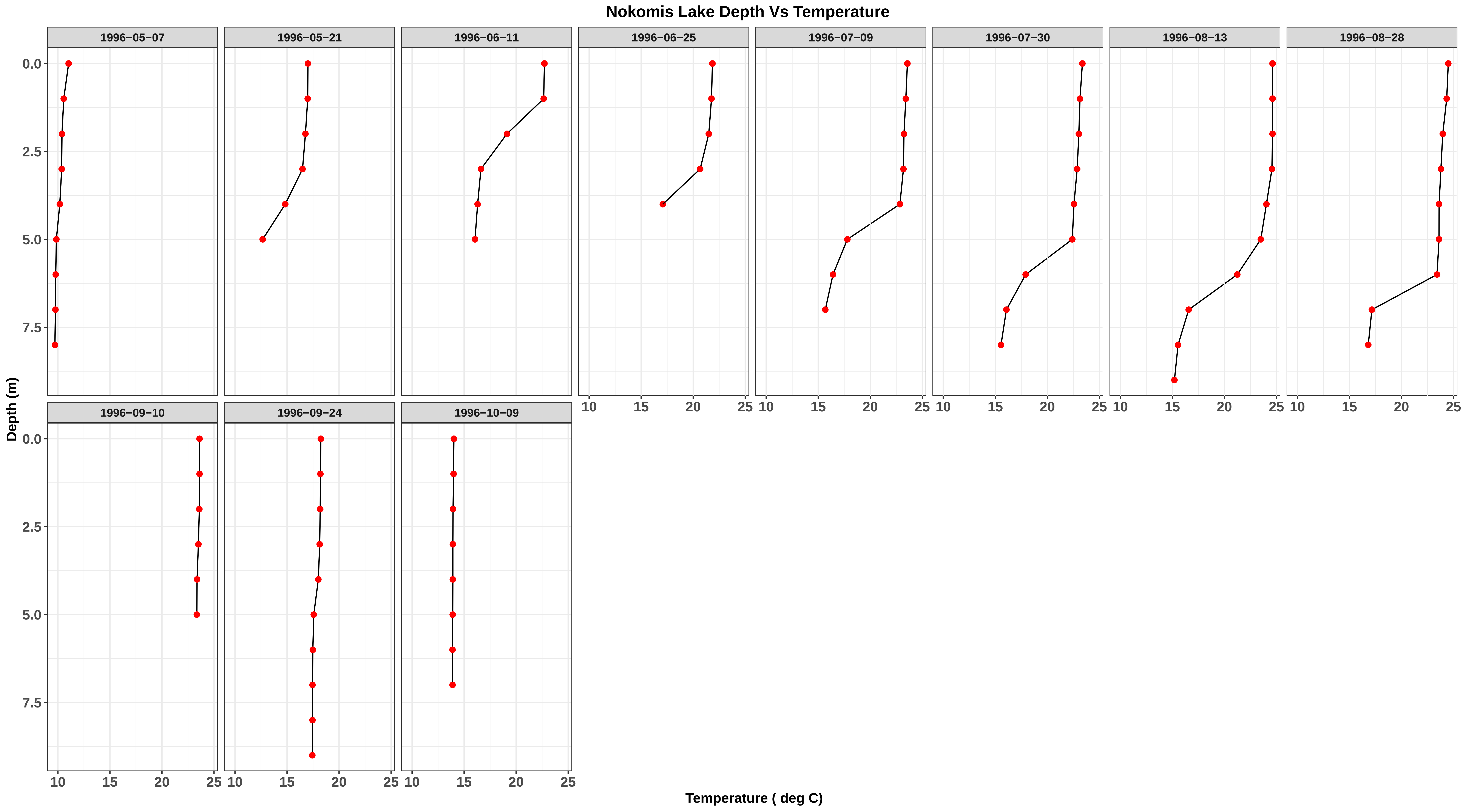
Nokomis Lake Depth Vs Temperature
1993−05−12
1993−05−26
1993−07−12
1993−07−26
1993−08−10
1993−08−25
1993−09−08
1993−10−14
Depth (m)
0
2
4
6
10
15
20
25
Temperature (deg C)



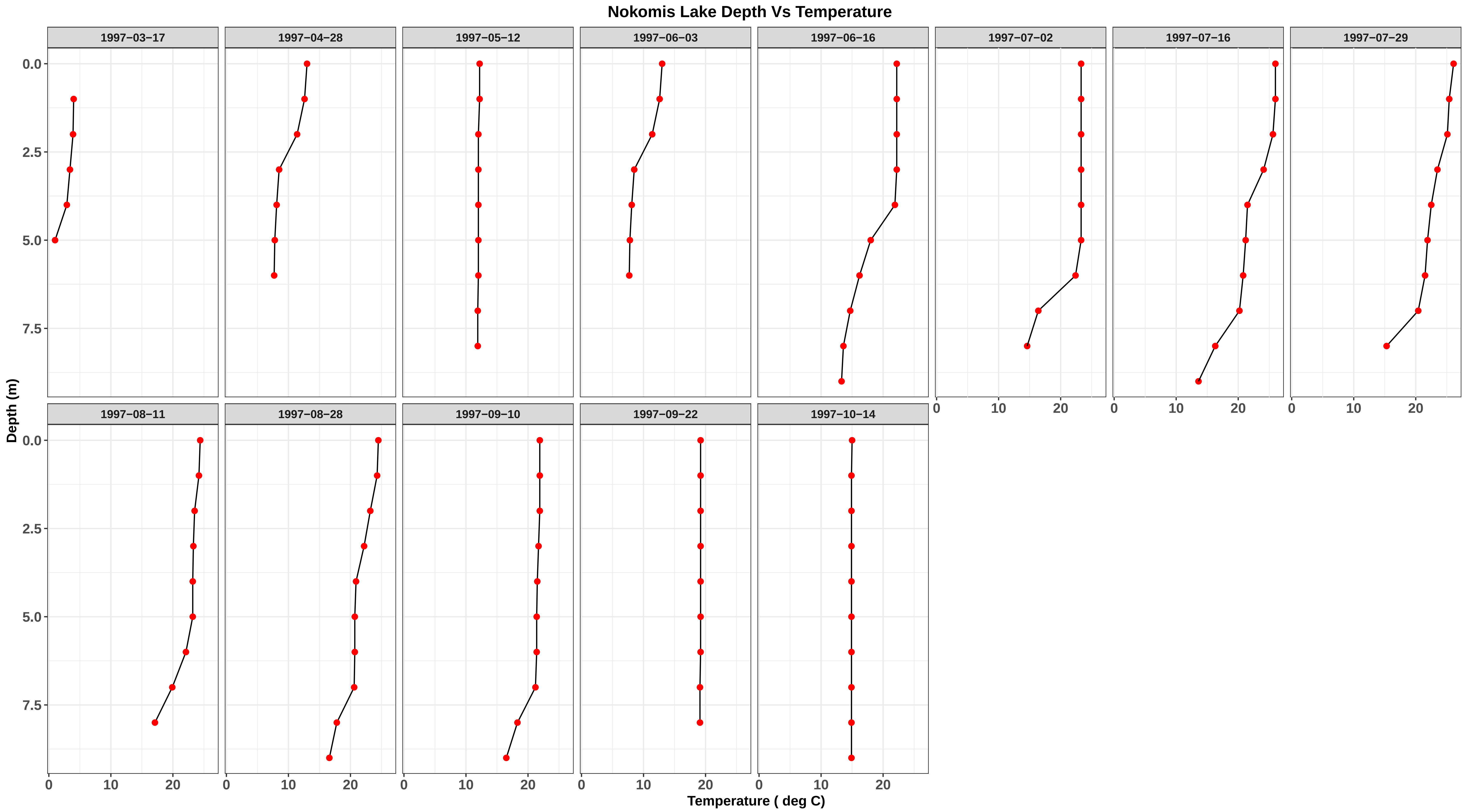
Nokomis Lake Depth Vs Temperature
1994−05−17
1994−05−31
1994−06−16
1994−06−28
1994−07−13
1994−08−01
1994−08−11
1994−08−25
1994−09−13
1994−09−29
1994−10−20
Depth (m)
0
2
4
6
8
14
16
18
20
22
24
Temperature (deg C)



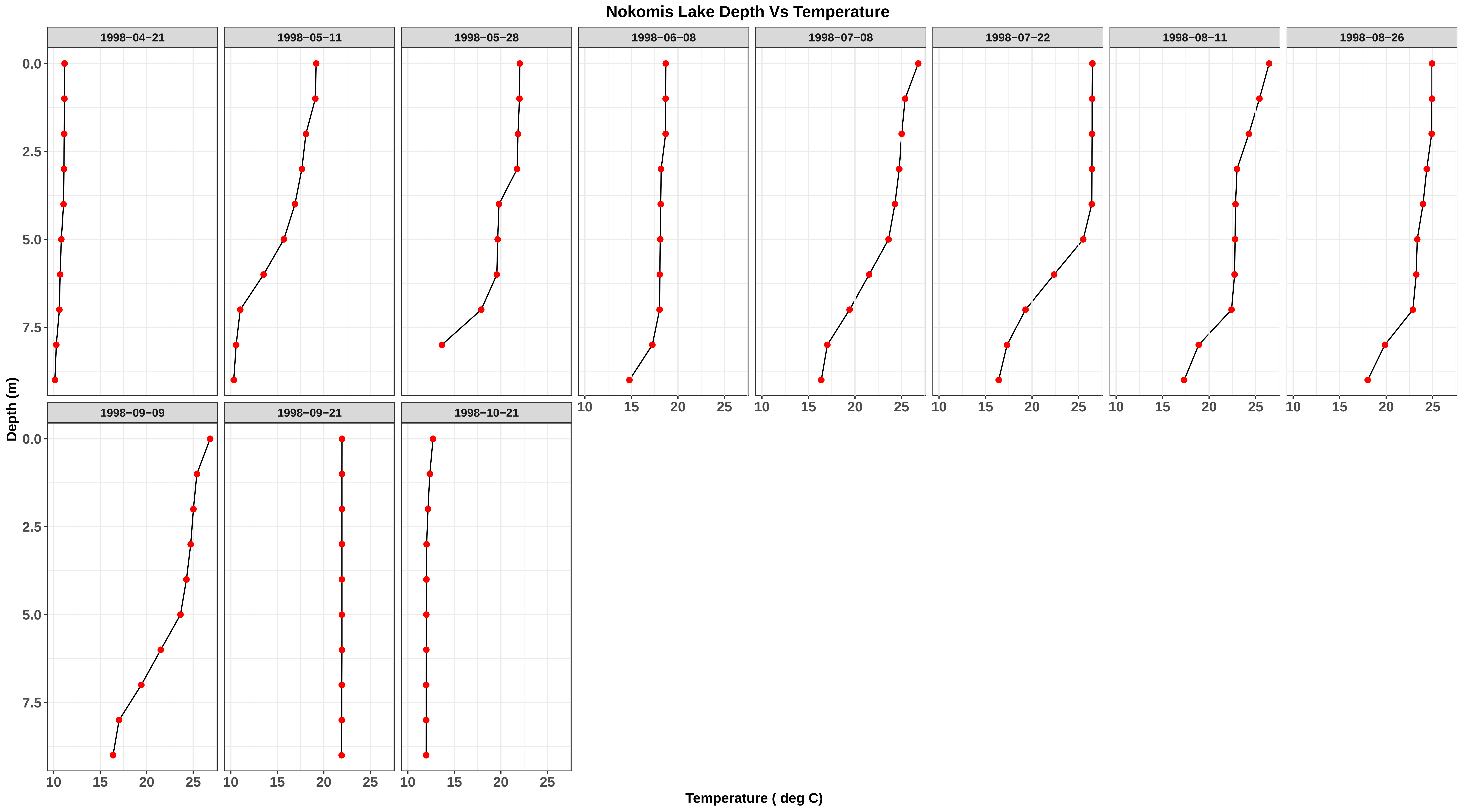
Nokomis Lake Depth Vs Temperature
1995−04−13
1995−05−10
1995−05−25
1995−06−08
1995−06−20
1995−07−11
1995−07−25
1995−08−09
1995−08−21
1995−09−05
1995−09−19
1995−10−11
Depth (m)
0.0
2.5
5.0
7.5
10
20
Temperature (deg C)



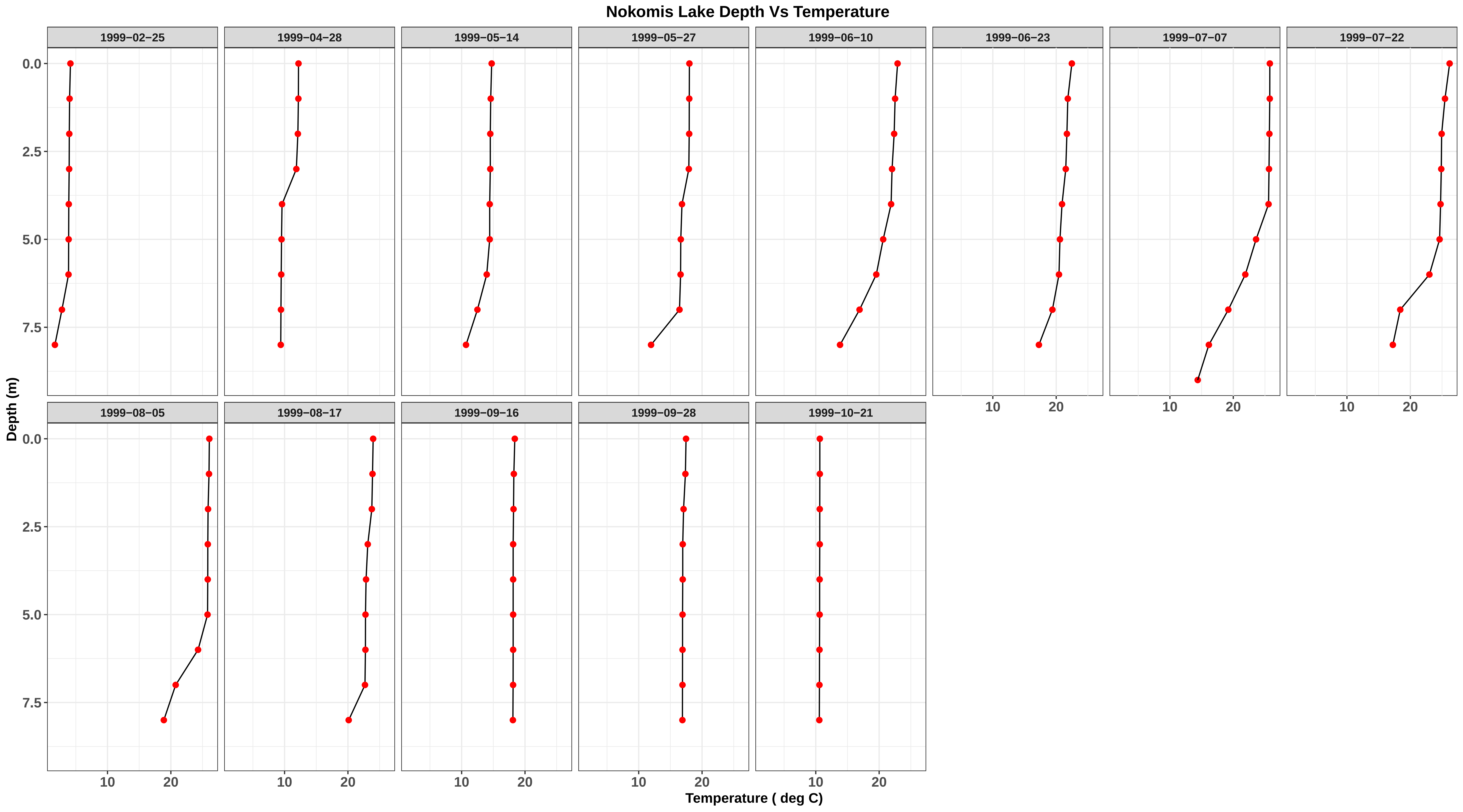
Nokomis Lake Depth Vs Temperature
1996−05−07
1996−05−21
1996−06−11
1996−06−25
1996−07−09
1996−07−30
1996−08−13
1996−08−28
1996−09−10
1996−09−24
1996−10−09
Depth (m)
0.0
2.5
5.0
7.5
10
15
20
25
Temperature (deg C)

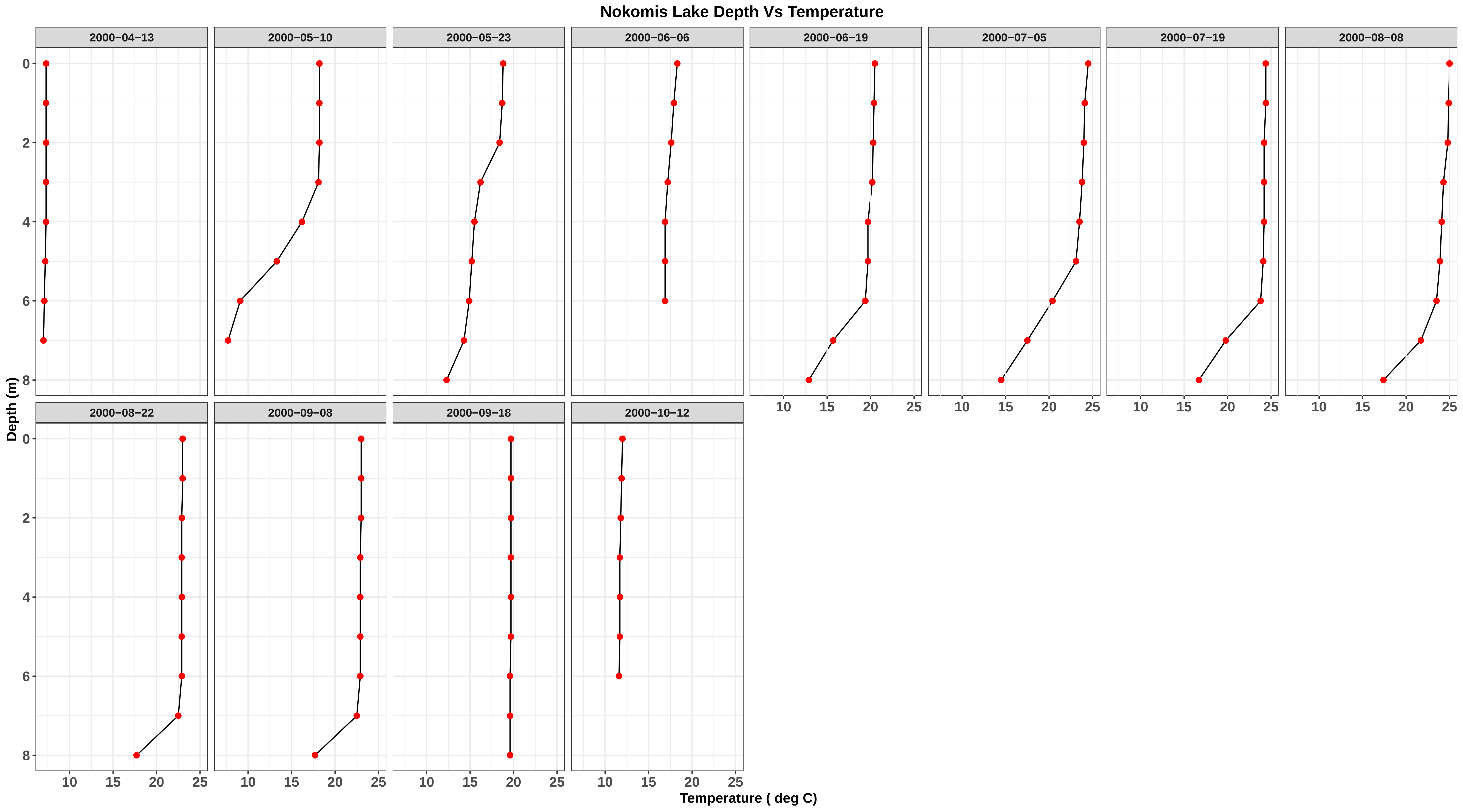


Nokomis Lake Depth Vs Temperature
1997−03−17
1997−04−28
1997−05−12
1997−06−03
1997−06−16
1997−07−02
1997−07−16
1997−07−29
1997−08−11
1997−08−28
1997−09−10
1997−09−22
1997−10−14
Depth (m)
0.0
2.5
5.0
7.5
0
10
20
Temperature (deg C)

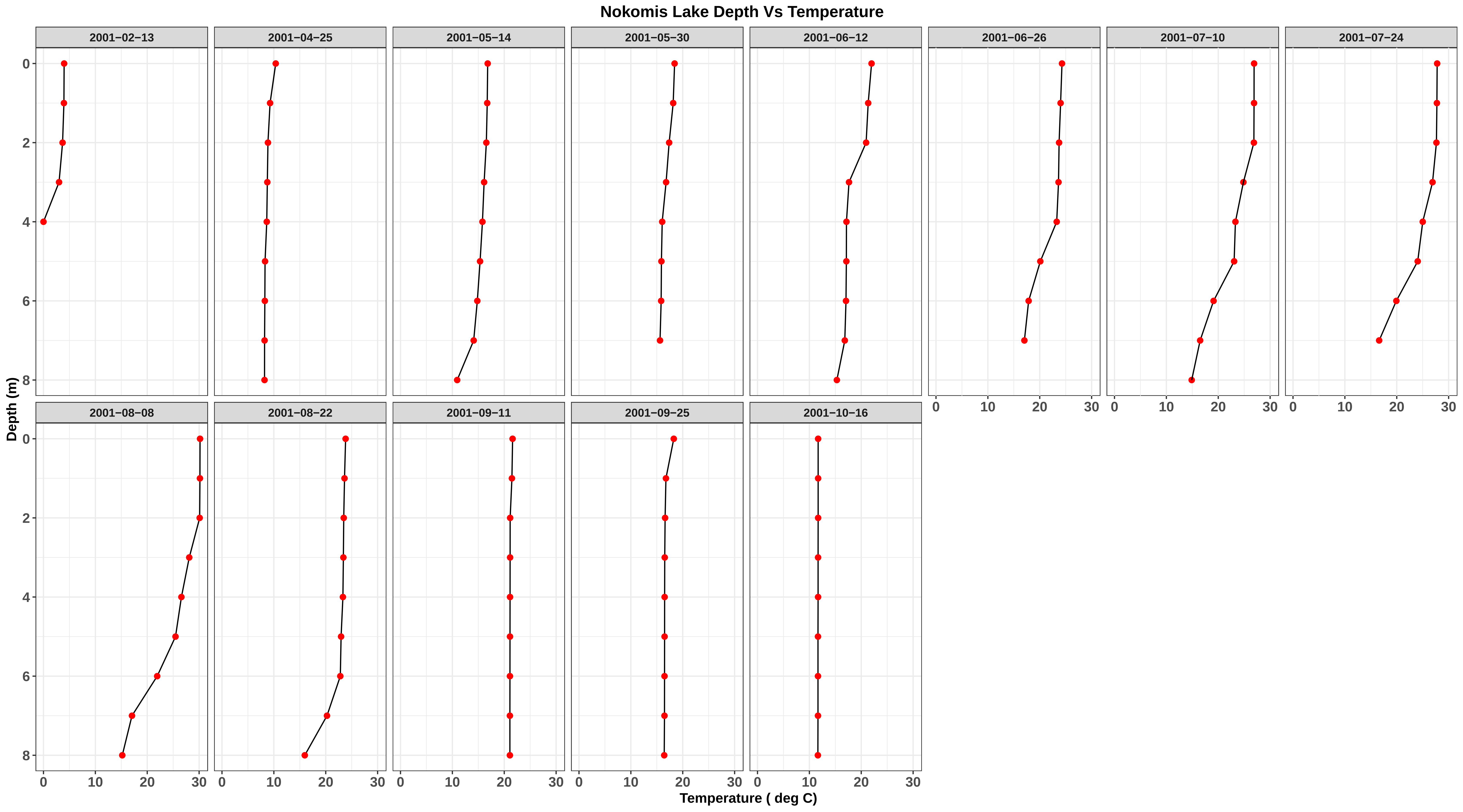


Nokomis Lake Depth Vs Temperature
1998−04−21
1998−05−11
1998−05−28
1998−06−08
1998−07−08
1998−07−22
1998−08−11
1998−08−26
1998−09−09
1998−09−21
1998−10−21
Depth (m)
0.0
2.5
5.0
7.5
10
15
20
25
Temperature (deg C)

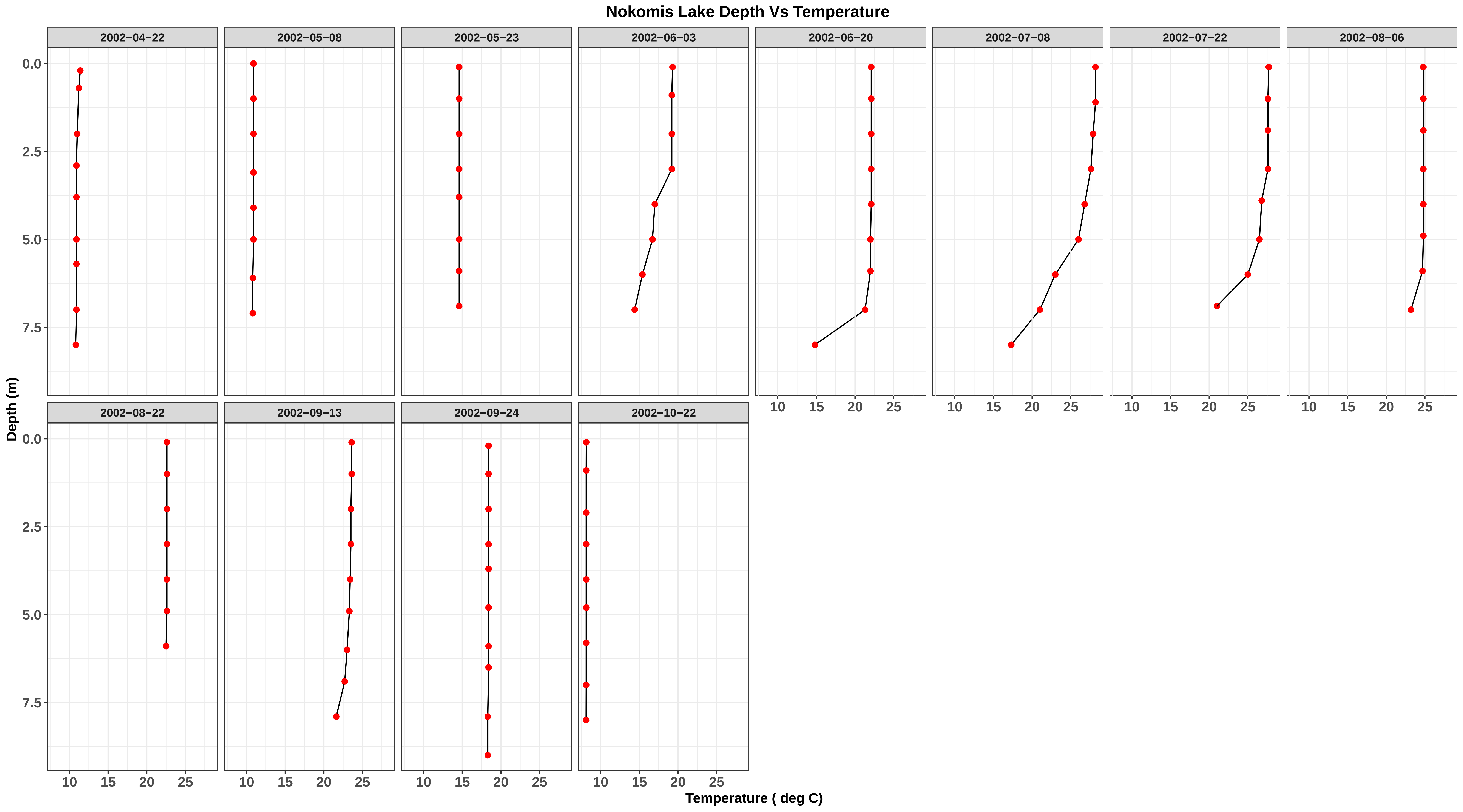

Nokomis Lake Depth Vs Temperature
1999−02−25
1999−04−28
1999−05−14
1999−05−27
1999−06−10
1999−06−23
1999−07−07
1999−07−22
1999−08−05
1999−08−17
1999−09−16
1999−09−28
1999−10−21
Depth (m)
0.0
2.5
5.0
7.5
10
20
Temperature (deg C)

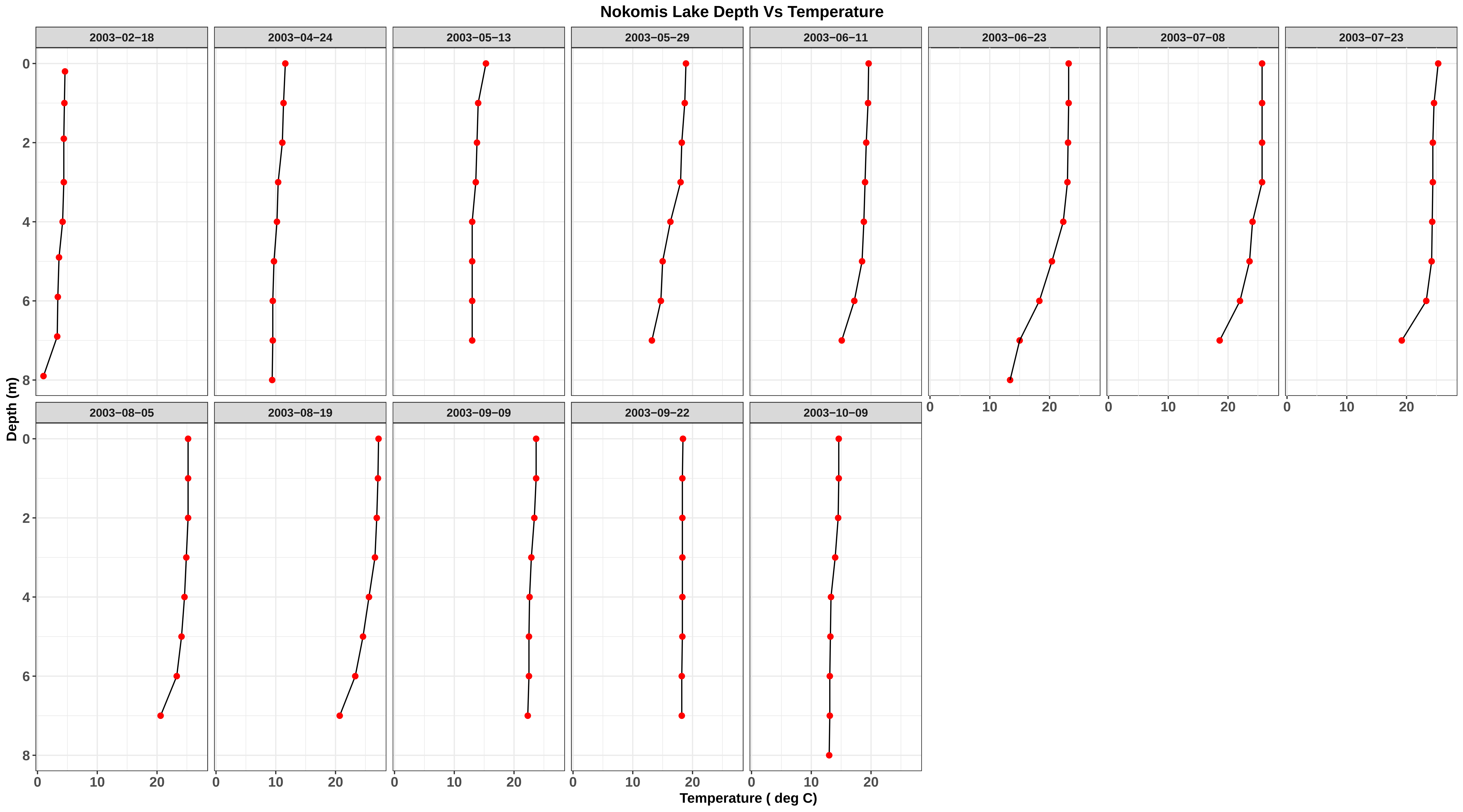


Nokomis Lake Depth Vs Temperature
2000−04−13
2000−05−10
2000−05−23
2000−06−06
2000−06−19
2000−07−05
2000−07−19
2000−08−08
2000−08−22
2000−09−08
2000−09−18
2000−10−12
Depth (m)
0
2
4
6
8
10
15
20
25
Temperature (deg C)

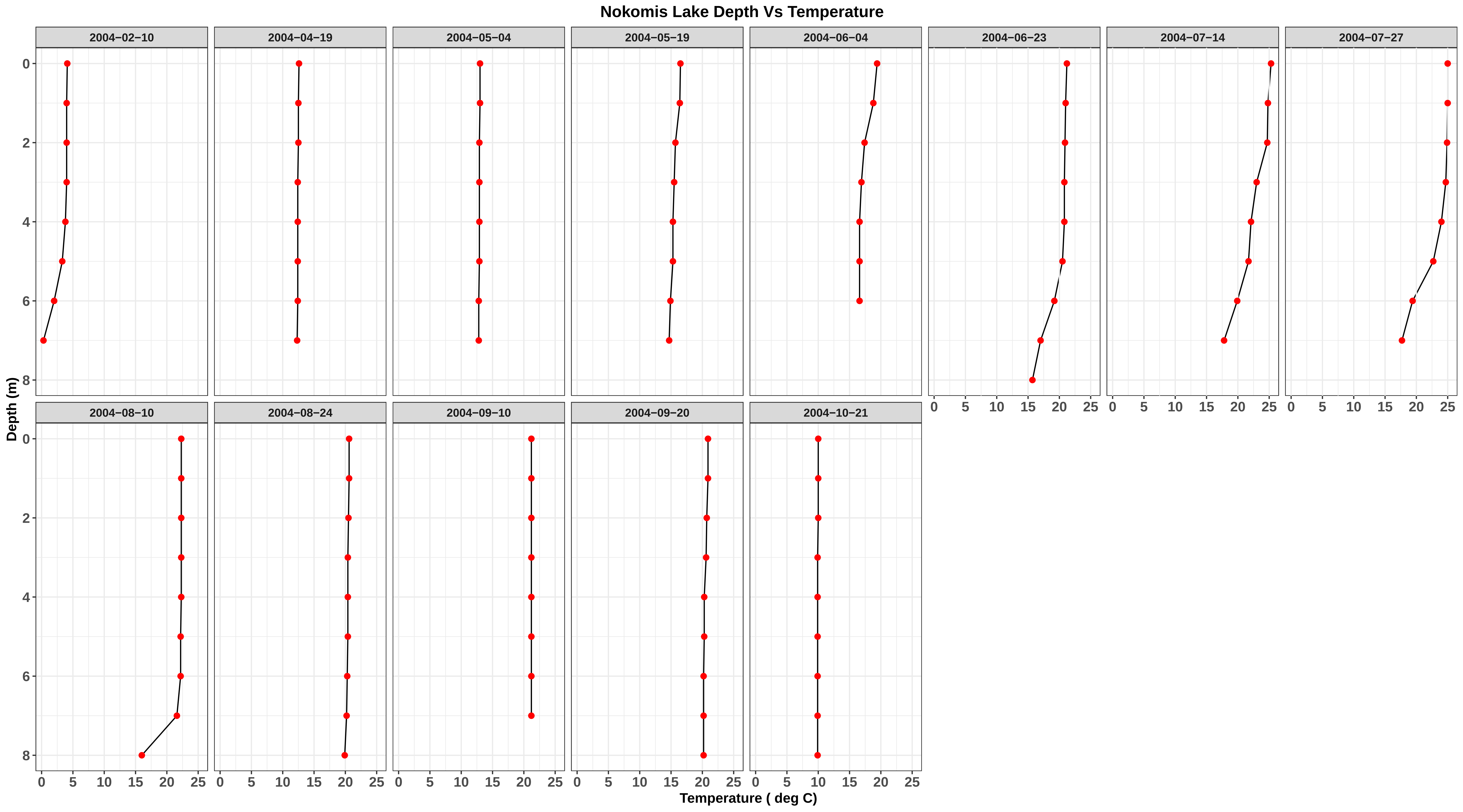


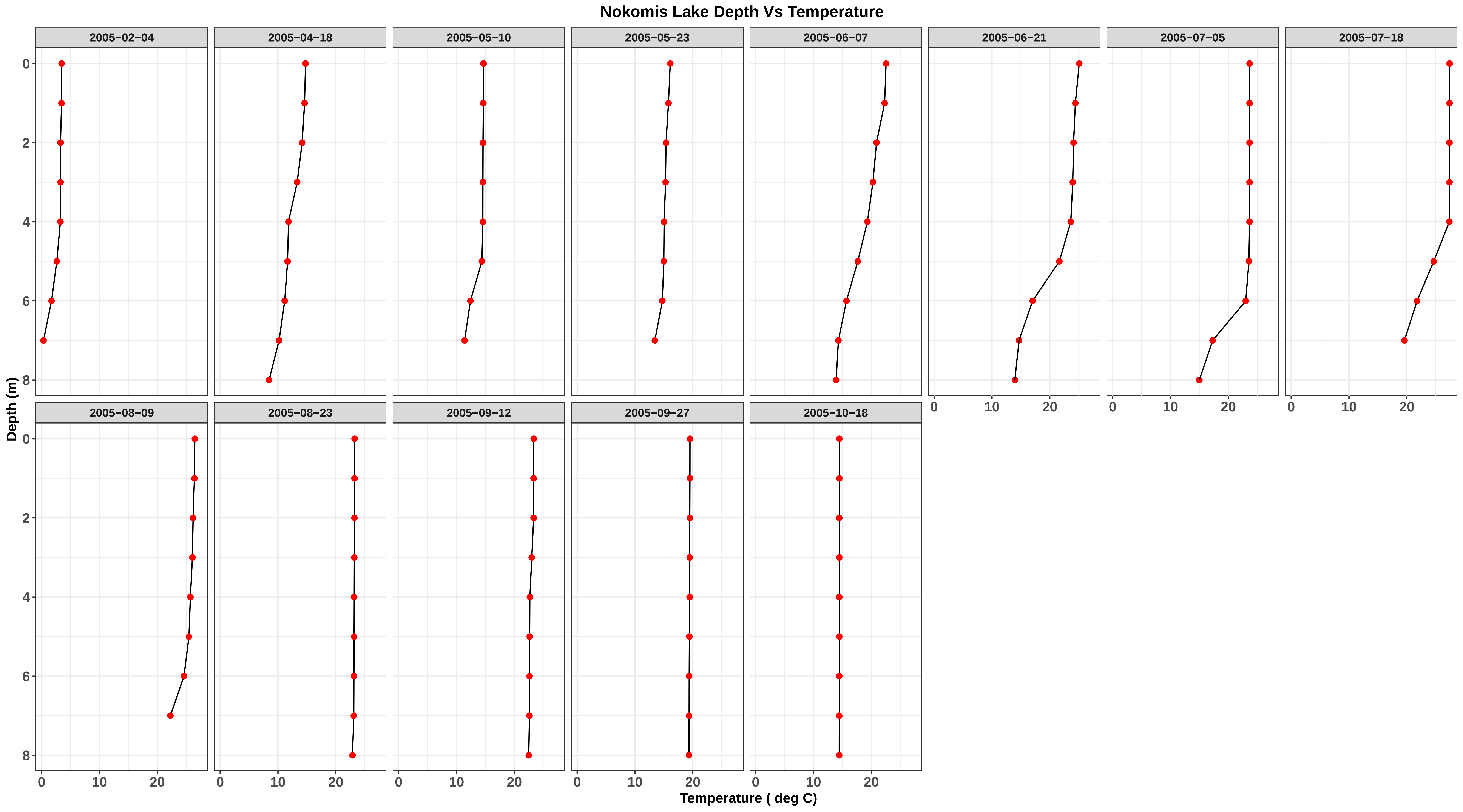
Nokomis Lake Depth Vs Temperature
2001−02−13
2001−04−25
2001−05−14
2001−05−30
2001−06−12
2001−06−26
2001−07−10
2001−07−24
2001−08−08
2001−08−22
2001−09−11
2001−09−25
2001−10−16
Depth (m)
0
2
4
6
8
0
10
20
30
Temperature (deg C)

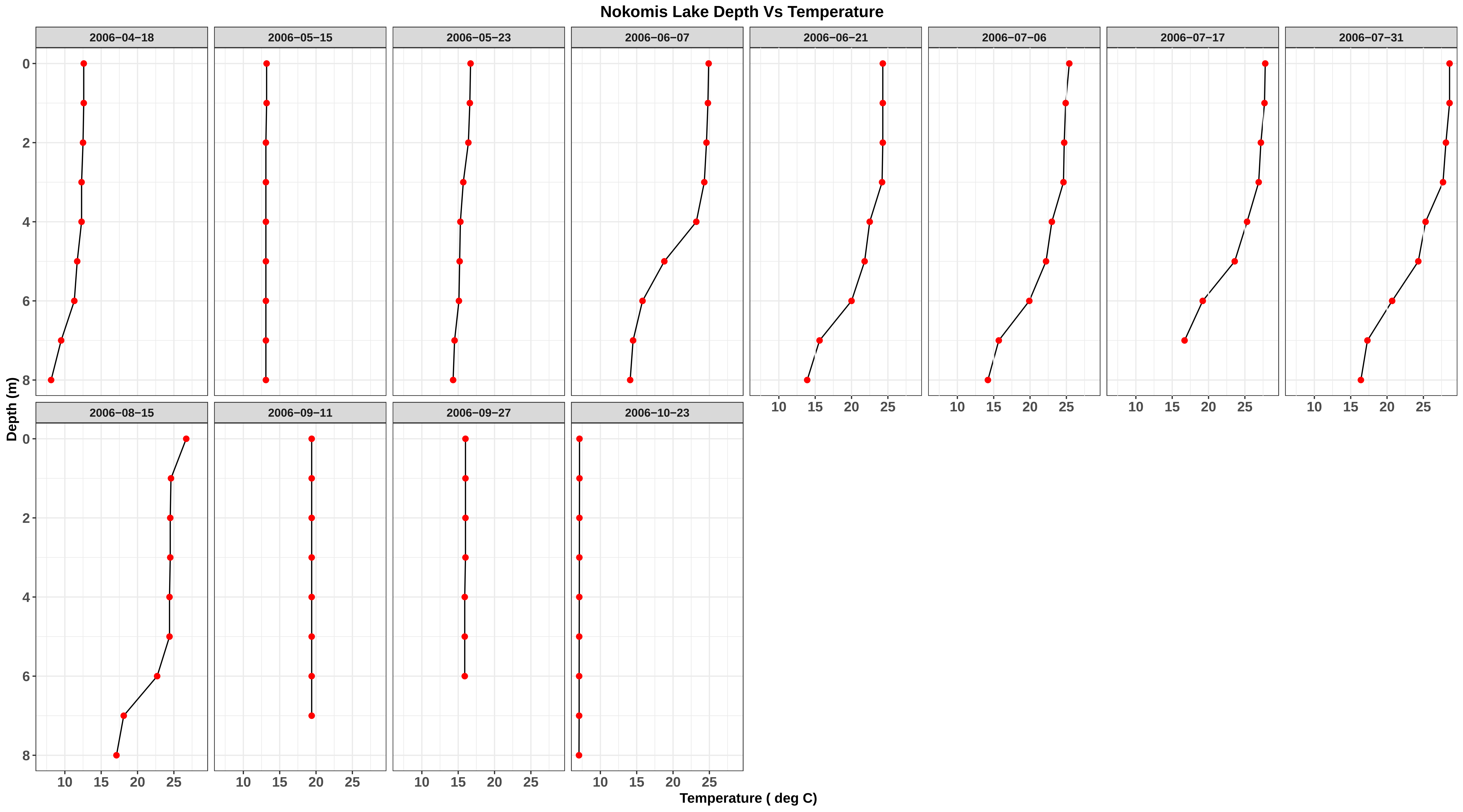

Nokomis Lake Depth Vs Temperature
2002−04−22
2002−05−08
2002−05−23
2002−06−03
2002−06−20
2002−07−08
2002−07−22
2002−08−06
2002−08−22
2002−09−13
2002−09−24
2002−10−22
Depth (m)
0.0
2.5
5.0
7.5
10
15
20
25
Temperature (deg C)



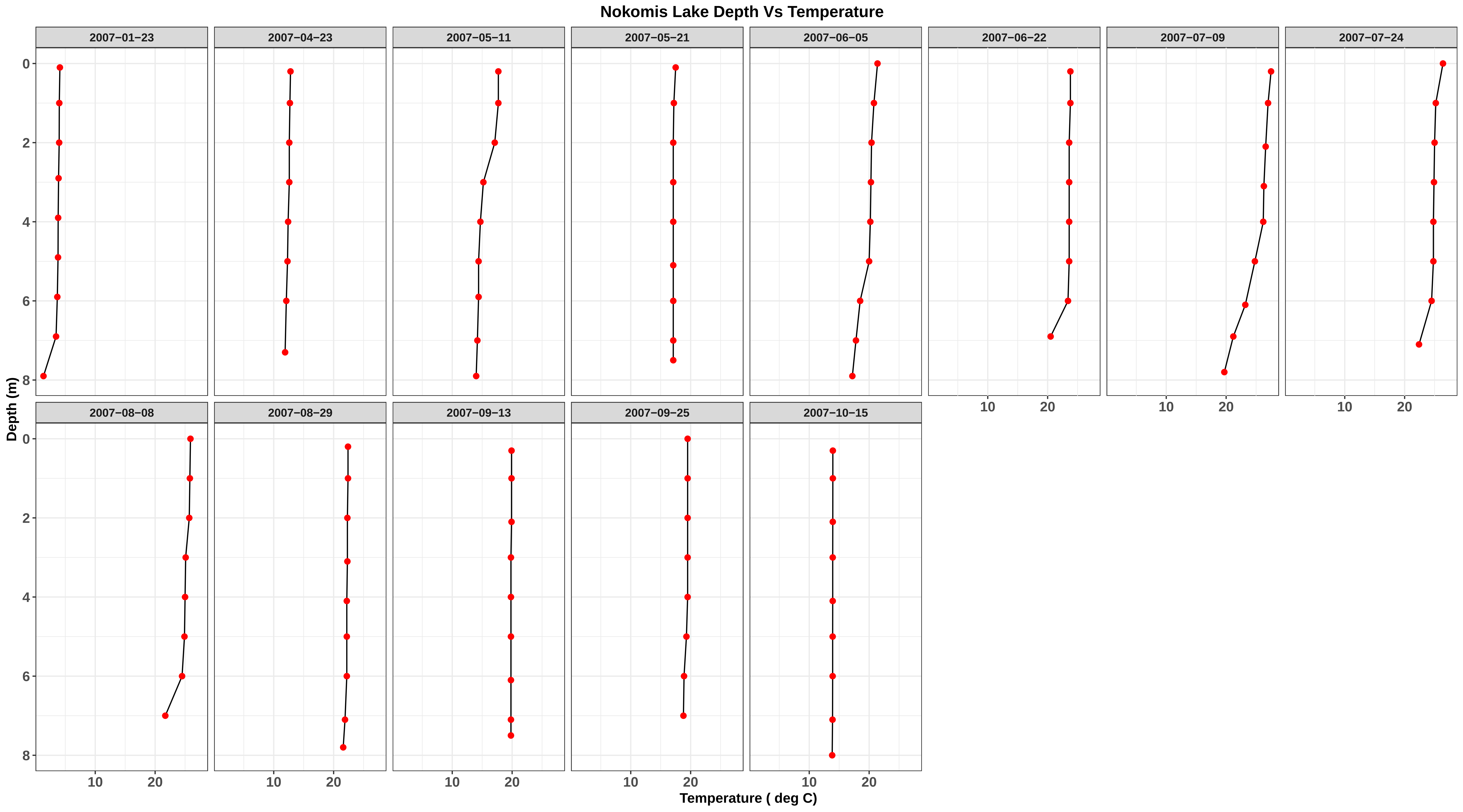
Nokomis Lake Depth Vs Temperature
2003−02−18
2003−04−24
2003−05−13
2003−05−29
2003−06−11
2003−06−23
2003−07−08
2003−07−23
2003−08−05
2003−08−19
2003−09−09
2003−09−22
2003−10−09
Depth (m)
Temperature (deg C)
0
2
4
6
8
0
10
20


Nokomis Lake Depth Vs Temperature
2004−02−10
2004−04−19
2004−05−04
2004−05−19
2004−06−04
2004−06−23
2004−07−14
2004−07−27
2004−08−10
2004−08−24
2004−09−10
2004−09−20
2004−10−21
Depth (m)
Temperature (deg C)
0
2
4
6
8
0
5
10
15
20
25

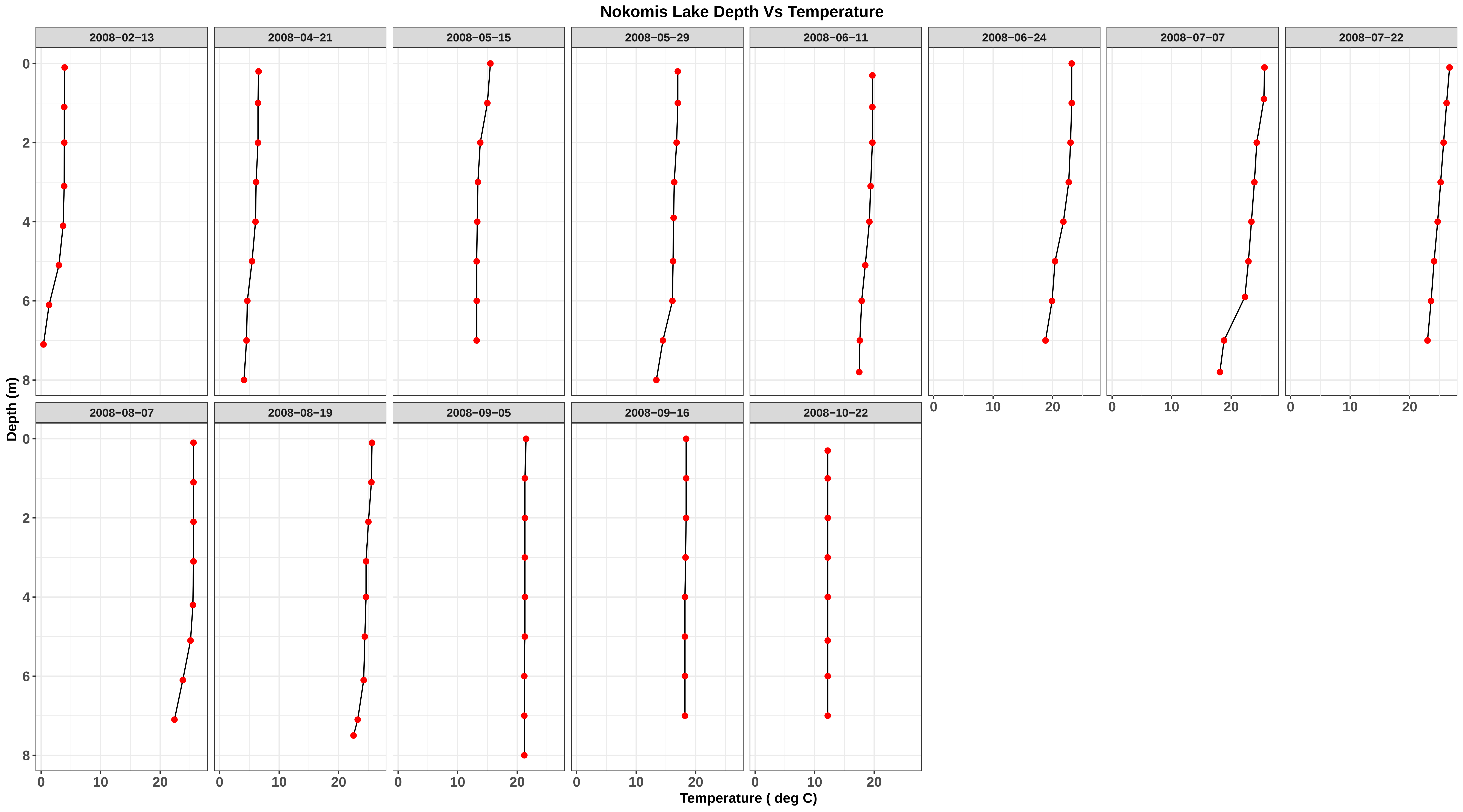

Nokomis Lake Depth Vs Temperature
2005−02−04
2005−04−18
2005−05−10
2005−05−23
2005−06−07
2005−06−21
2005−07−05
2005−07−18
2005−08−09
2005−08−23
2005−09−12
2005−09−27
2005−10−18
Depth (m)
0
2
4
6
8
0
10
20
Temperature (deg C)

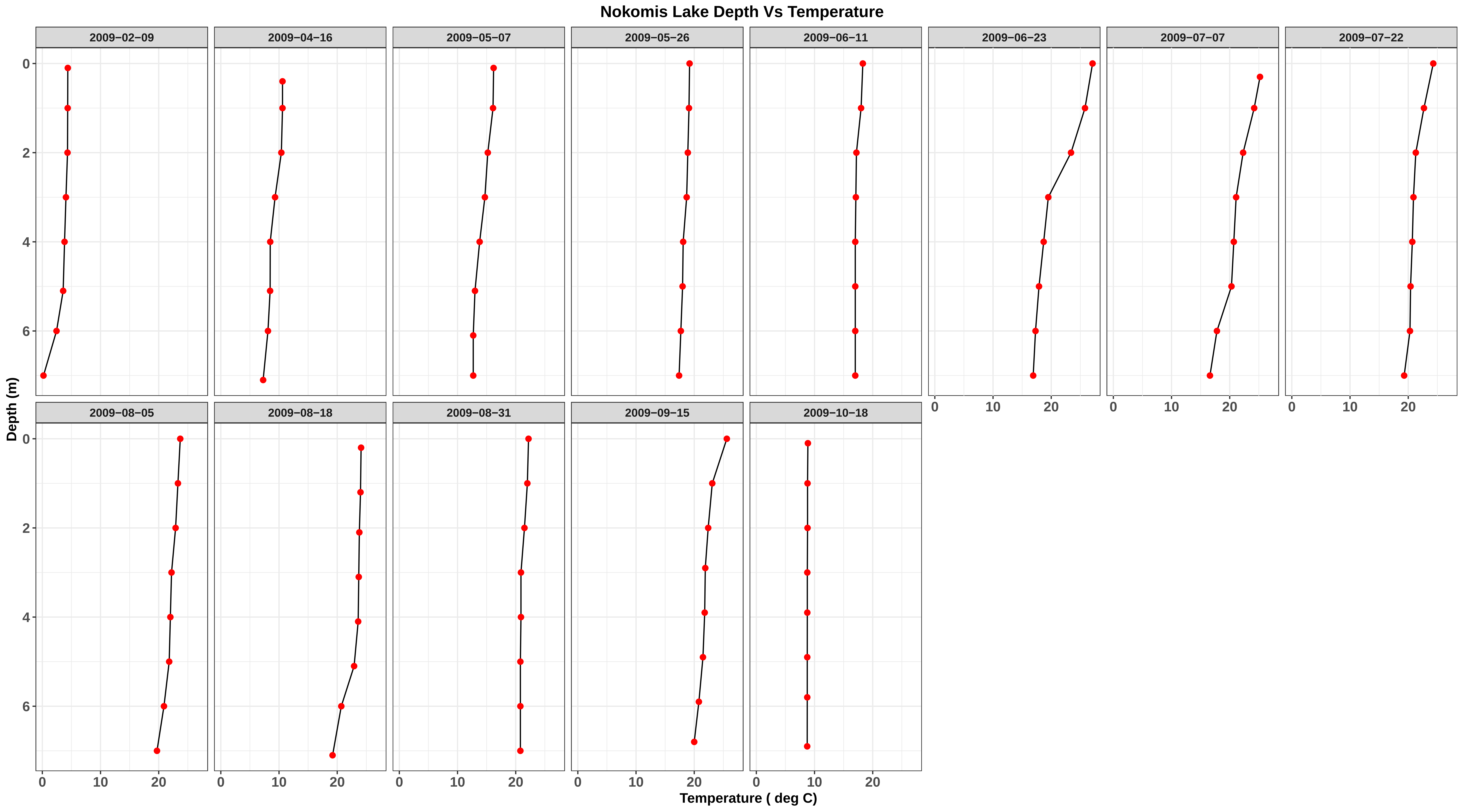


Nokomis Lake Depth Vs Temperature
2006−04−18
2006−05−15
2006−05−23
2006−06−07
2006−06−21
2006−07−06
2006−07−17
2006−07−31
2006−08−15
2006−09−11
2006−09−27
2006−10−23
Depth (m)
Temperature (deg C)
0
2
4
6
8
10
15
20
25

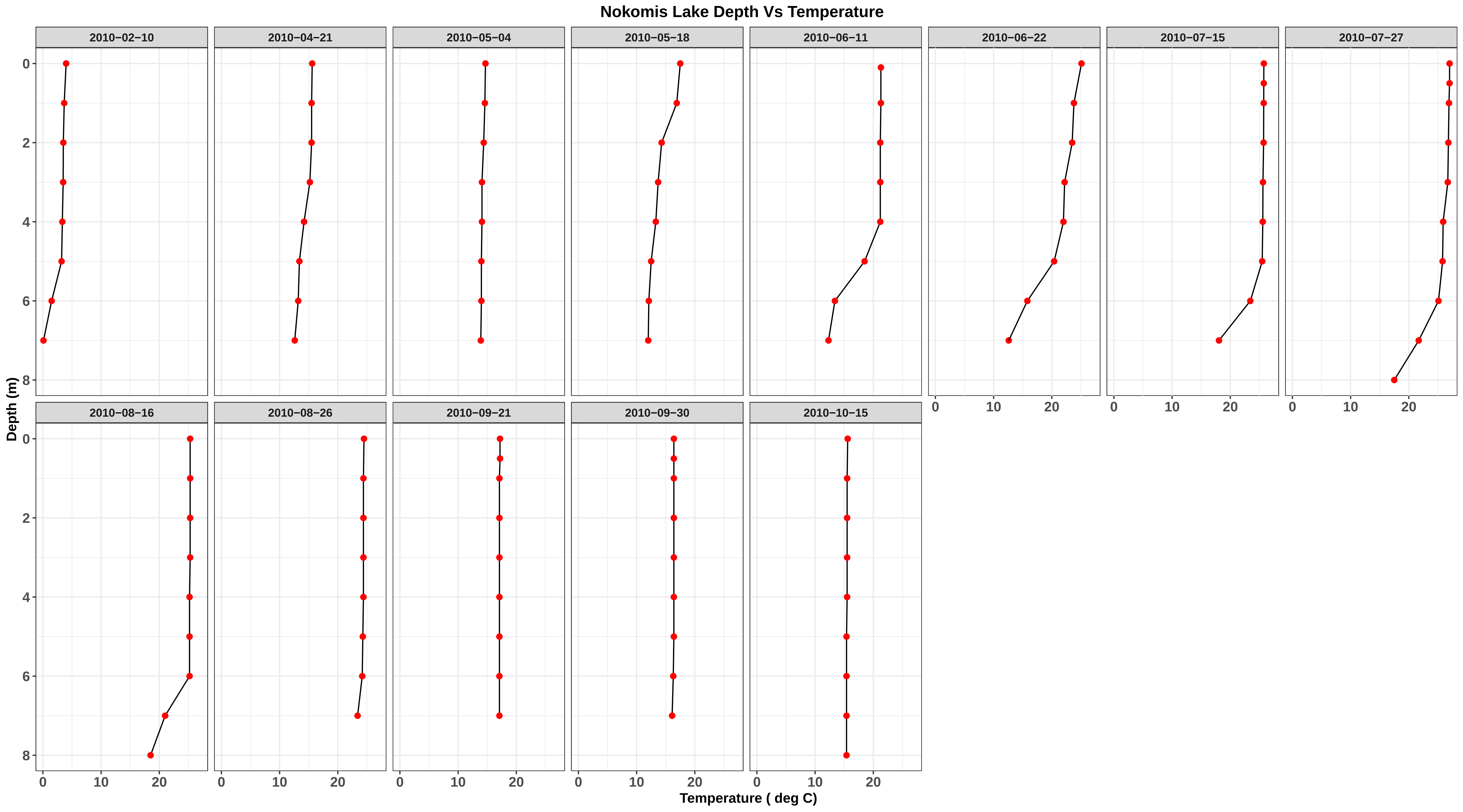


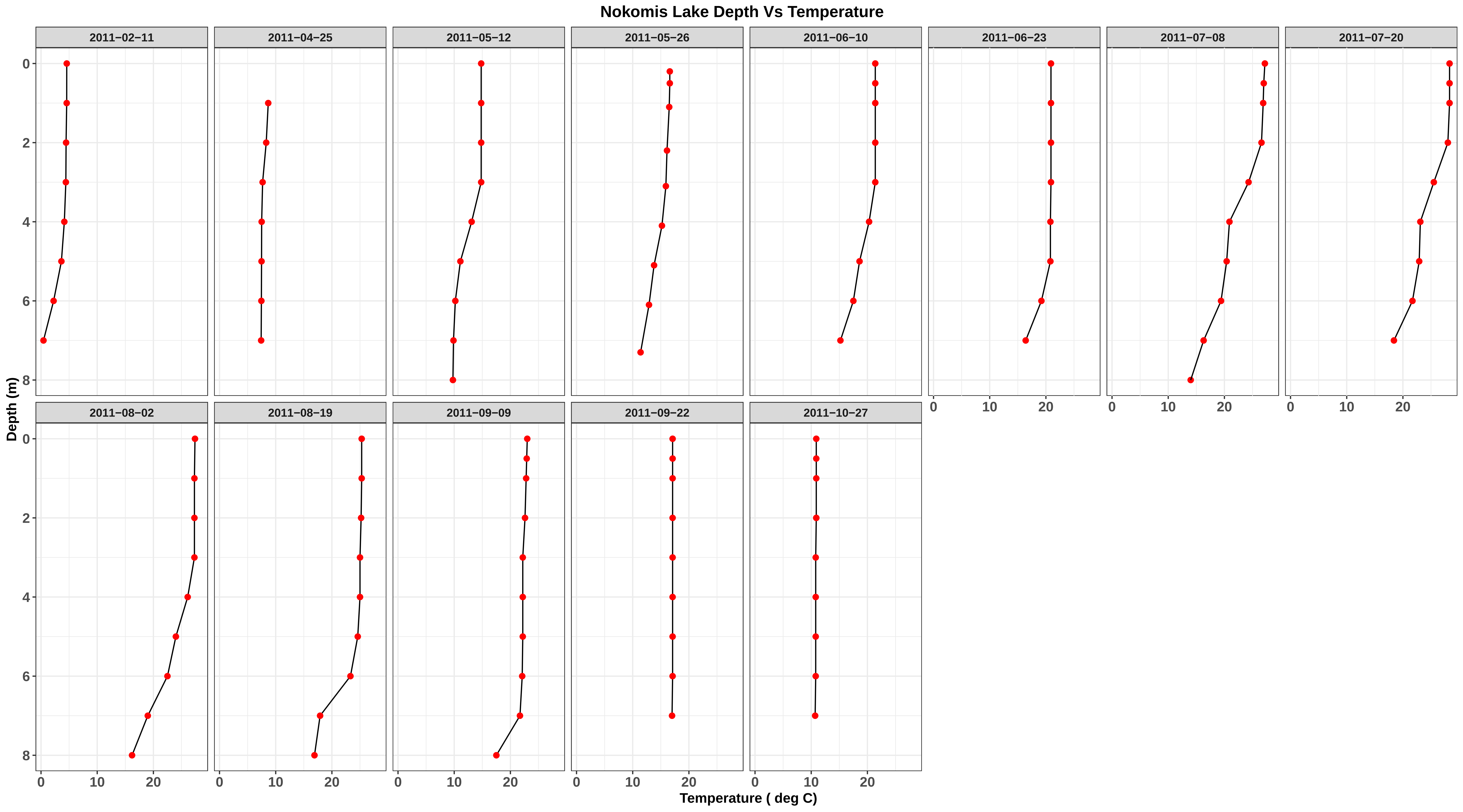
Nokomis Lake Depth Vs Temperature
2007−01−23
2007−04−23
2007−05−11
2007−05−21
2007−06−05
2007−06−22
2007−07−09
2007−07−24
2007−08−08
2007−08−29
2007−09−13
2007−09−25
2007−10−15
Depth (m)
Temperature (deg C)
0
2
4
6
8
10
20


Nokomis Lake Depth Vs Temperature
2008−02−13
2008−04−21
2008−05−15
2008−05−29
2008−06−11
2008−06−24
2008−07−07
2008−07−22
2008−08−07
2008−08−19
2008−09−05
2008−09−16
2008−10−22
Depth (m)
0
2
4
6
8
0
10
20
Temperature (deg C)

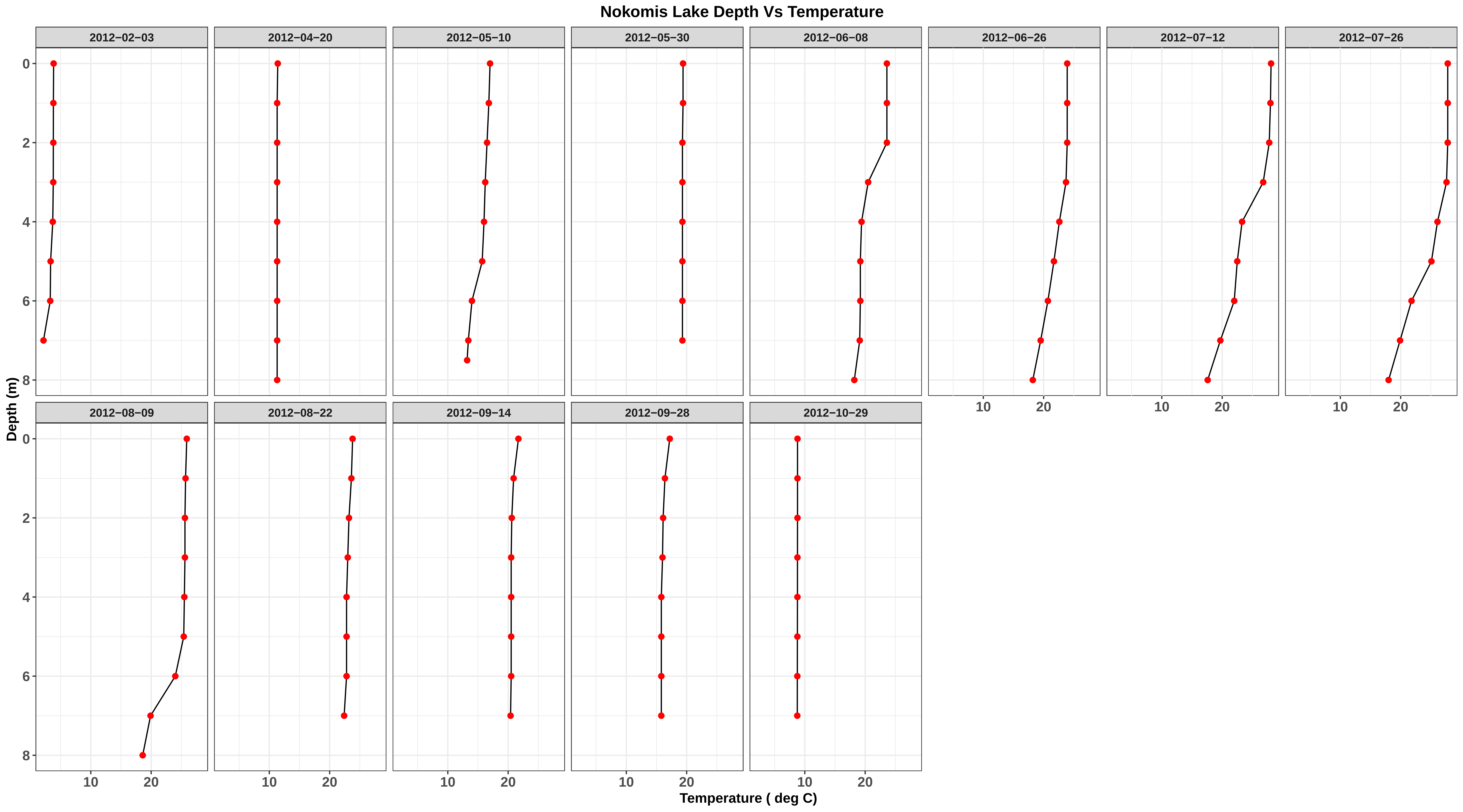


Nokomis Lake Depth Vs Temperature
2009−02−09
2009−04−16
2009−05−07
2009−05−26
2009−06−11
2009−06−23
2009−07−07
2009−07−22
2009−08−05
2009−08−18
2009−08−31
2009−09−15
2009−10−18
Depth (m)
0
2
4
6
0
10
20
Temperature (deg C)

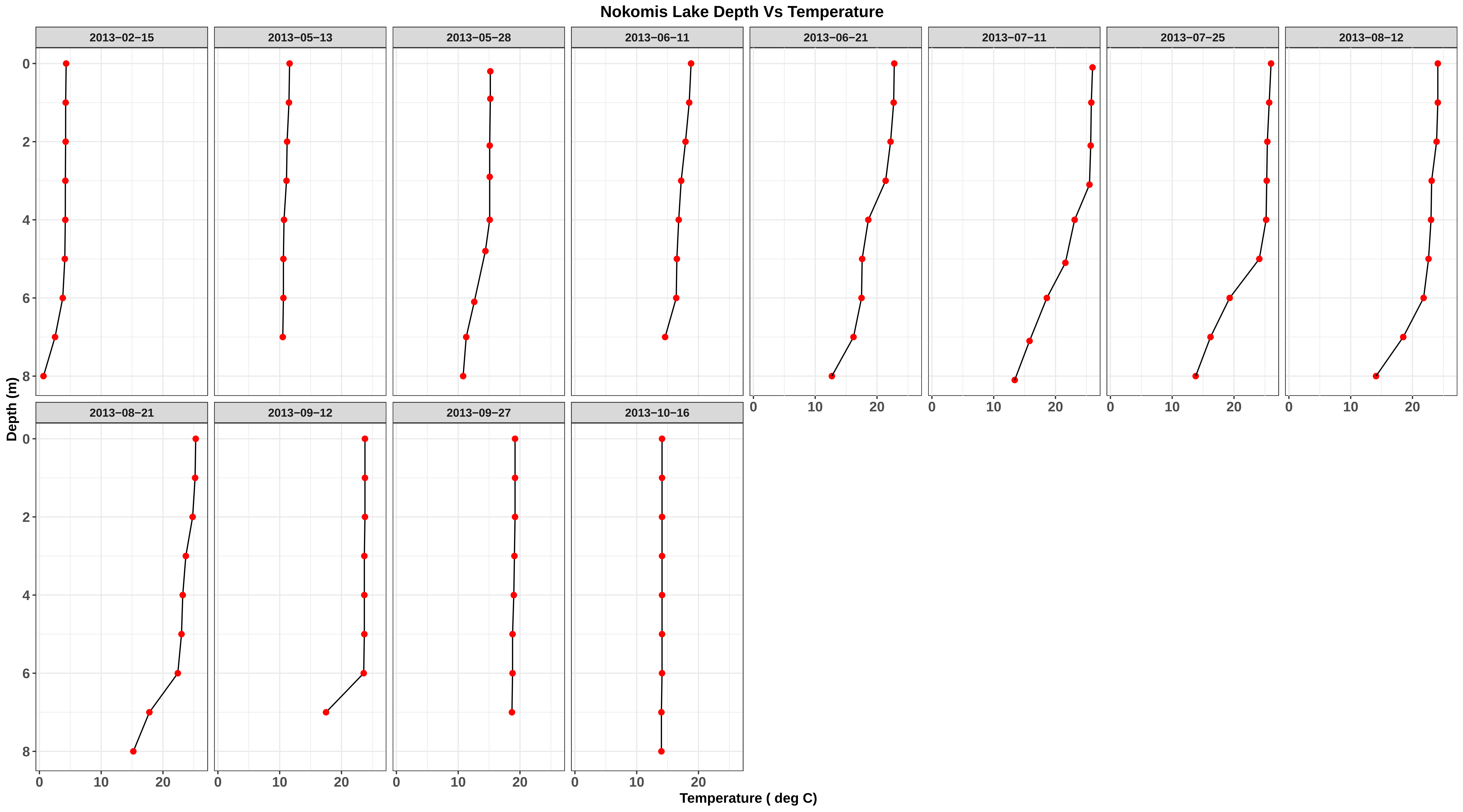

Nokomis Lake Depth Vs Temperature
2010−02−10
2010−04−21
2010−05−04
2010−05−18
2010−06−11
2010−06−22
2010−07−15
2010−07−27
2010−08−16
2010−08−26
2010−09−21
2010−09−30
2010−10−15
Depth (m)
0
2
4
6
8
0
10
20
Temperature (deg C)

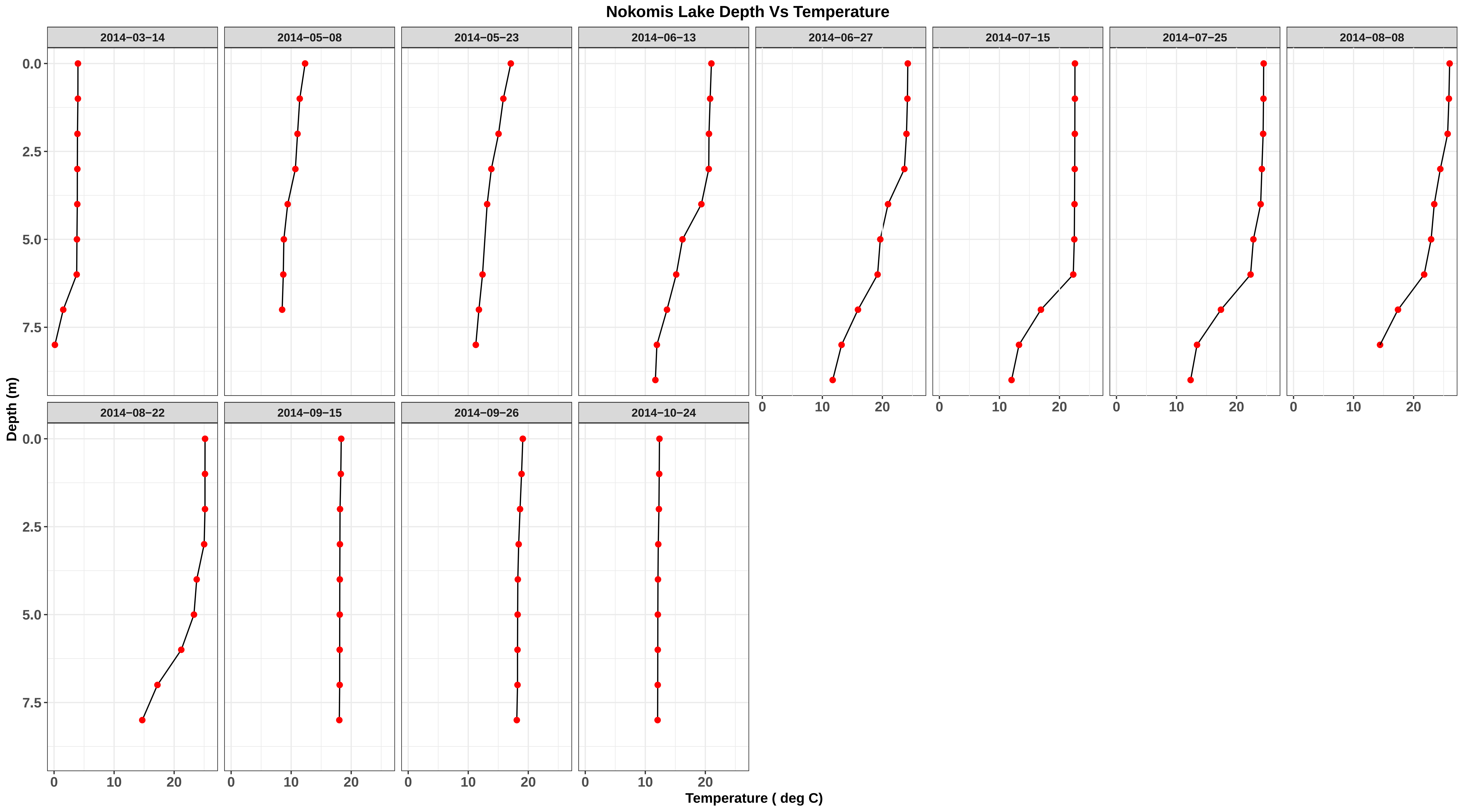


Nokomis Lake Depth Vs Temperature
2011−02−11
2011−04−25
2011−05−12
2011−05−26
2011−06−10
2011−06−23
2011−07−08
2011−07−20
2011−08−02
2011−08−19
2011−09−09
2011−09−22
2011−10−27
Depth (m)
Temperature (deg C)
0
2
4
6
8
0
10
20

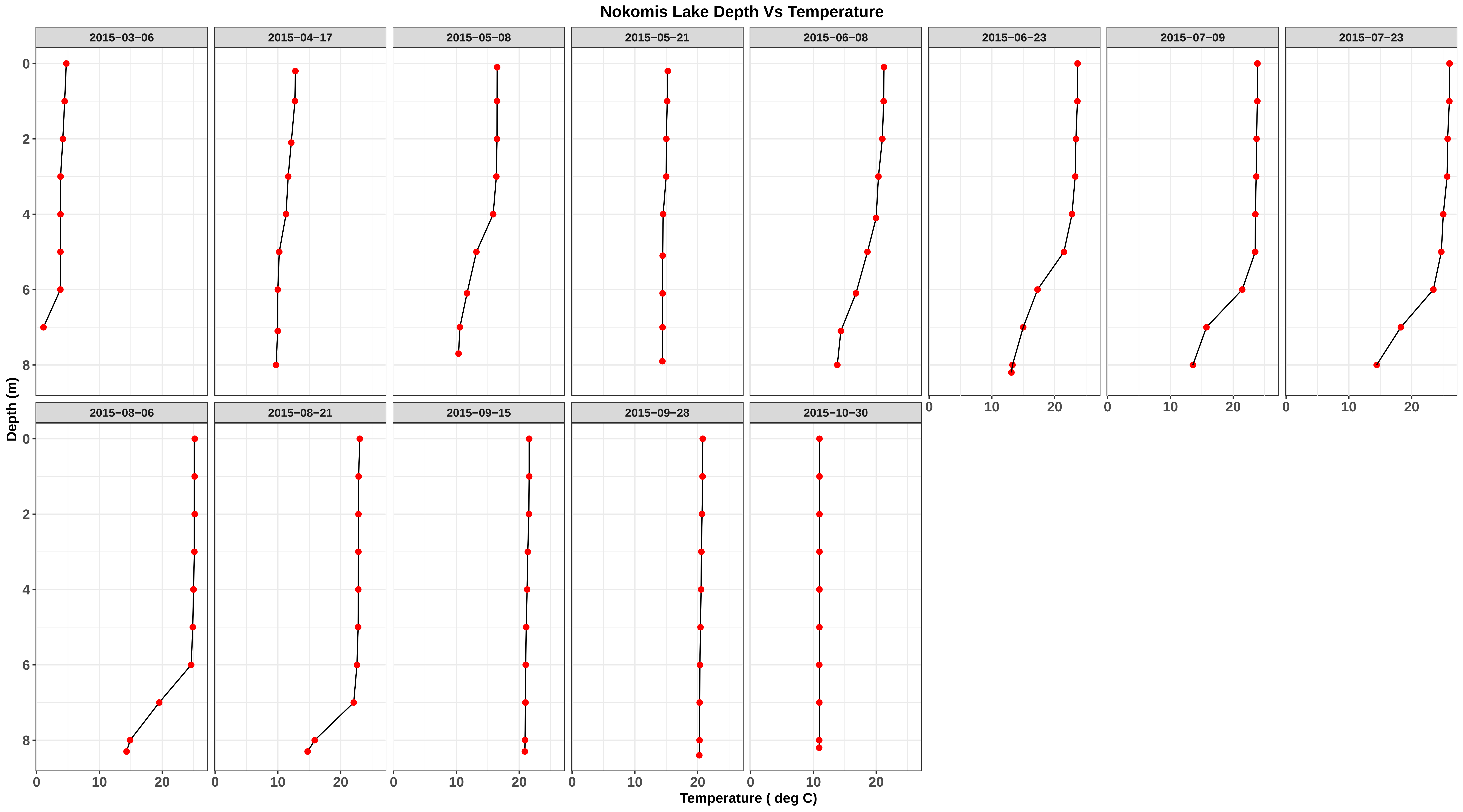


Nokomis Lake Depth Vs Temperature
2012−02−03
2012−04−20
2012−05−10
2012−05−30
2012−06−08
2012−06−26
2012−07−12
2012−07−26
2012−08−09
2012−08−22
2012−09−14
2012−09−28
2012−10−29
Depth (m)
0
2
4
6
8
10
20
Temperature (deg C)

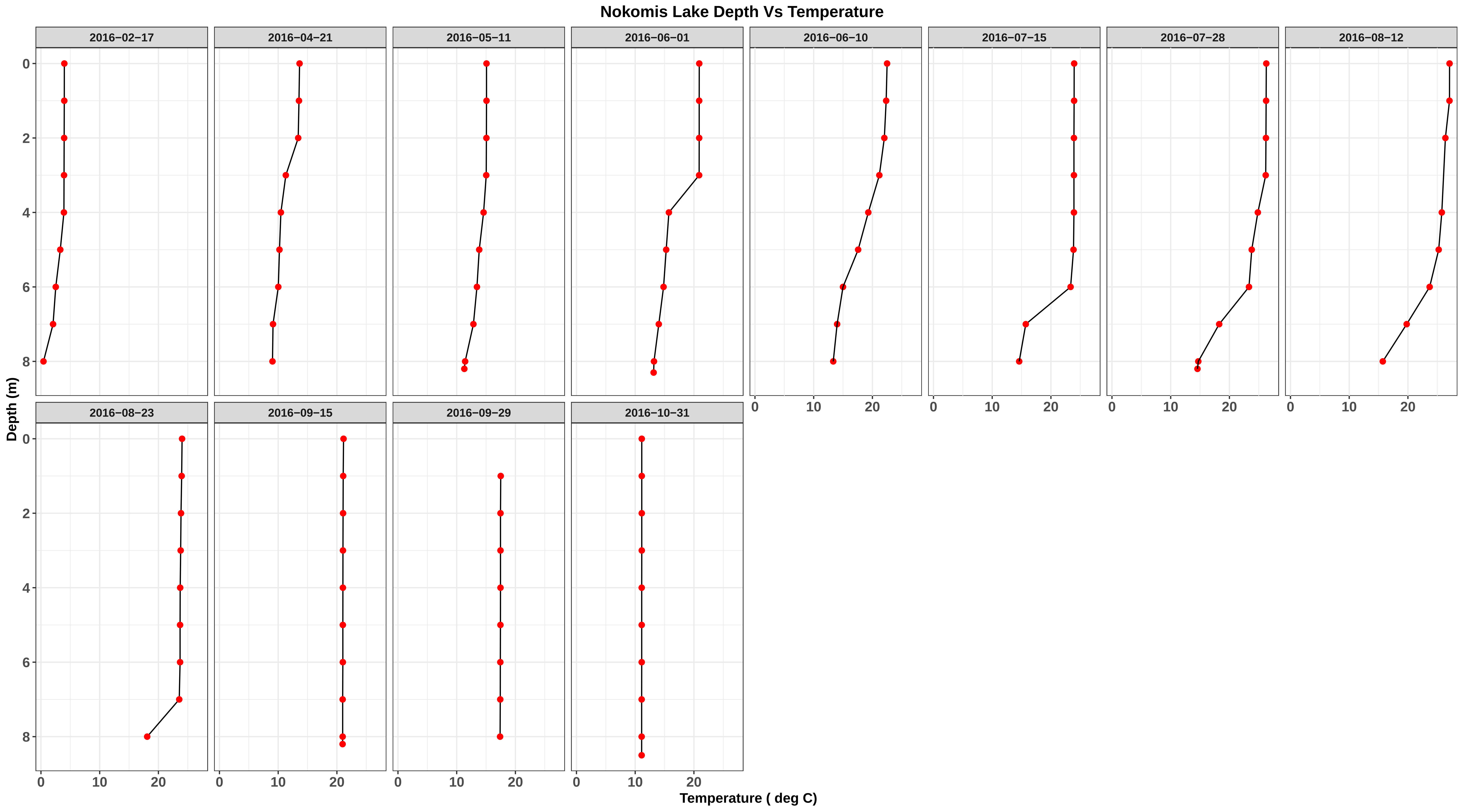

Nokomis Lake Depth Vs Temperature
2013−02−15
2013−05−13
2013−05−28
2013−06−11
2013−06−21
2013−07−11
2013−07−25
2013−08−12
2013−08−21
2013−09−12
2013−09−27
2013−10−16
Depth (m)
Temperature (deg C)
0
2
4
6
8
0
10
20



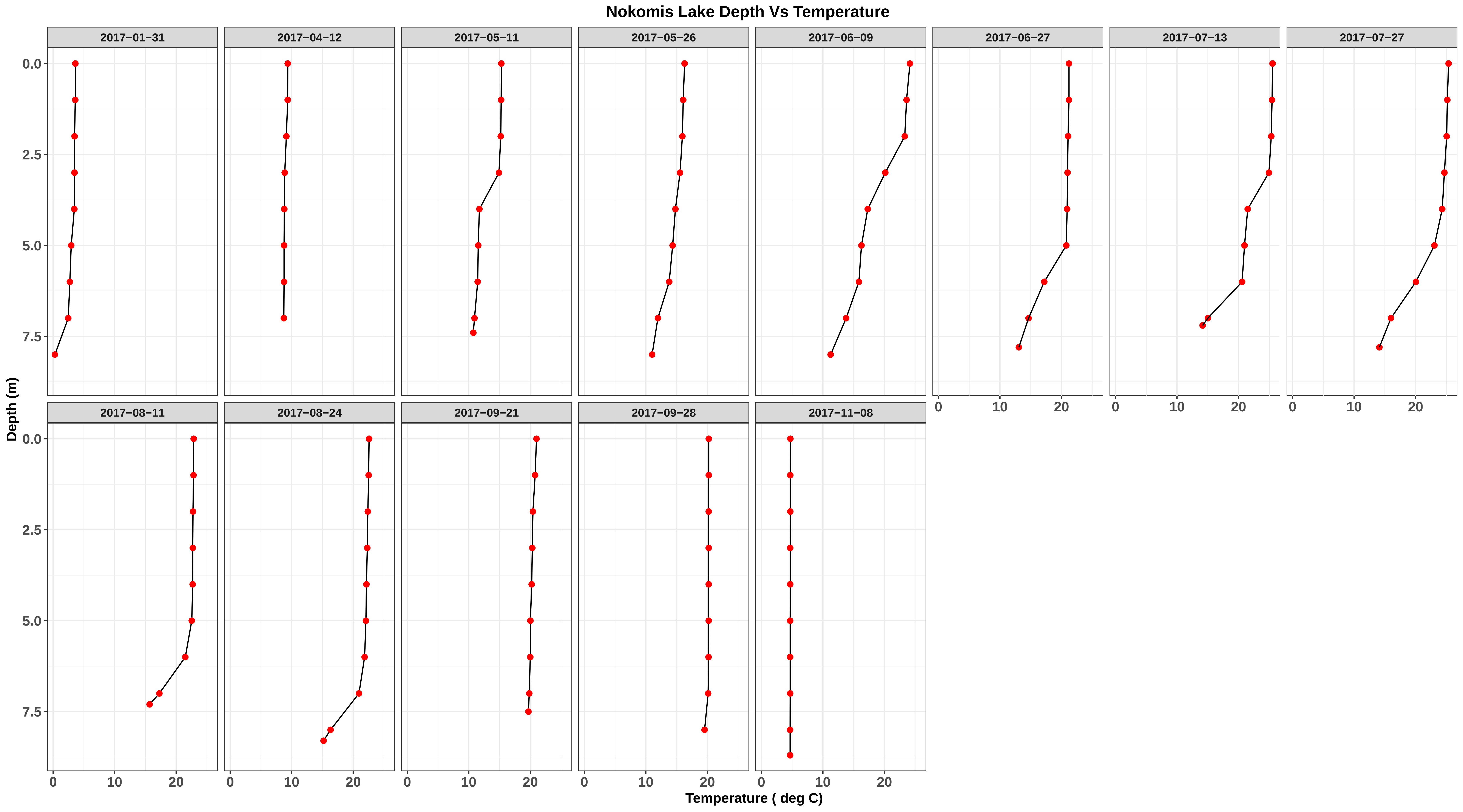
Nokomis Lake Depth Vs Temperature
2014−03−14
2014−05−08
2014−05−23
2014−06−13
2014−06−27
2014−07−15
2014−07−25
2014−08−08
2014−08−22
2014−09−15
2014−09−26
2014−10−24
Depth (m)
0.0
2.5
5.0
7.5
0
10
20
Temperature (deg C)



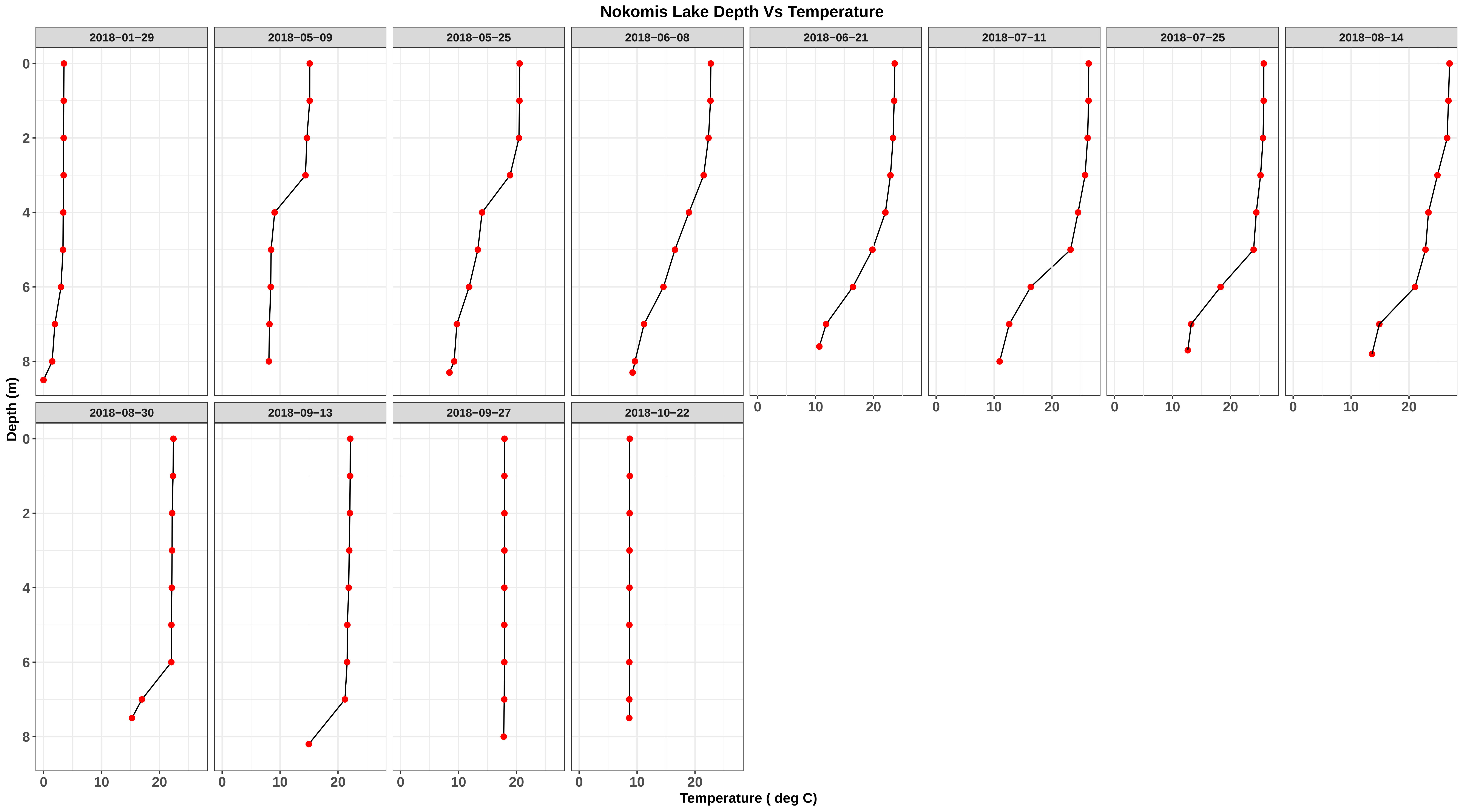
Nokomis Lake Depth Vs Temperature
2015−03−06
2015−04−17
2015−05−08
2015−05−21
2015−06−08
2015−06−23
2015−07−09
2015−07−23
2015−08−06
2015−08−21
2015−09−15
2015−09−28
2015−10−30
Depth (m)
Temperature (deg C)
0
2
4
6
8
0
10
20



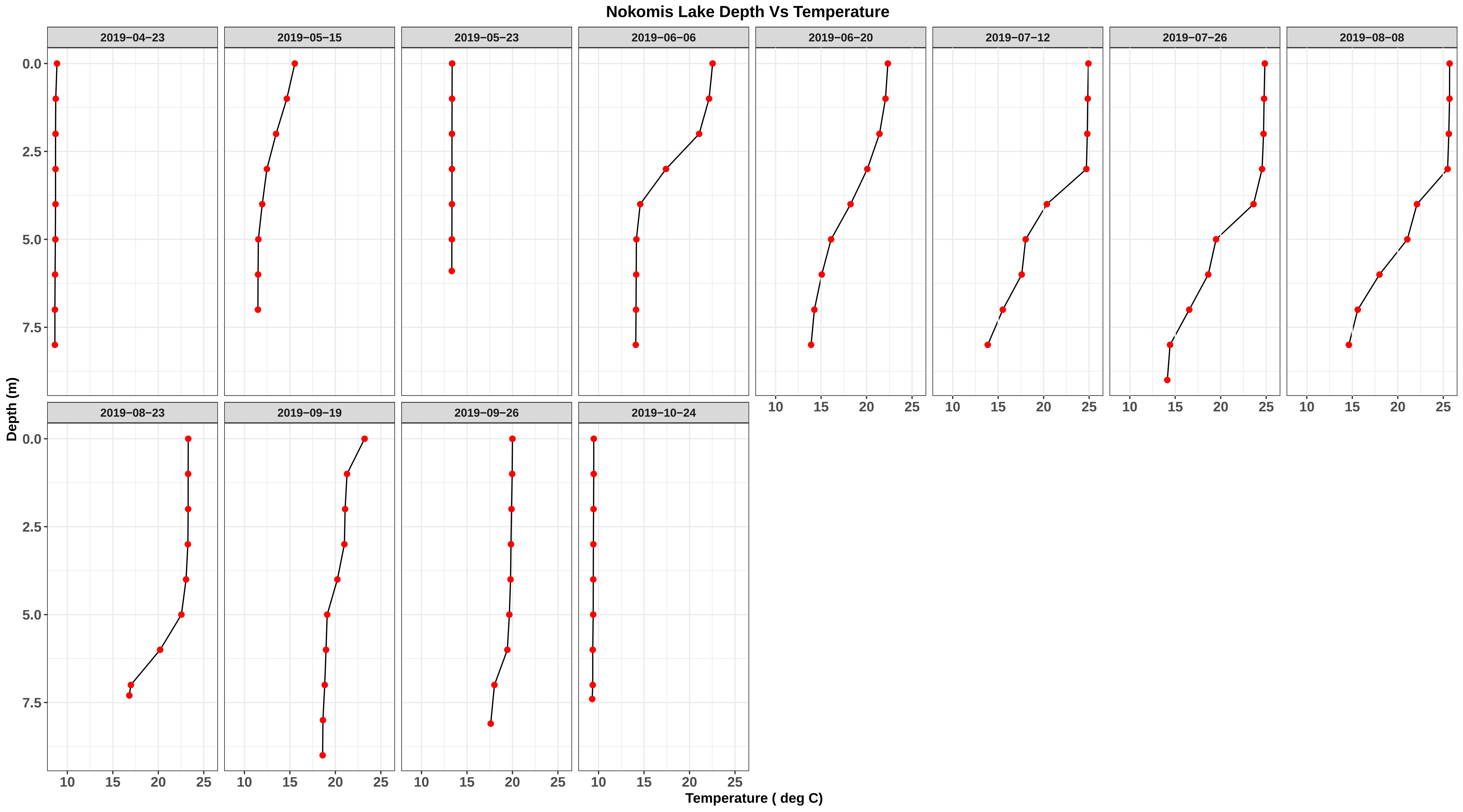
Nokomis Lake Depth Vs Temperature
2016−02−17
2016−04−21
2016−05−11
2016−06−01
2016−06−10
2016−07−15
2016−07−28
2016−08−12
2016−08−23
2016−09−15
2016−09−29
2016−10−31
Depth (m)
Temperature (deg C)
0
2
4
6
8
0
10
20

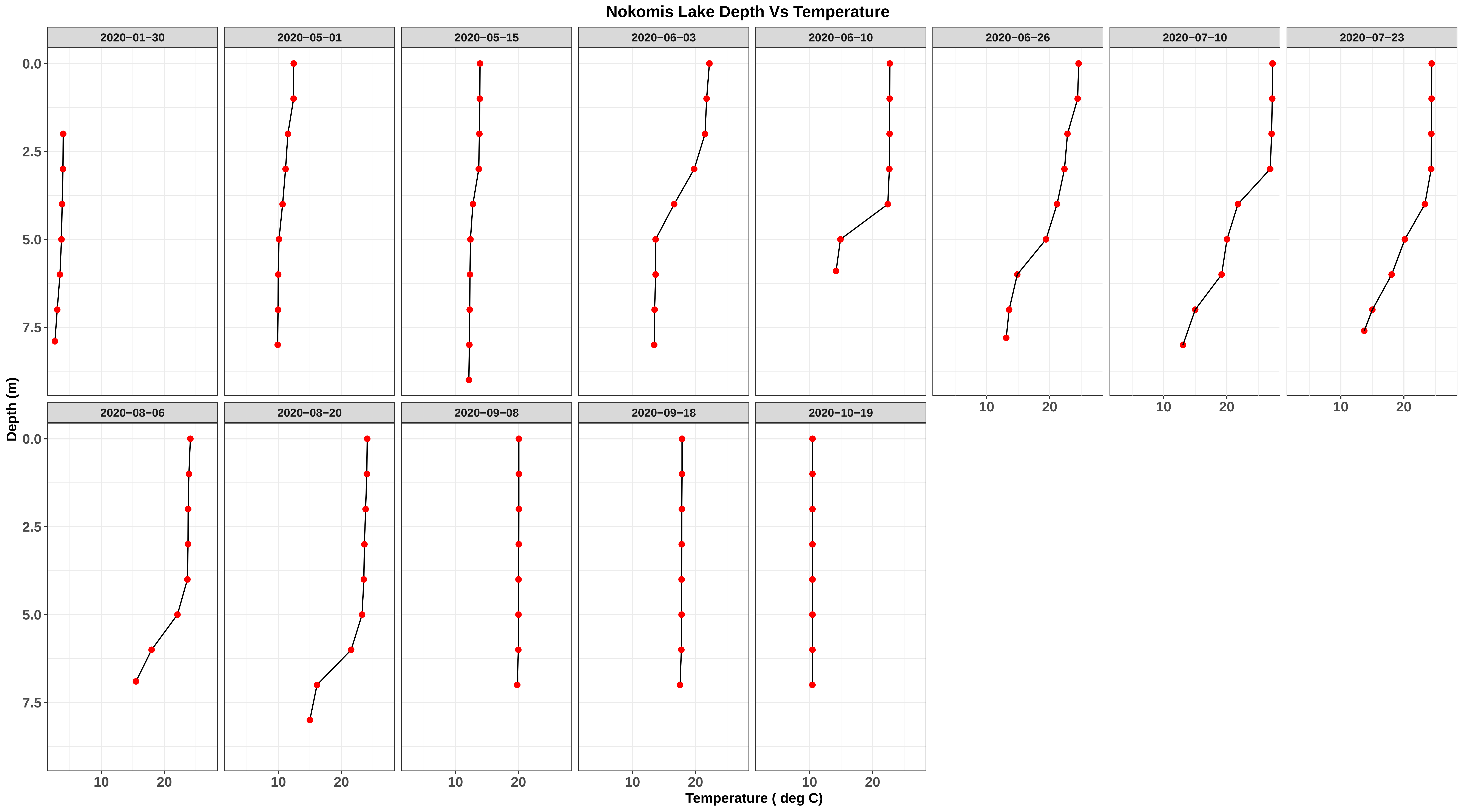


Nokomis Lake Depth Vs Temperature
2017−01−31
2017−04−12
2017−05−11
2017−05−26
2017−06−09
2017−06−27
2017−07−13
2017−07−27
2017−08−11
2017−08−24
2017−09−21
2017−09−28
2017−11−08
Depth (m)
0.0
2.5
5.0
7.5
0
10
20
Temperature (deg C)

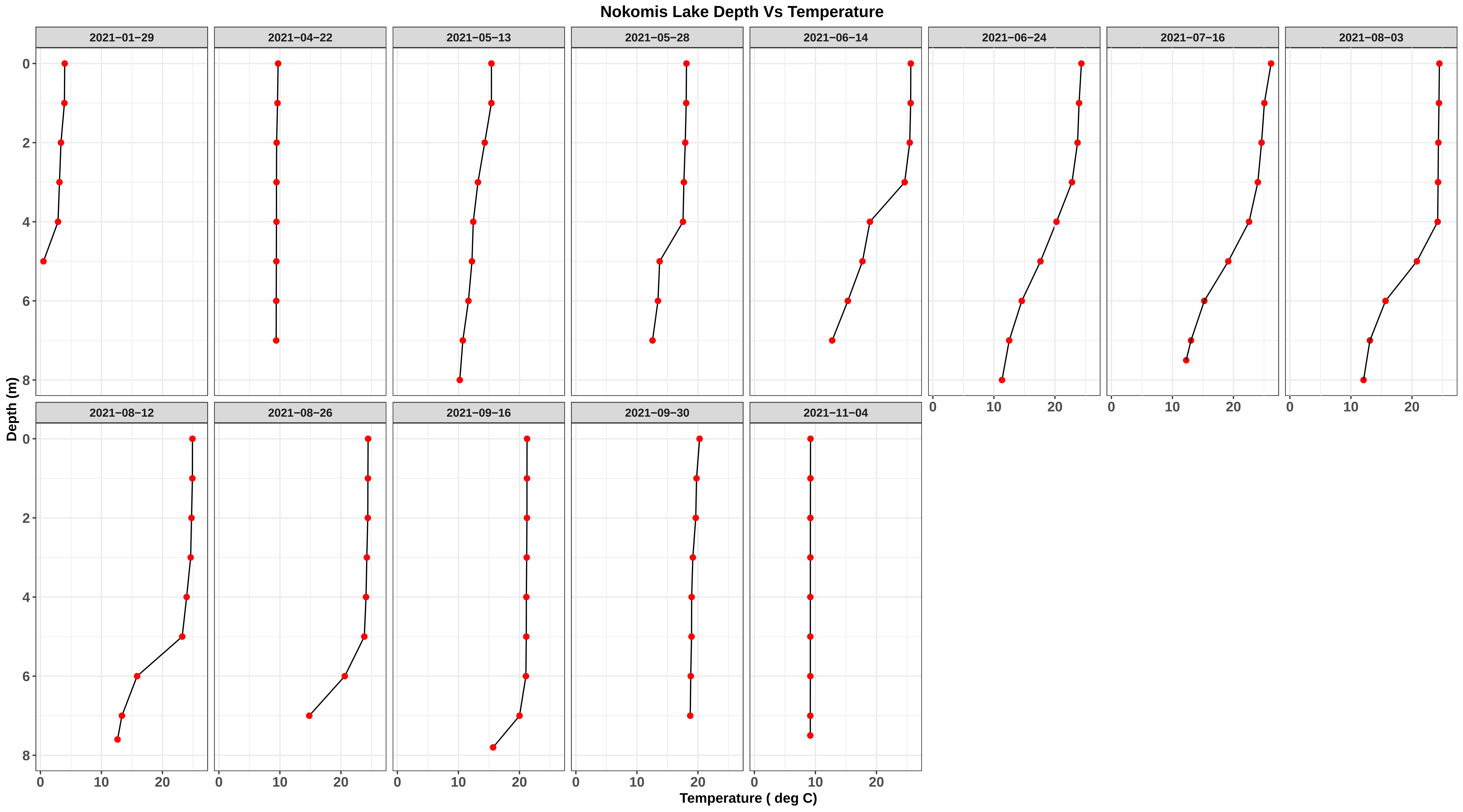


Nokomis Lake Depth Vs Temperature
2018−01−29
2018−05−09
2018−05−25
2018−06−08
2018−06−21
2018−07−11
2018−07−25
2018−08−14
2018−08−30
2018−09−13
2018−09−27
2018−10−22
Depth (m)
0
2
4
6
8
0
10
20
Temperature (deg C)

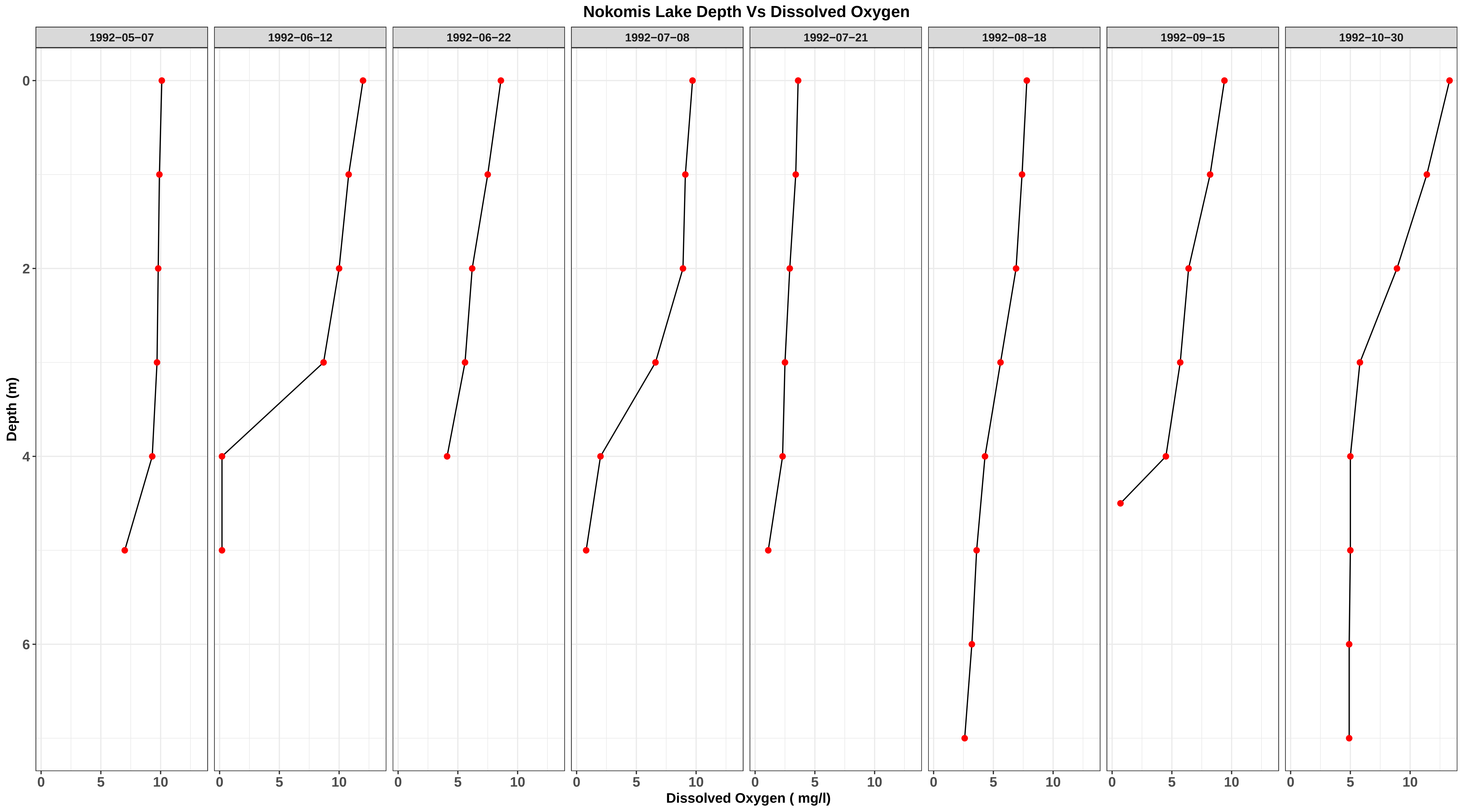

Nokomis Lake Depth Vs Temperature
2019−04−23
2019−05−15
2019−05−23
2019−06−06
2019−06−20
2019−07−12
2019−07−26
2019−08−08
2019−08−23
2019−09−19
2019−09−26
2019−10−24
Depth (m)
Temperature (deg C)
0.0
2.5
5.0
7.5
10
15
20
25



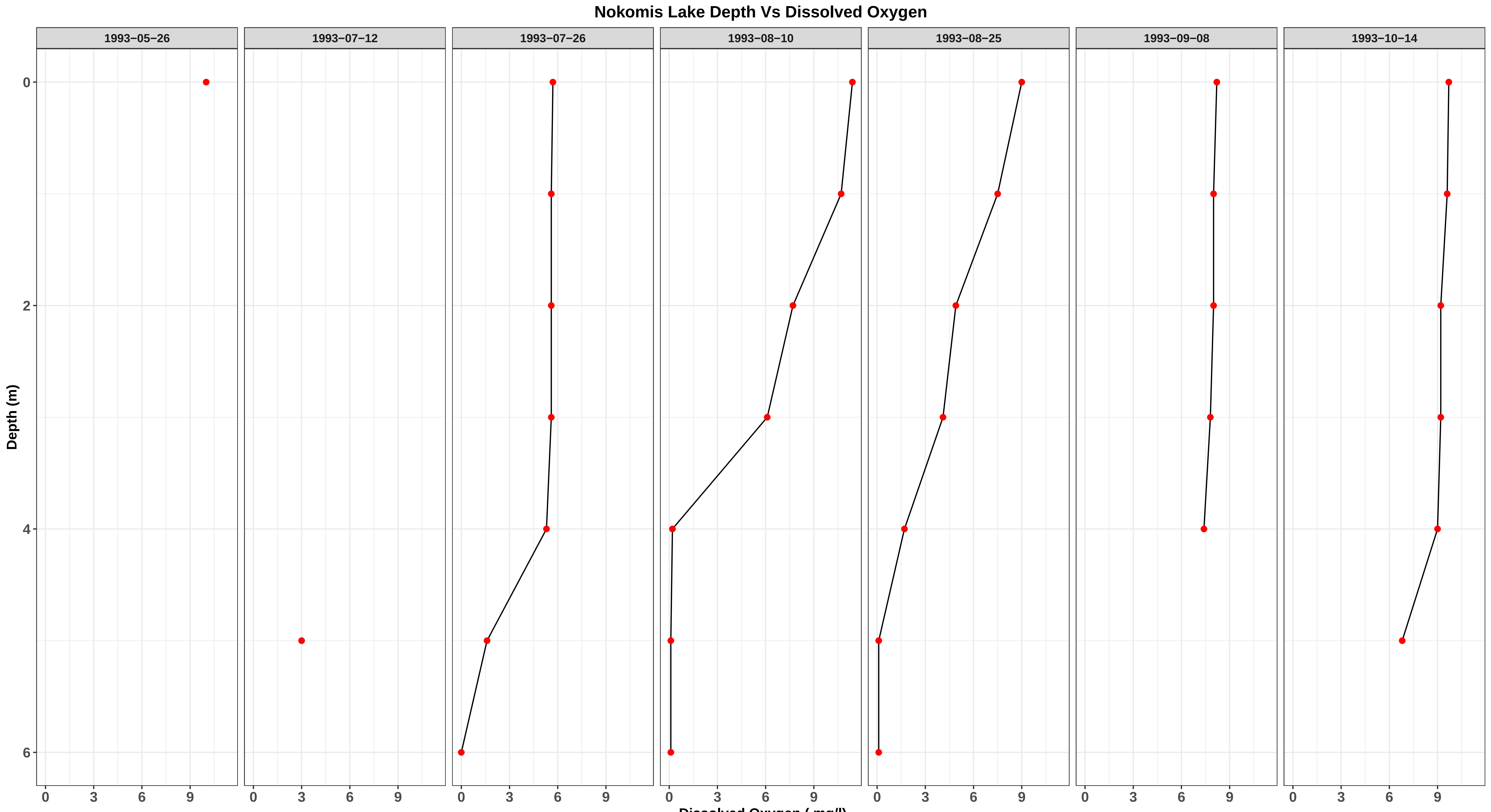
Nokomis Lake Depth Vs Temperature
2020−01−30
2020−05−01
2020−05−15
2020−06−03
2020−06−10
2020−06−26
2020−07−10
2020−07−23
2020−08−06
2020−08−20
2020−09−08
2020−09−18
2020−10−19
Depth (m)
0.0
2.5
5.0
7.5
10
20
Temperature (deg C)



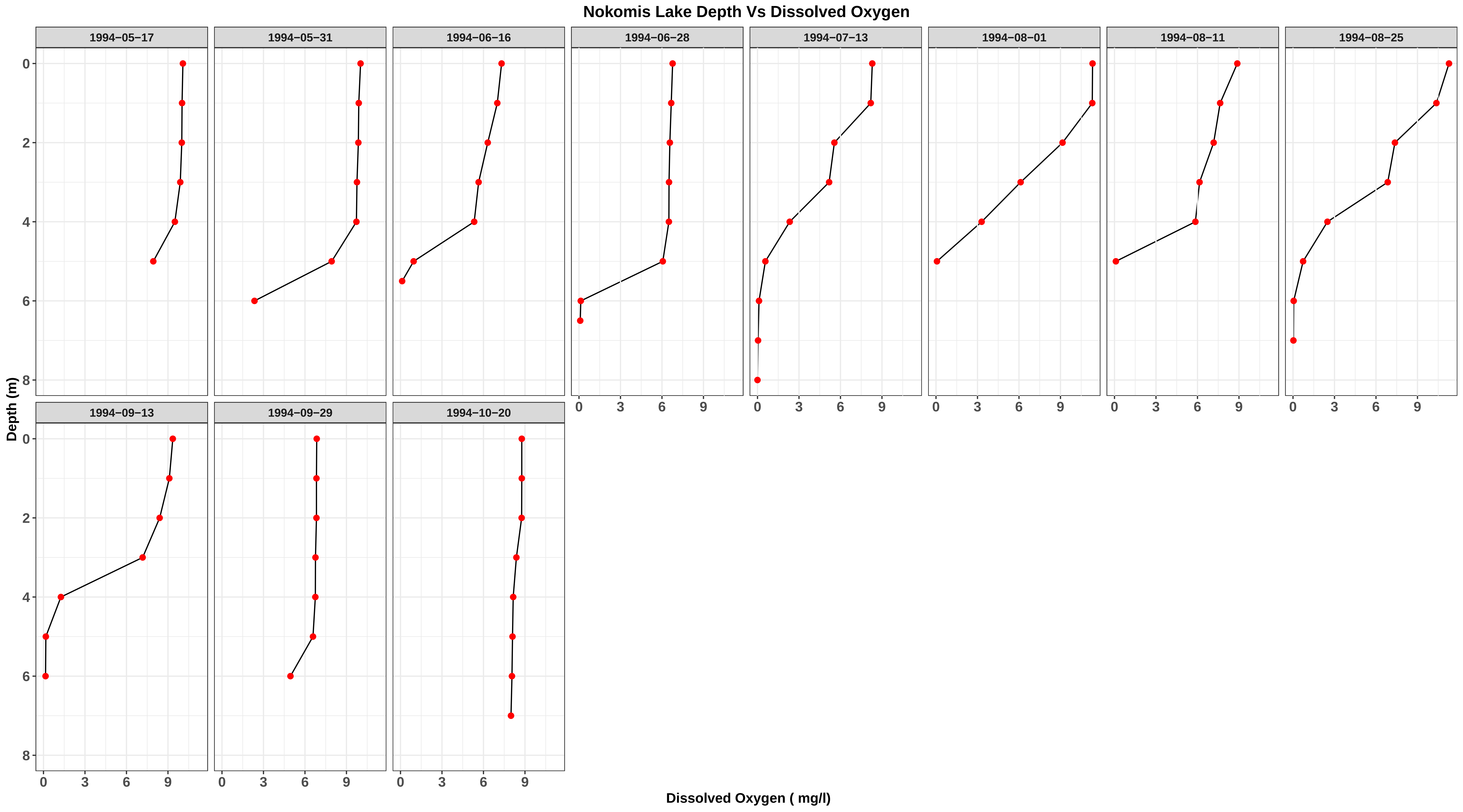
Nokomis Lake Depth Vs Temperature
2021−01−29
2021−04−22
2021−05−13
2021−05−28
2021−06−14
2021−06−24
2021−07−16
2021−08−03
2021−08−12
2021−08−26
2021−09−16
2021−09−30
2021−11−04
Depth (m)
0
2
4
6
8
0
10
20
Temperature (deg C)

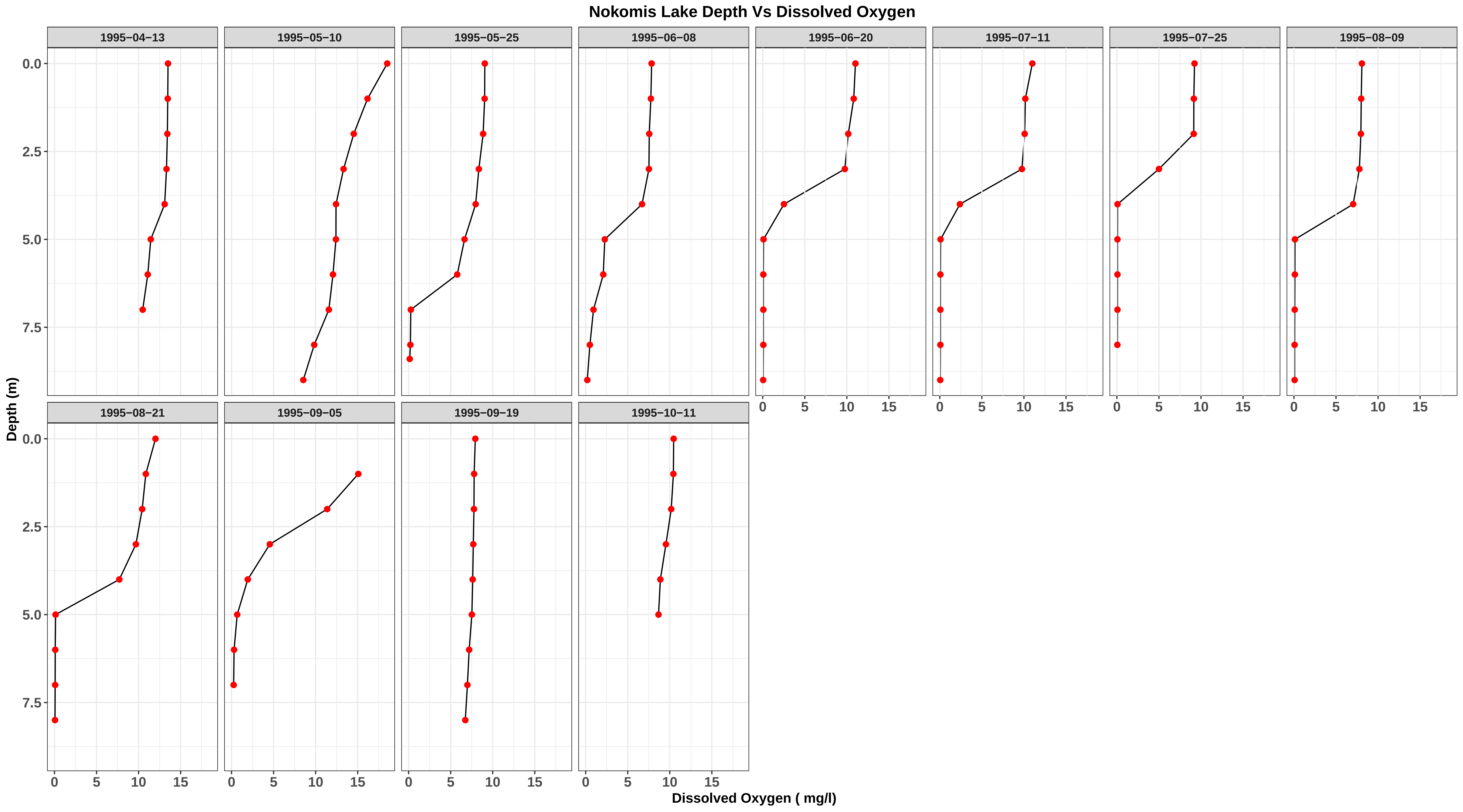


Nokomis Lake Depth Vs Dissolved Oxygen
1992−05−07
1992−06−12
1992−06−22
1992−07−08
1992−07−21
1992−08−18
1992−09−15
1992−10−30
Depth (m)
0
2
4
6
0
5
10
Dissolved Oxygen (mg/l)

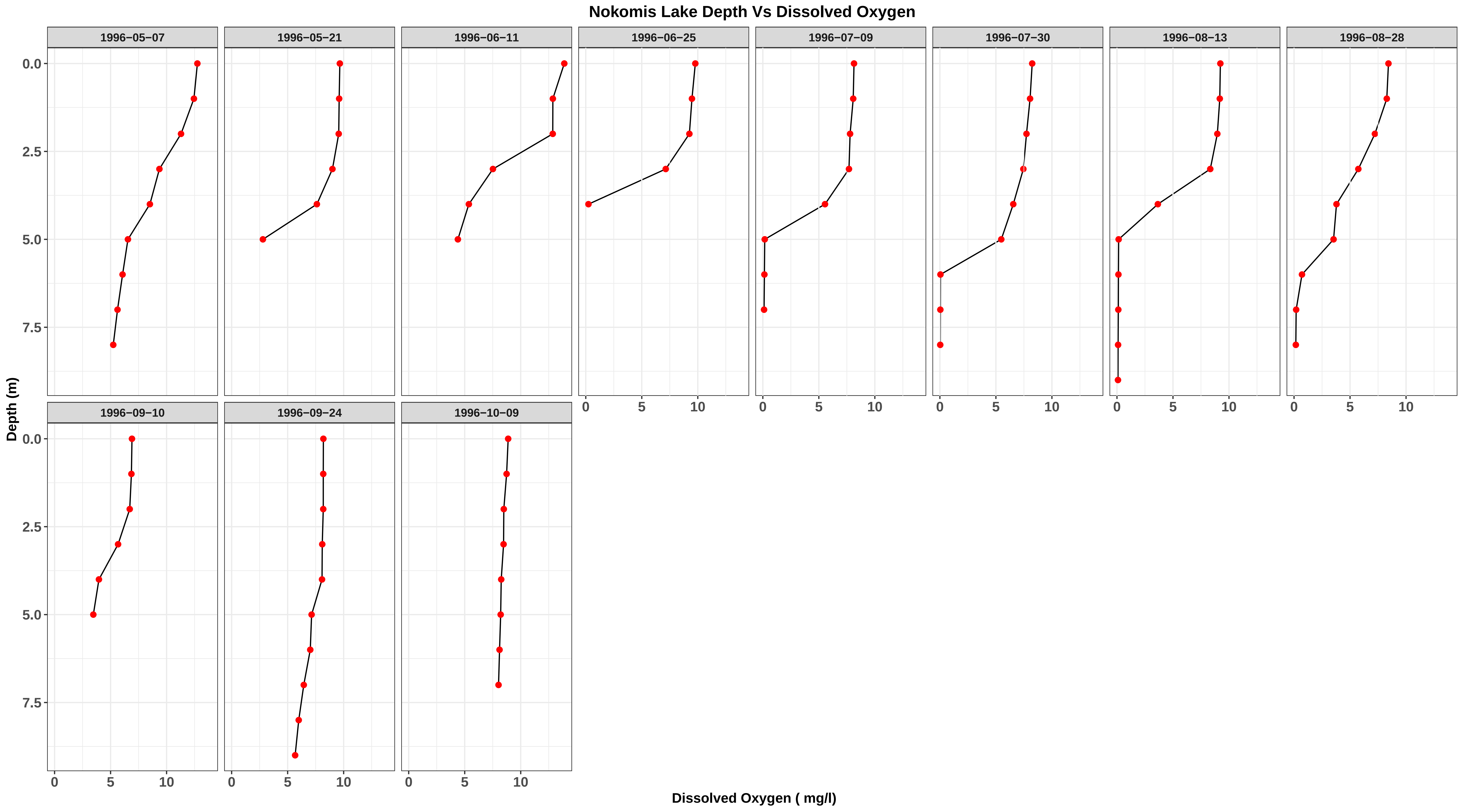


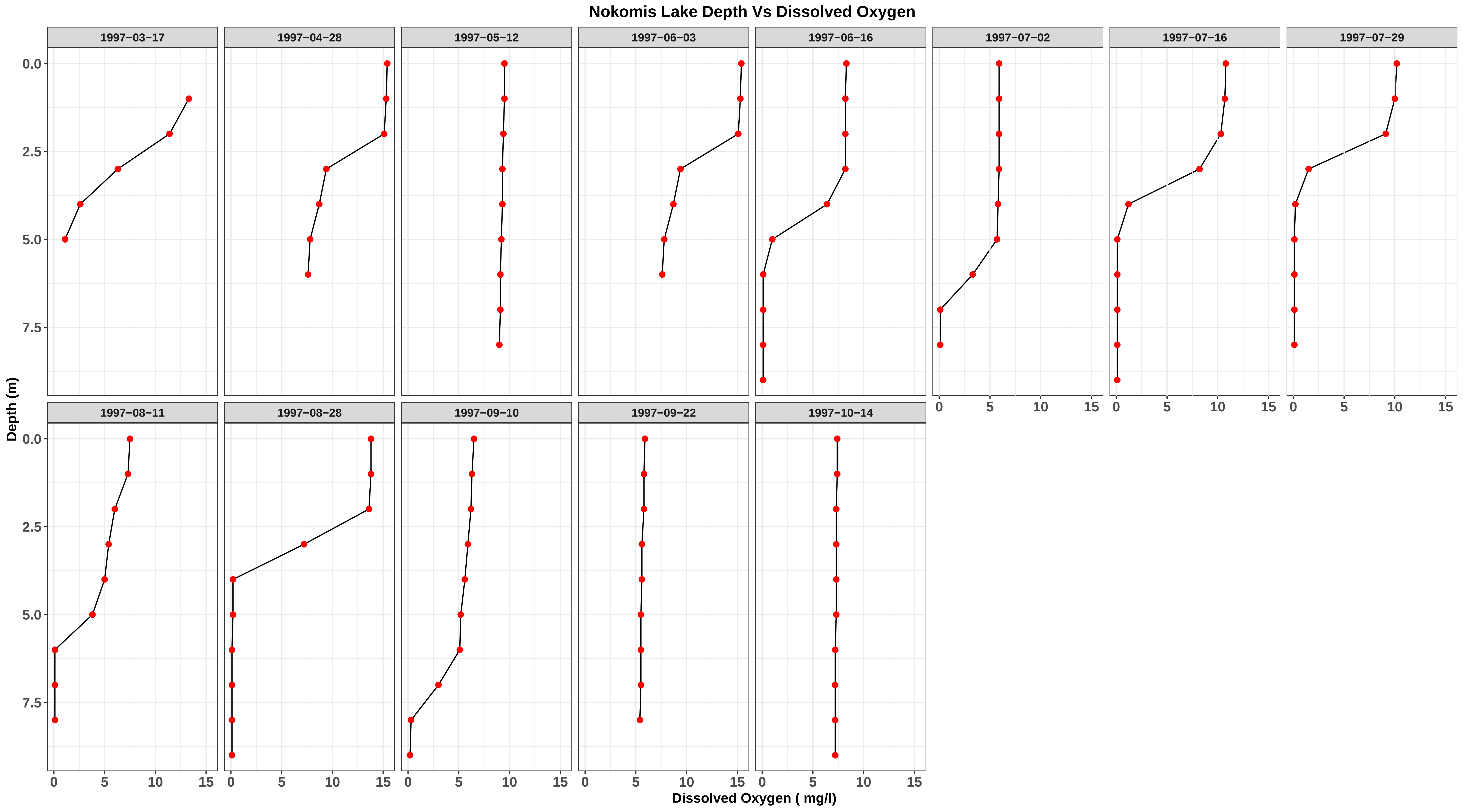
Nokomis Lake Depth Vs Dissolved Oxygen
1993−05−26
1993−07−12
1993−07−26
1993−08−10
1993−08−25
1993−09−08
1993−10−14
Depth (m)
0
2
4
6
0
3
6
9
Dissolved Oxygen (mg/l)


Nokomis Lake Depth Vs Dissolved Oxygen
1994−05−17
1994−05−31
1994−06−16
1994−06−28
1994−07−13
1994−08−01
1994−08−11
1994−08−25
1994−09−13
1994−09−29
1994−10−20
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
0
3
6
9

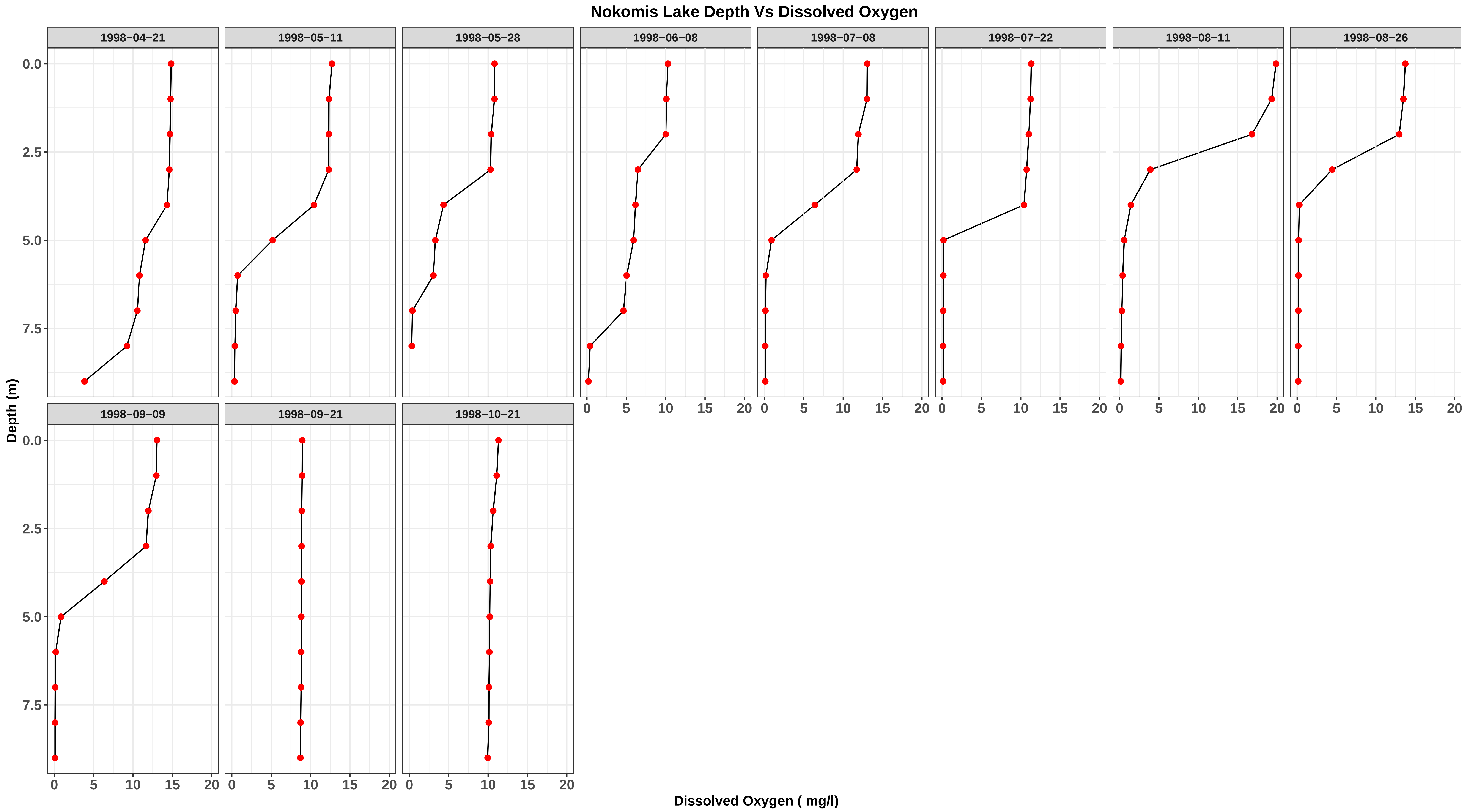


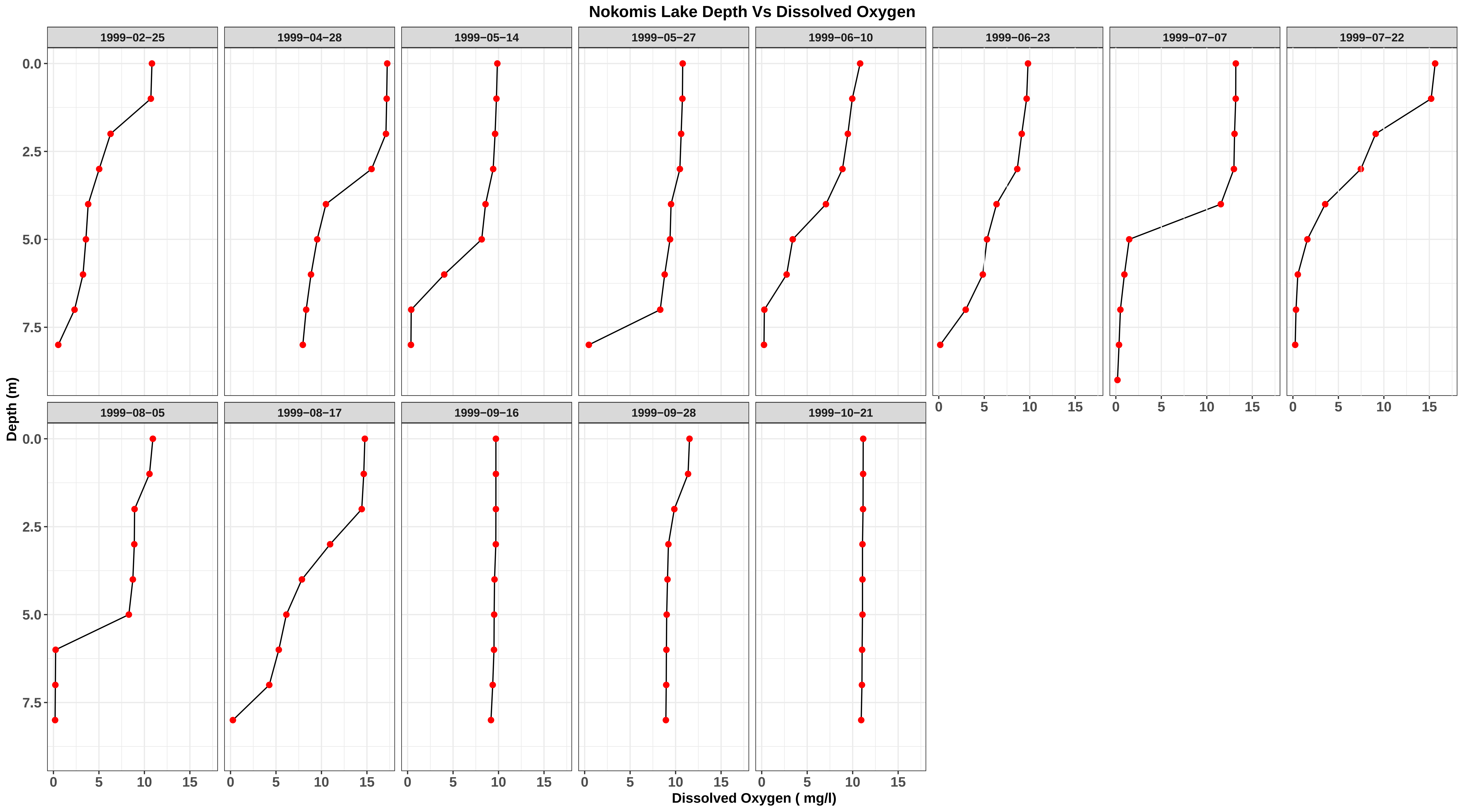
Nokomis Lake Depth Vs Dissolved Oxygen
1995−04−13
1995−05−10
1995−05−25
1995−06−08
1995−06−20
1995−07−11
1995−07−25
1995−08−09
1995−08−21
1995−09−05
1995−09−19
1995−10−11
Depth (m)
0.0
2.5
5.0
7.5
0
5
10
15
Dissolved Oxygen (mg/l)


Nokomis Lake Depth Vs Dissolved Oxygen
1996−05−07
1996−05−21
1996−06−11
1996−06−25
1996−07−09
1996−07−30
1996−08−13
1996−08−28
1996−09−10
1996−09−24
1996−10−09
Depth (m)
0.0
2.5
5.0
7.5
0
5
10
Dissolved Oxygen (mg/l)

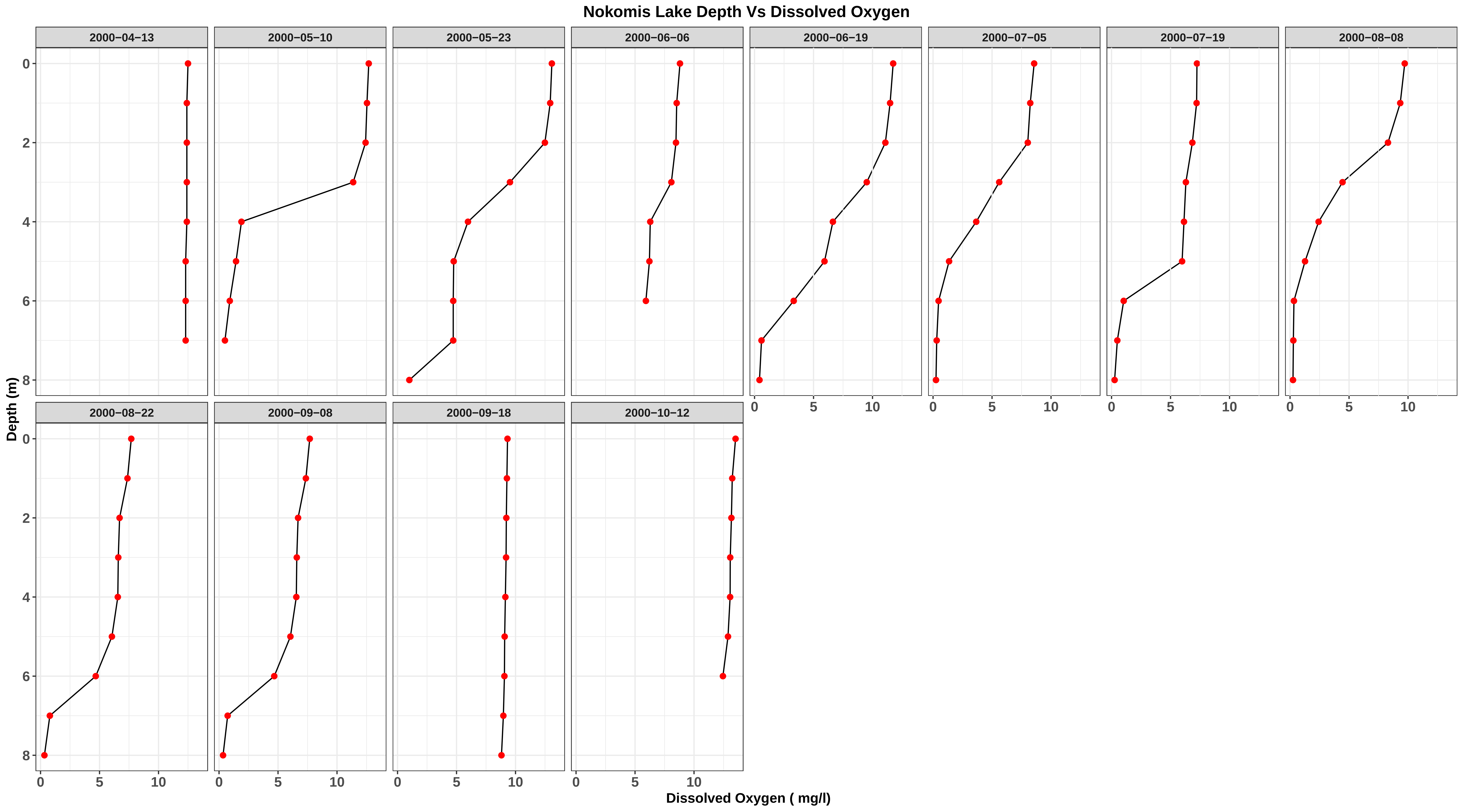


Nokomis Lake Depth Vs Dissolved Oxygen
1997−03−17
1997−04−28
1997−05−12
1997−06−03
1997−06−16
1997−07−02
1997−07−16
1997−07−29
1997−08−11
1997−08−28
1997−09−10
1997−09−22
1997−10−14
Depth (m)
0.0
2.5
5.0
7.5
0
5
10
15
Dissolved Oxygen (mg/l)

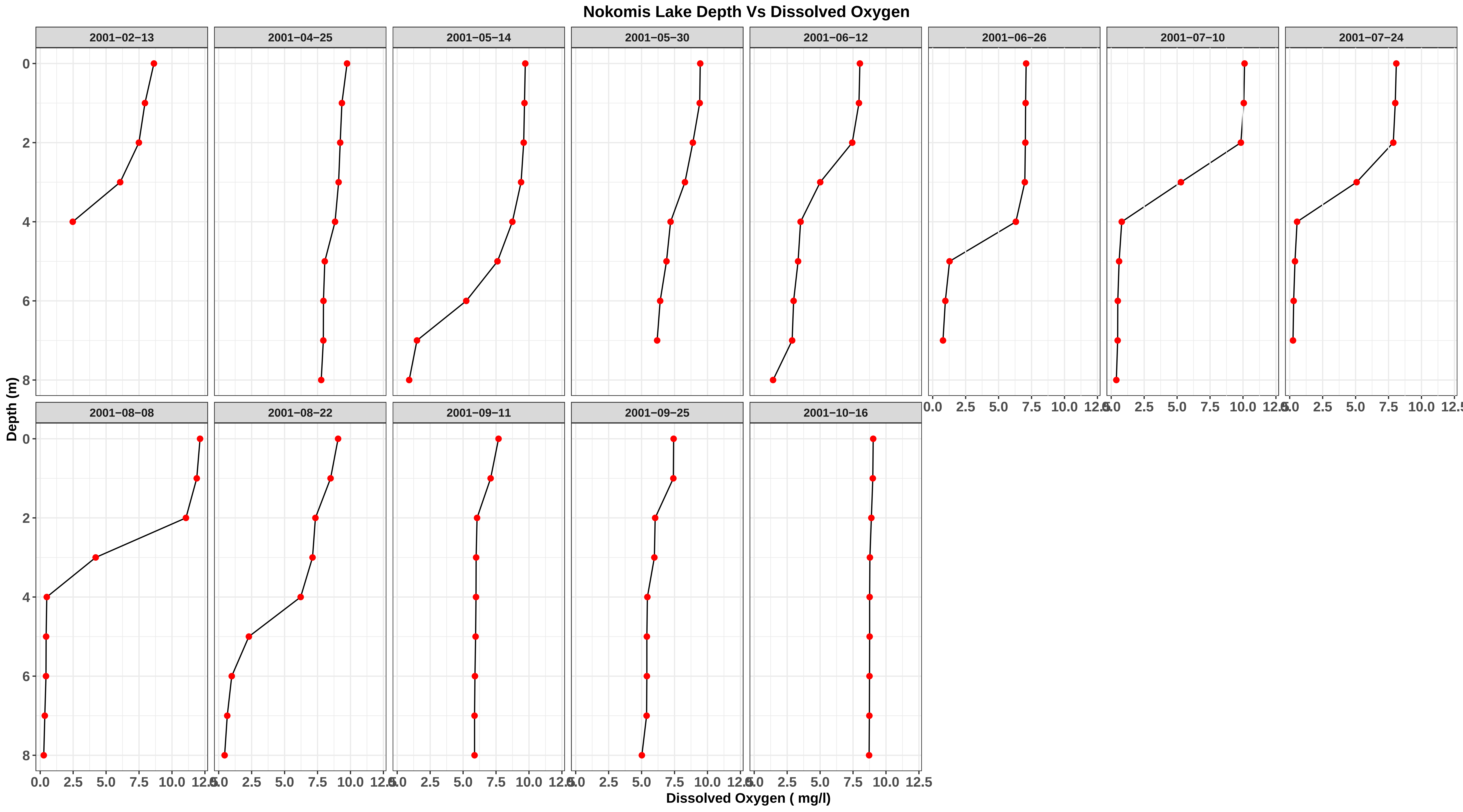

Nokomis Lake Depth Vs Dissolved Oxygen
1998−04−21
1998−05−11
1998−05−28
1998−06−08
1998−07−08
1998−07−22
1998−08−11
1998−08−26
1998−09−09
1998−09−21
1998−10−21
Depth (m)
0.0
2.5
5.0
7.5
0
5
10
15
20
Dissolved Oxygen (mg/l)



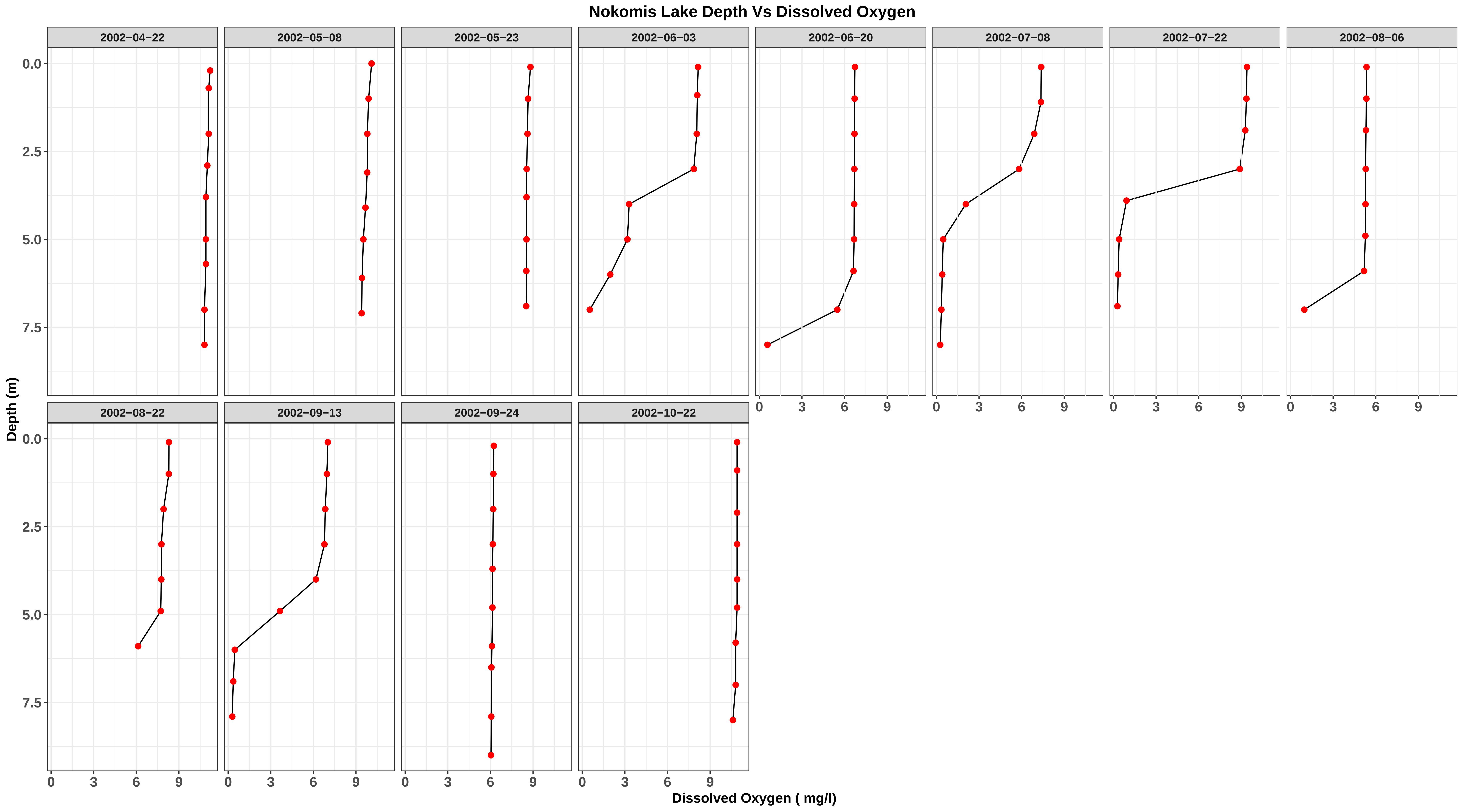
Nokomis Lake Depth Vs Dissolved Oxygen
1999−02−25
1999−04−28
1999−05−14
1999−05−27
1999−06−10
1999−06−23
1999−07−07
1999−07−22
1999−08−05
1999−08−17
1999−09−16
1999−09−28
1999−10−21
Depth (m)
0.0
2.5
5.0
7.5
0
5
10
15
Dissolved Oxygen (mg/l)



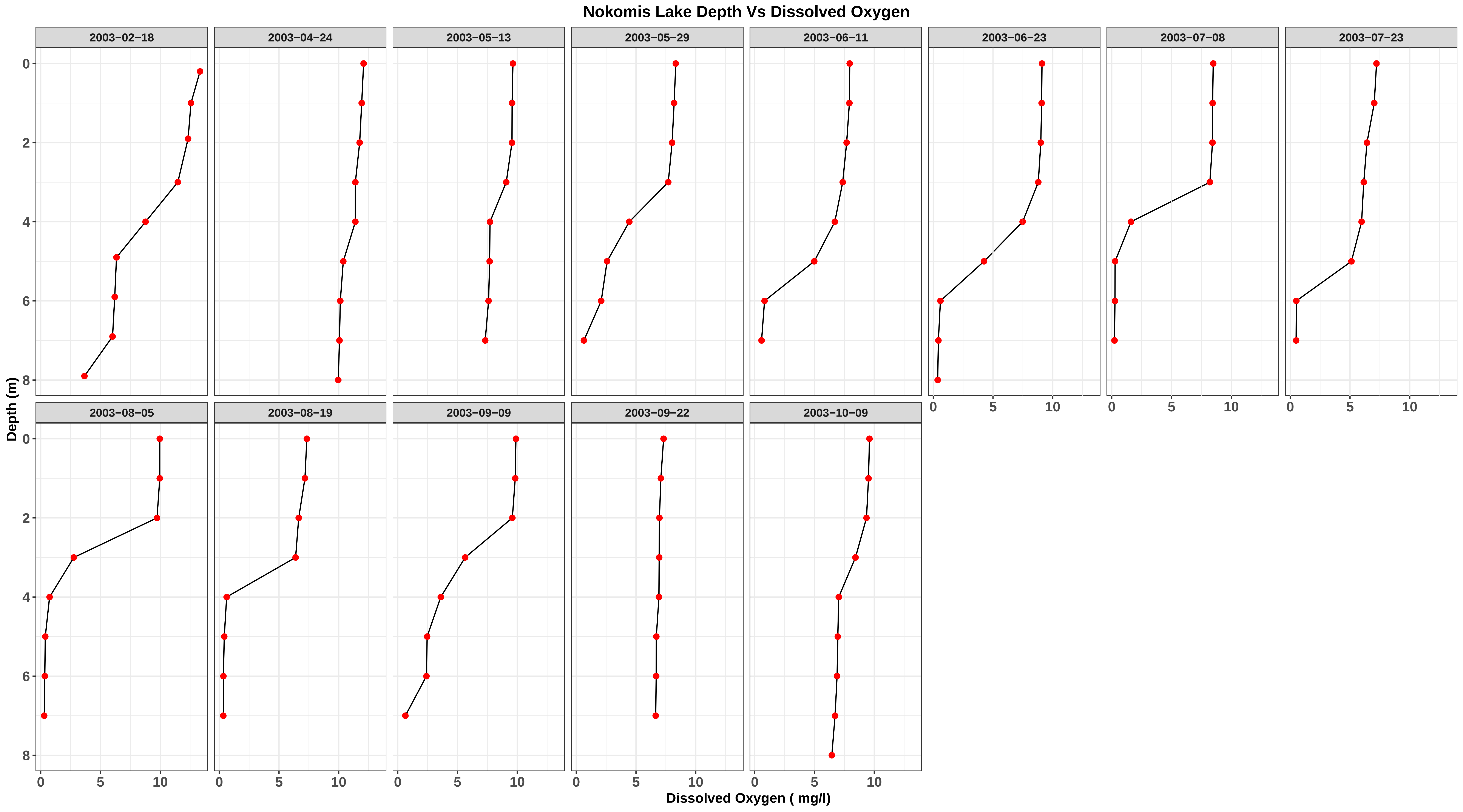
Nokomis Lake Depth Vs Dissolved Oxygen
2000−04−13
2000−05−10
2000−05−23
2000−06−06
2000−06−19
2000−07−05
2000−07−19
2000−08−08
2000−08−22
2000−09−08
2000−09−18
2000−10−12
Depth (m)
0
2
4
6
8
0
5
10
Dissolved Oxygen (mg/l)



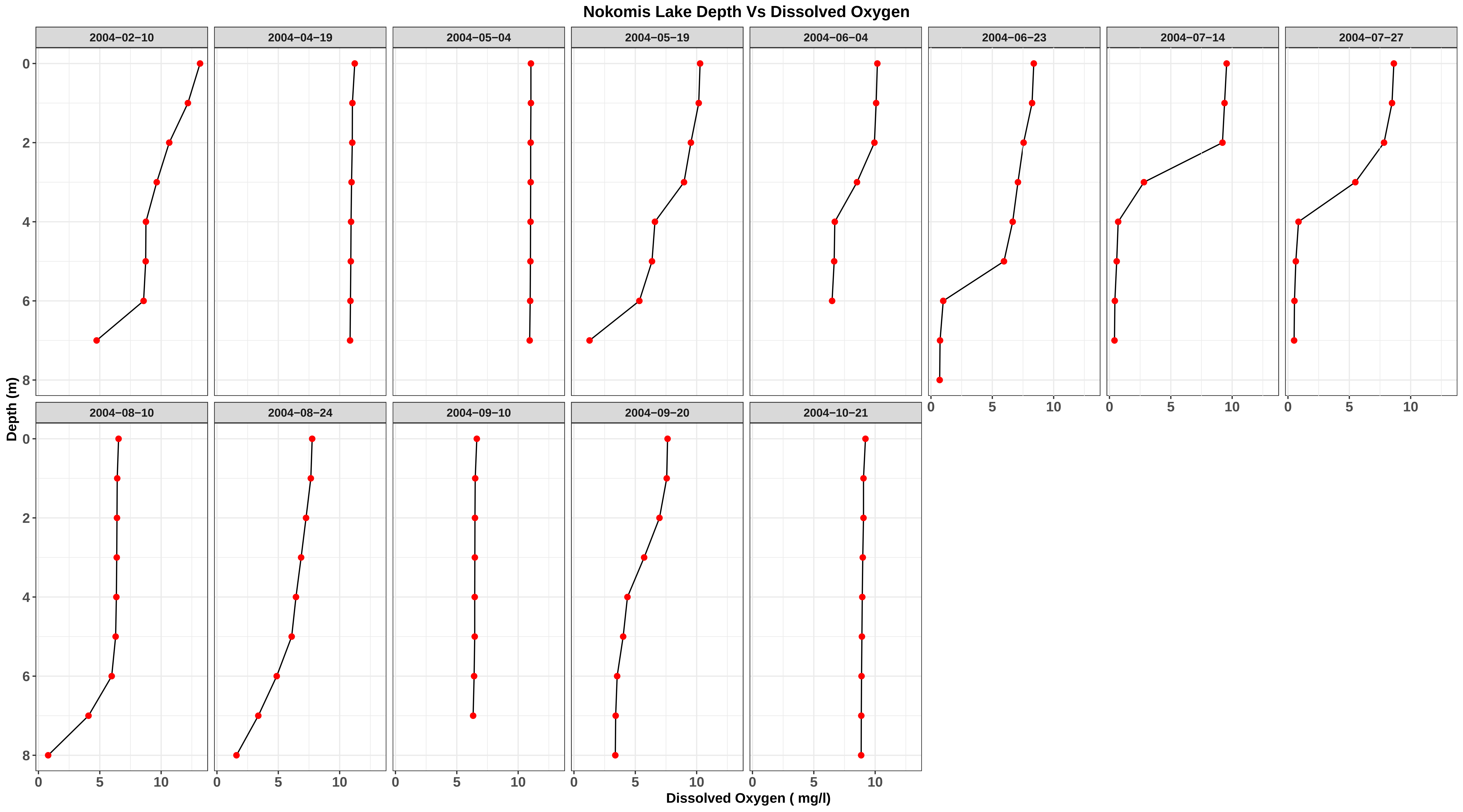
Nokomis Lake Depth Vs Dissolved Oxygen
2001−02−13
2001−04−25
2001−05−14
2001−05−30
2001−06−12
2001−06−26
2001−07−10
2001−07−24
2001−08−08
2001−08−22
2001−09−11
2001−09−25
2001−10−16
Depth (m)
0
2
4
6
8
0.0
2.5
5.0
7.5
10.0
12.5
Dissolved Oxygen (mg/l)



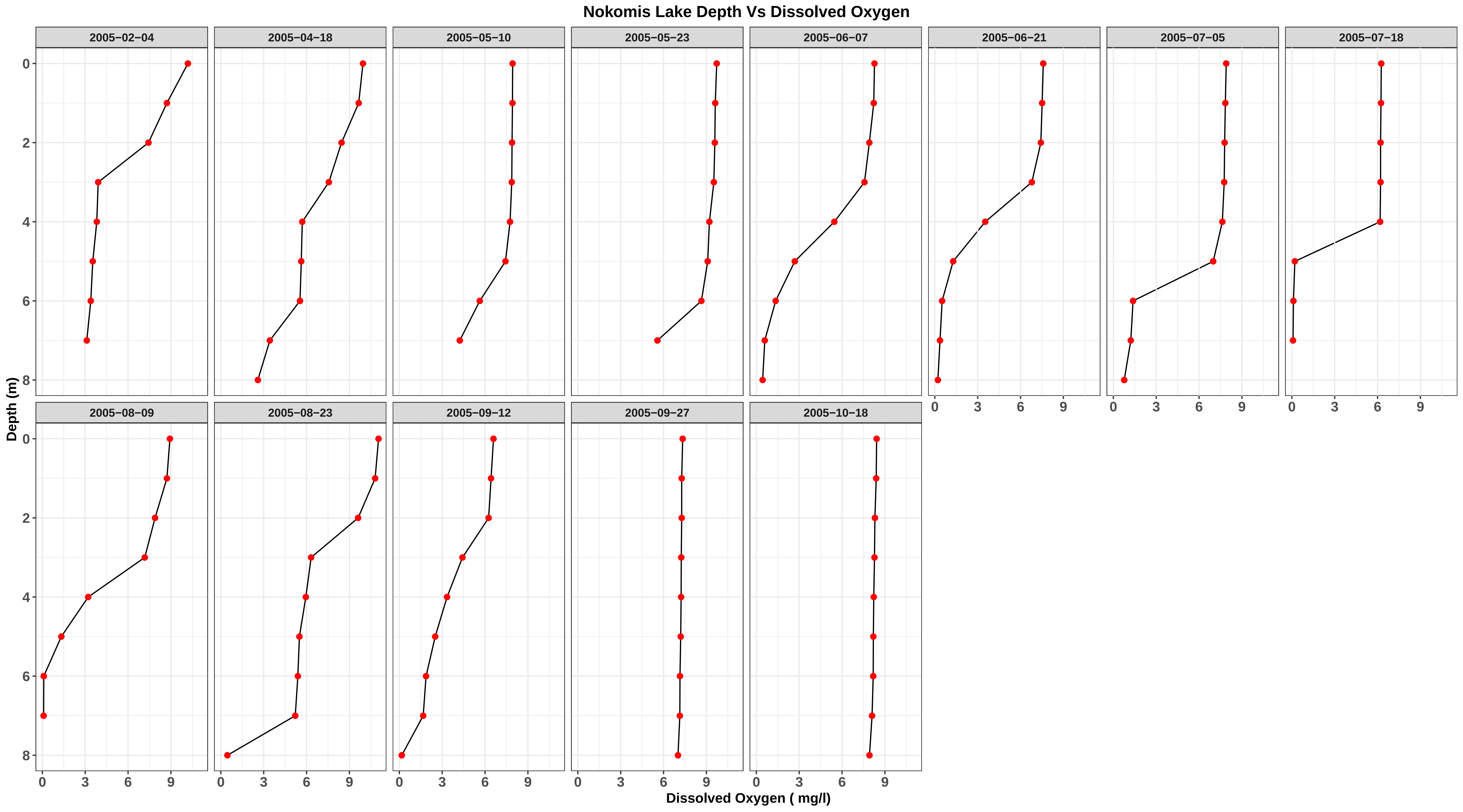
Nokomis Lake Depth Vs Dissolved Oxygen
2002−04−22
2002−05−08
2002−05−23
2002−06−03
2002−06−20
2002−07−08
2002−07−22
2002−08−06
2002−08−22
2002−09−13
2002−09−24
2002−10−22
Depth (m)
0.0
2.5
5.0
7.5
0
3
6
9
Dissolved Oxygen (mg/l)



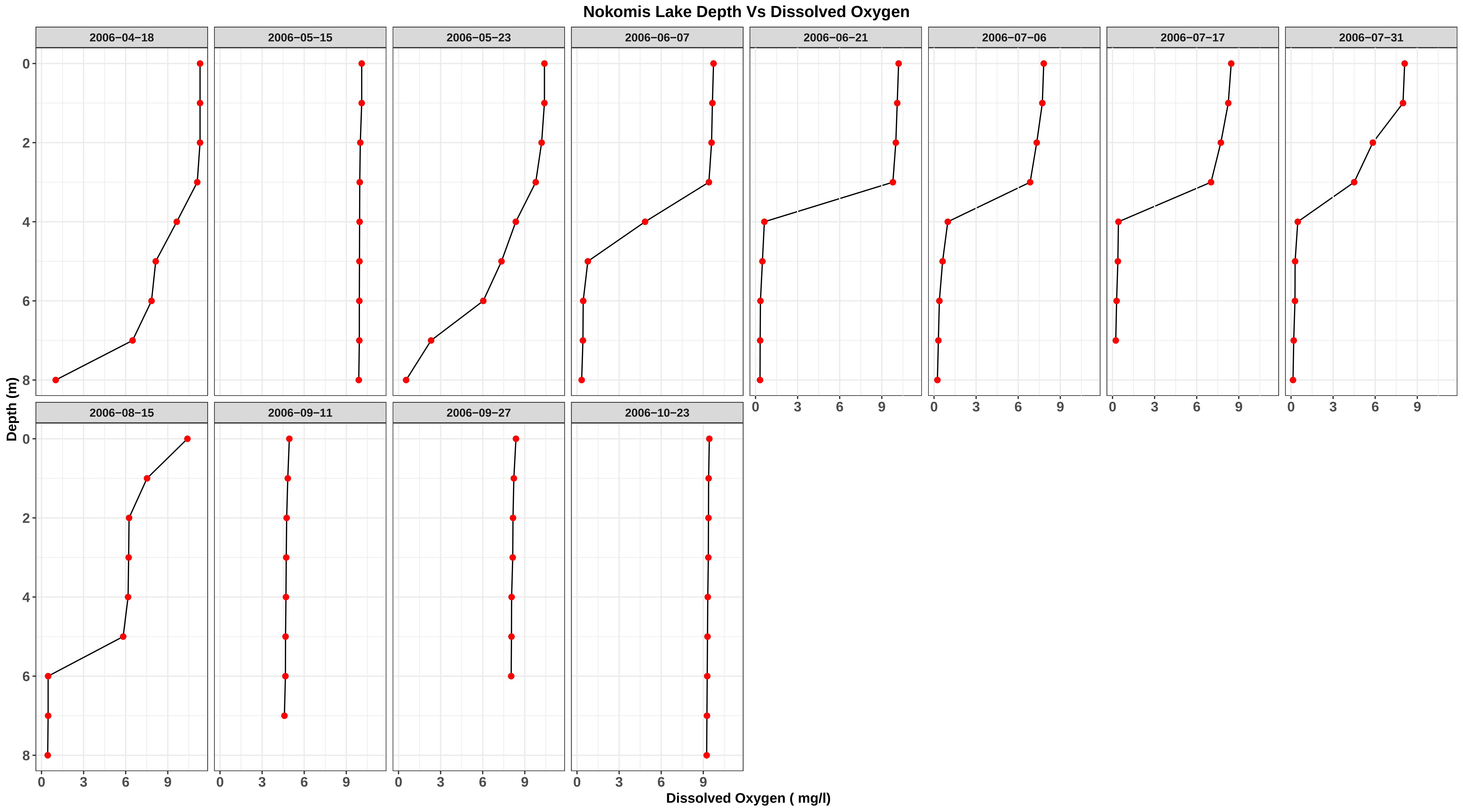
Nokomis Lake Depth Vs Dissolved Oxygen
2003−02−18
2003−04−24
2003−05−13
2003−05−29
2003−06−11
2003−06−23
2003−07−08
2003−07−23
2003−08−05
2003−08−19
2003−09−09
2003−09−22
2003−10−09
Depth (m)
0
2
4
6
8
0
5
10
Dissolved Oxygen (mg/l)



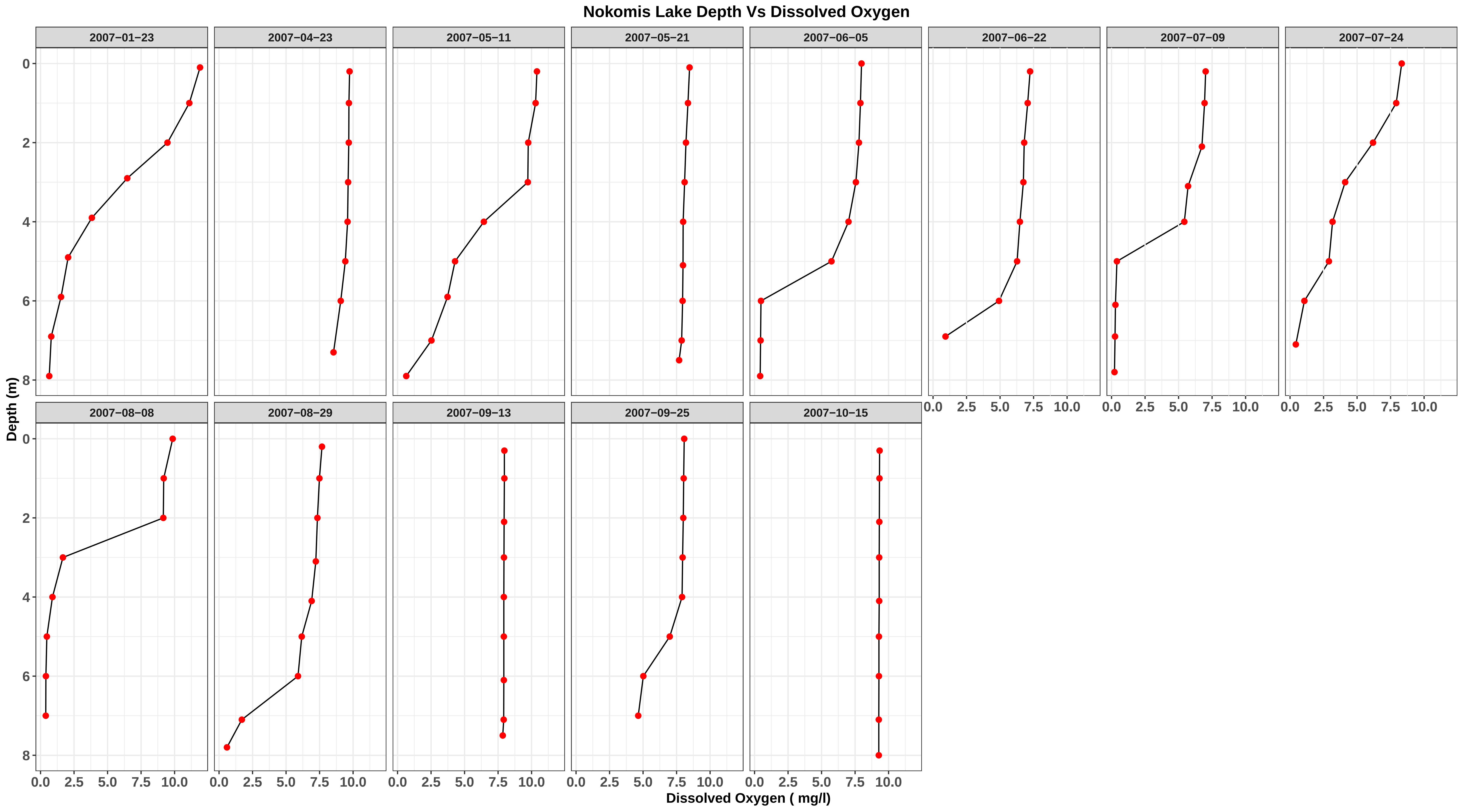
Nokomis Lake Depth Vs Dissolved Oxygen
2004−02−10
2004−04−19
2004−05−04
2004−05−19
2004−06−04
2004−06−23
2004−07−14
2004−07−27
2004−08−10
2004−08−24
2004−09−10
2004−09−20
2004−10−21
Depth (m)
0
2
4
6
8
0
5
10
Dissolved Oxygen (mg/l)



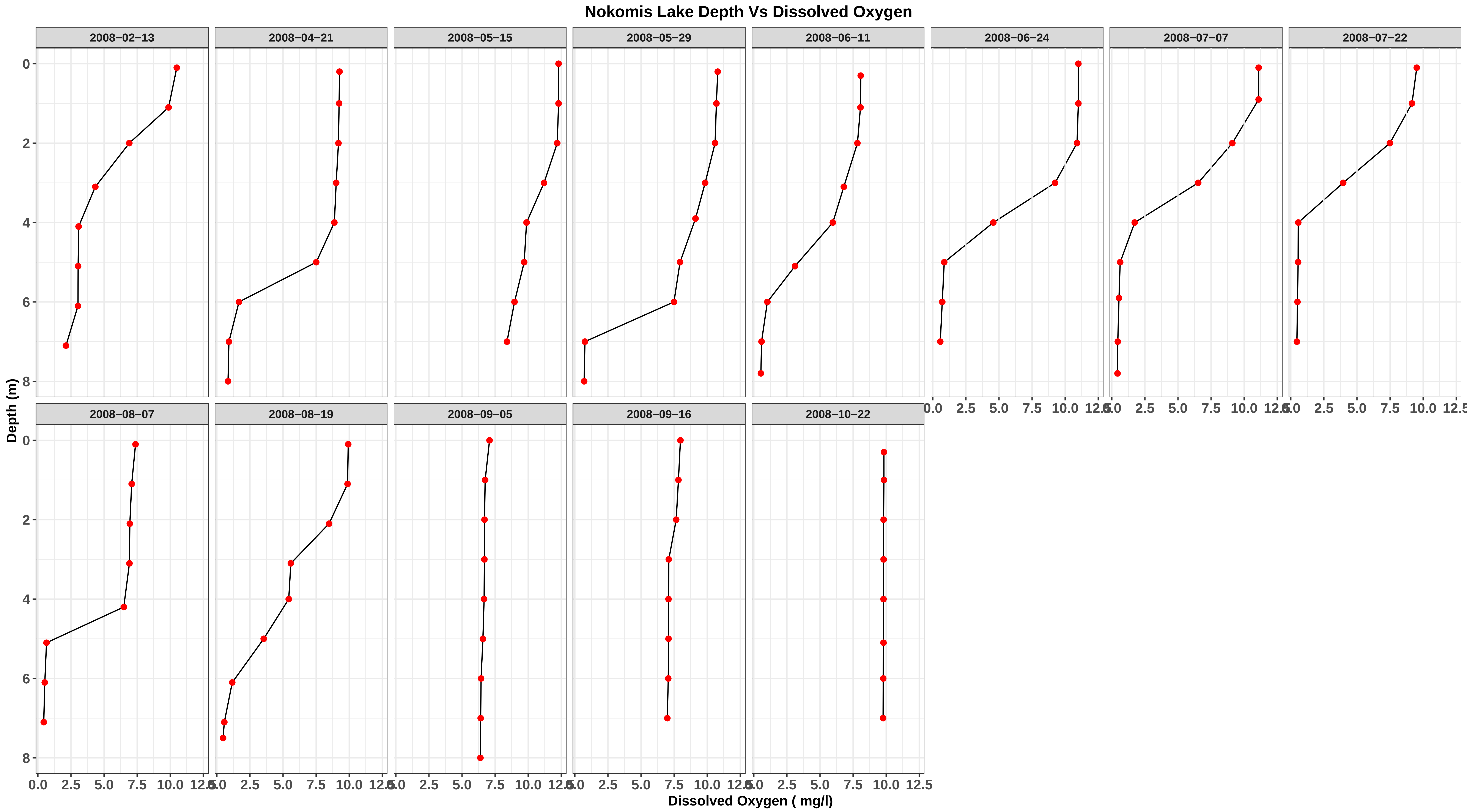
Nokomis Lake Depth Vs Dissolved Oxygen
2005−02−04
2005−04−18
2005−05−10
2005−05−23
2005−06−07
2005−06−21
2005−07−05
2005−07−18
2005−08−09
2005−08−23
2005−09−12
2005−09−27
2005−10−18
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
0
3
6
9



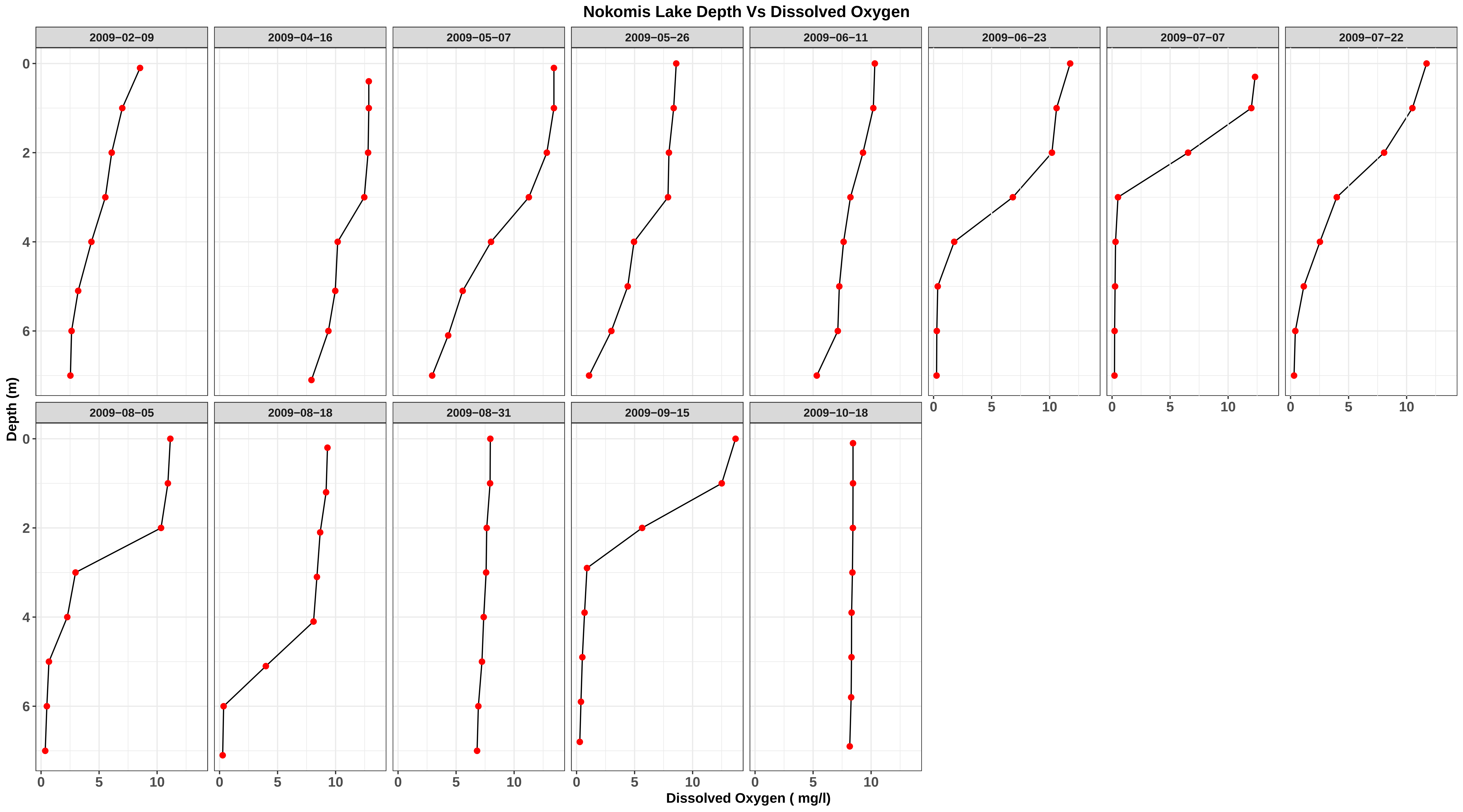
Nokomis Lake Depth Vs Dissolved Oxygen
2006−04−18
2006−05−15
2006−05−23
2006−06−07
2006−06−21
2006−07−06
2006−07−17
2006−07−31
2006−08−15
2006−09−11
2006−09−27
2006−10−23
Depth (m)
0
2
4
6
8
0
3
6
9
Dissolved Oxygen (mg/l)



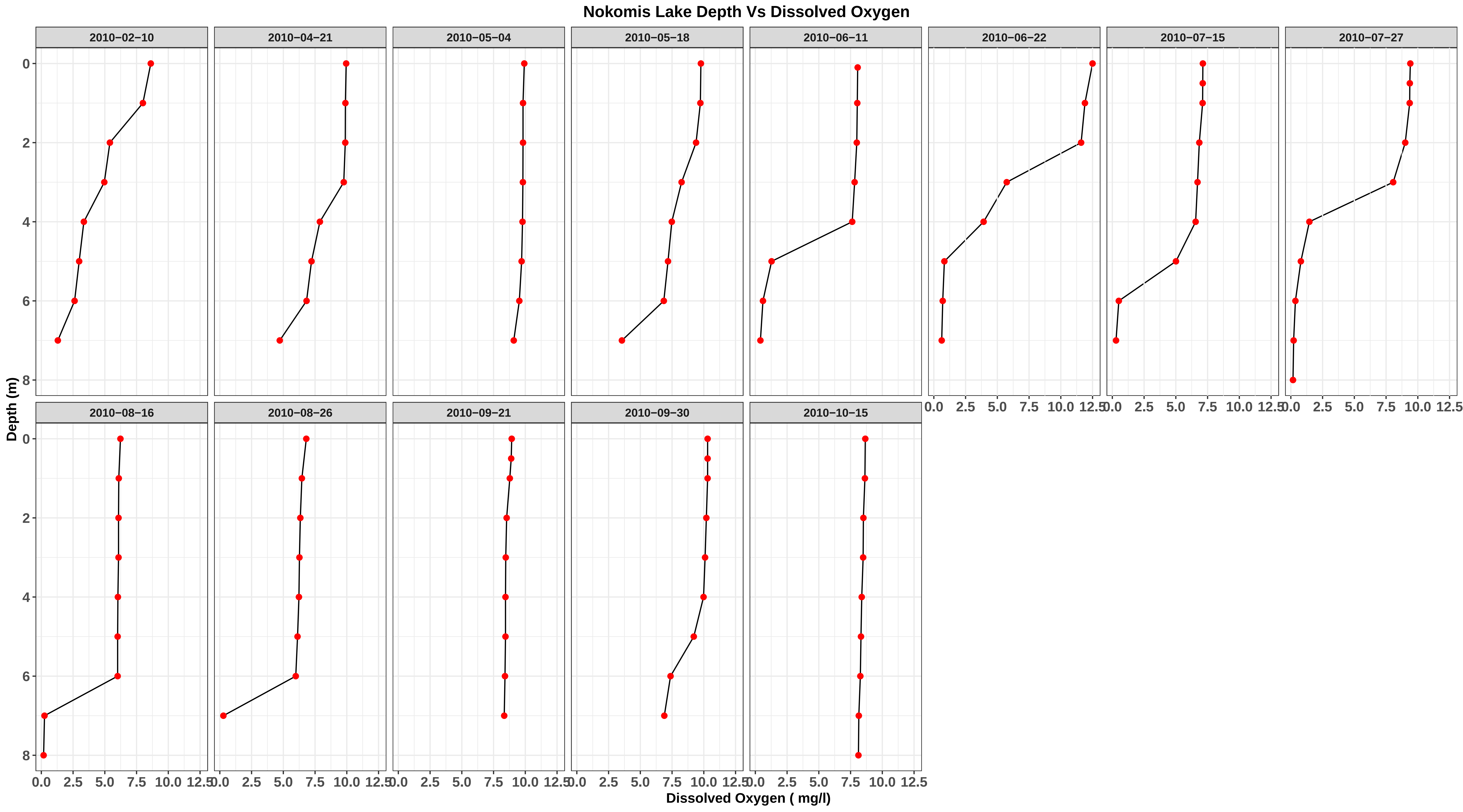
Nokomis Lake Depth Vs Dissolved Oxygen
2007−01−23
2007−04−23
2007−05−11
2007−05−21
2007−06−05
2007−06−22
2007−07−09
2007−07−24
2007−08−08
2007−08−29
2007−09−13
2007−09−25
2007−10−15
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
0.0
2.5
5.0
7.5
10.0

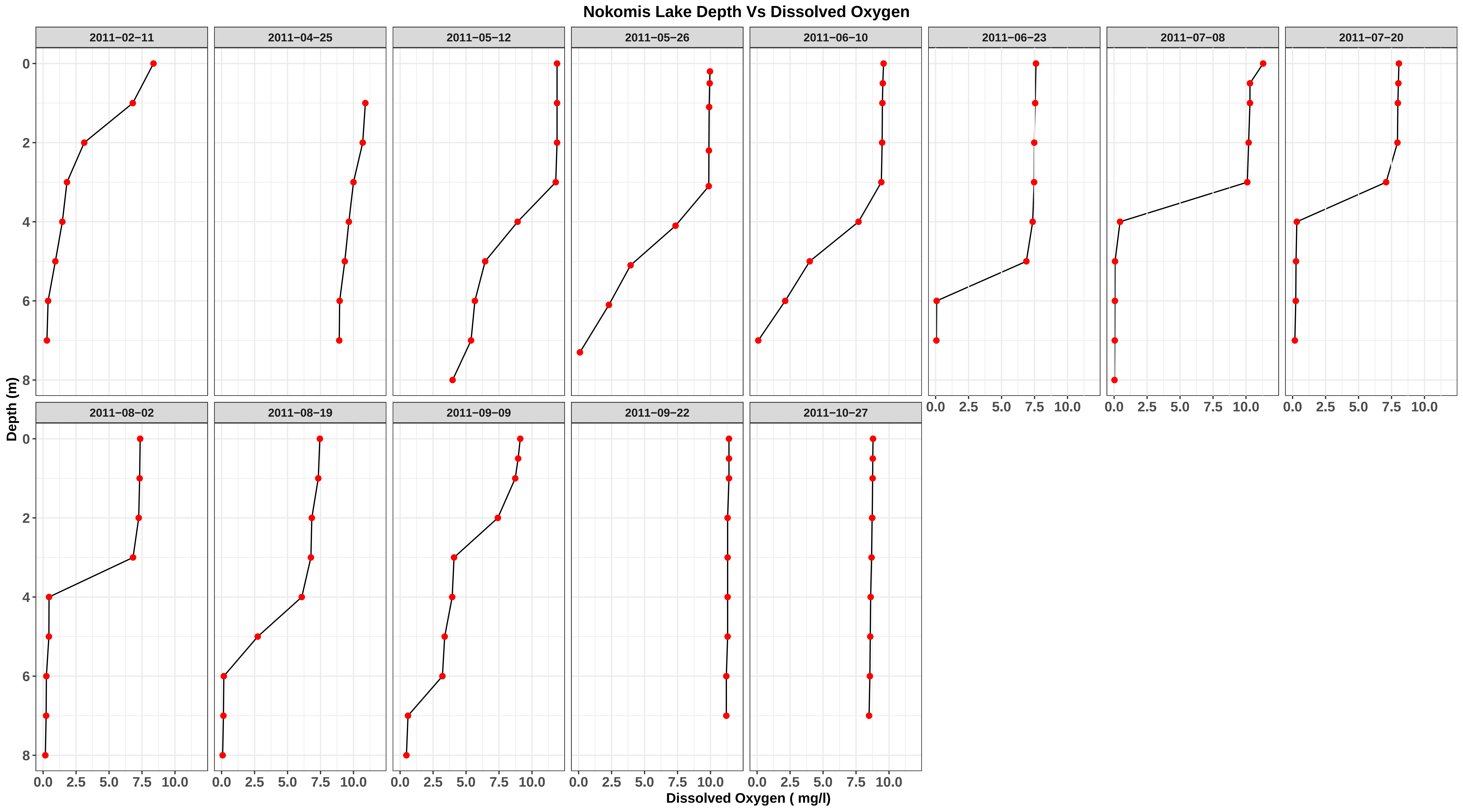


Nokomis Lake Depth Vs Dissolved Oxygen
2008−02−13
2008−04−21
2008−05−15
2008−05−29
2008−06−11
2008−06−24
2008−07−07
2008−07−22
2008−08−07
2008−08−19
2008−09−05
2008−09−16
2008−10−22
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
0.0 2.5 5.0 7.5 10.0 12.5

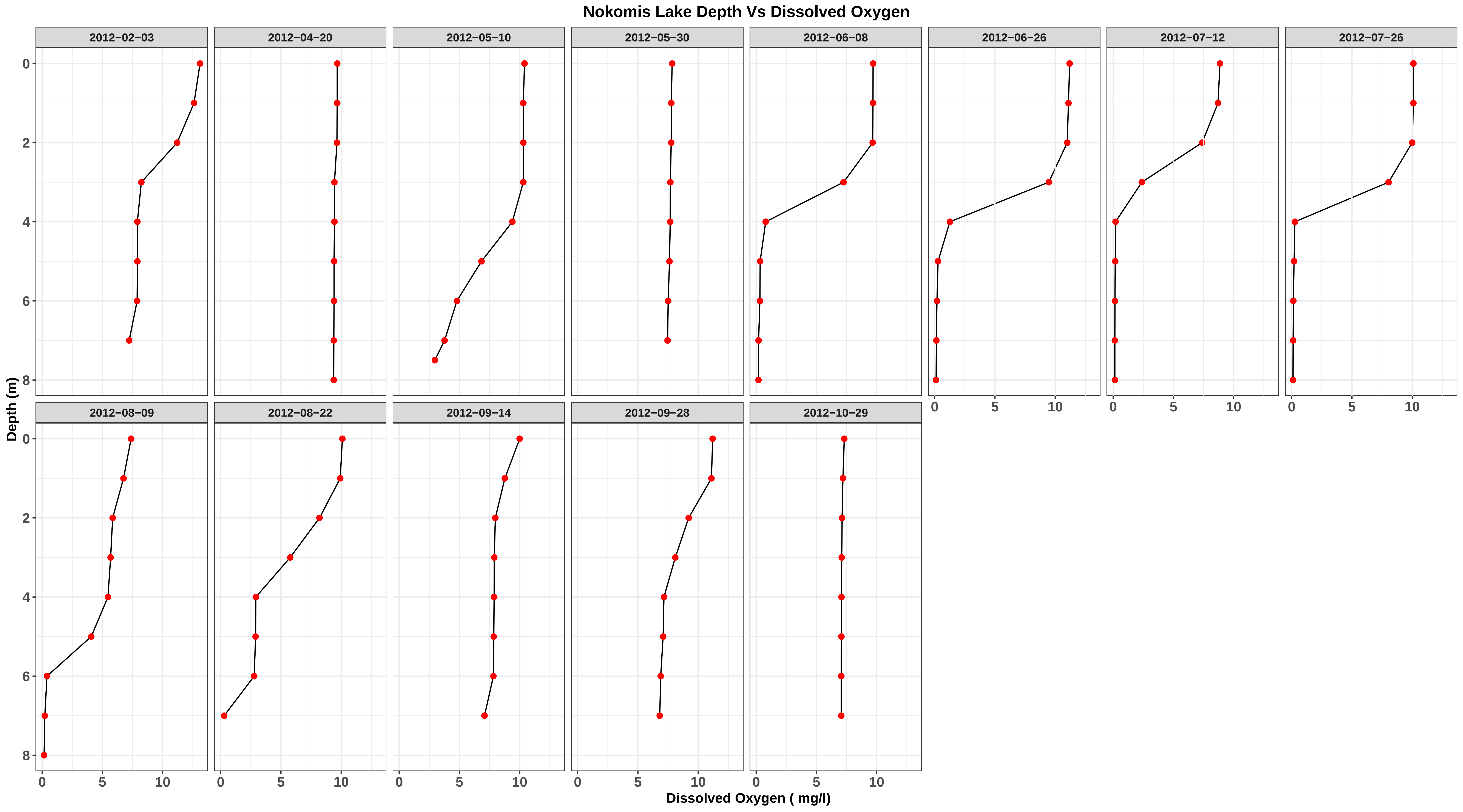


Nokomis Lake Depth Vs Dissolved Oxygen
2009−02−09
2009−04−16
2009−05−07
2009−05−26
2009−06−11
2009−06−23
2009−07−07
2009−07−22
2009−08−05
2009−08−18
2009−08−31
2009−09−15
2009−10−18
Depth (m)
0
2
4
6
0
5
10
Dissolved Oxygen (mg/l)

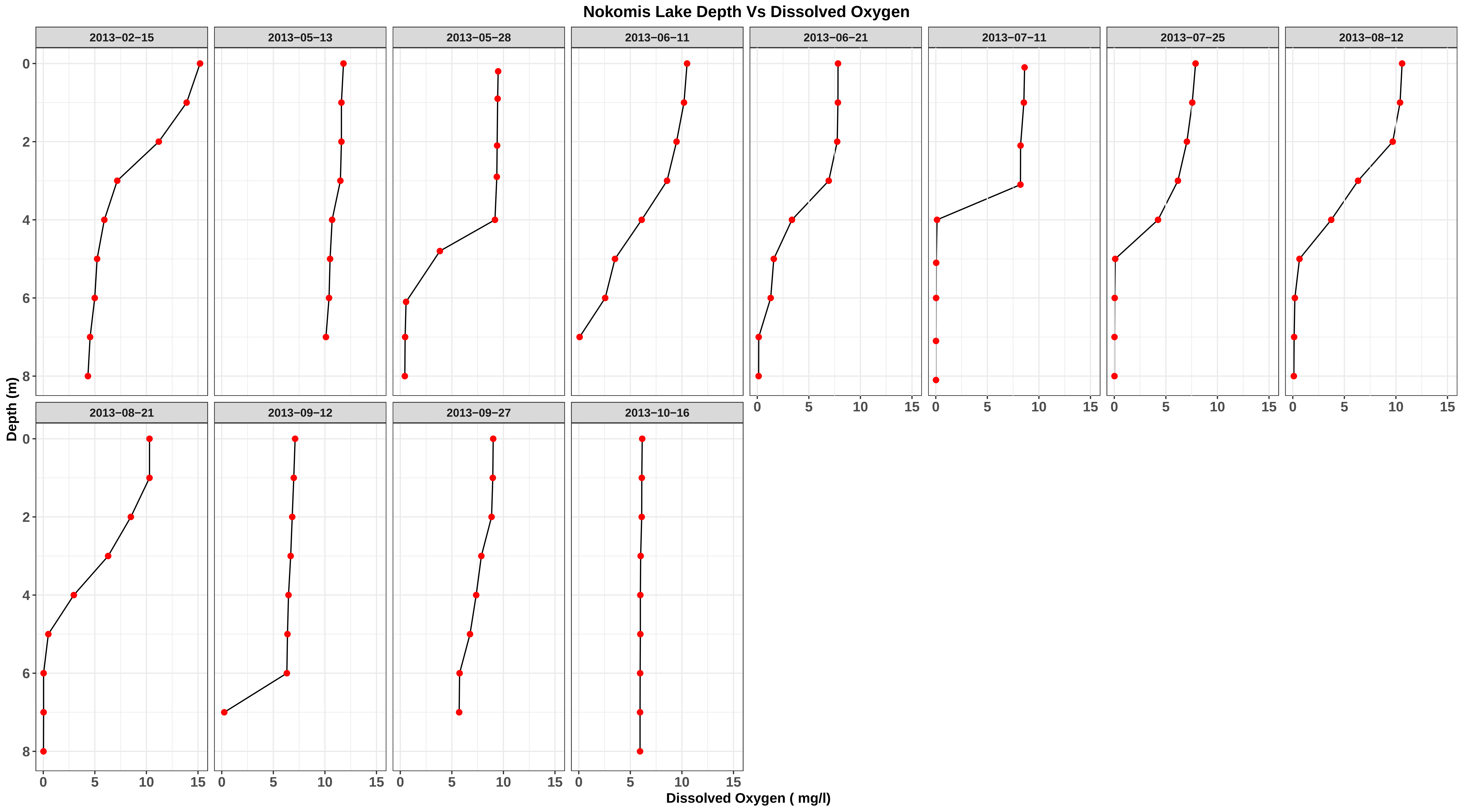

Nokomis Lake Depth Vs Dissolved Oxygen
2010−02−10
2010−04−21
2010−05−04
2010−05−18
2010−06−11
2010−06−22
2010−07−15
2010−07−27
2010−08−16
2010−08−26
2010−09−21
2010−09−30
2010−10−15
Depth (m)
0
2
4
6
8
0.0
2.5
5.0
7.5
10.0
12.5
Dissolved Oxygen (mg/l)

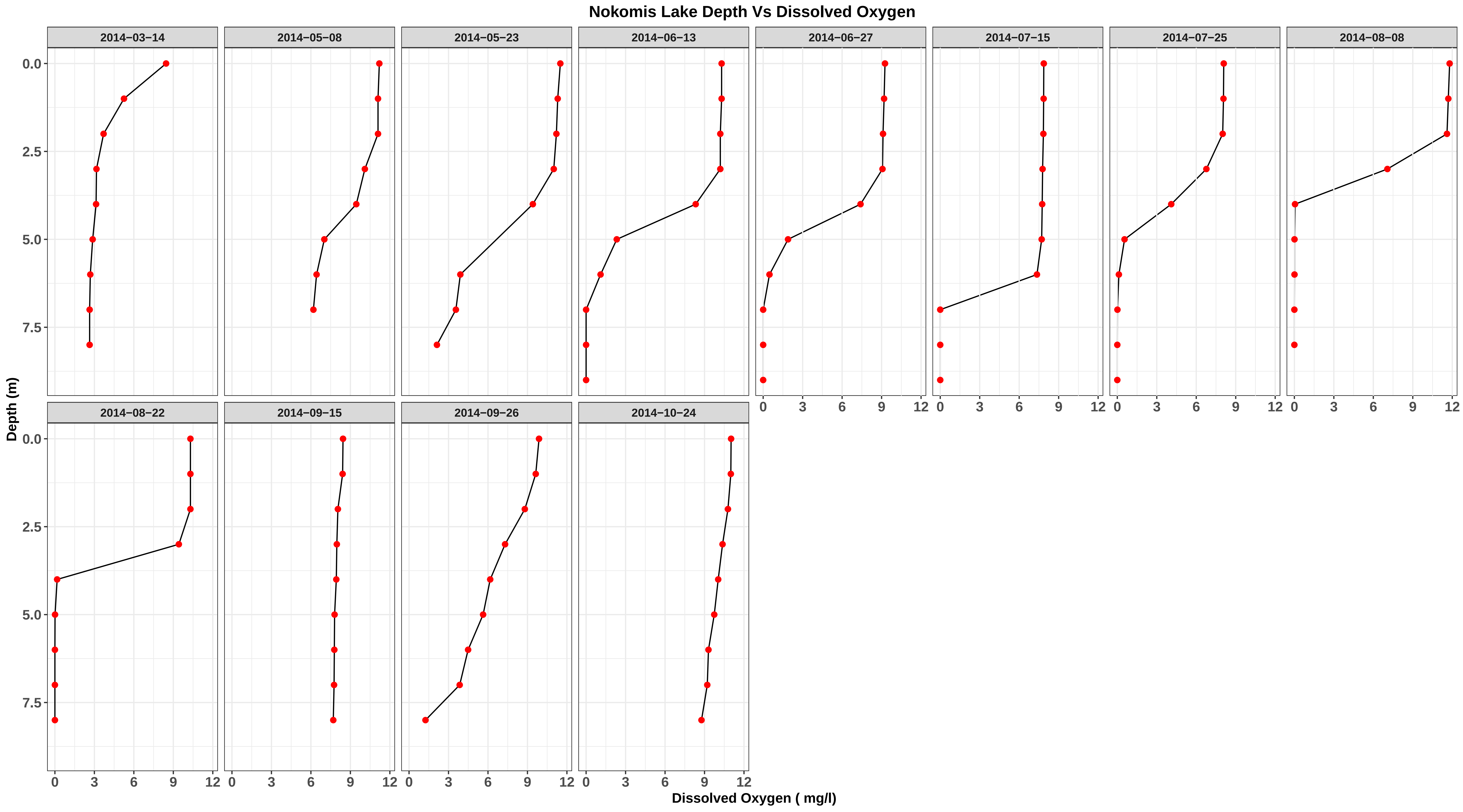


Nokomis Lake Depth Vs Dissolved Oxygen
2011−02−11
2011−04−25
2011−05−12
2011−05−26
2011−06−10
2011−06−23
2011−07−08
2011−07−20
2011−08−02
2011−08−19
2011−09−09
2011−09−22
2011−10−27
Depth (m)
0
2
4
6
8
0.0
2.5
5.0
7.5
10.0
Dissolved Oxygen (mg/l)

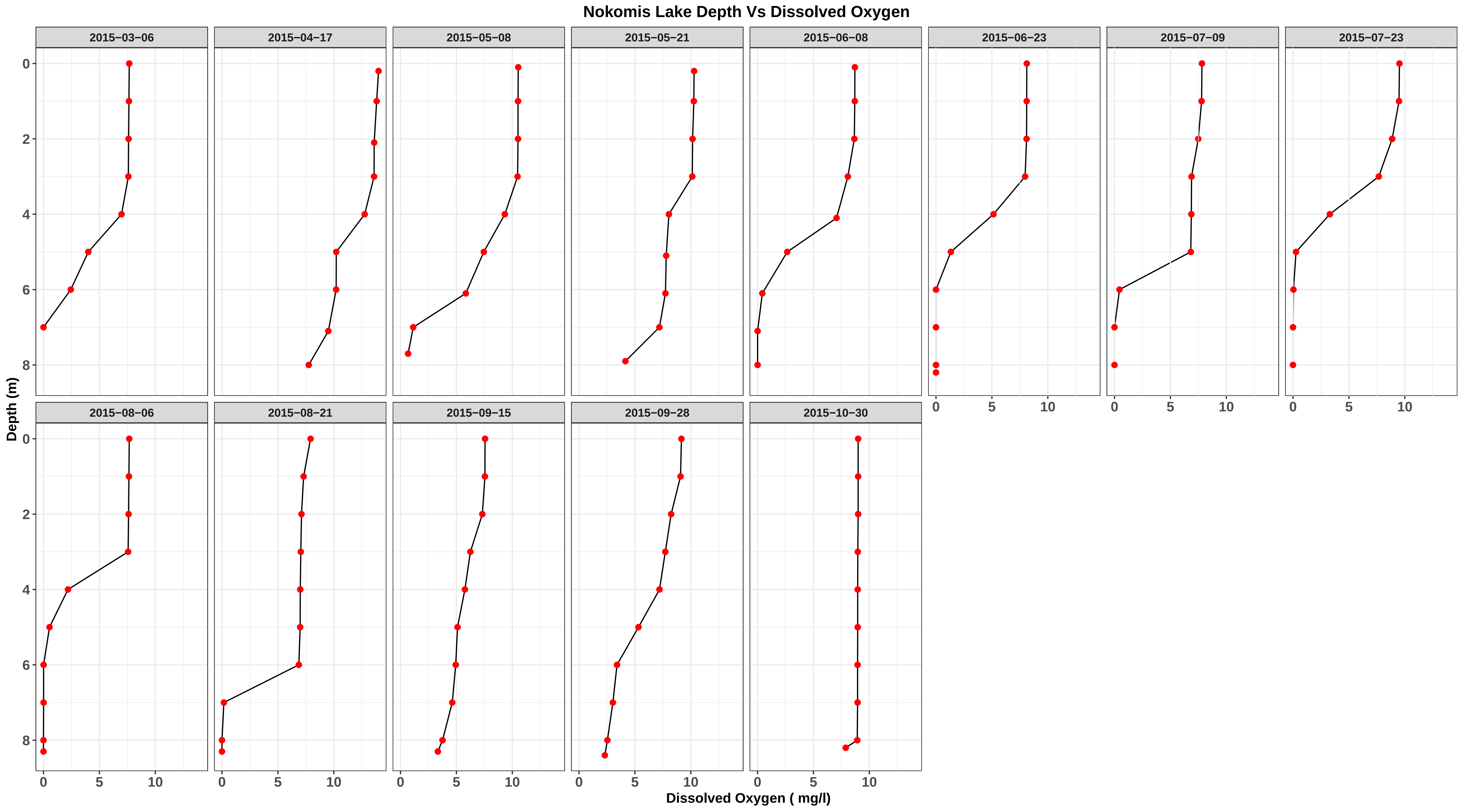


Nokomis Lake Depth Vs Dissolved Oxygen
2012−02−03
2012−04−20
2012−05−10
2012−05−30
2012−06−08
2012−06−26
2012−07−12
2012−07−26
2012−08−09
2012−08−22
2012−09−14
2012−09−28
2012−10−29
Depth (m)
0
2
4
6
8
0
5
10
Dissolved Oxygen (mg/l)

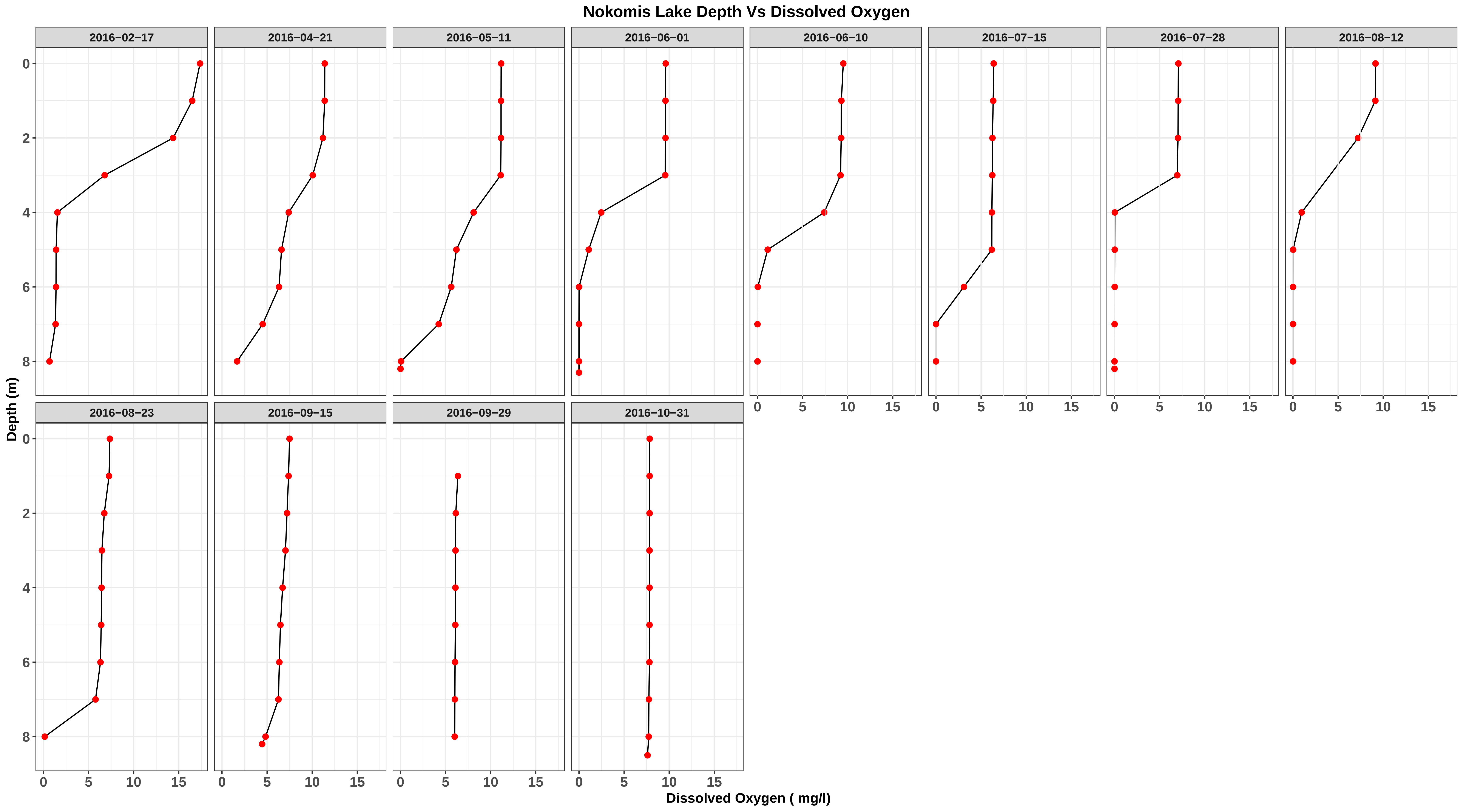

Nokomis Lake Depth Vs Dissolved Oxygen
2013−02−15
2013−05−13
2013−05−28
2013−06−11
2013−06−21
2013−07−11
2013−07−25
2013−08−12
2013−08−21
2013−09−12
2013−09−27
2013−10−16
Depth (m)
Dissolved Oxygen (mg/l)

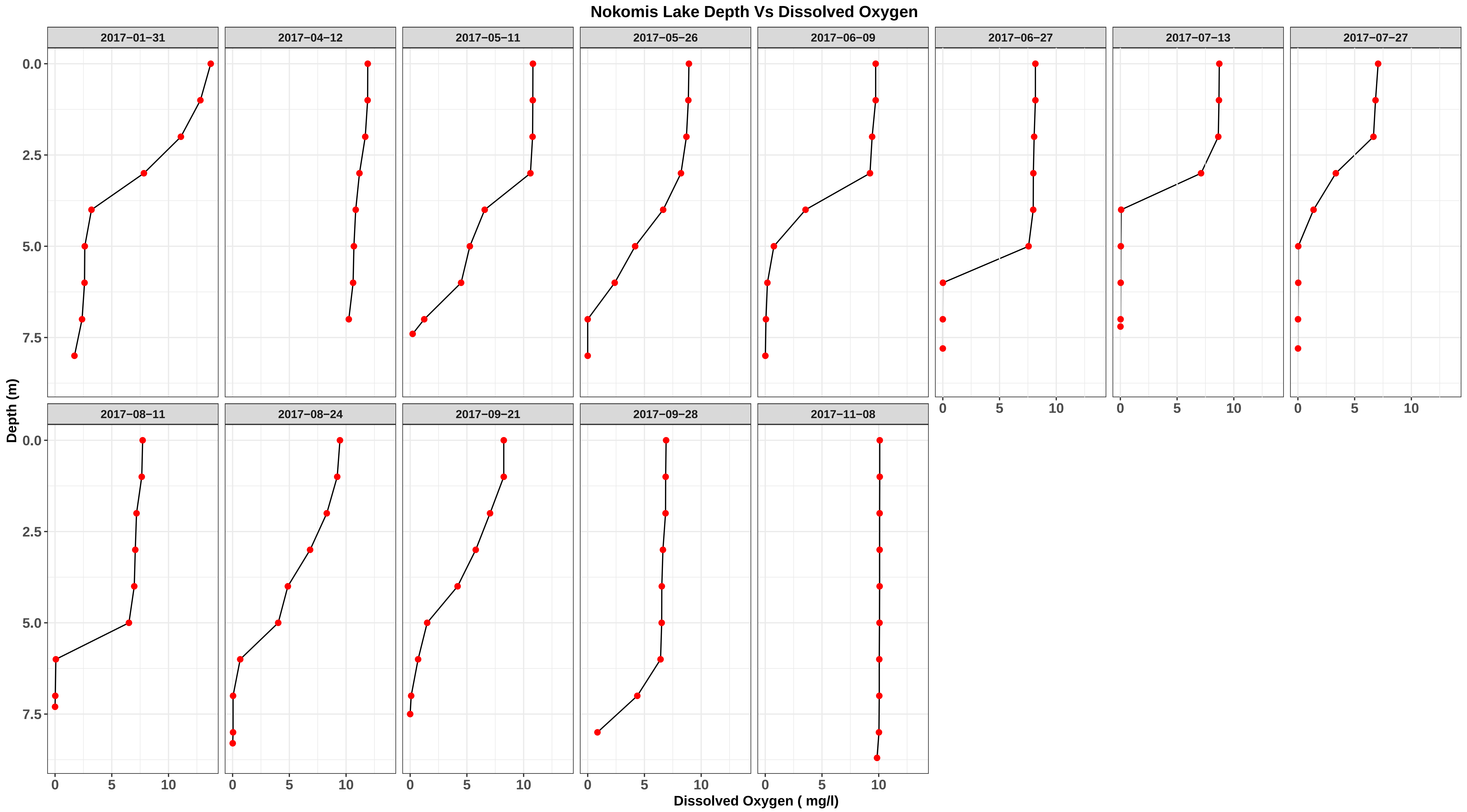


Nokomis Lake Depth Vs Dissolved Oxygen
2014−03−14
2014−05−08
2014−05−23
2014−06−13
2014−06−27
2014−07−15
2014−07−25
2014−08−08
2014−08−22
2014−09−15
2014−09−26
2014−10−24
Depth (m)
0.0
2.5
5.0
7.5
0
3
6
9
12
Dissolved Oxygen (mg/l)

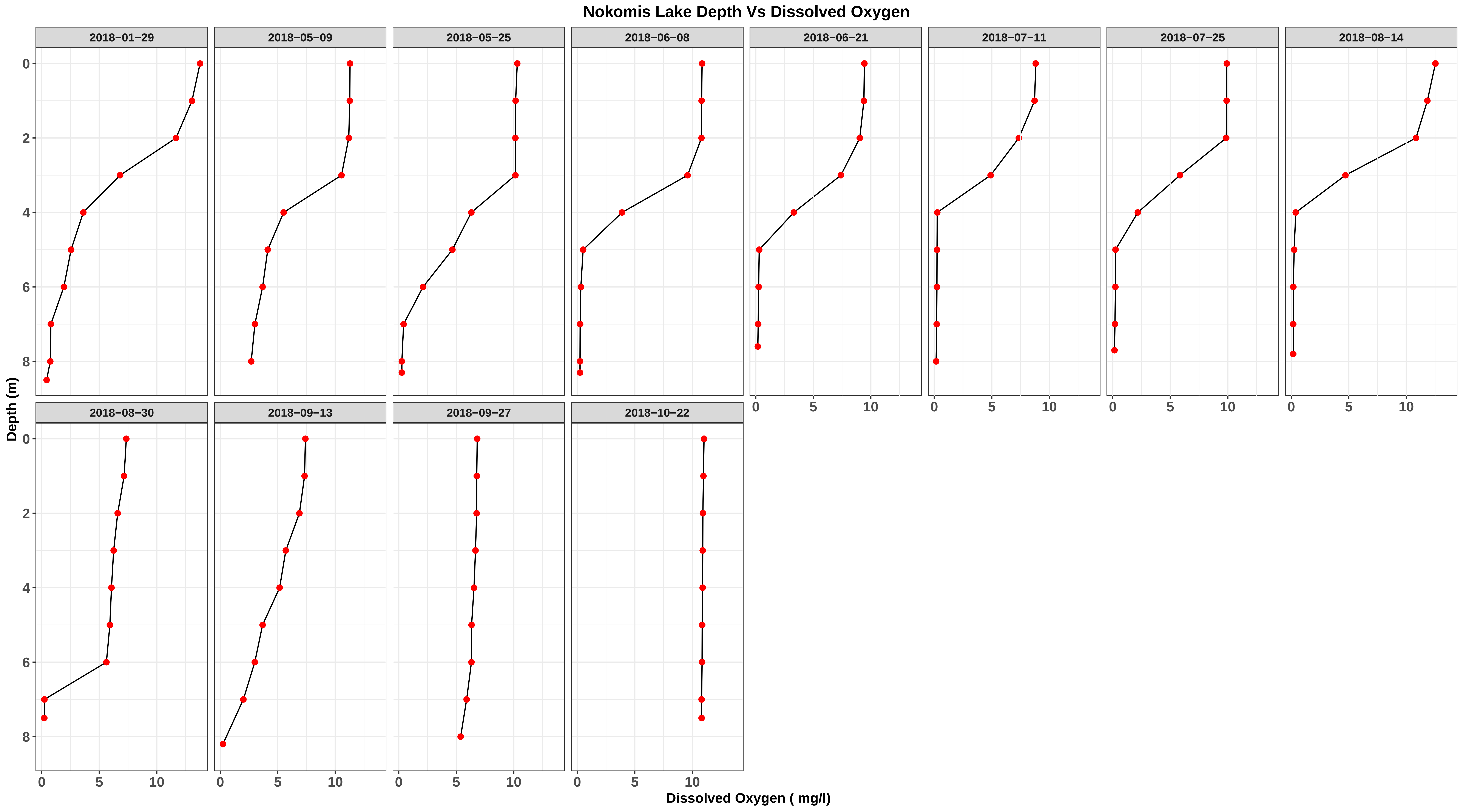


Nokomis Lake Depth Vs Dissolved Oxygen
2015−03−06
2015−04−17
2015−05−08
2015−05−21
2015−06−08
2015−06−23
2015−07−09
2015−07−23
2015−08−06
2015−08−21
2015−09−15
2015−09−28
2015−10−30
Depth (m)
0
2
4
6
8
0
5
10
Dissolved Oxygen (mg/l)

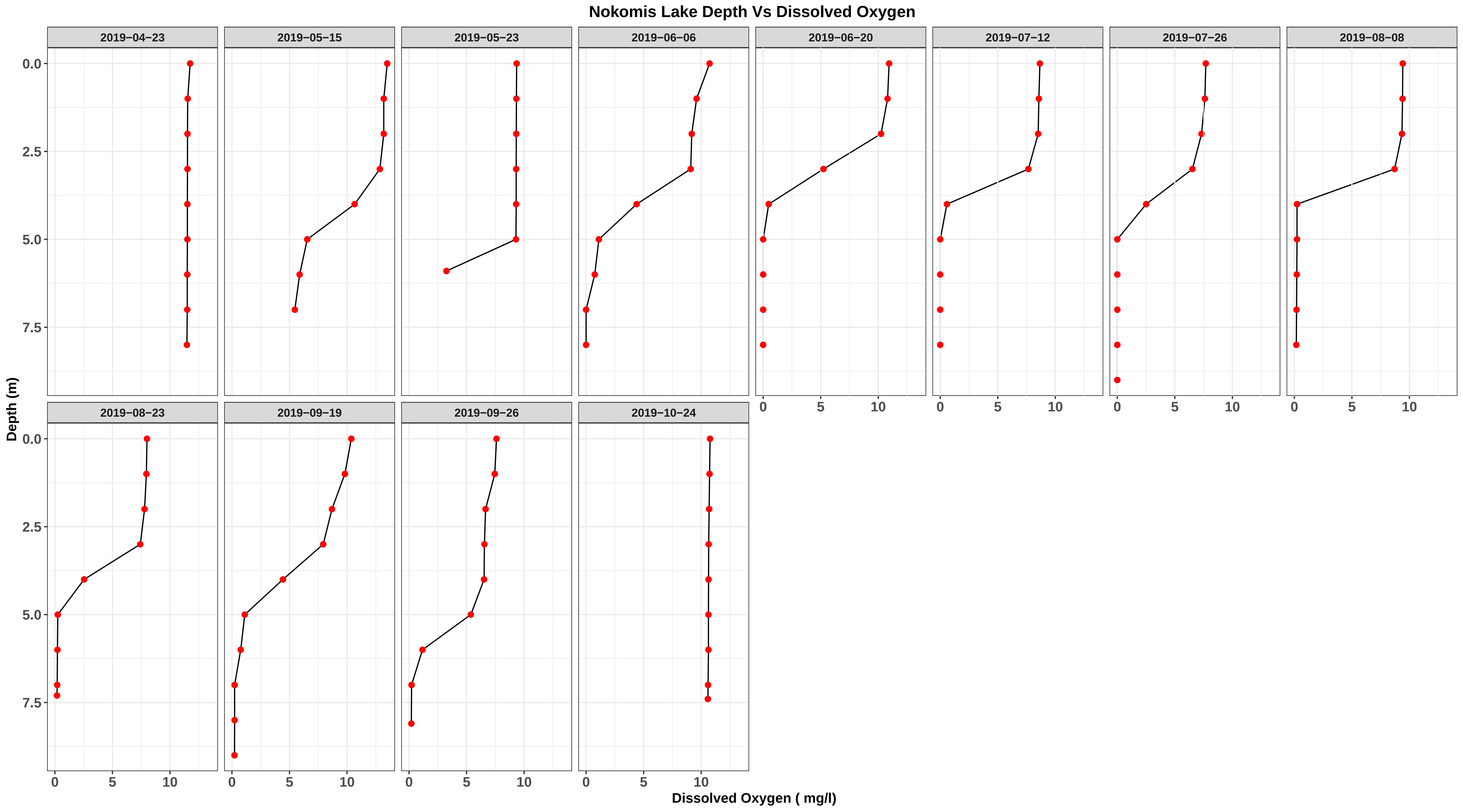

Nokomis Lake Depth Vs Dissolved Oxygen
2016−02−17
2016−04−21
2016−05−11
2016−06−01
2016−06−10
2016−07−15
2016−07−28
2016−08−12
2016−08−23
2016−09−15
2016−09−29
2016−10−31
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
0
5
10
15

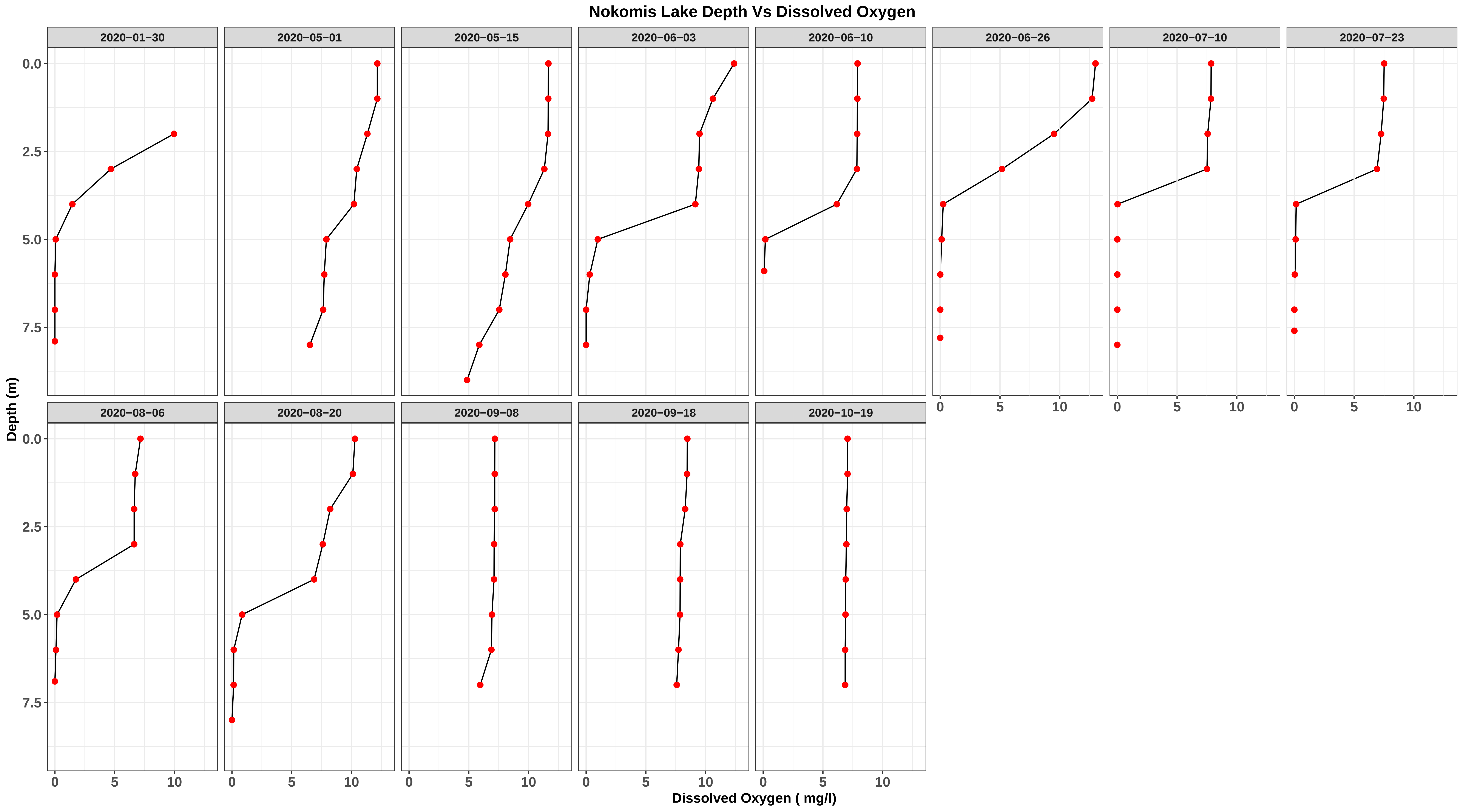


Nokomis Lake Depth Vs Dissolved Oxygen
2017−01−31
2017−04−12
2017−05−11
2017−05−26
2017−06−09
2017−06−27
2017−07−13
2017−07−27
2017−08−11
2017−08−24
2017−09−21
2017−09−28
2017−11−08
Depth (m)
0.0
2.5
5.0
7.5
0
5
10
Dissolved Oxygen (mg/l)

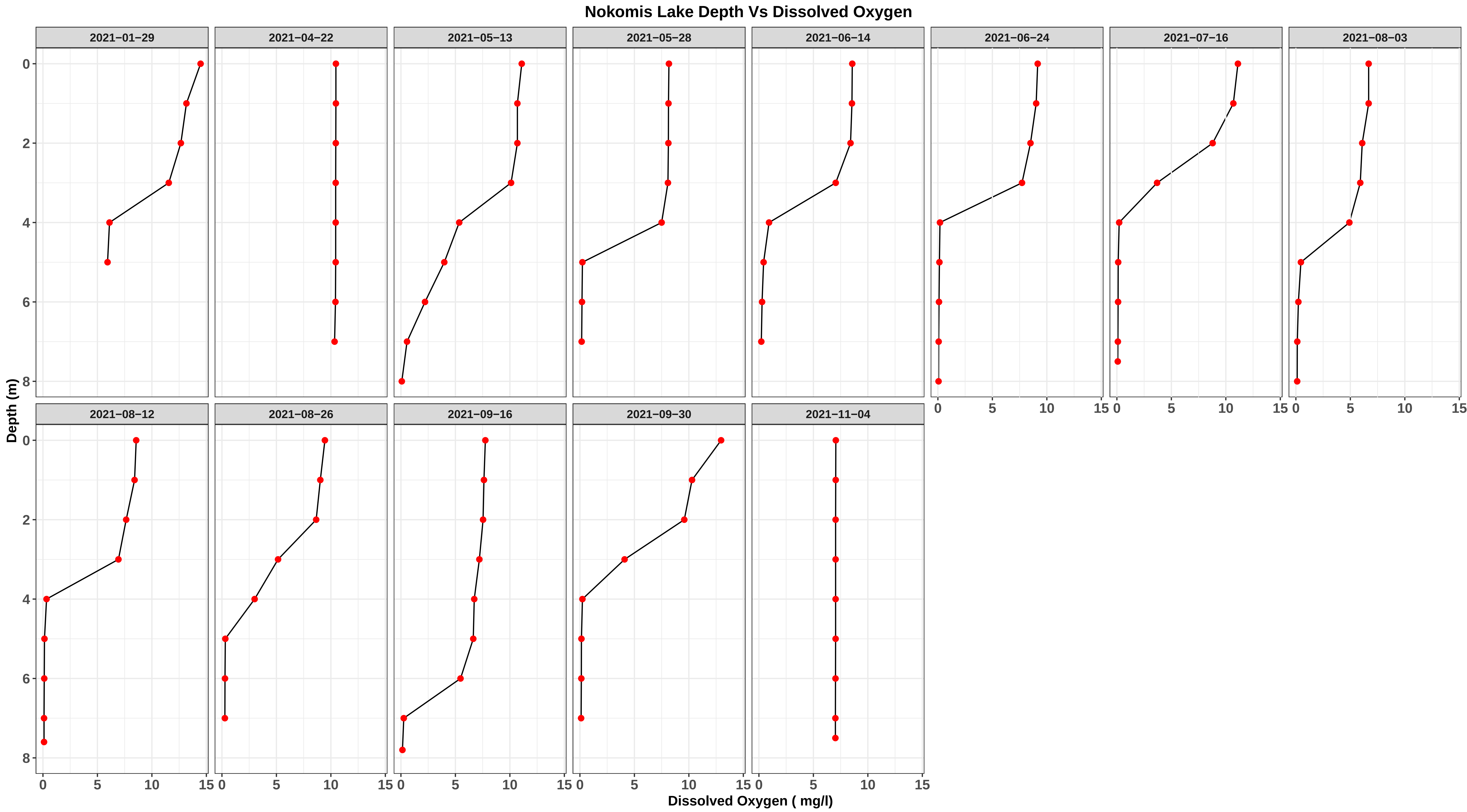


Nokomis Lake Depth Vs Dissolved Oxygen
2018−01−29
2018−05−09
2018−05−25
2018−06−08
2018−06−21
2018−07−11
2018−07−25
2018−08−14
2018−08−30
2018−09−13
2018−09−27
2018−10−22
Depth (m)
0
2
4
6
8
0
5
10
Dissolved Oxygen (mg/l)

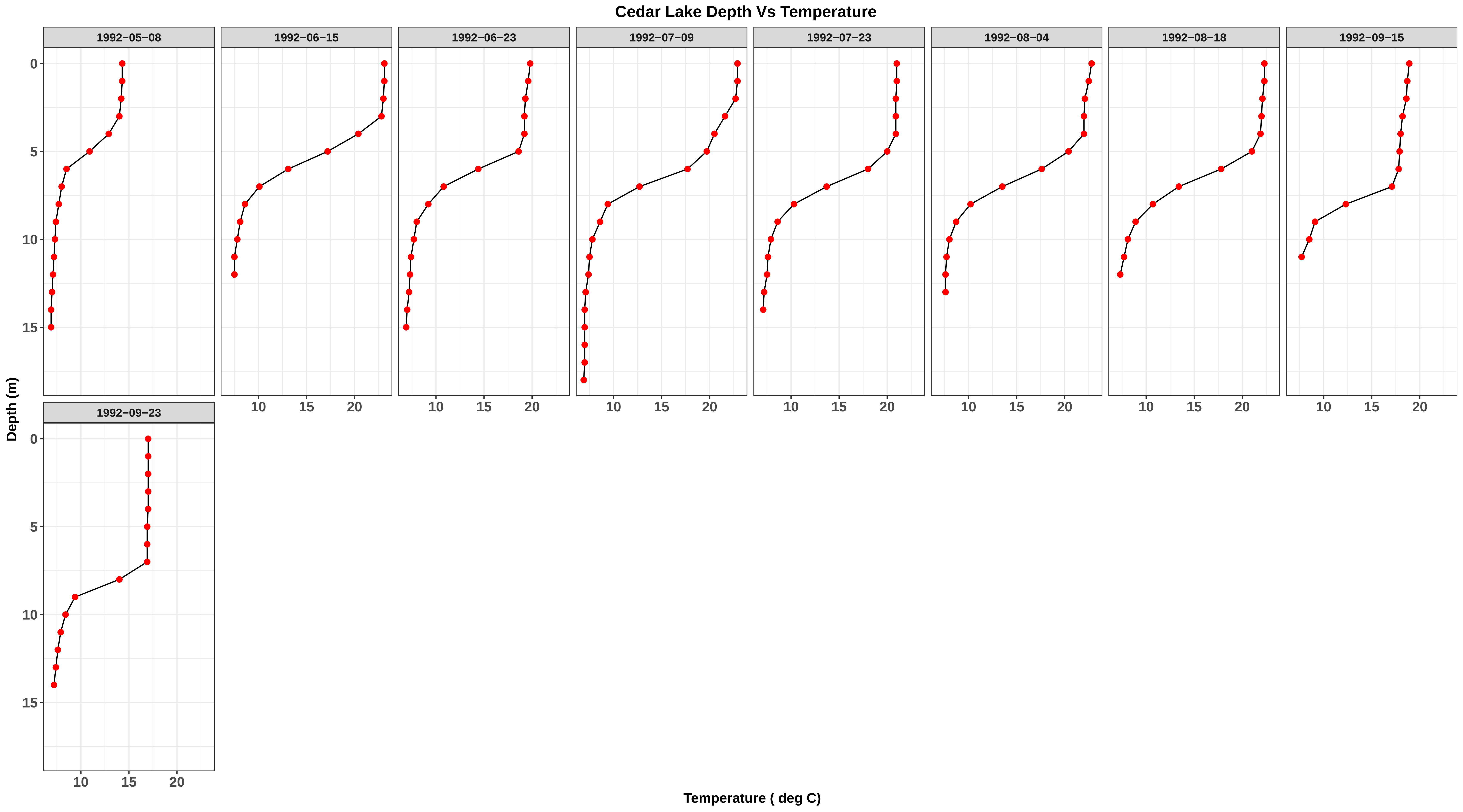

Nokomis Lake Depth Vs Dissolved Oxygen
2019−04−23
2019−05−15
2019−05−23
2019−06−06
2019−06−20
2019−07−12
2019−07−26
2019−08−08
2019−08−23
2019−09−19
2019−09−26
2019−10−24
Depth (m)
0.0
2.5
5.0
7.5
0
5
10
Dissolved Oxygen (mg/l)

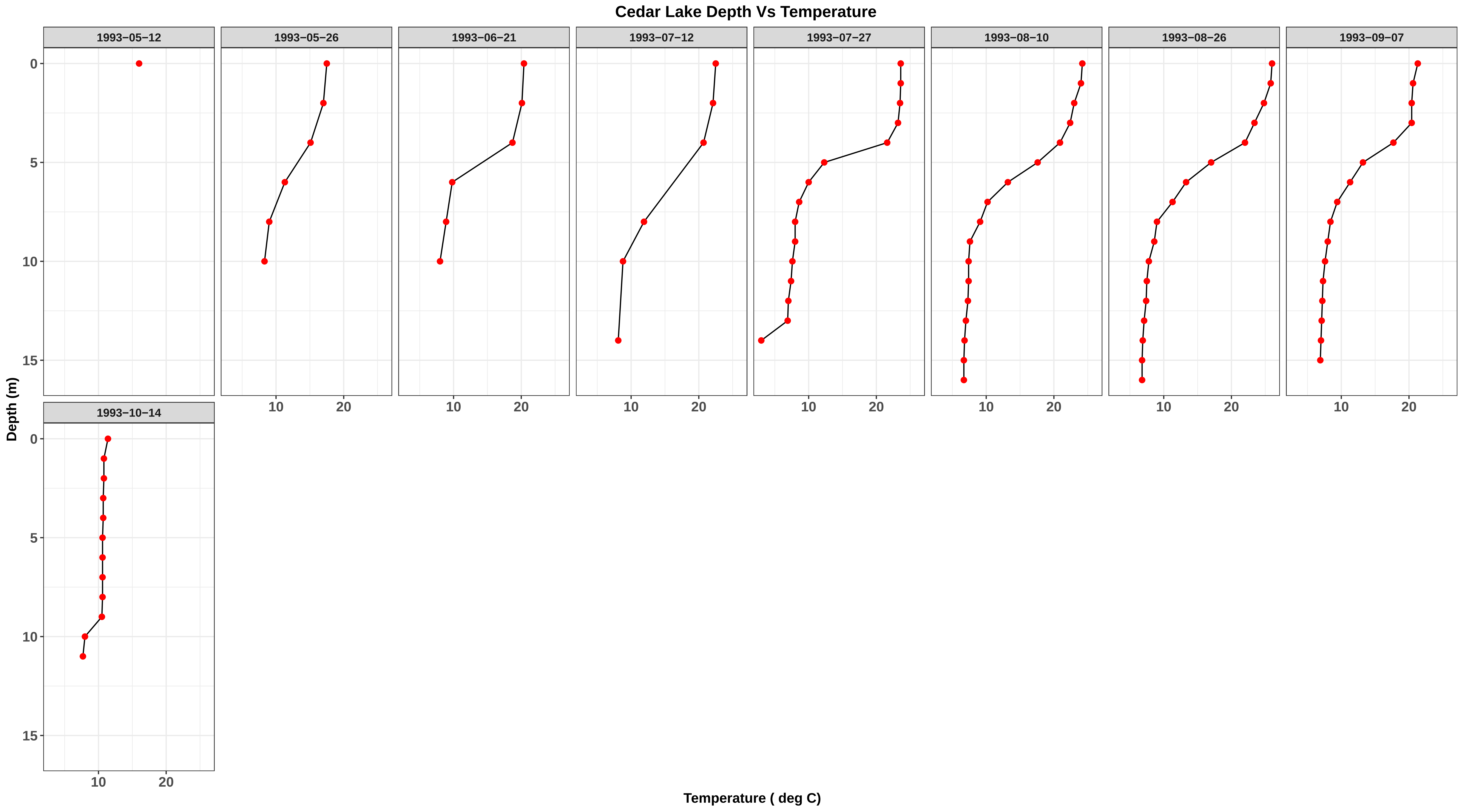


Nokomis Lake Depth Vs Dissolved Oxygen
2020−01−30
2020−05−01
2020−05−15
2020−06−03
2020−06−10
2020−06−26
2020−07−10
2020−07−23
2020−08−06
2020−08−20
2020−09−08
2020−09−18
2020−10−19
Depth (m)
0.0
2.5
5.0
7.5
0
5
10
Dissolved Oxygen (mg/l)

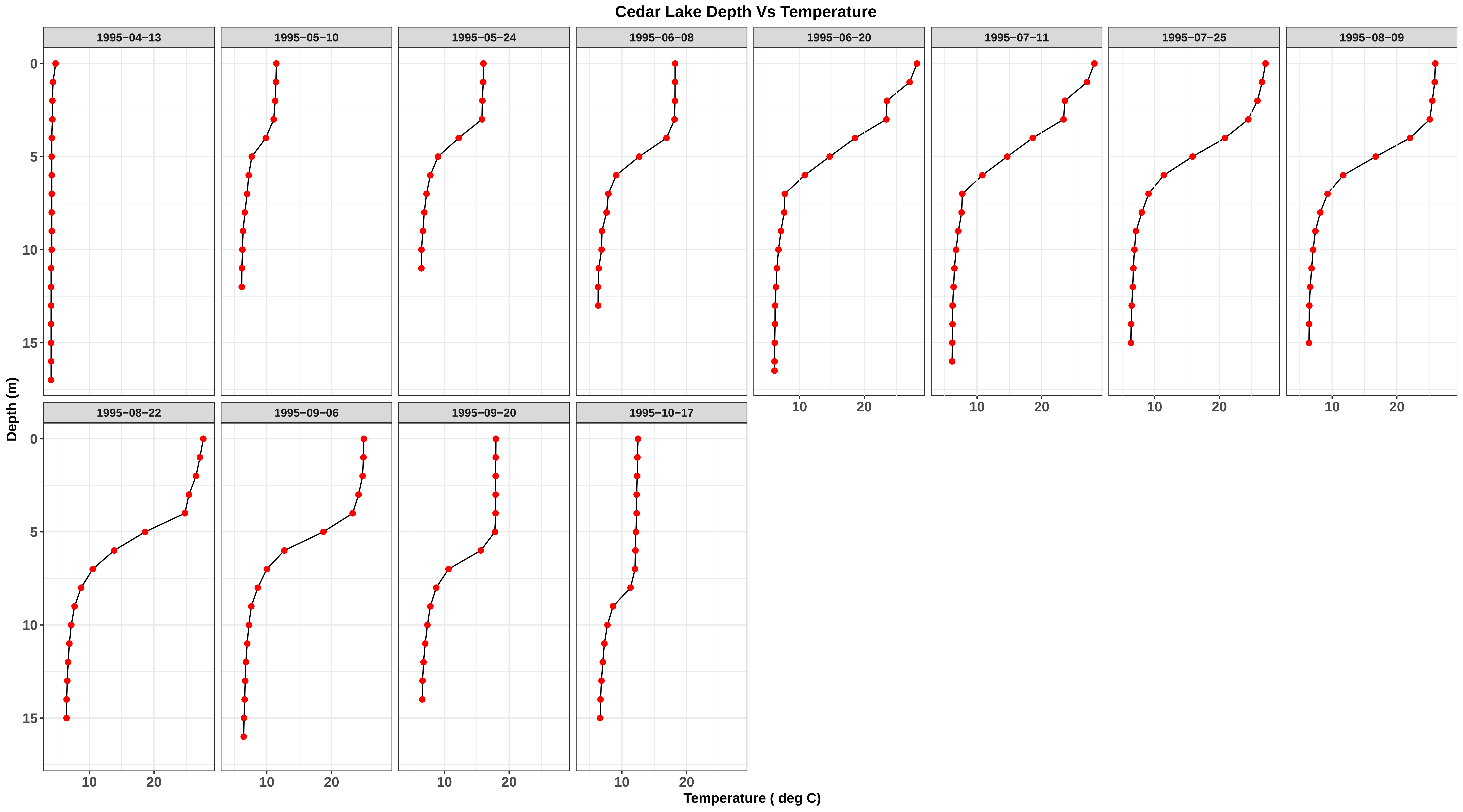


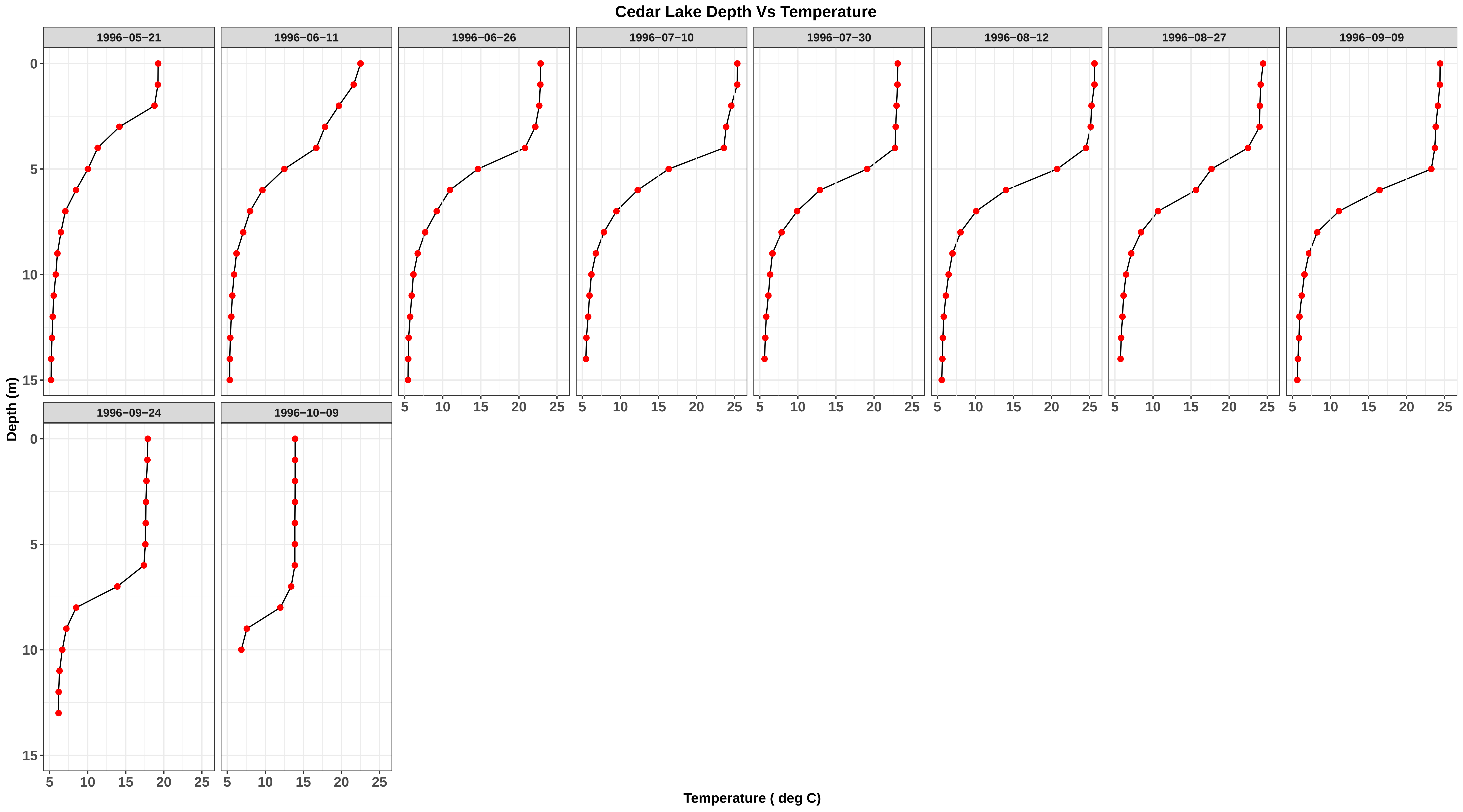
Nokomis Lake Depth Vs Dissolved Oxygen
2021−01−29
2021−04−22
2021−05−13
2021−05−28
2021−06−14
2021−06−24
2021−07−16
2021−08−03
2021−08−12
2021−08−26
2021−09−16
2021−09−30
2021−11−04
Depth (m)
0
2
4
6
8
0
5
10
15
Dissolved Oxygen (mg/l)


Cedar Lake Depth Vs Temperature
1992−05−08
1992−06−15
1992−06−23
1992−07−09
1992−07−23
1992−08−04
1992−08−18
1992−09−15
1992−09−23
Depth (m)
Temperature (deg C)
0
5
10
15
20

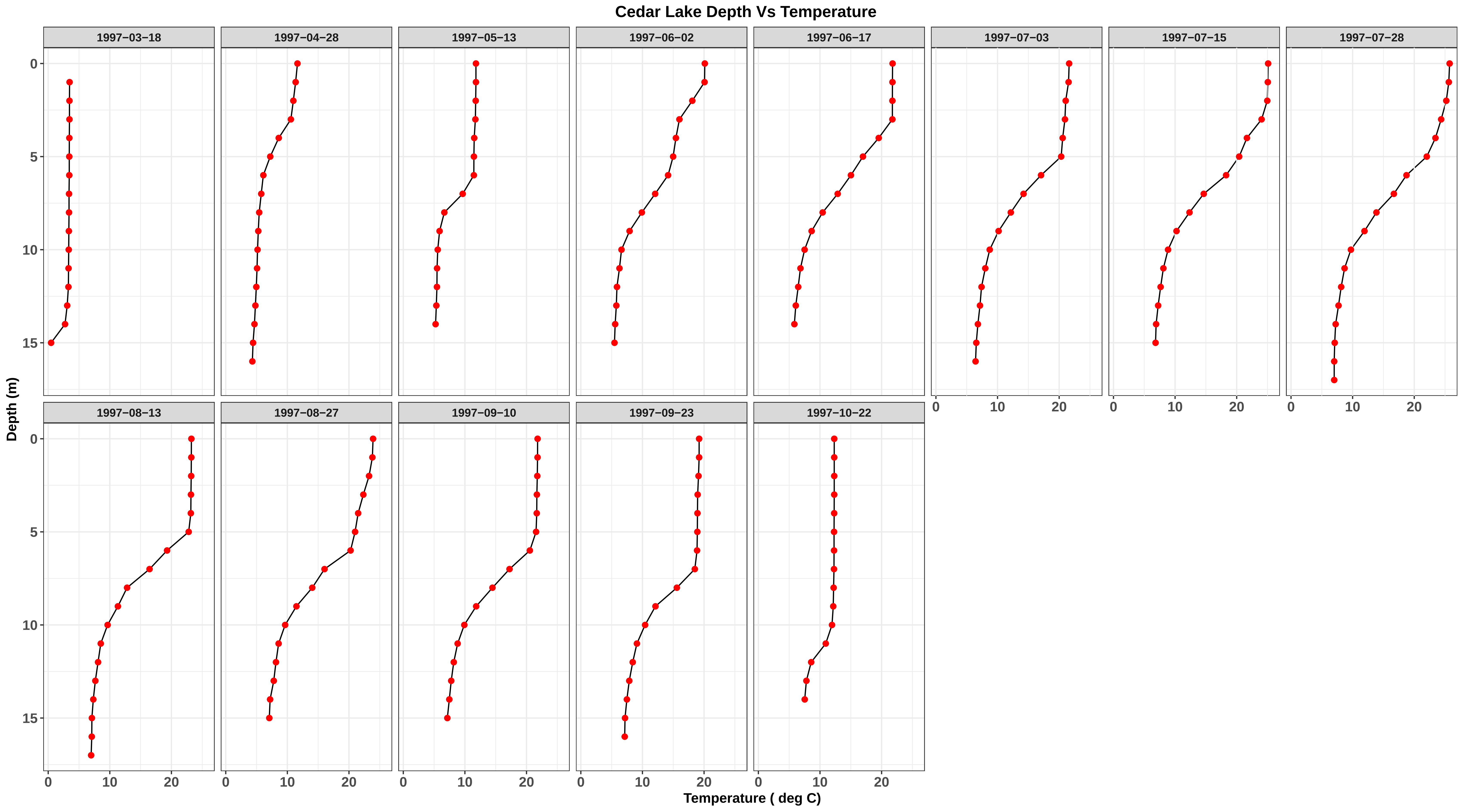


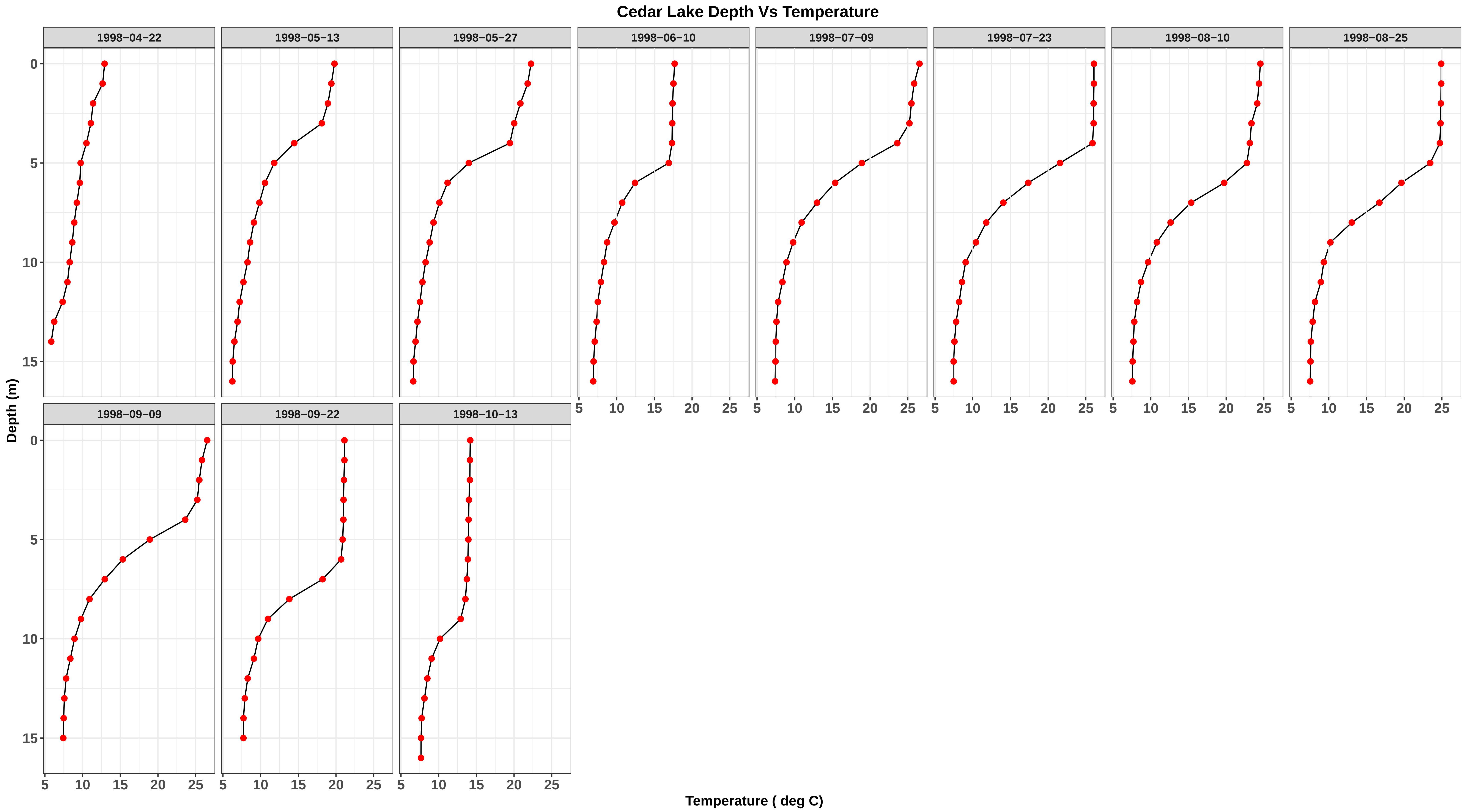
Cedar Lake Depth Vs Temperature
1993−05−12
1993−05−26
1993−06−21
1993−07−12
1993−07−27
1993−08−10
1993−08−26
1993−09−07
1993−10−14
0
5
10
15
10
20
Depth (m)
Temperature (deg C)


Cedar Lake Depth Vs Temperature
1995−04−13
1995−05−10
1995−05−24
1995−06−08
1995−06−20
1995−07−11
1995−07−25
1995−08−09
1995−08−22
1995−09−06
1995−09−20
1995−10−17
Depth (m)
Temperature (deg C)
0
5
10
15
10
20

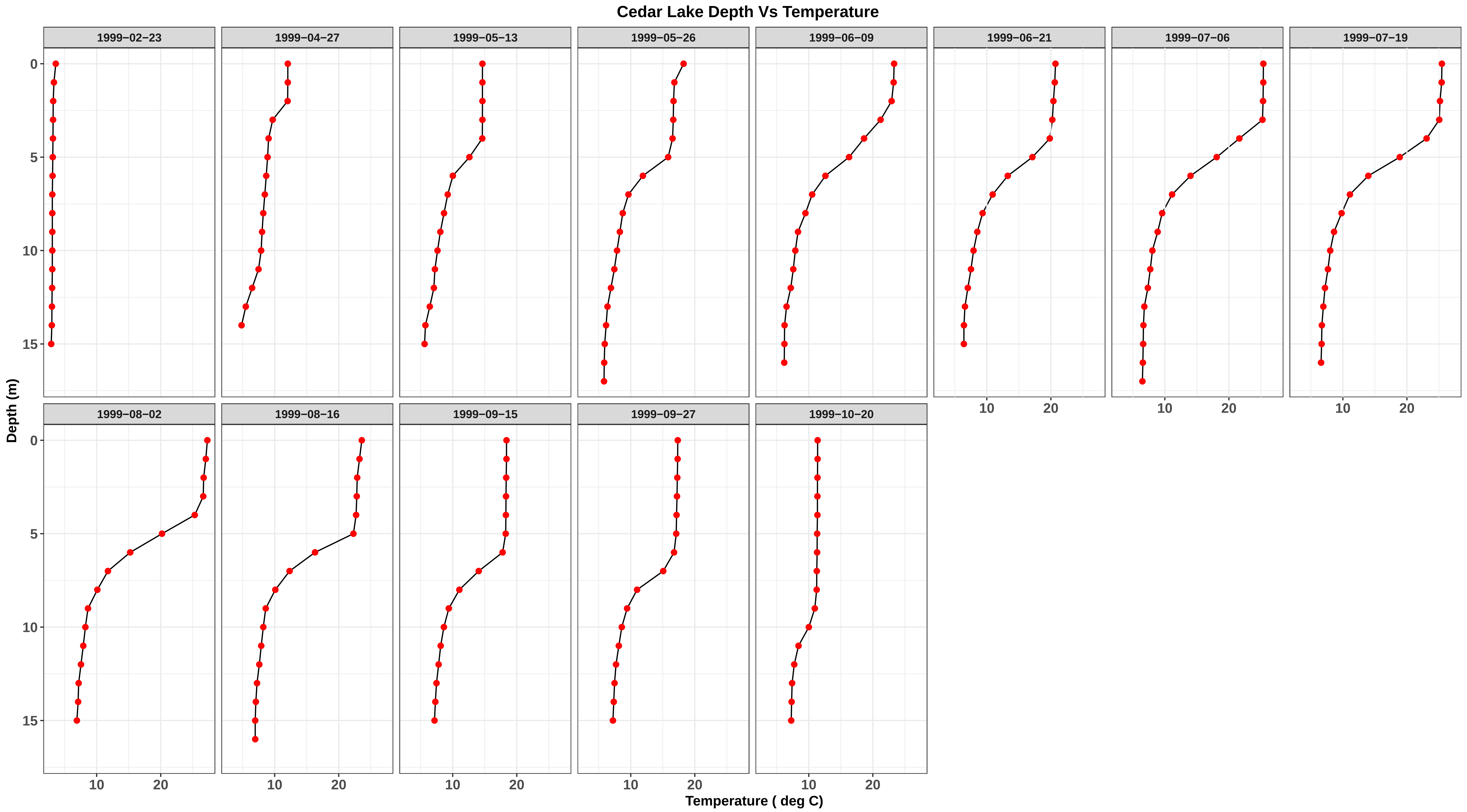


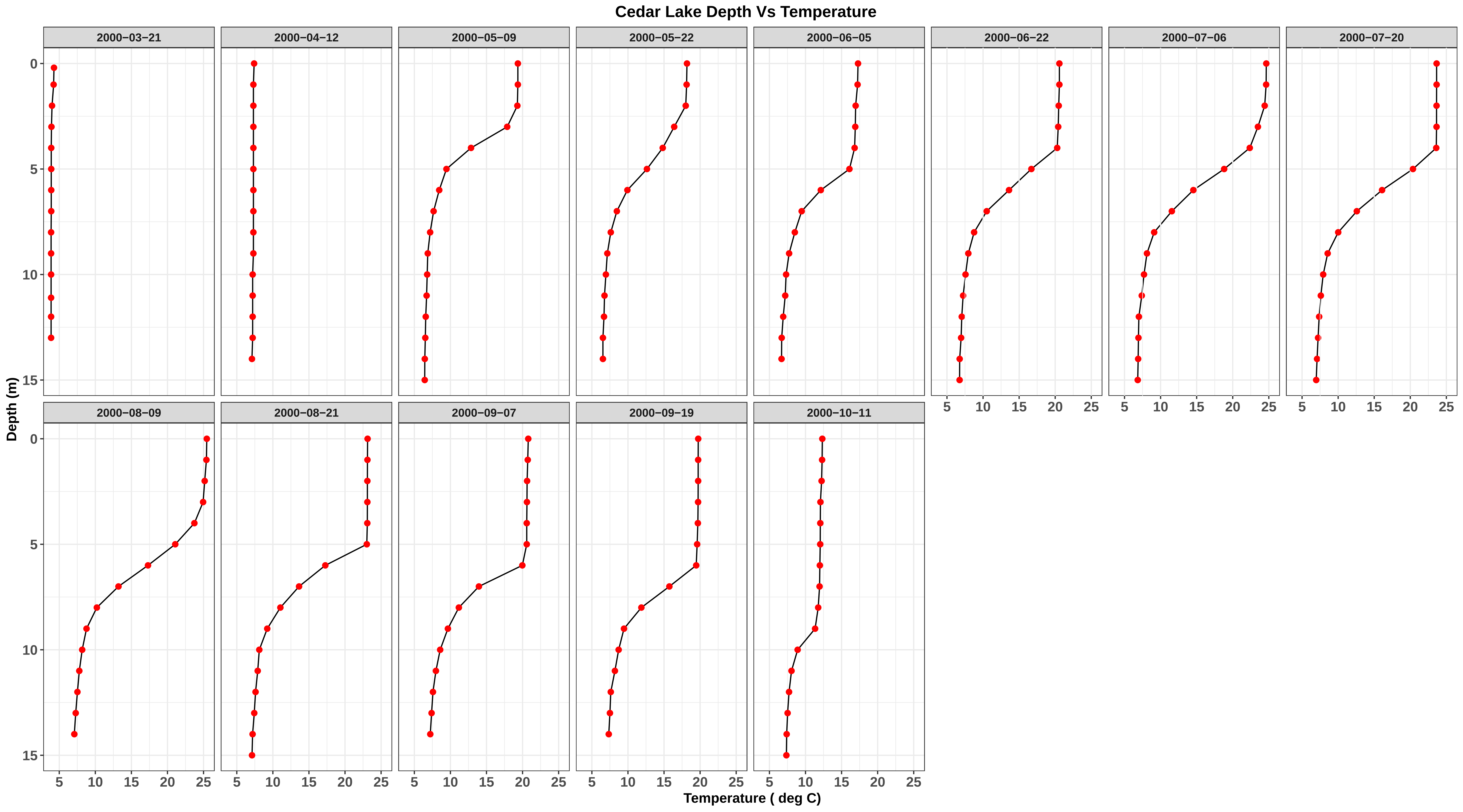
Cedar Lake Depth Vs Temperature
1996−05−21
1996−06−11
1996−06−26
1996−07−10
1996−07−30
1996−08−12
1996−08−27
1996−09−09
1996−09−24
1996−10−09
Depth (m)
Temperature (deg C)
0
5
10
15
5
10
15
20
25

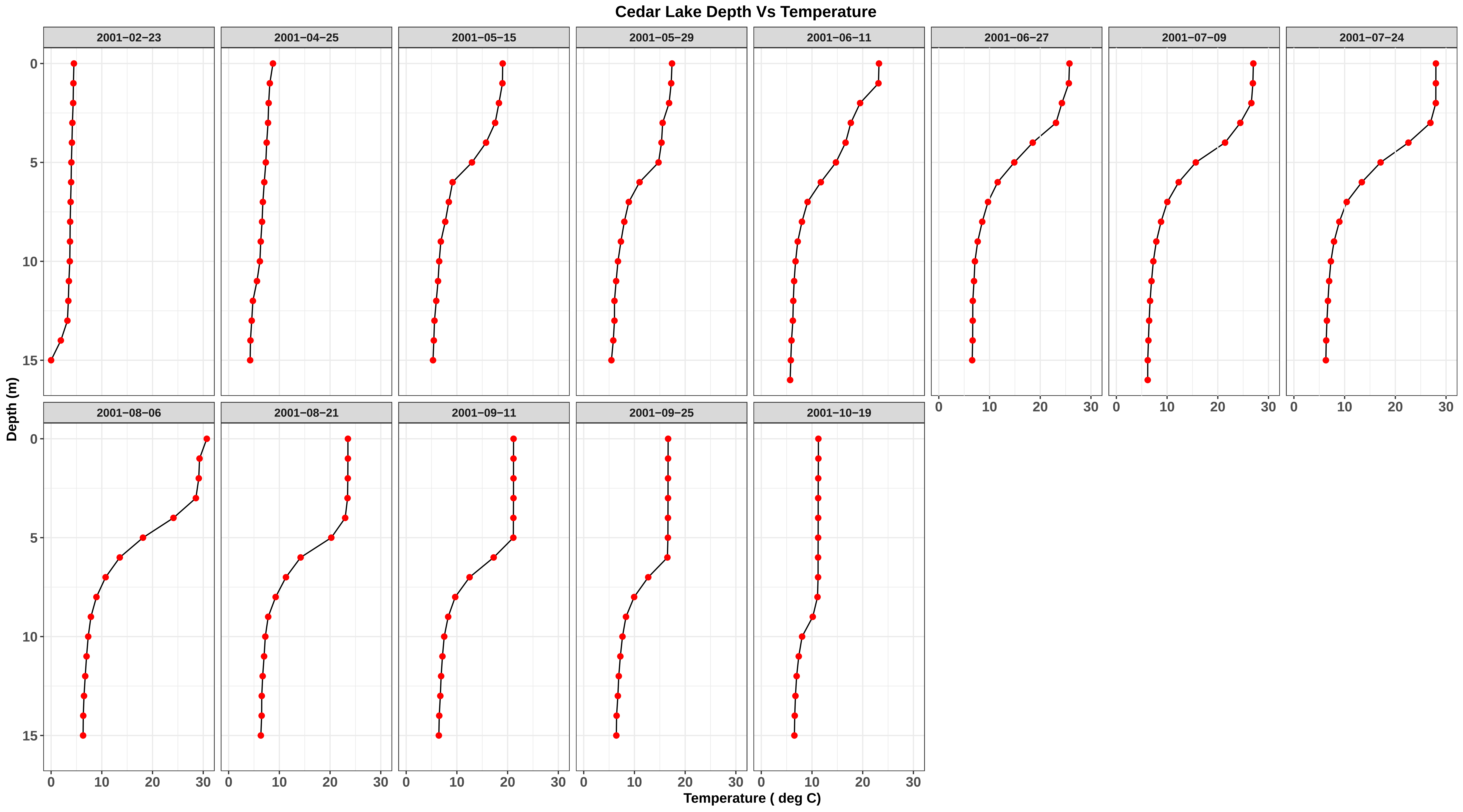

Cedar Lake Depth Vs Temperature
1997−03−18
1997−04−28
1997−05−13
1997−06−02
1997−06−17
1997−07−03
1997−07−15
1997−07−28
1997−08−13
1997−08−27
1997−09−10
1997−09−23
1997−10−22
Depth (m)
Temperature (deg C)
0
5
10
15
20

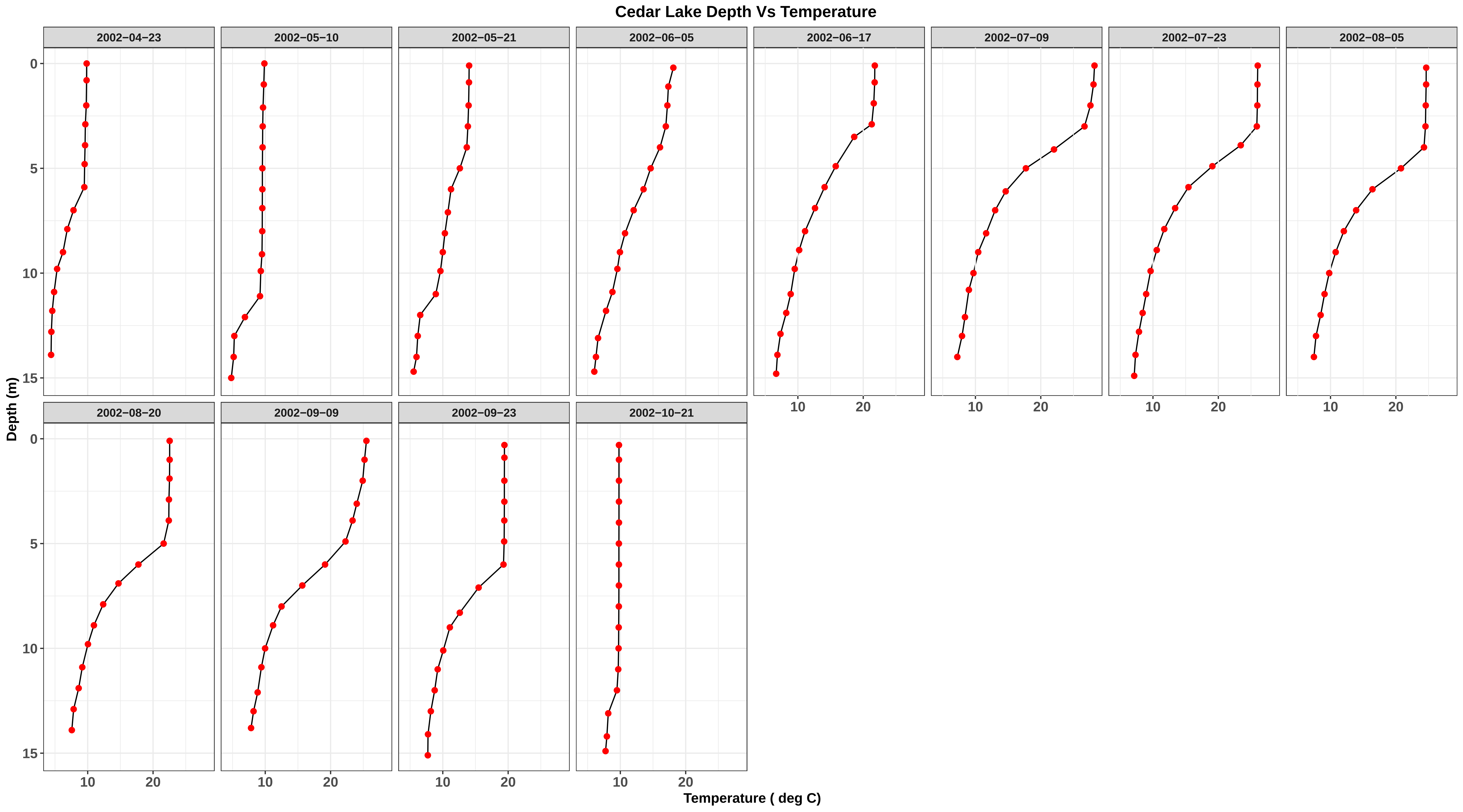


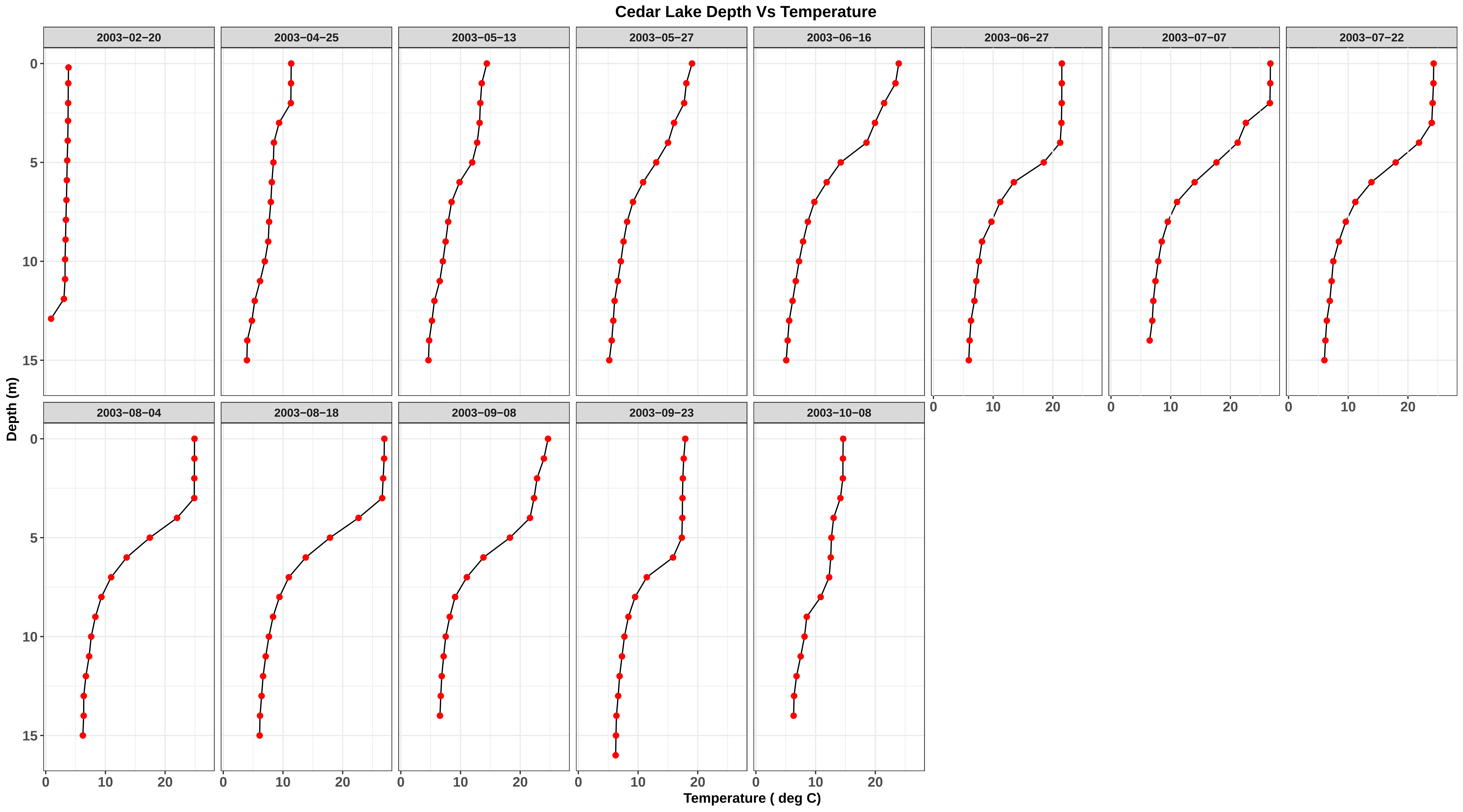
Cedar Lake Depth Vs Temperature
1998−04−22
1998−05−13
1998−05−27
1998−06−10
1998−07−09
1998−07−23
1998−08−10
1998−08−25
1998−09−09
1998−09−22
1998−10−13
Depth (m)
Temperature (deg C)


Cedar Lake Depth Vs Temperature
1999−02−23
1999−04−27
1999−05−13
1999−05−26
1999−06−09
1999−06−21
1999−07−06
1999−07−19
1999−08−02
1999−08−16
1999−09−15
1999−09−27
1999−10−20
Depth (m)
0
5
10
15
10
20
Temperature (deg C)

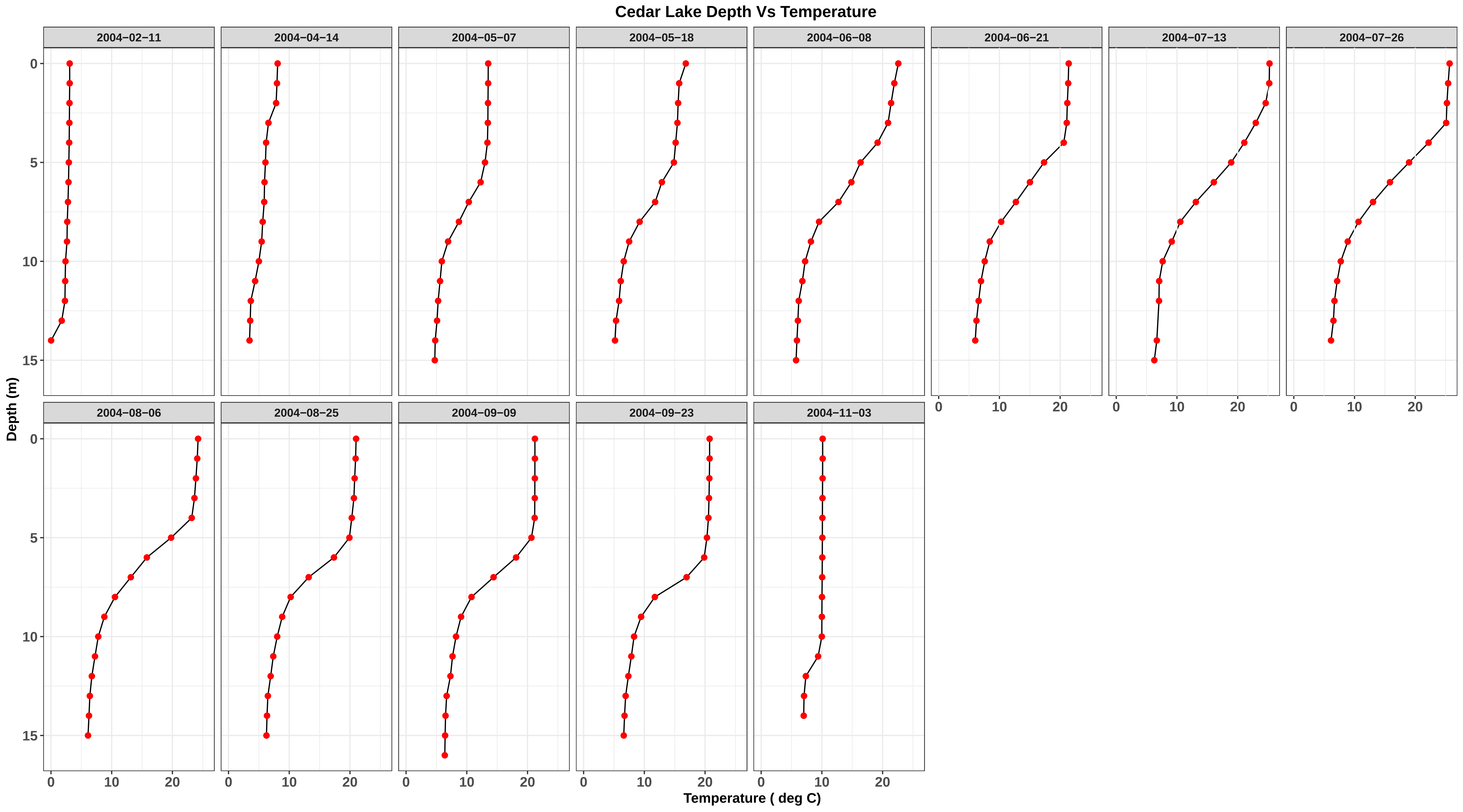

Cedar Lake Depth Vs Temperature
2000−03−21
2000−04−12
2000−05−09
2000−05−22
2000−06−05
2000−06−22
2000−07−06
2000−07−20
2000−08−09
2000−08−21
2000−09−07
2000−09−19
2000−10−11
Depth (m)
Temperature (deg C)
0
5
10
15
5 10 15 20 25

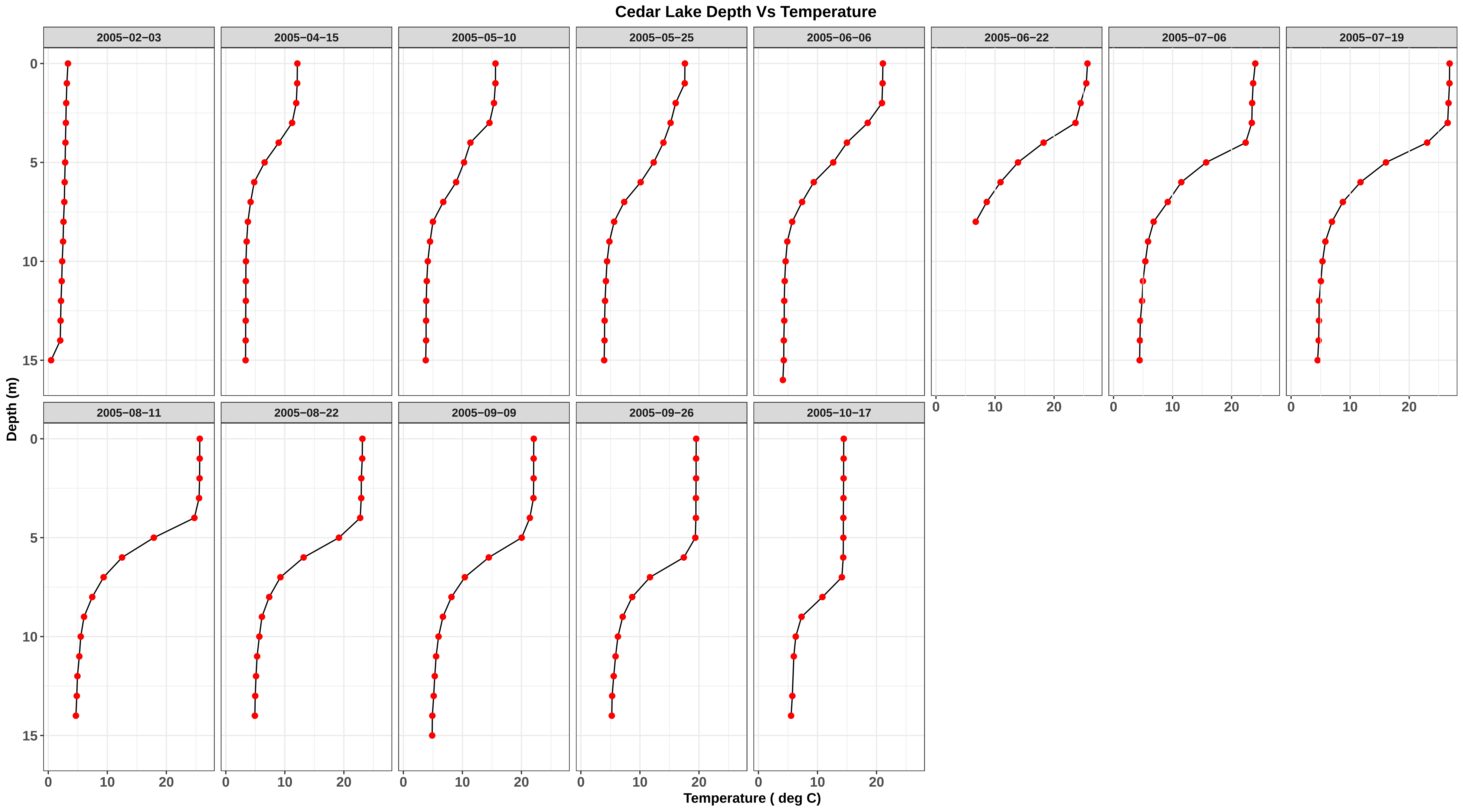

Cedar Lake Depth Vs Temperature
2001−02−23
2001−04−25
2001−05−15
2001−05−29
2001−06−11
2001−06−27
2001−07−09
2001−07−24
2001−08−06
2001−08−21
2001−09−11
2001−09−25
2001−10−19
Depth (m)
0
5
10
15
0 10 20 30
Temperature (deg C)


Cedar Lake Depth Vs Temperature
2002−04−23
2002−05−10
2002−05−21
2002−06−05
2002−06−17
2002−07−09
2002−07−23
2002−08−05
2002−08−20
2002−09−09
2002−09−23
2002−10−21
Depth (m)
0
5
10
15
10
20
Temperature (deg C)

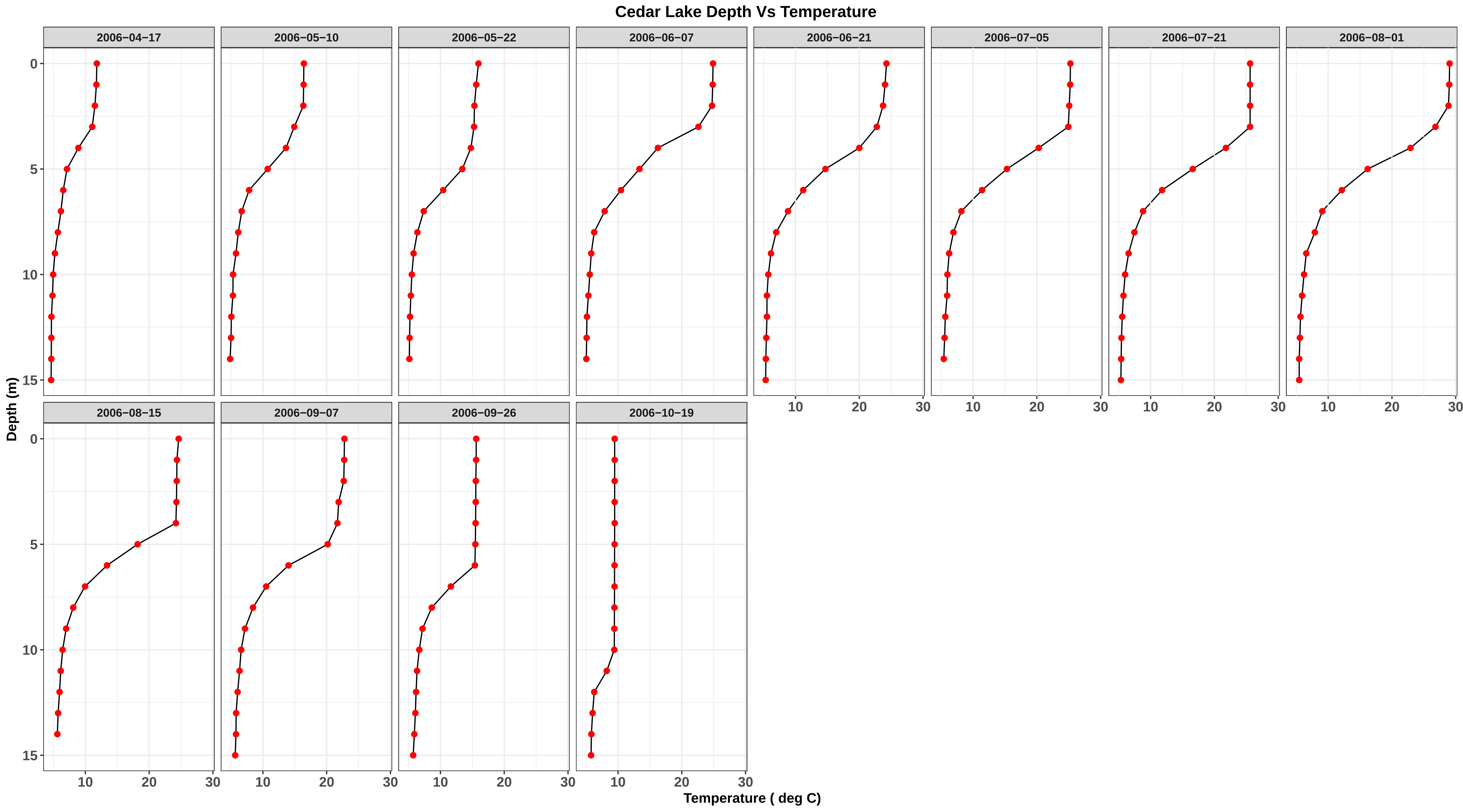


Cedar Lake Depth Vs Temperature
2003−02−20
2003−04−25
2003−05−13
2003−05−27
2003−06−16
2003−06−27
2003−07−07
2003−07−22
2003−08−04
2003−08−18
2003−09−08
2003−09−23
2003−10−08
Depth (m)
Temperature (deg C)
0
5
10
15
0
10
20

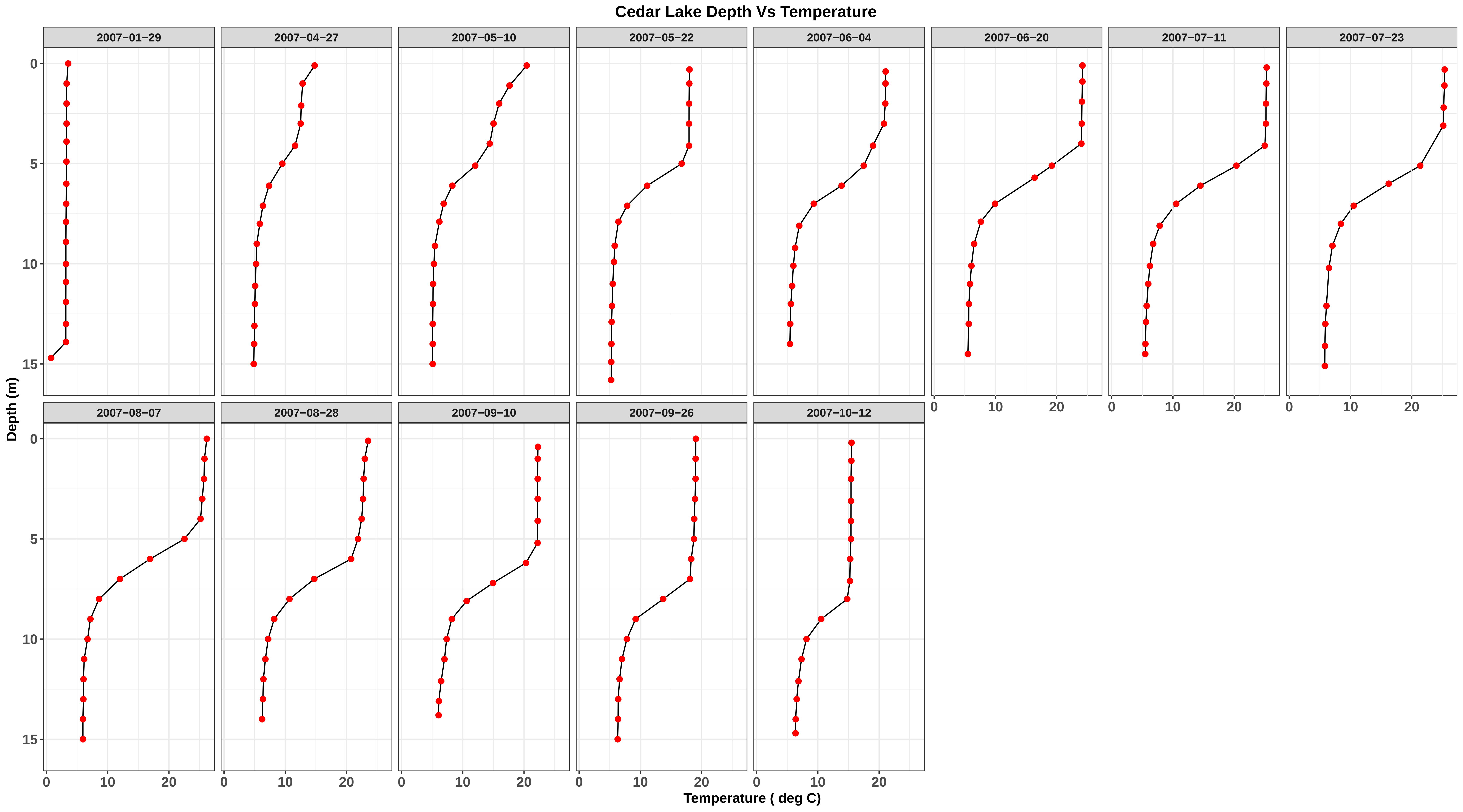

Cedar Lake Depth Vs Temperature
2004−02−11
2004−04−14
2004−05−07
2004−05−18
2004−06−08
2004−06−21
2004−07−13
2004−07−26
2004−08−06
2004−08−25
2004−09−09
2004−09−23
2004−11−03
Depth (m)
Temperature (deg C)
0
5
10
15
0
10
20

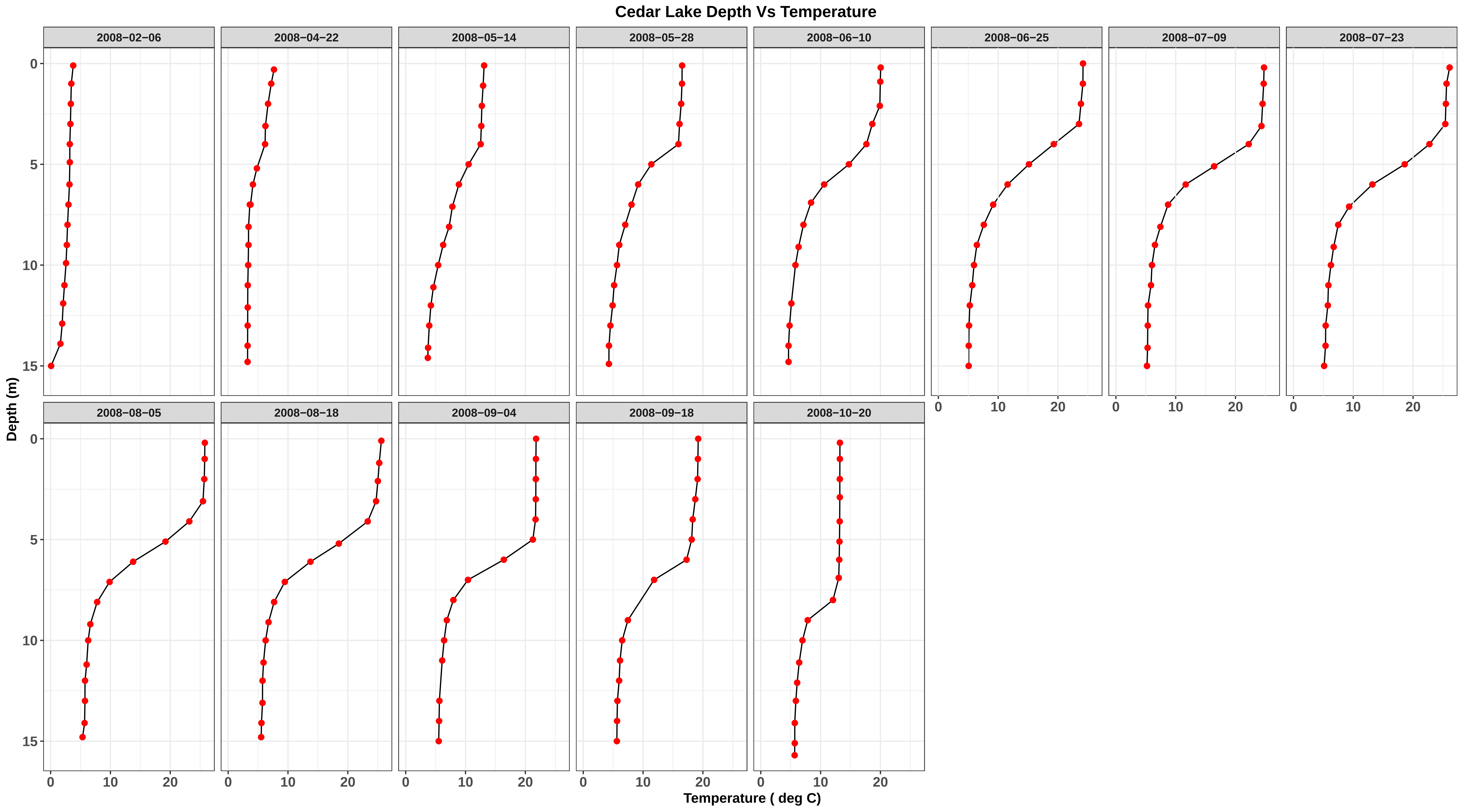


Cedar Lake Depth Vs Temperature
2005−02−03
2005−04−15
2005−05−10
2005−05−25
2005−06−06
2005−06−22
2005−07−06
2005−07−19
2005−08−11
2005−08−22
2005−09−09
2005−09−26
2005−10−17
Depth (m)
0
5
10
15
0
10
20
Temperature (deg C)

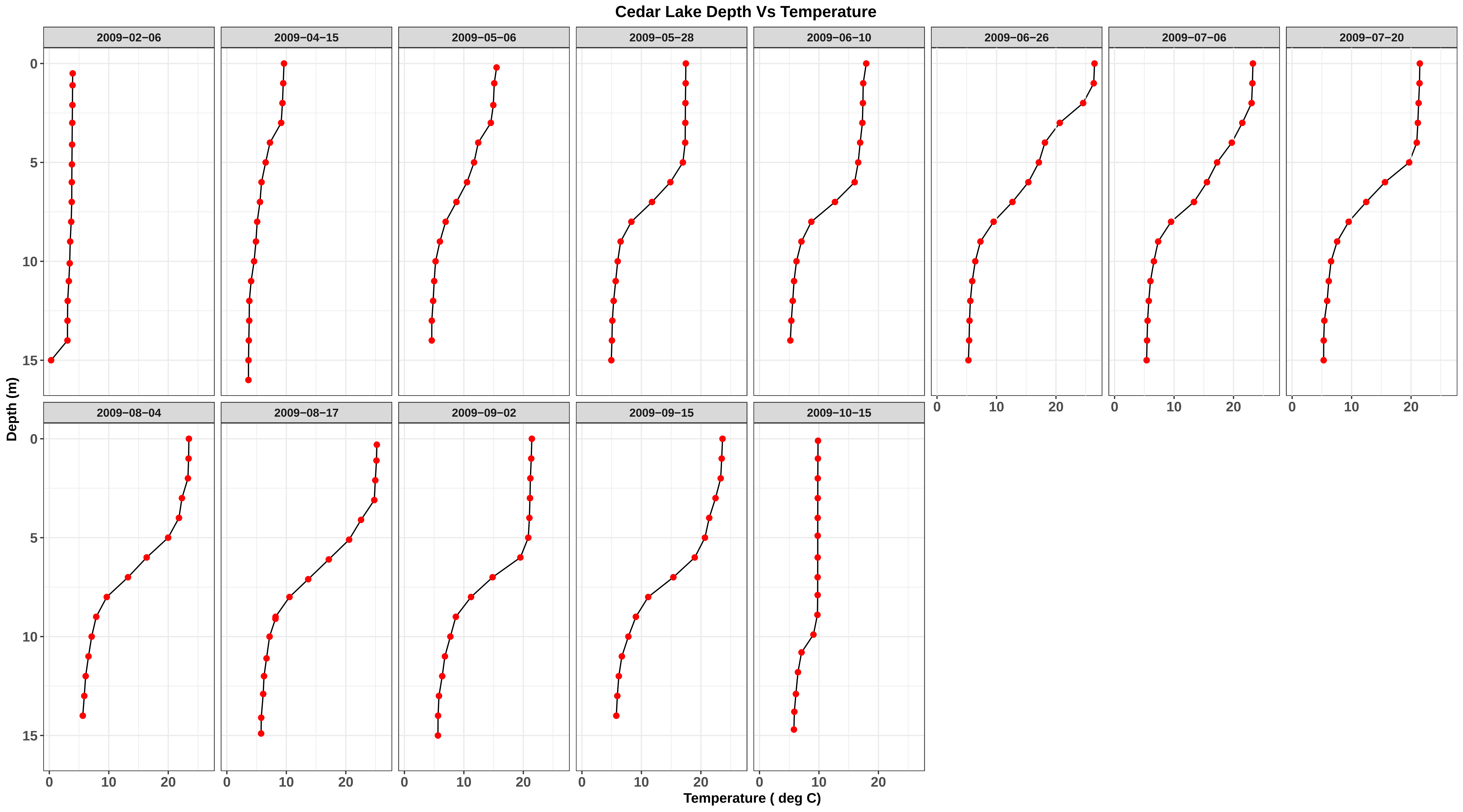


Cedar Lake Depth Vs Temperature
2006−04−17
2006−05−10
2006−05−22
2006−06−07
2006−06−21
2006−07−05
2006−07−21
2006−08−01
2006−08−15
2006−09−07
2006−09−26
2006−10−19
Depth (m)
Temperature (deg C)
0
5
10
15
10
20
30

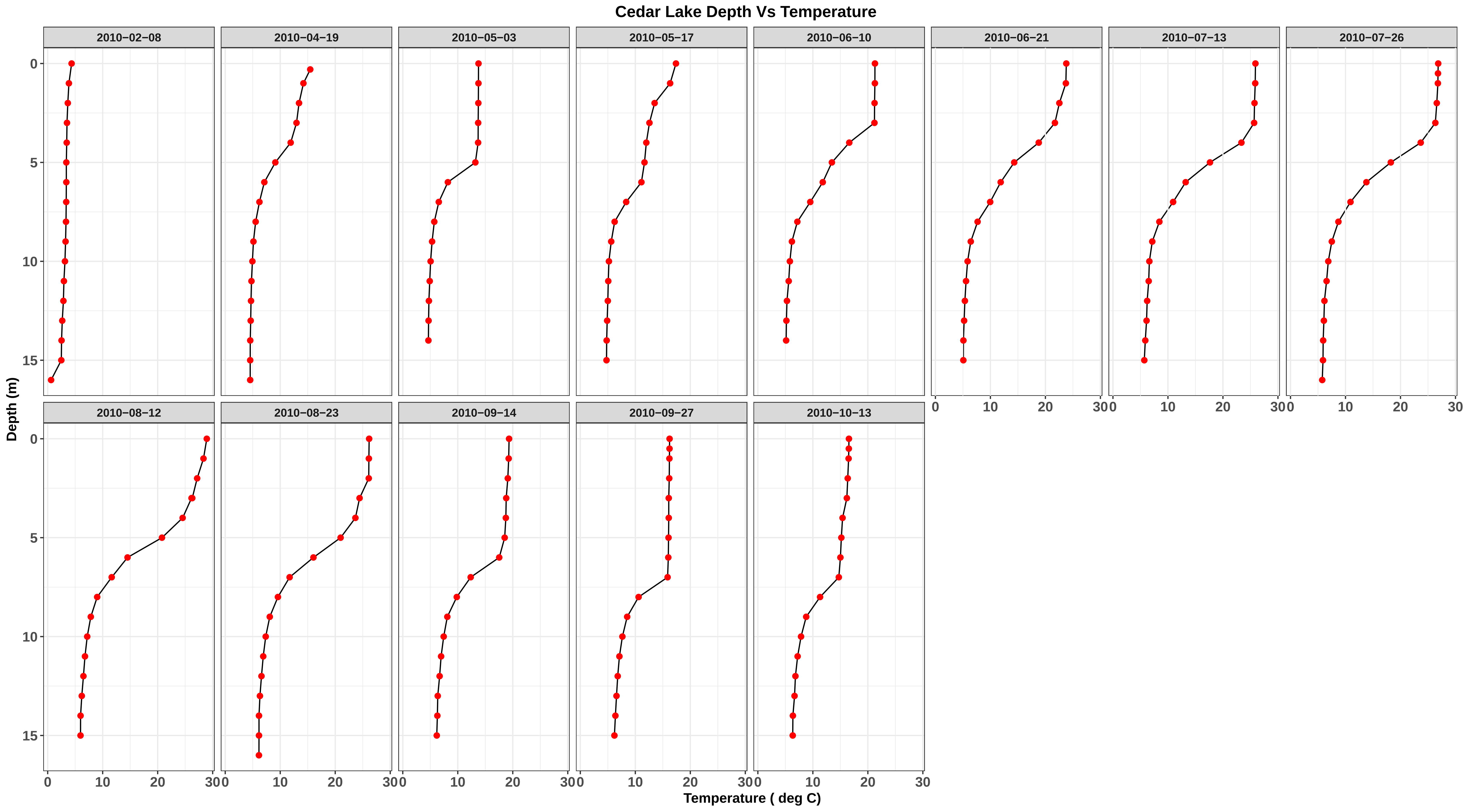

Cedar Lake Depth Vs Temperature
2007−01−29
2007−04−27
2007−05−10
2007−05−22
2007−06−04
2007−06−20
2007−07−11
2007−07−23
2007−08−07
2007−08−28
2007−09−10
2007−09−26
2007−10−12
Depth (m)
0
5
10
15
0
10
20
Temperature (deg C)



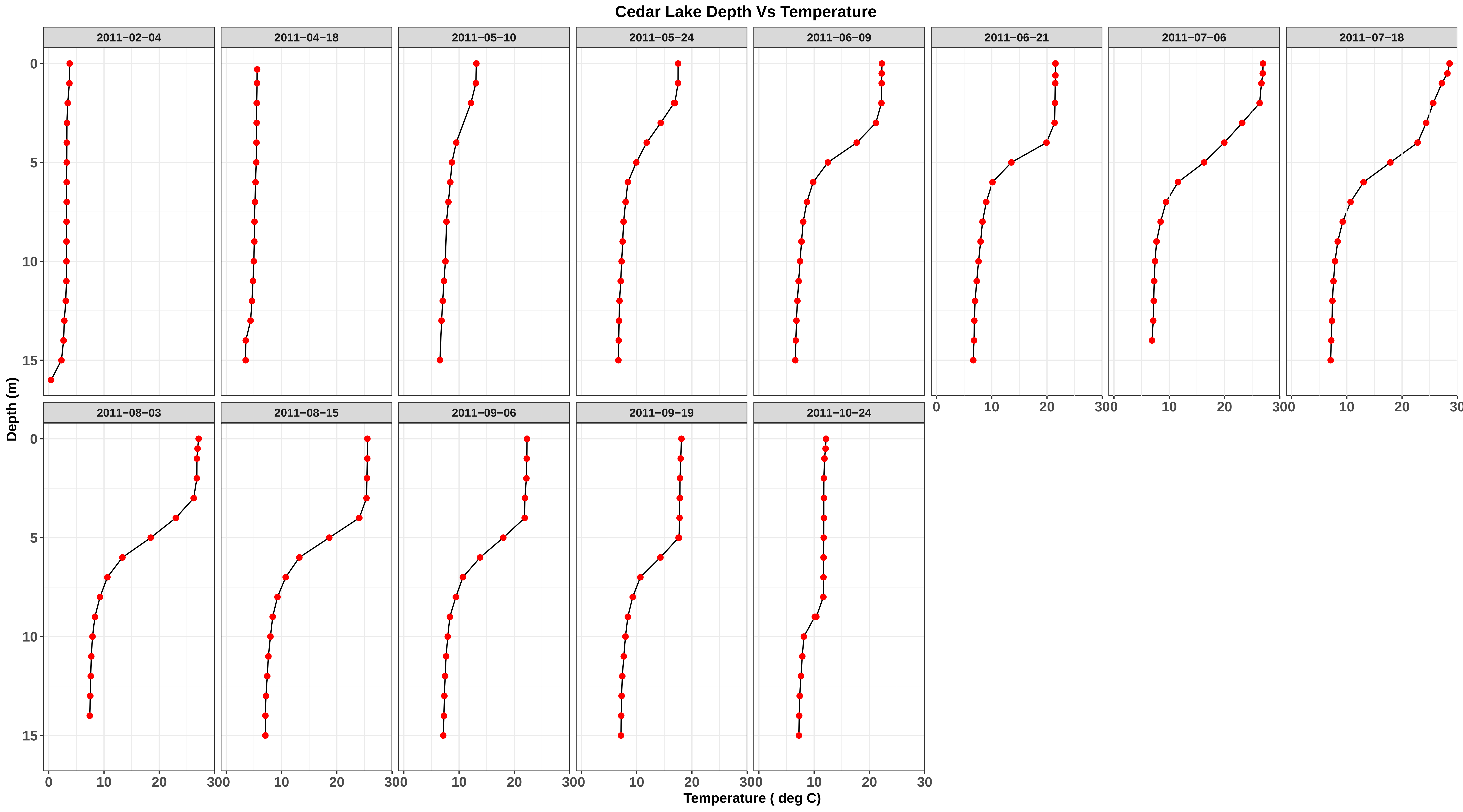
Cedar Lake Depth Vs Temperature
2008−02−06
2008−04−22
2008−05−14
2008−05−28
2008−06−10
2008−06−25
2008−07−09
2008−07−23
2008−08−05
2008−08−18
2008−09−04
2008−09−18
2008−10−20
Depth (m)
0
5
10
15
0
10
20
Temperature (deg C)



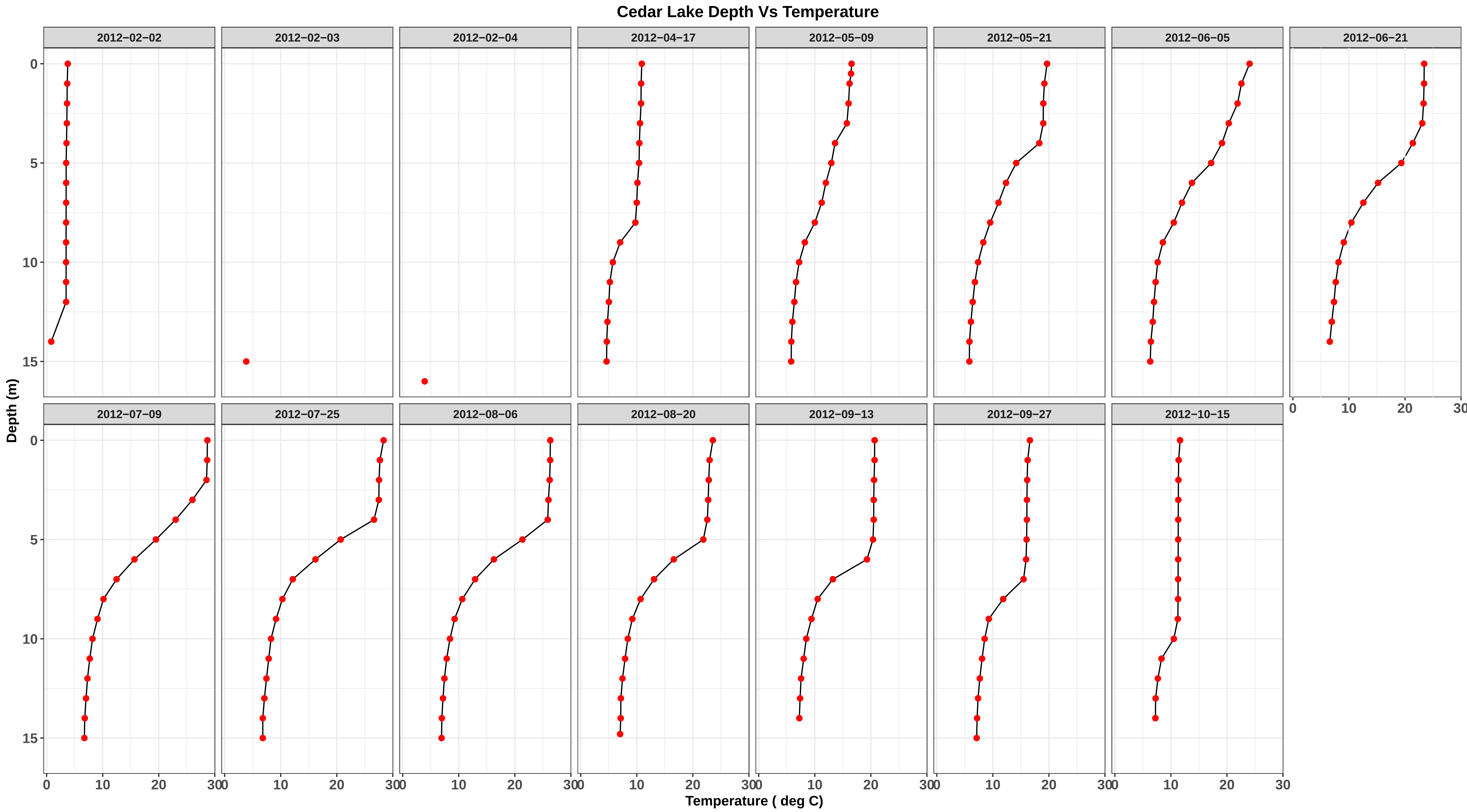
Cedar Lake Depth Vs Temperature
2009−02−06
2009−04−15
2009−05−06
2009−05−28
2009−06−10
2009−06−26
2009−07−06
2009−07−20
2009−08−04
2009−08−17
2009−09−02
2009−09−15
2009−10−15
Depth (m)
0
5
10
15
0
10
20
Temperature (deg C)

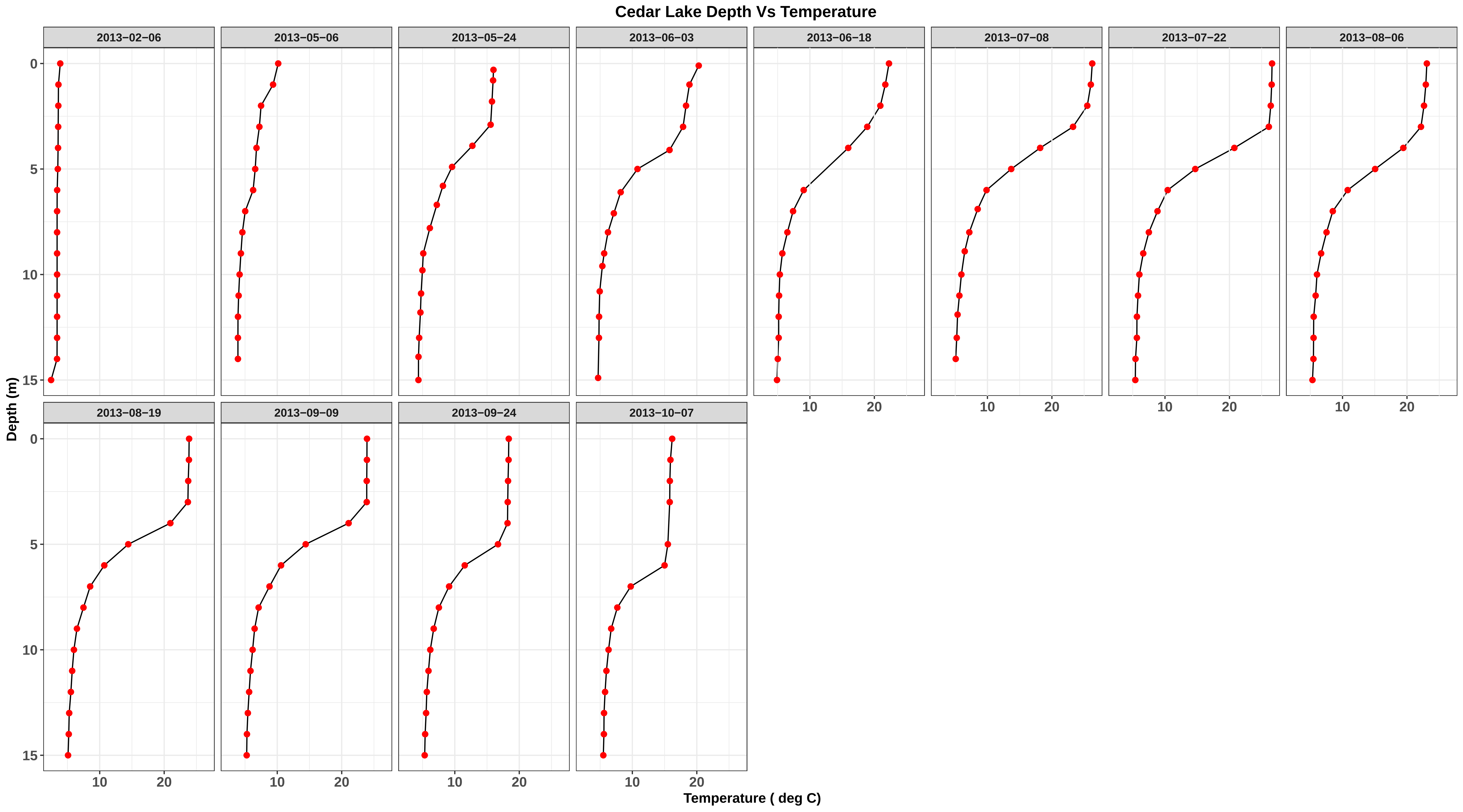


Cedar Lake Depth Vs Temperature
2010−02−08
2010−04−19
2010−05−03
2010−05−17
2010−06−10
2010−06−21
2010−07−13
2010−07−26
2010−08−12
2010−08−23
2010−09−14
2010−09−27
2010−10−13
Depth (m)
Temperature (deg C)
0
5
10
15
0
10
20
30

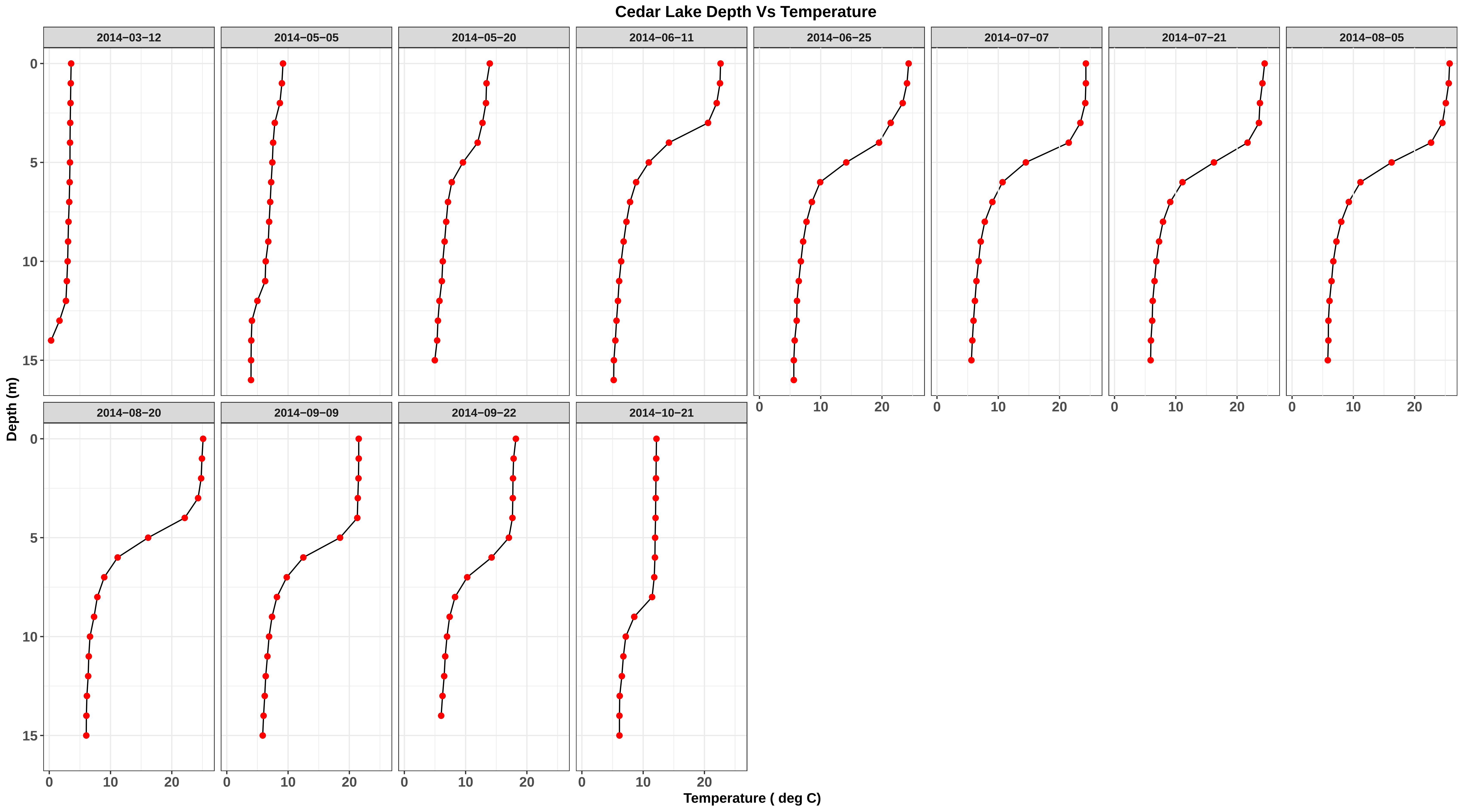


Cedar Lake Depth Vs Temperature
2011−02−04
2011−04−18
2011−05−10
2011−05−24
2011−06−09
2011−06−21
2011−07−06
2011−07−18
2011−08−03
2011−08−15
2011−09−06
2011−09−19
2011−10−24
Depth (m)
0
5
10
15
0
10
20
30
Temperature (deg C)

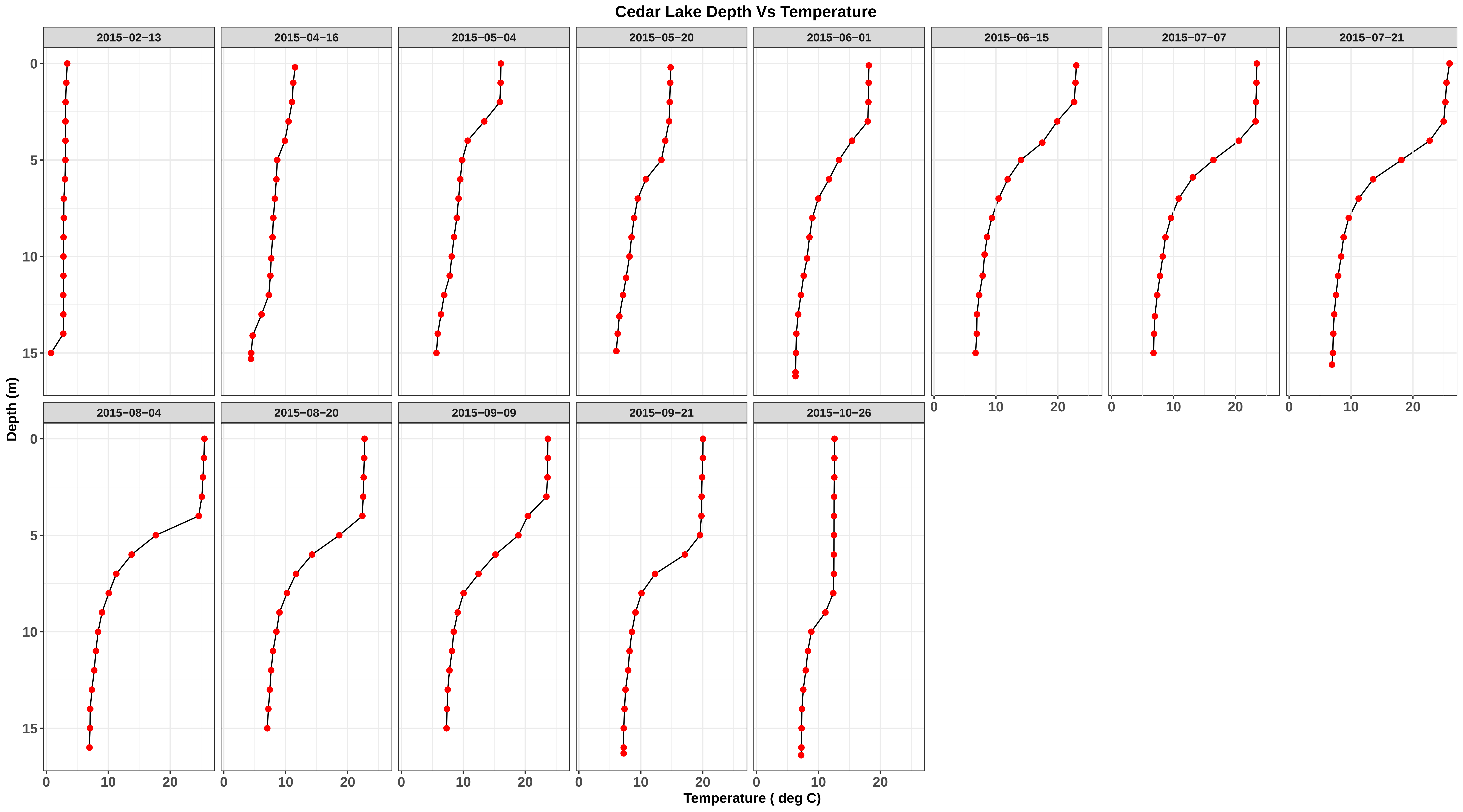

Cedar Lake Depth Vs Temperature
2012−02−02
2012−02−03
2012−02−04
2012−04−17
2012−05−09
2012−05−21
2012−06−05
2012−06−21
2012−07−09
2012−07−25
2012−08−06
2012−08−20
2012−09−13
2012−09−27
2012−10−15
Depth (m)
Temperature (deg C)
0
5
10
15
0
10
20
30



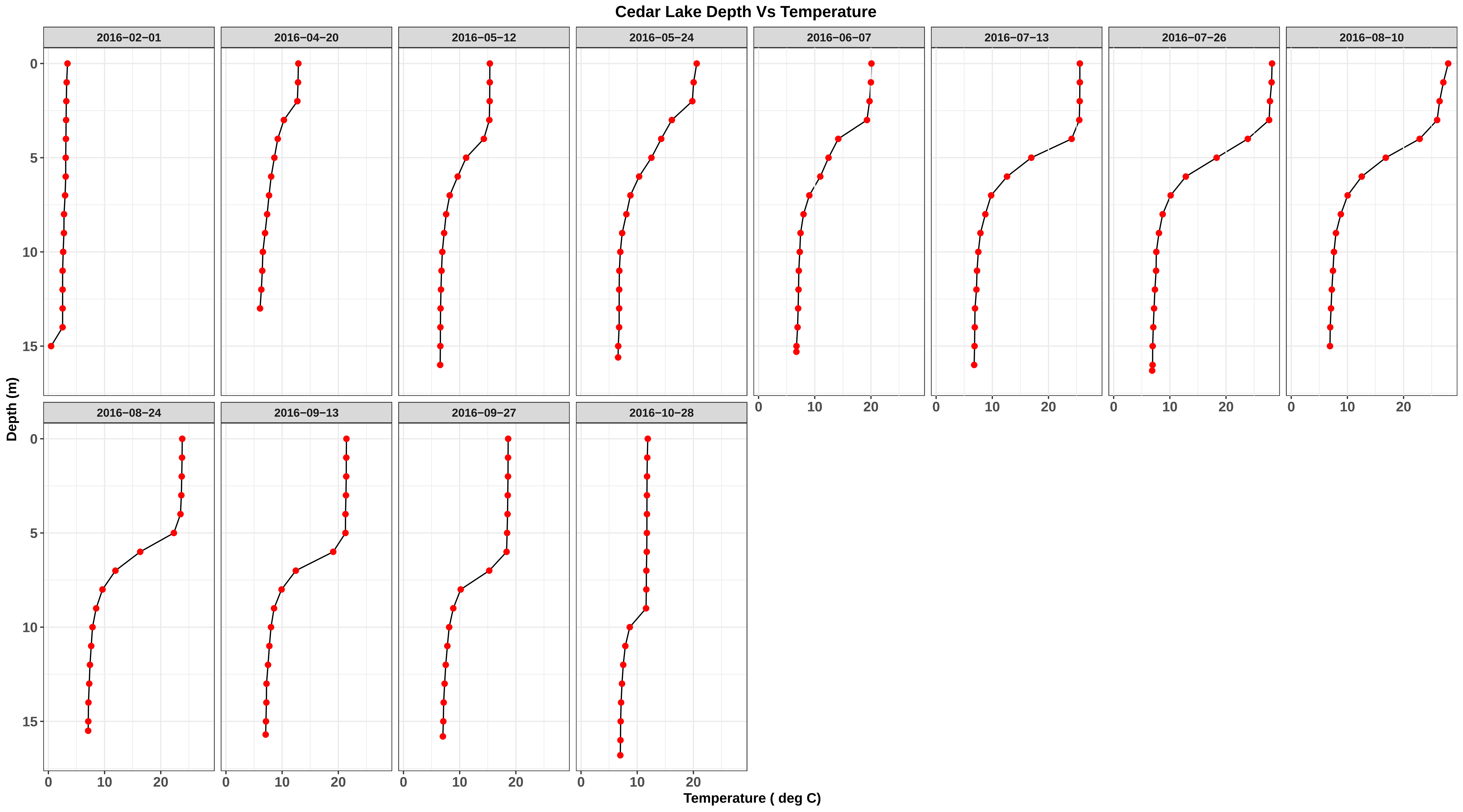
Cedar Lake Depth Vs Temperature
2013−02−06
2013−05−06
2013−05−24
2013−06−03
2013−06−18
2013−07−08
2013−07−22
2013−08−06
2013−08−19
2013−09−09
2013−09−24
2013−10−07
Depth (m)
0
5
10
15
10
20
Temperature (deg C)



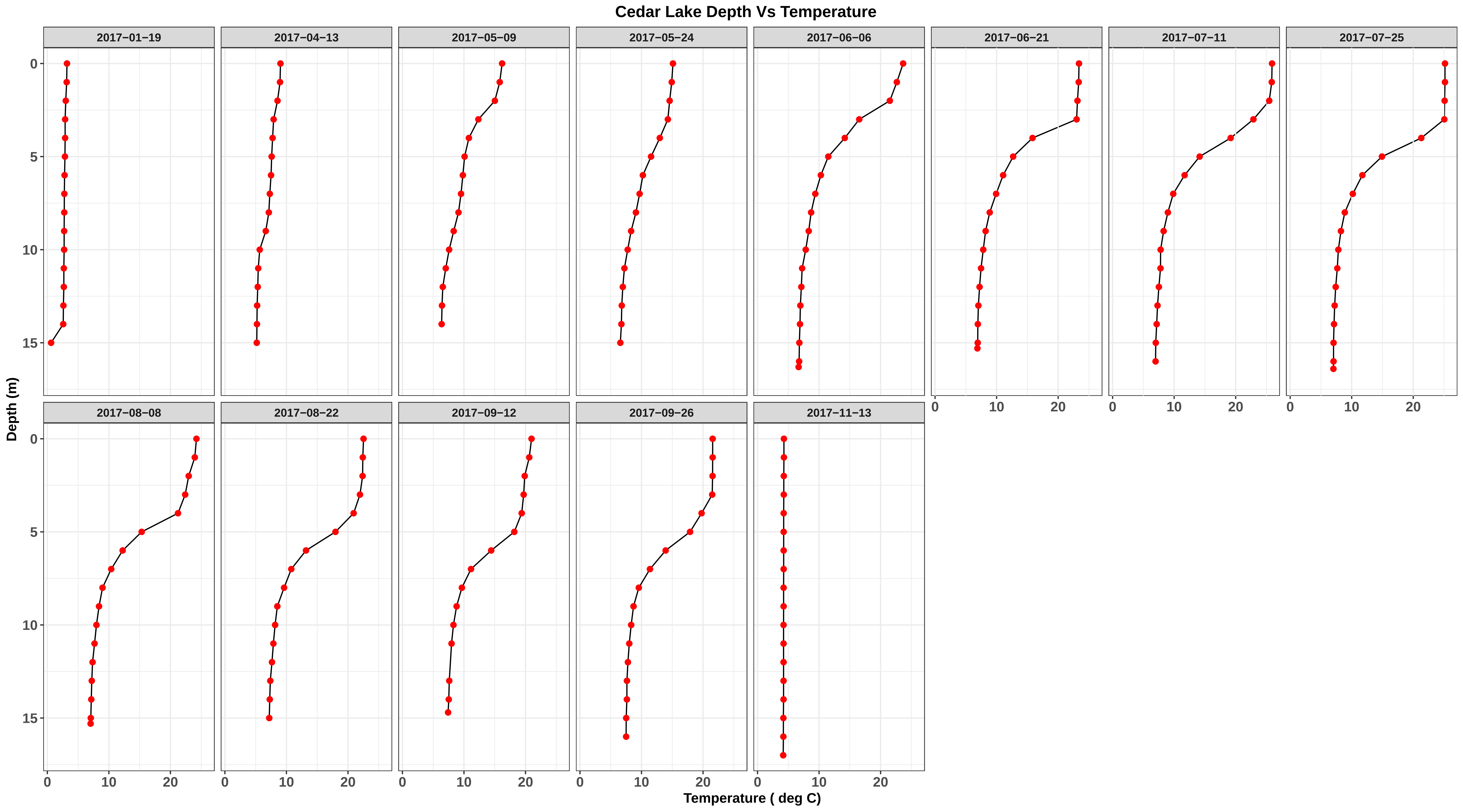
Cedar Lake Depth Vs Temperature
2014−03−12
2014−05−05
2014−05−20
2014−06−11
2014−06−25
2014−07−07
2014−07−21
2014−08−05
2014−08−20
2014−09−09
2014−09−22
2014−10−21
Depth (m)
0
5
10
15
0
10
20
Temperature (deg C)



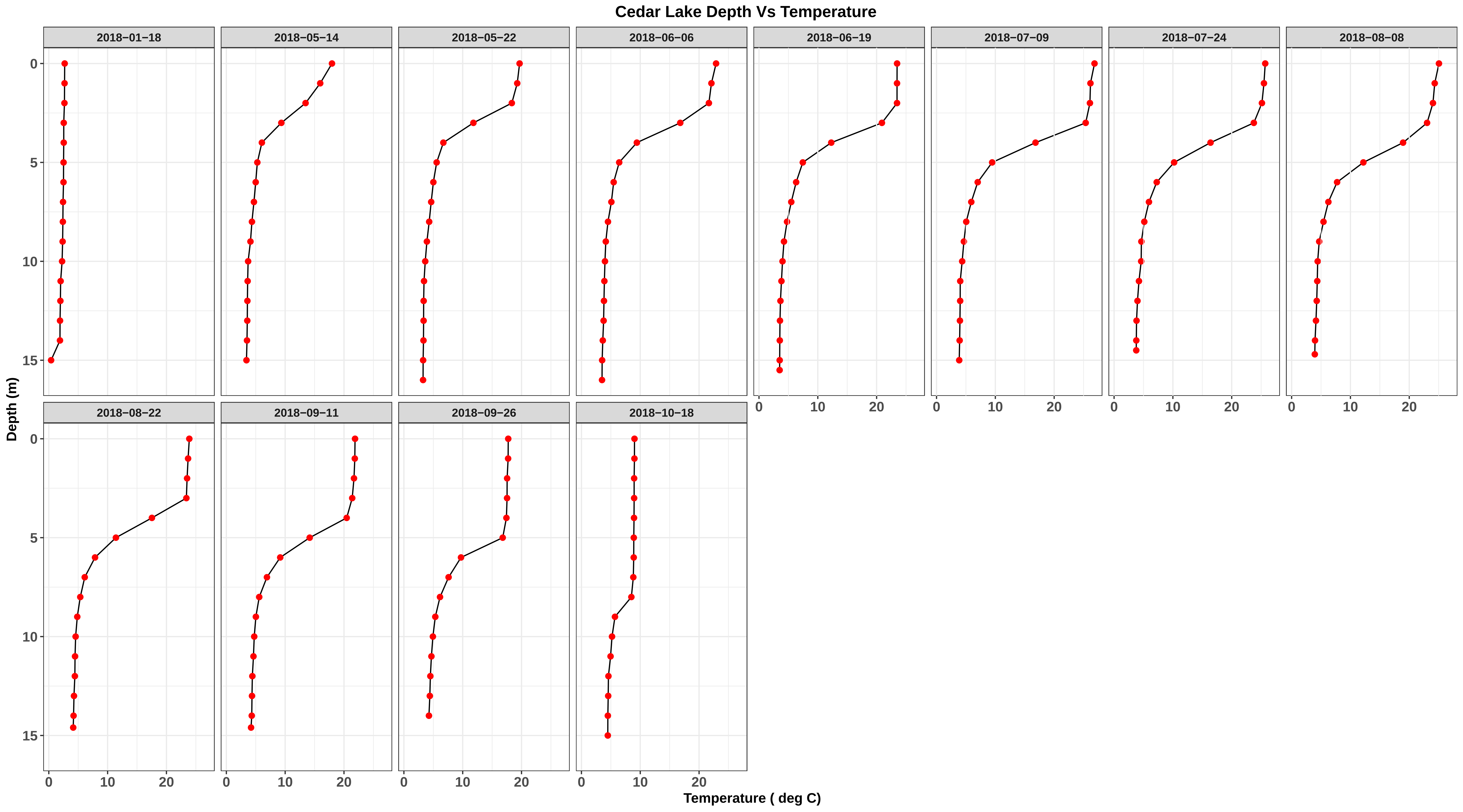
Cedar Lake Depth Vs Temperature
2015−02−13
2015−04−16
2015−05−04
2015−05−20
2015−06−01
2015−06−15
2015−07−07
2015−07−21
2015−08−04
2015−08−20
2015−09−09
2015−09−21
2015−10−26
Depth (m)
Temperature (deg C)
0
5
10
15
20



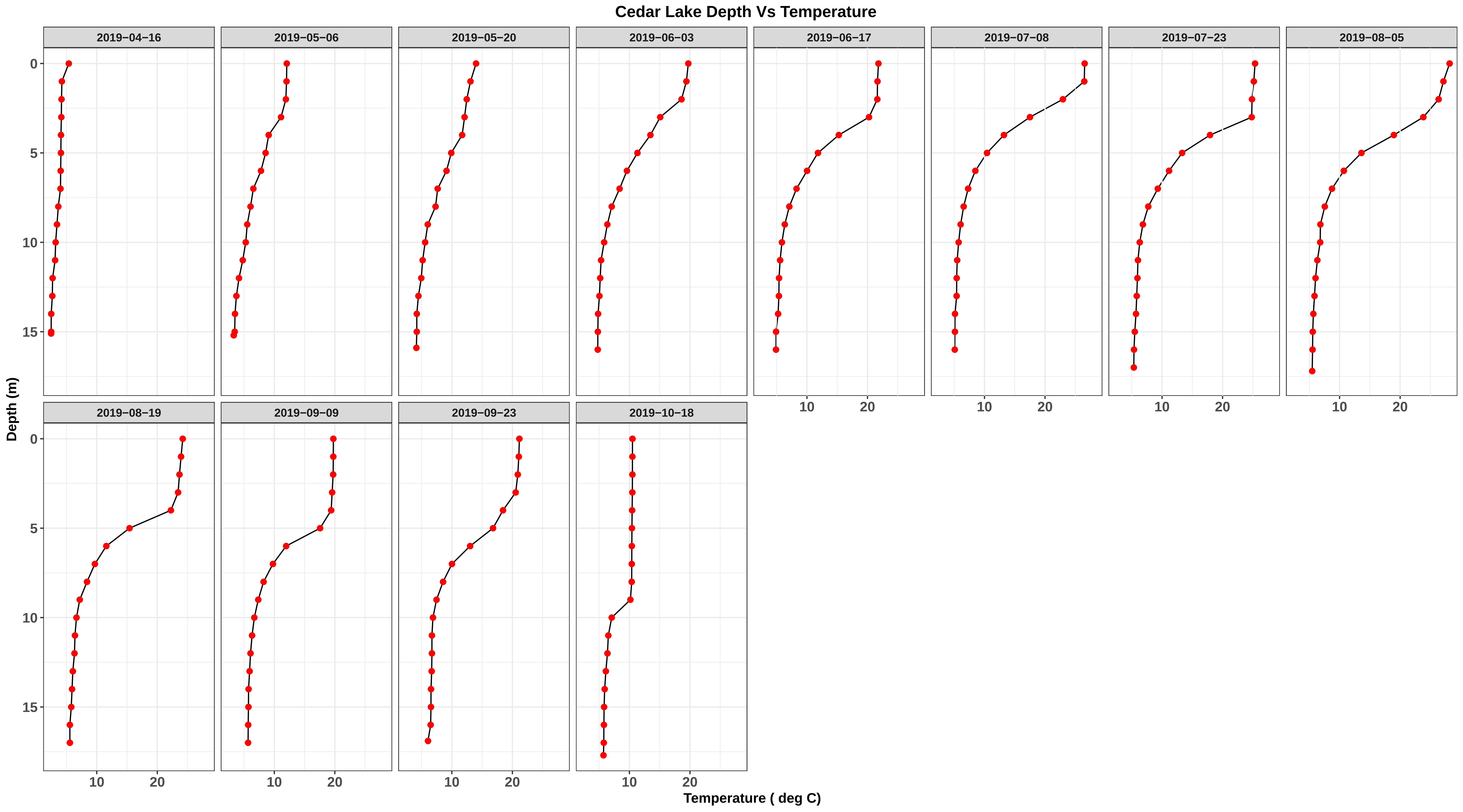
Cedar Lake Depth Vs Temperature
2016−02−01
2016−04−20
2016−05−12
2016−05−24
2016−06−07
2016−07−13
2016−07−26
2016−08−10
2016−08−24
2016−09−13
2016−09−27
2016−10−28
Depth (m)
0
5
10
15
0
10
20
Temperature (deg C)



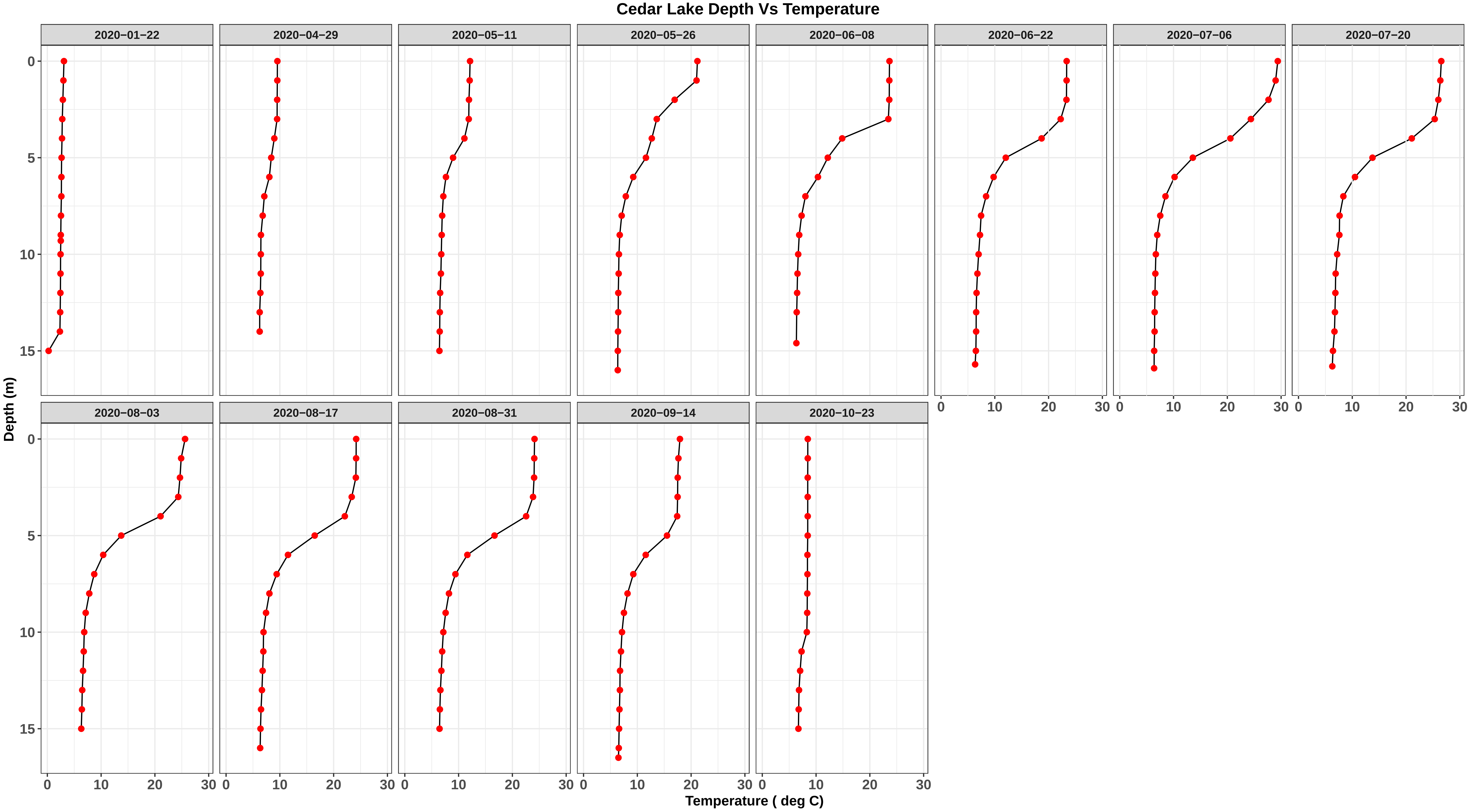
Cedar Lake Depth Vs Temperature
2017−01−19
2017−04−13
2017−05−09
2017−05−24
2017−06−06
2017−06−21
2017−07−11
2017−07−25
2017−08−08
2017−08−22
2017−09−12
2017−09−26
2017−11−13
Depth (m)
0
5
10
15
0
10
20
Temperature (deg C)



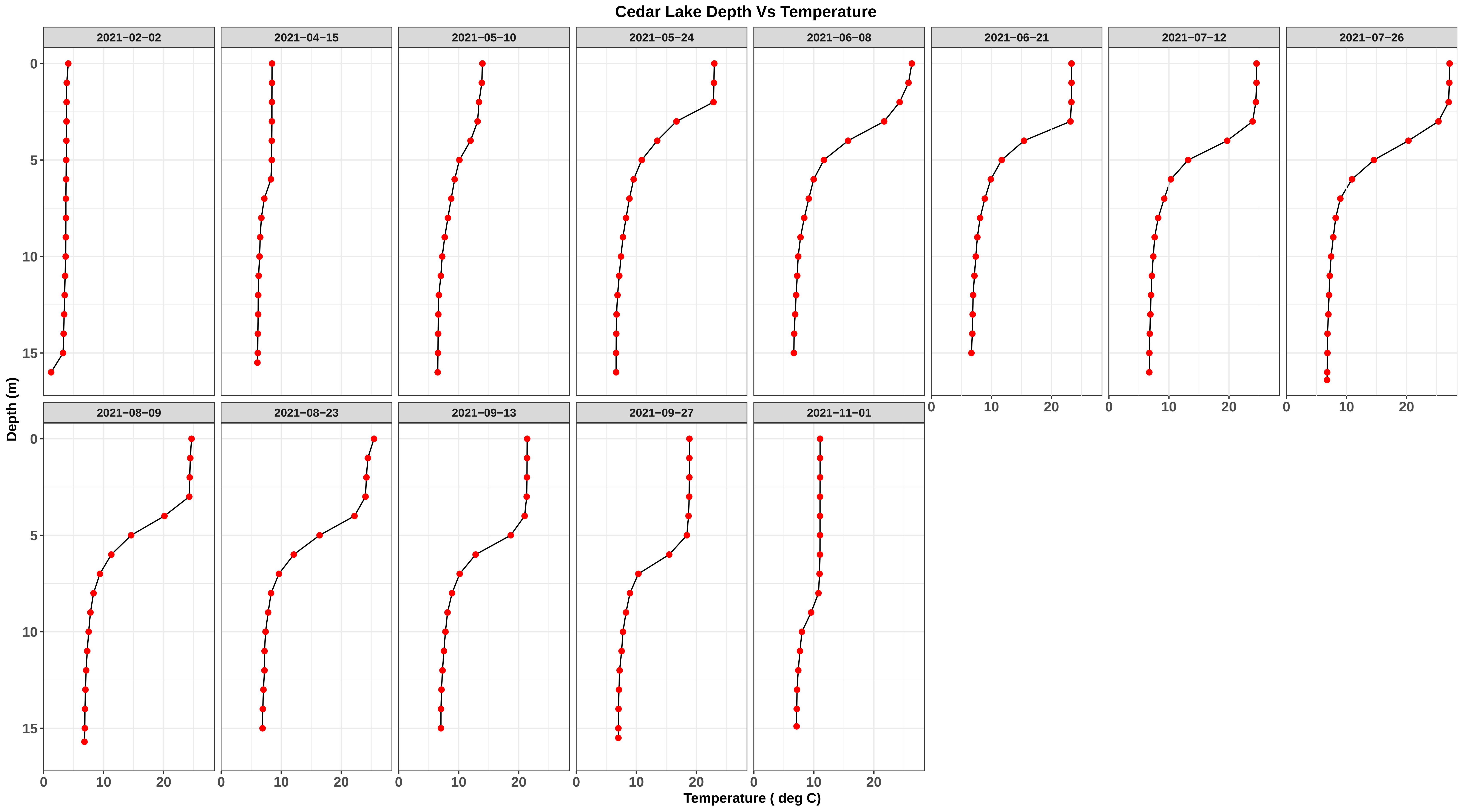
Cedar Lake Depth Vs Temperature
2018−01−18
2018−05−14
2018−05−22
2018−06−06
2018−06−19
2018−07−09
2018−07−24
2018−08−08
2018−08−22
2018−09−11
2018−09−26
2018−10−18
Depth (m)
Temperature (deg C)
0
5
10
15
0
10
20



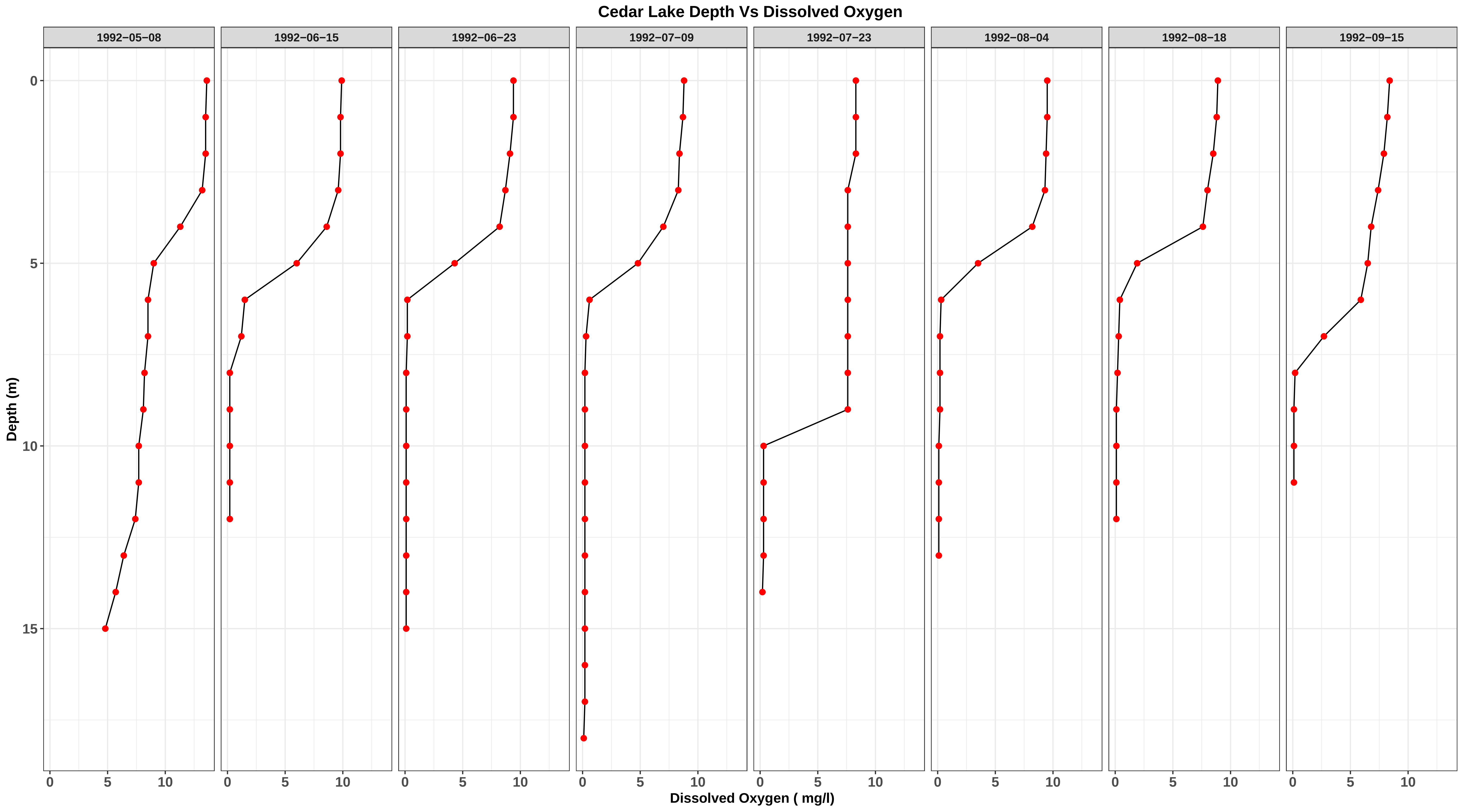
Cedar Lake Depth Vs Temperature
2019−04−16
2019−05−06
2019−05−20
2019−06−03
2019−06−17
2019−07−08
2019−07−23
2019−08−05
2019−08−19
2019−09−09
2019−09−23
2019−10−18
Depth (m)
0
5
10
15
10
20
Temperature (deg C)



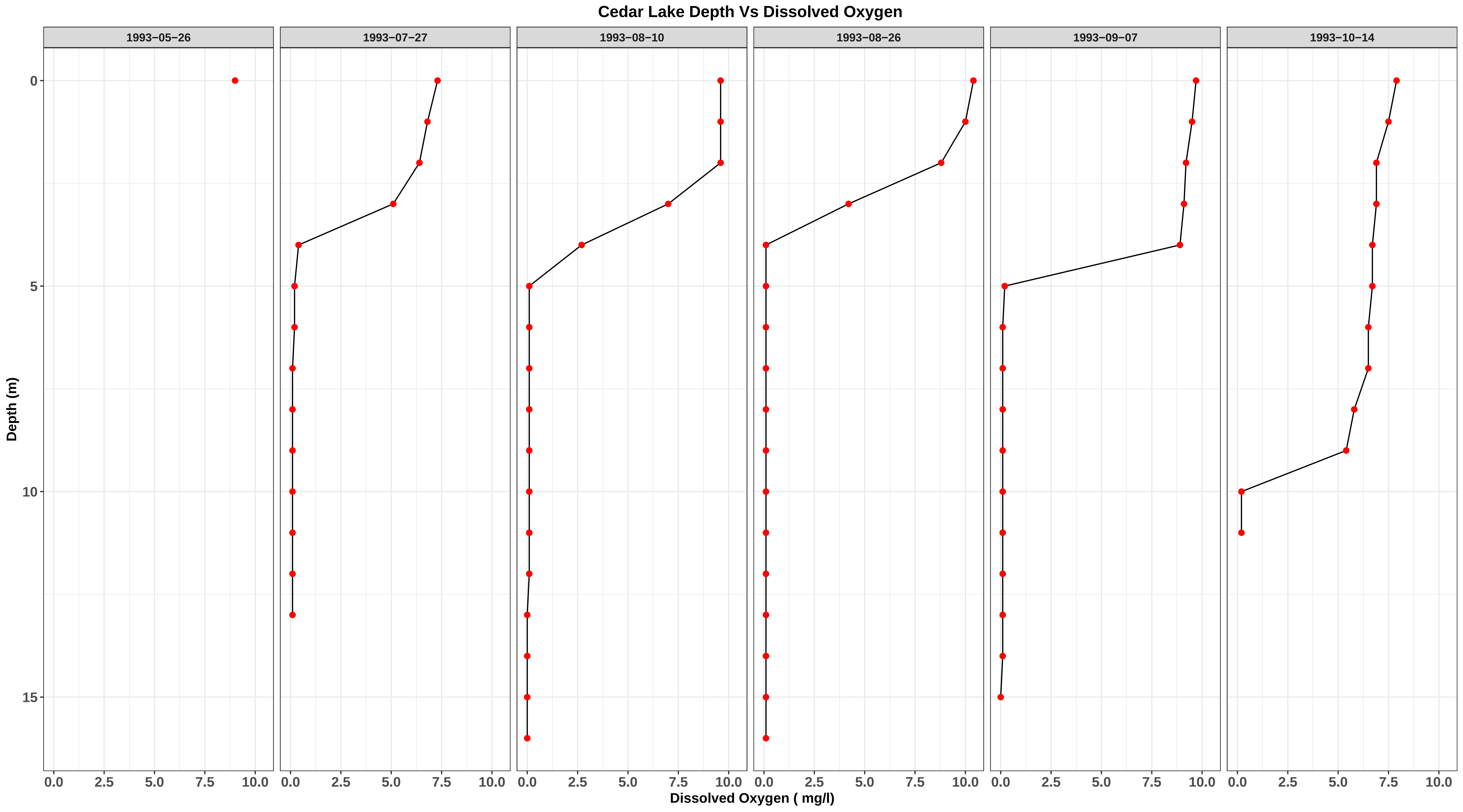
Cedar Lake Depth Vs Temperature
2020−01−22
2020−04−29
2020−05−11
2020−05−26
2020−06−08
2020−06−22
2020−07−06
2020−07−20
2020−08−03
2020−08−17
2020−08−31
2020−09−14
2020−10−23
Depth (m)
Temperature (deg C)
0
5
10
15
0
10
20
30



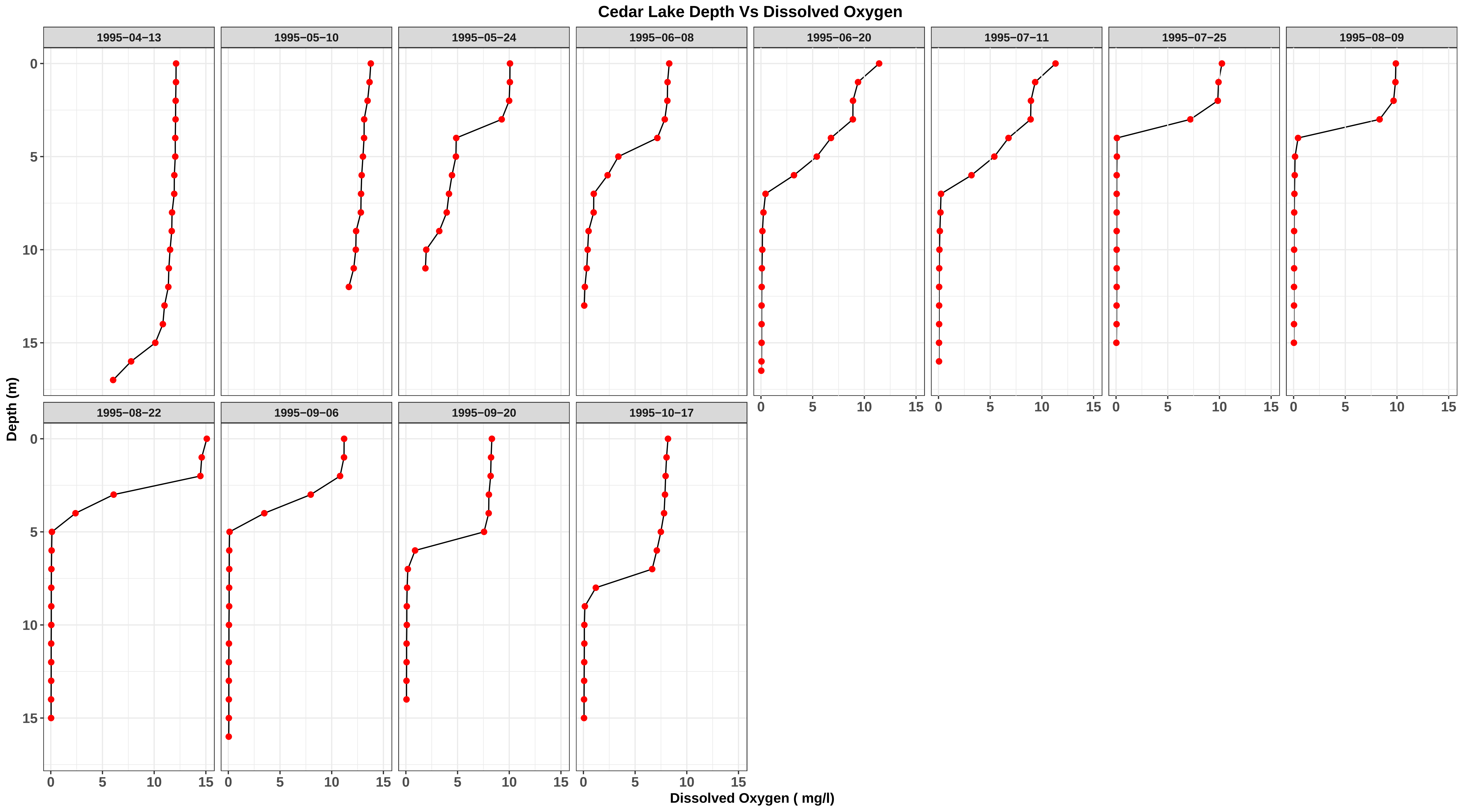
Cedar Lake Depth Vs Temperature
2021−02−02
2021−04−15
2021−05−10
2021−05−24
2021−06−08
2021−06−21
2021−07−12
2021−07−26
2021−08−09
2021−08−23
2021−09−13
2021−09−27
2021−11−01
Depth (m)
0
5
10
15
0
10
20
Temperature (deg C)



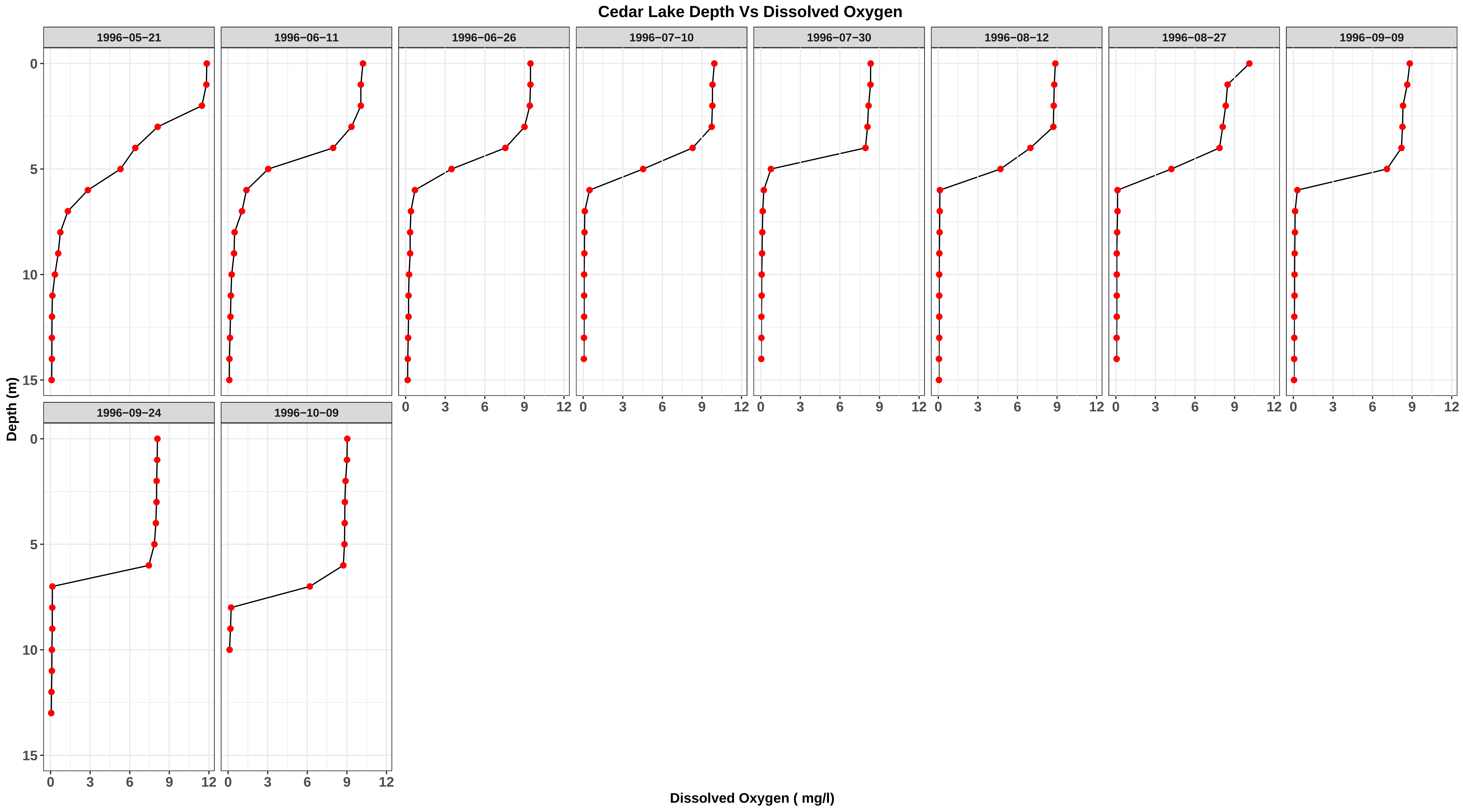
Cedar Lake Depth Vs Dissolved Oxygen
1992−05−08
1992−06−15
1992−06−23
1992−07−09
1992−07−23
1992−08−04
1992−08−18
1992−09−15
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)

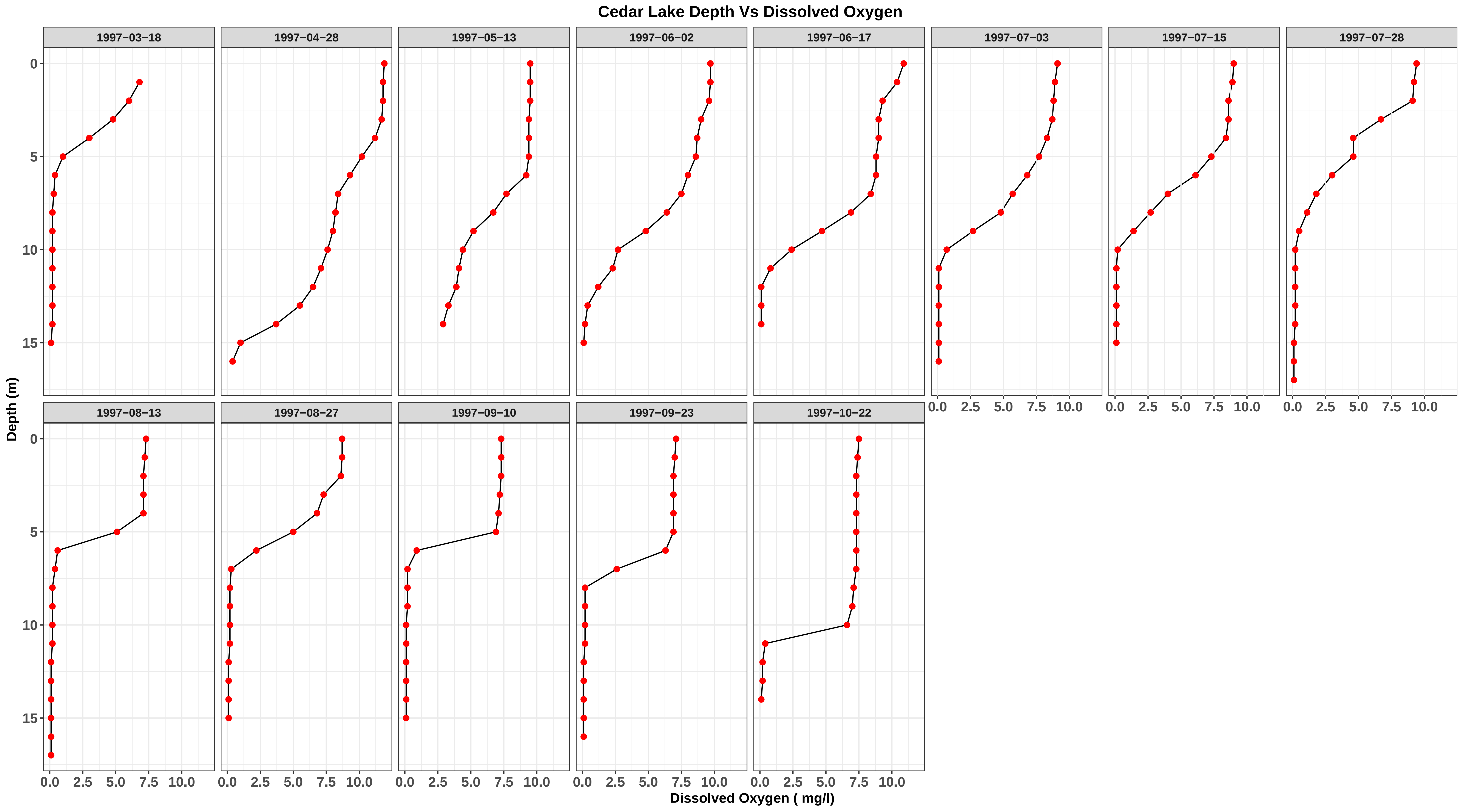


Cedar Lake Depth Vs Dissolved Oxygen
1993−05−26
1993−07−27
1993−08−10
1993−08−26
1993−09−07
1993−10−14
Depth (m)
0
5
10
15
0.0
2.5
5.0
7.5
10.0
Dissolved Oxygen (mg/l)

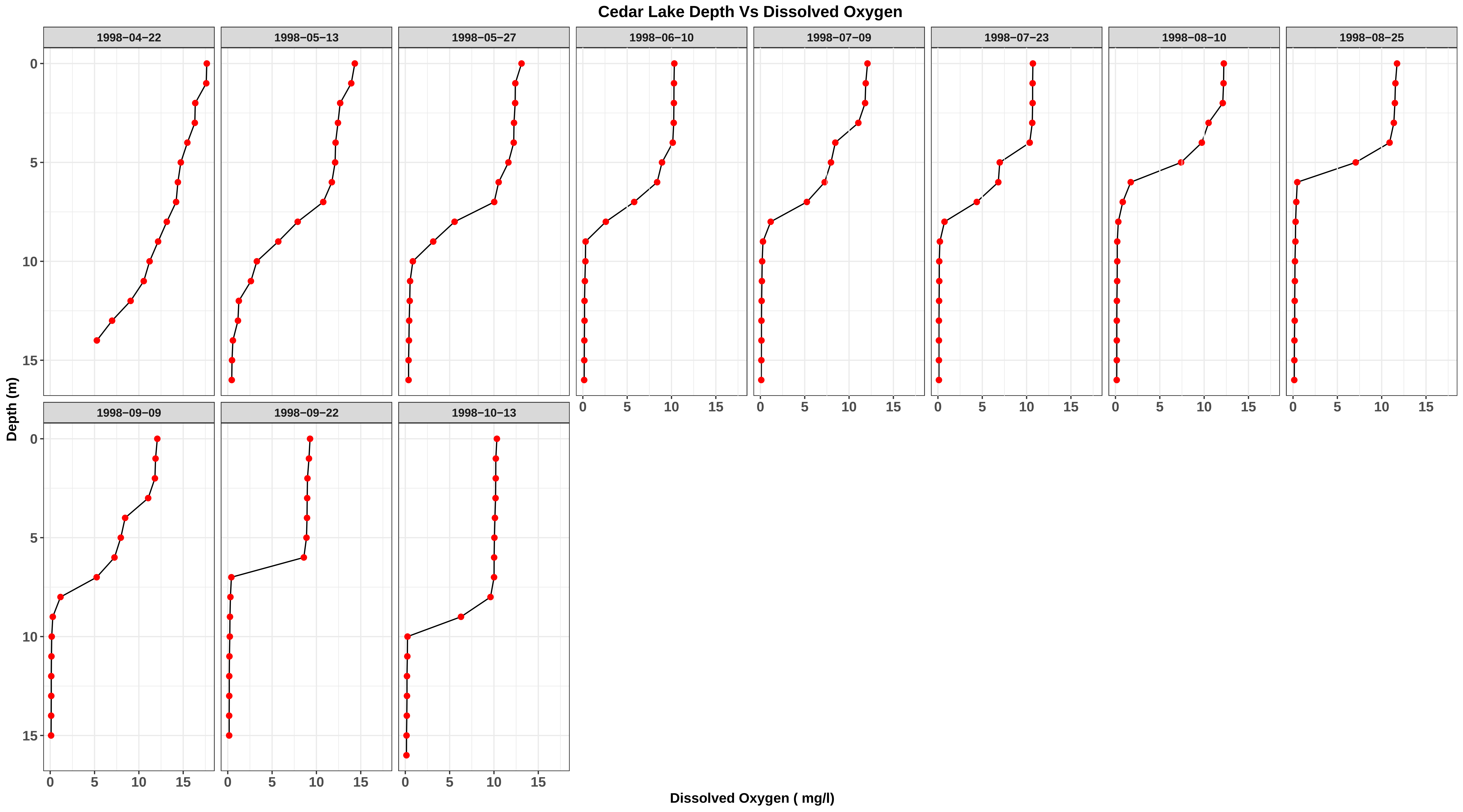


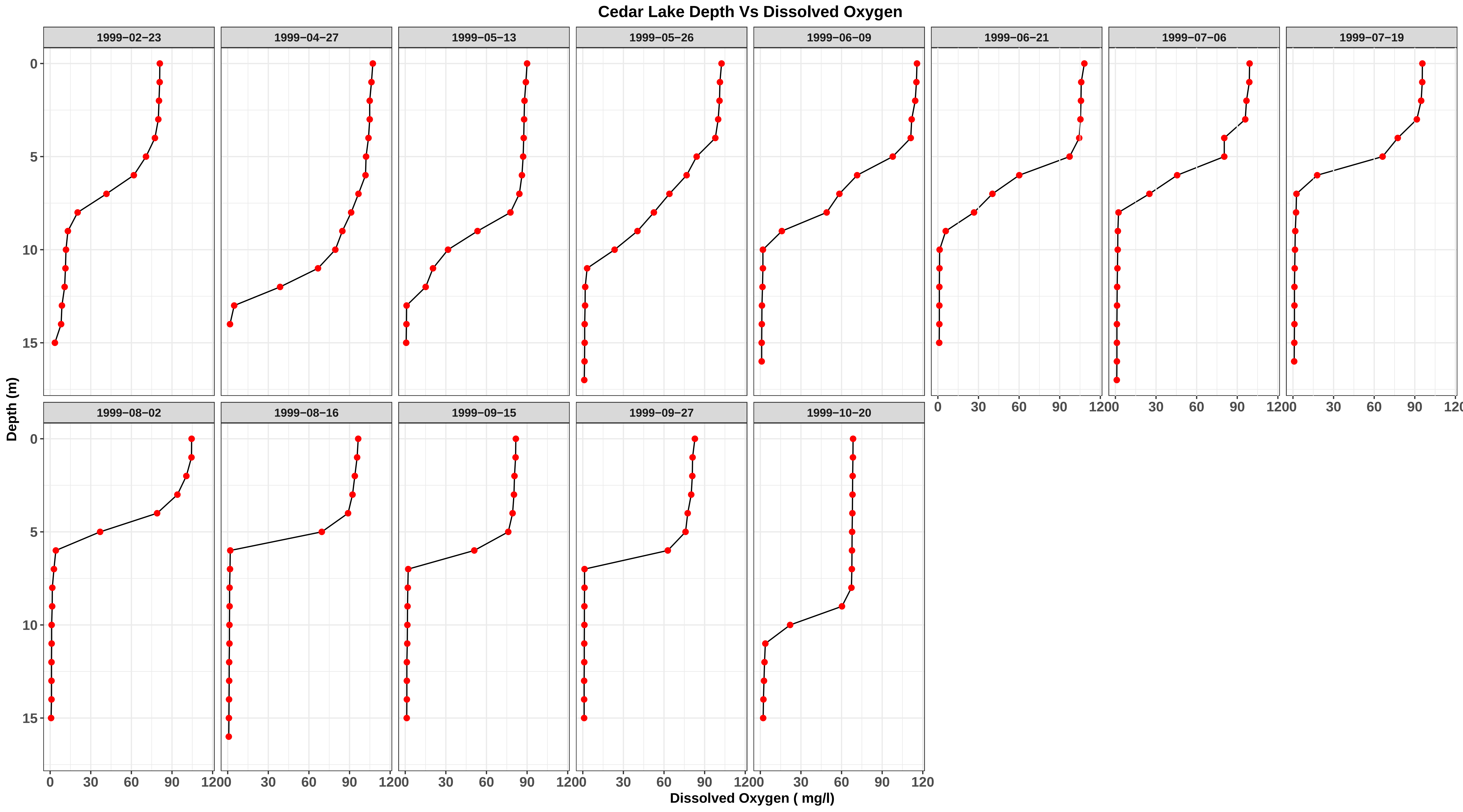
Cedar Lake Depth Vs Dissolved Oxygen
1995−04−13
1995−05−10
1995−05−24
1995−06−08
1995−06−20
1995−07−11
1995−07−25
1995−08−09
1995−08−22
1995−09−06
1995−09−20
1995−10−17
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)


Cedar Lake Depth Vs Dissolved Oxygen
1996−05−21
1996−06−11
1996−06−26
1996−07−10
1996−07−30
1996−08−12
1996−08−27
1996−09−09
1996−09−24
1996−10−09
Depth (m)
0
5
10
15
0
3
6
9
12
Dissolved Oxygen (mg/l)

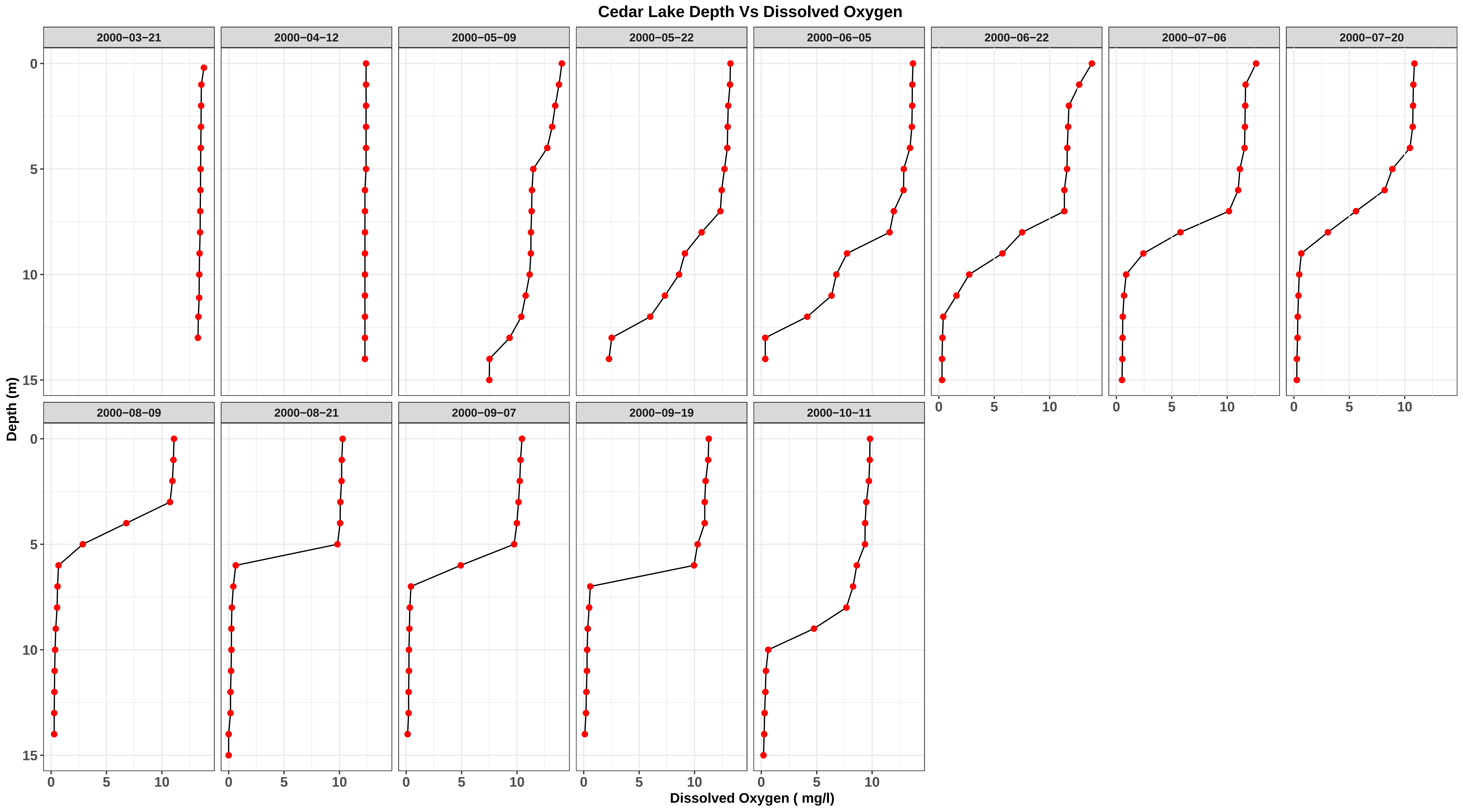


Cedar Lake Depth Vs Dissolved Oxygen
1997−03−18
1997−04−28
1997−05−13
1997−06−02
1997−06−17
1997−07−03
1997−07−15
1997−07−28
1997−08−13
1997−08−27
1997−09−10
1997−09−23
1997−10−22
Depth (m)
0
5
10
15
0.0
2.5
5.0
7.5
10.0
Dissolved Oxygen (mg/l)

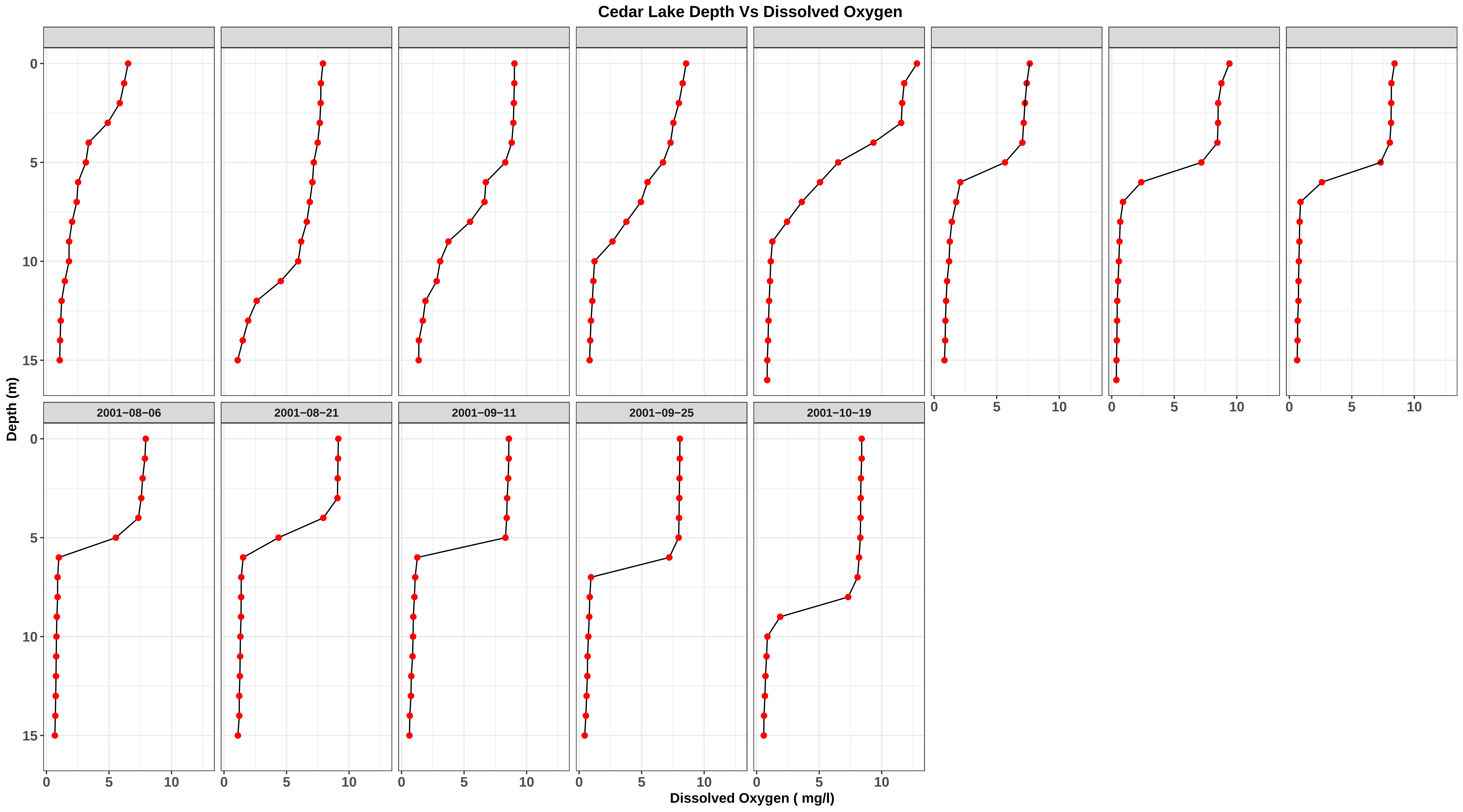

Cedar Lake Depth Vs Dissolved Oxygen
1998−04−22
1998−05−13
1998−05−27
1998−06−10
1998−07−09
1998−07−23
1998−08−10
1998−08−25
1998−09−09
1998−09−22
1998−10−13
Depth (m)
Dissolved Oxygen (mg/l)



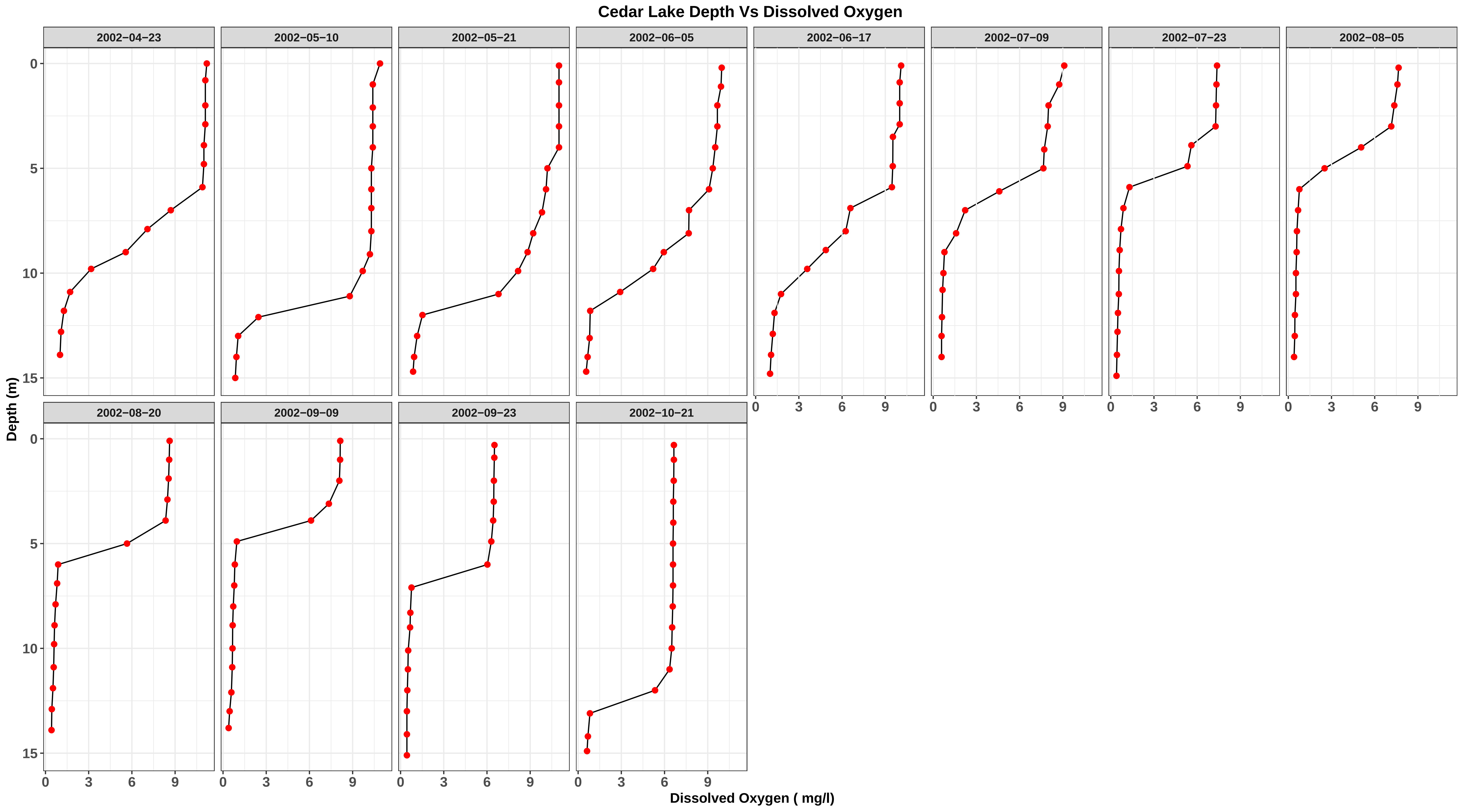
Cedar Lake Depth Vs Dissolved Oxygen
1999−02−23
1999−04−27
1999−05−13
1999−05−26
1999−06−09
1999−06−21
1999−07−06
1999−07−19
1999−08−02
1999−08−16
1999−09−15
1999−09−27
1999−10−20
Depth (m)
Dissolved Oxygen (mg/l)
0
5
10
15
0
30
60
90
120

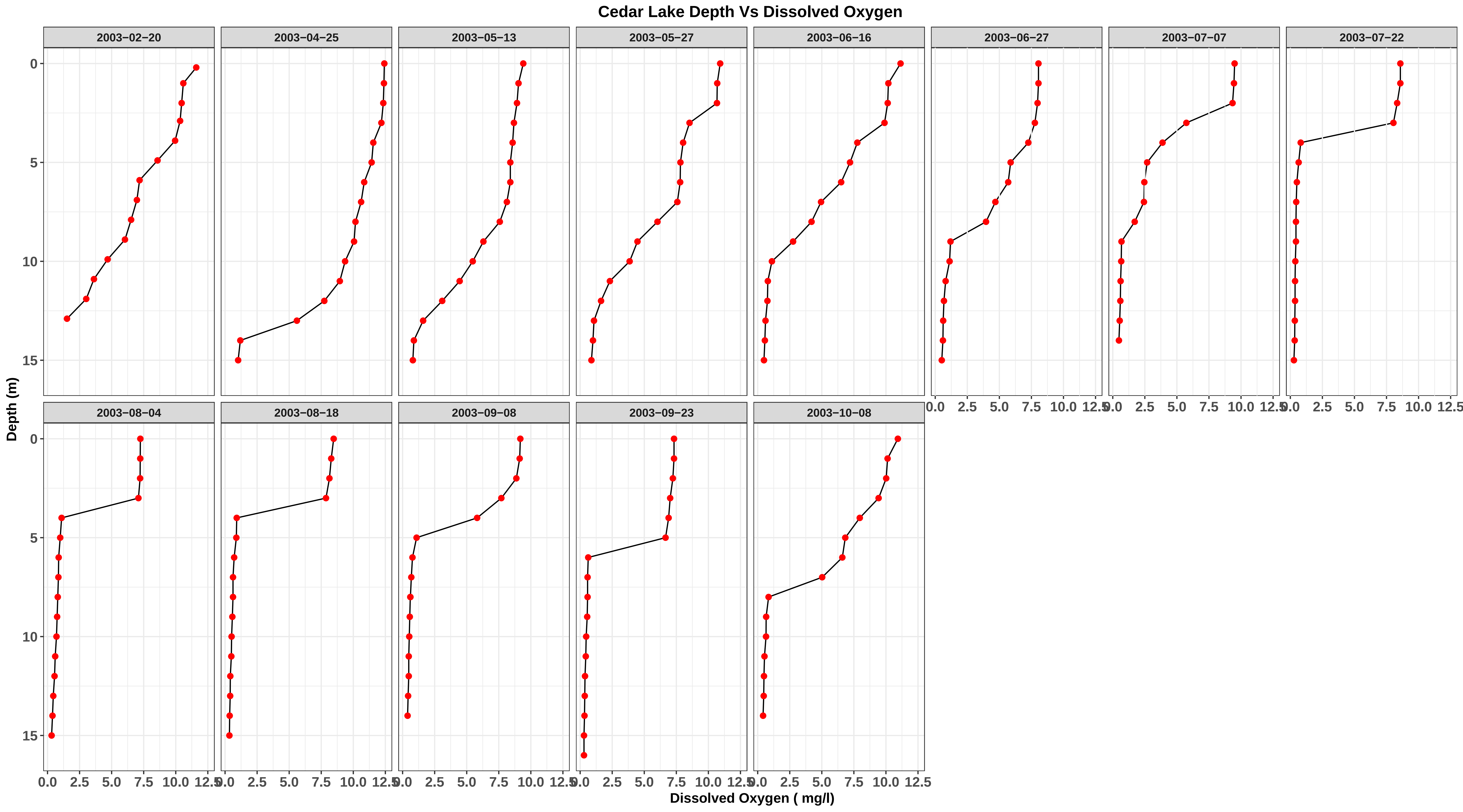


Cedar Lake Depth Vs Dissolved Oxygen
2000−03−21
2000−04−12
2000−05−09
2000−05−22
2000−06−05
2000−06−22
2000−07−06
2000−07−20
2000−08−09
2000−08−21
2000−09−07
2000−09−19
2000−10−11
Depth (m)
Dissolved Oxygen (mg/l)
0
5
10
15

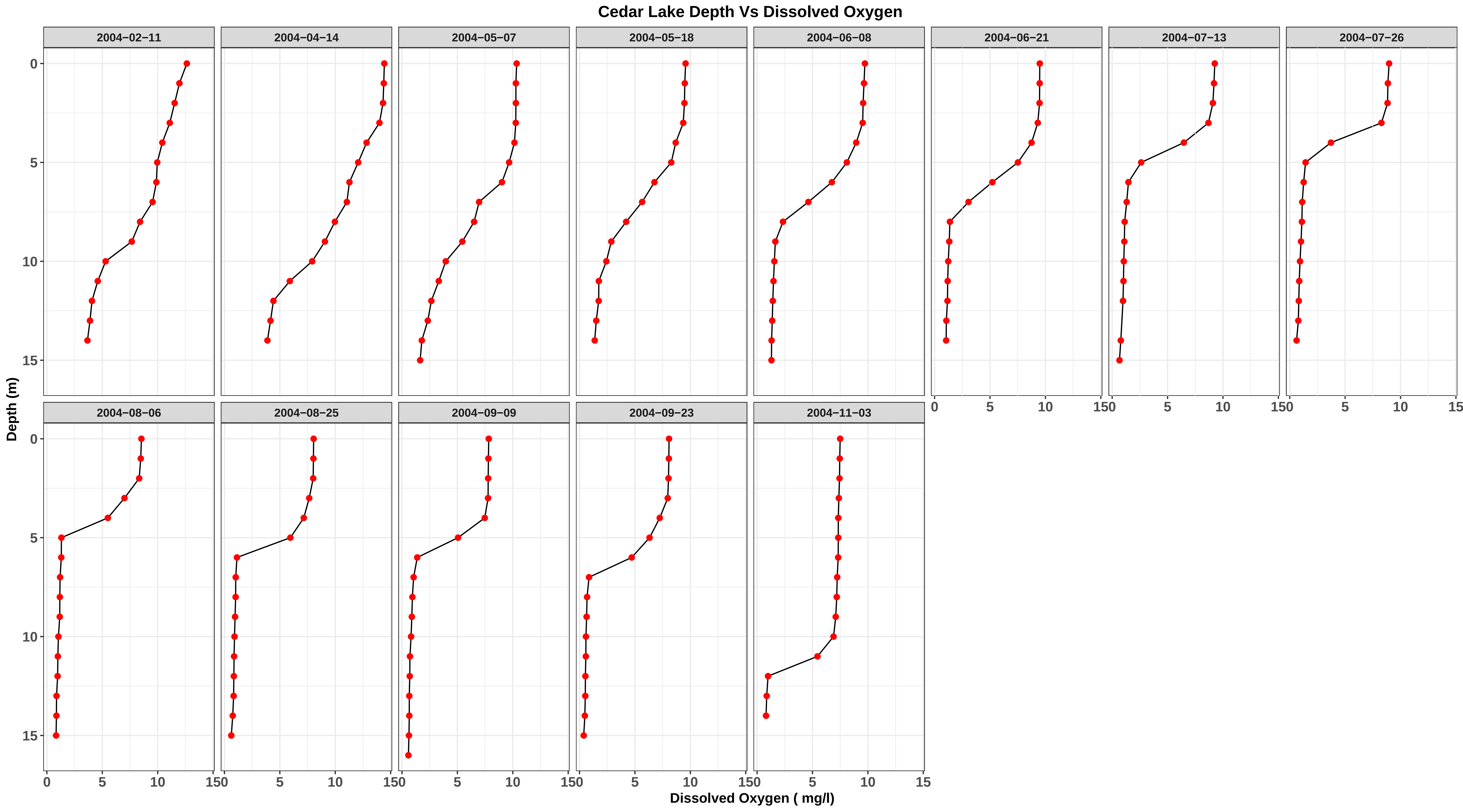


Cedar Lake Depth Vs Dissolved Oxygen
2001−08−06
2001−08−21
2001−09−11
2001−09−25
2001−10−19
Depth (m)
Dissolved Oxygen (mg/l)
0
5
10
15

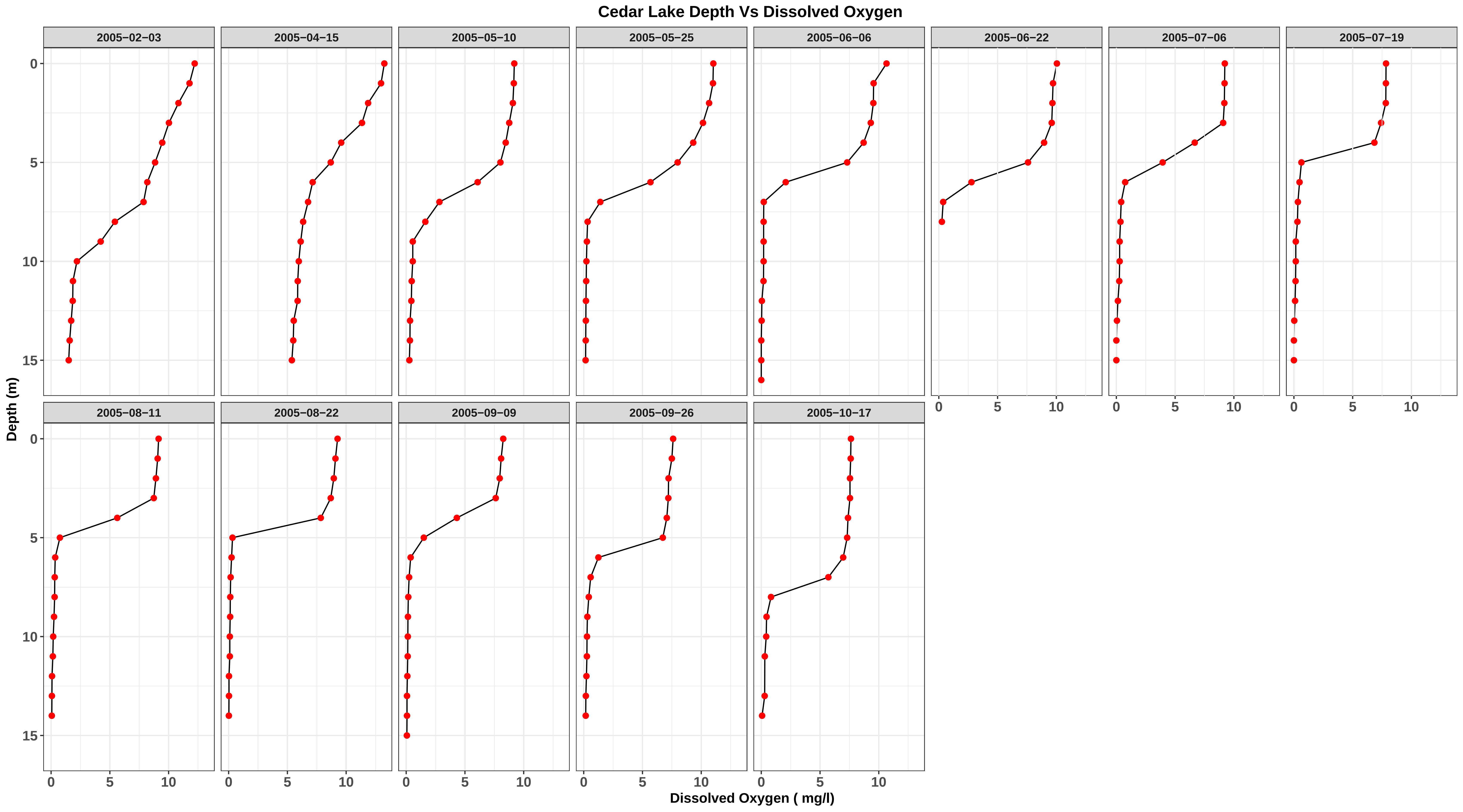

Cedar Lake Depth Vs Dissolved Oxygen
2002−04−23
2002−05−10
2002−05−21
2002−06−05
2002−06−17
2002−07−09
2002−07−23
2002−08−05
2002−08−20
2002−09−09
2002−09−23
2002−10−21
Depth (m)
0
5
10
15
0
3
6
9
Dissolved Oxygen (mg/l)

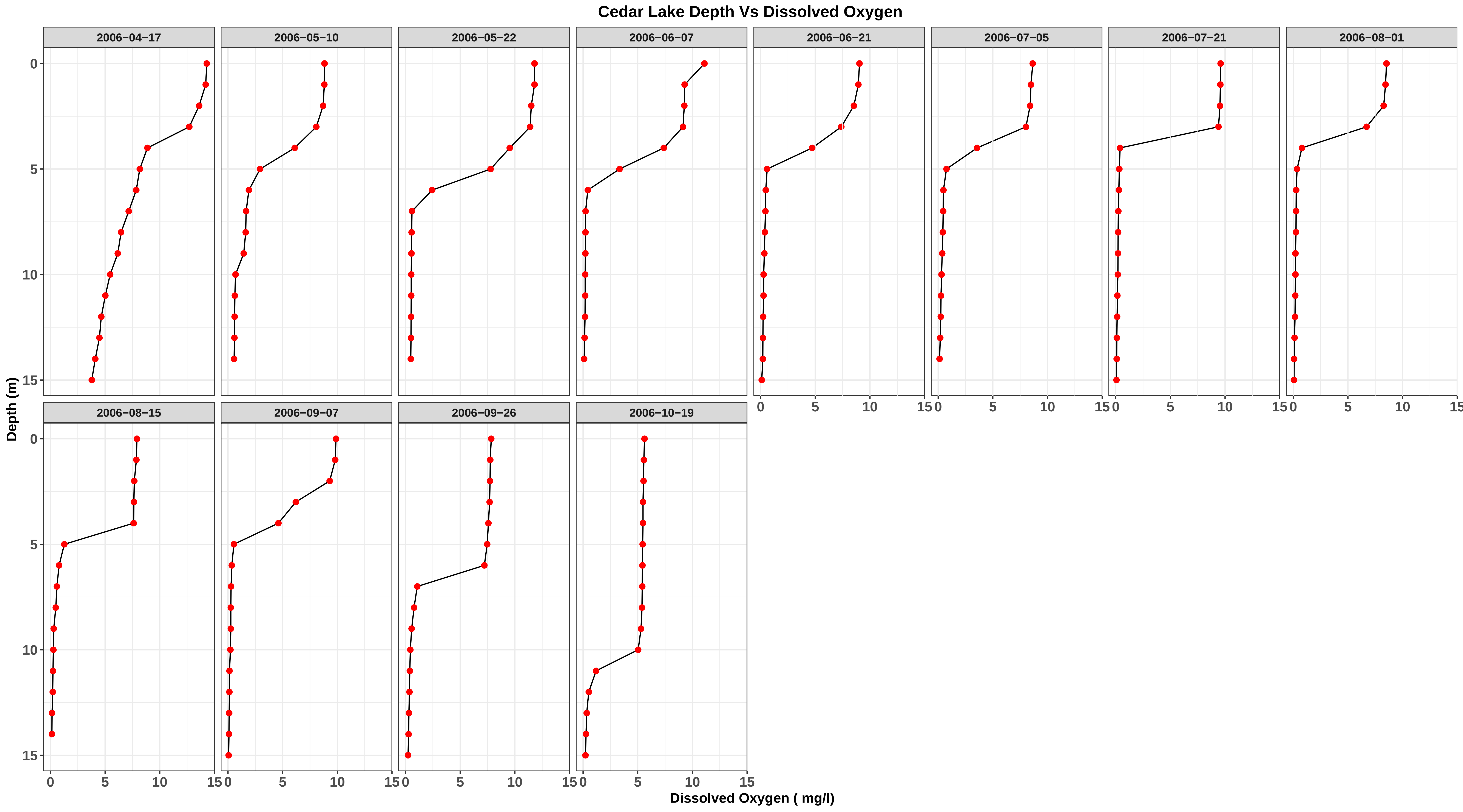


Cedar Lake Depth Vs Dissolved Oxygen
2003−02−20
2003−04−25
2003−05−13
2003−05−27
2003−06−16
2003−06−27
2003−07−07
2003−07−22
2003−08−04
2003−08−18
2003−09−08
2003−09−23
2003−10−08
Depth (m)
Dissolved Oxygen (mg/l)
0
5
10
15
0.0
2.5
5.0
7.5
10.0
12.5

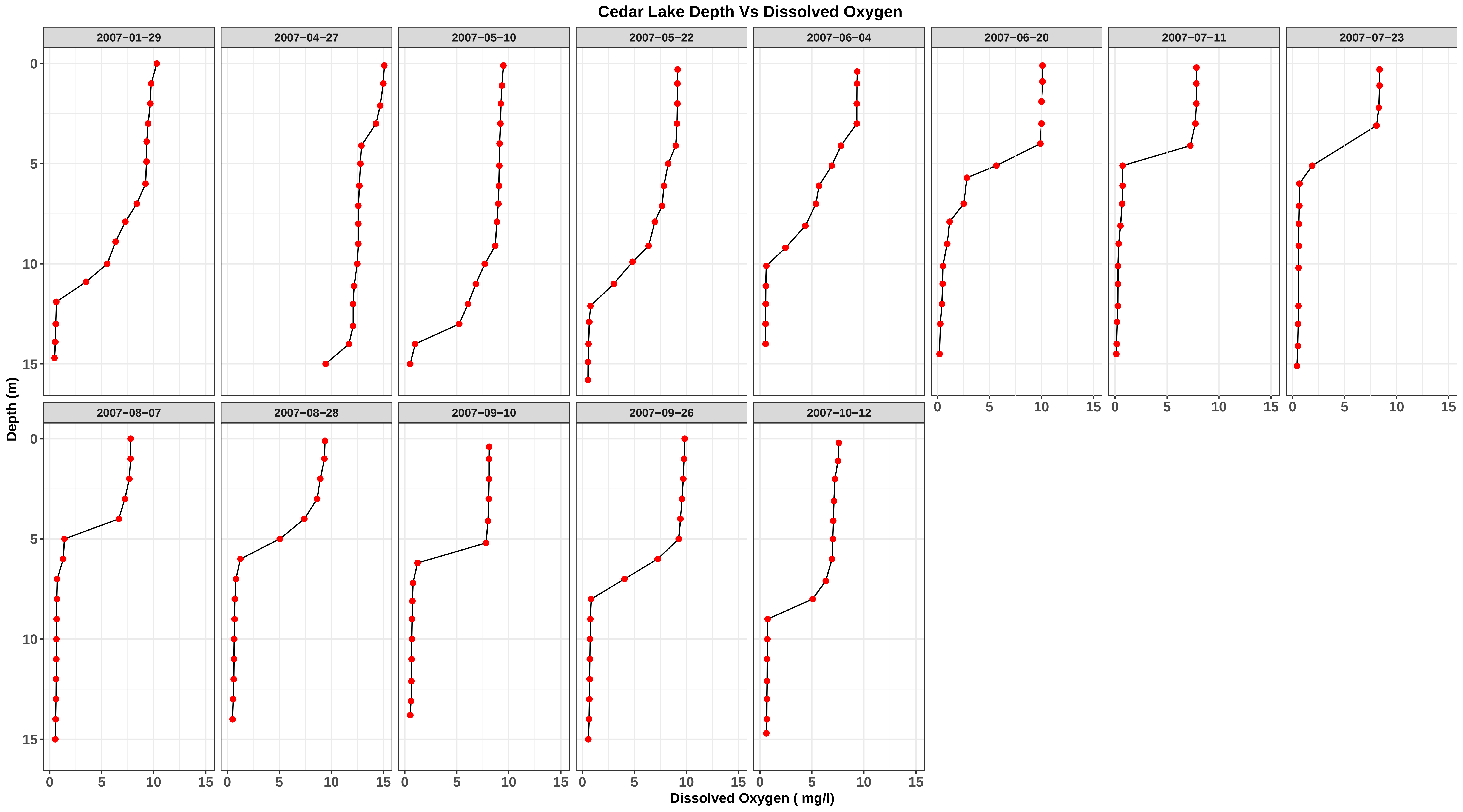


Cedar Lake Depth Vs Dissolved Oxygen
2004−02−11
2004−04−14
2004−05−07
2004−05−18
2004−06−08
2004−06−21
2004−07−13
2004−07−26
2004−08−06
2004−08−25
2004−09−09
2004−09−23
2004−11−03
Depth (m)
Dissolved Oxygen (mg/l)
0
5
10
15

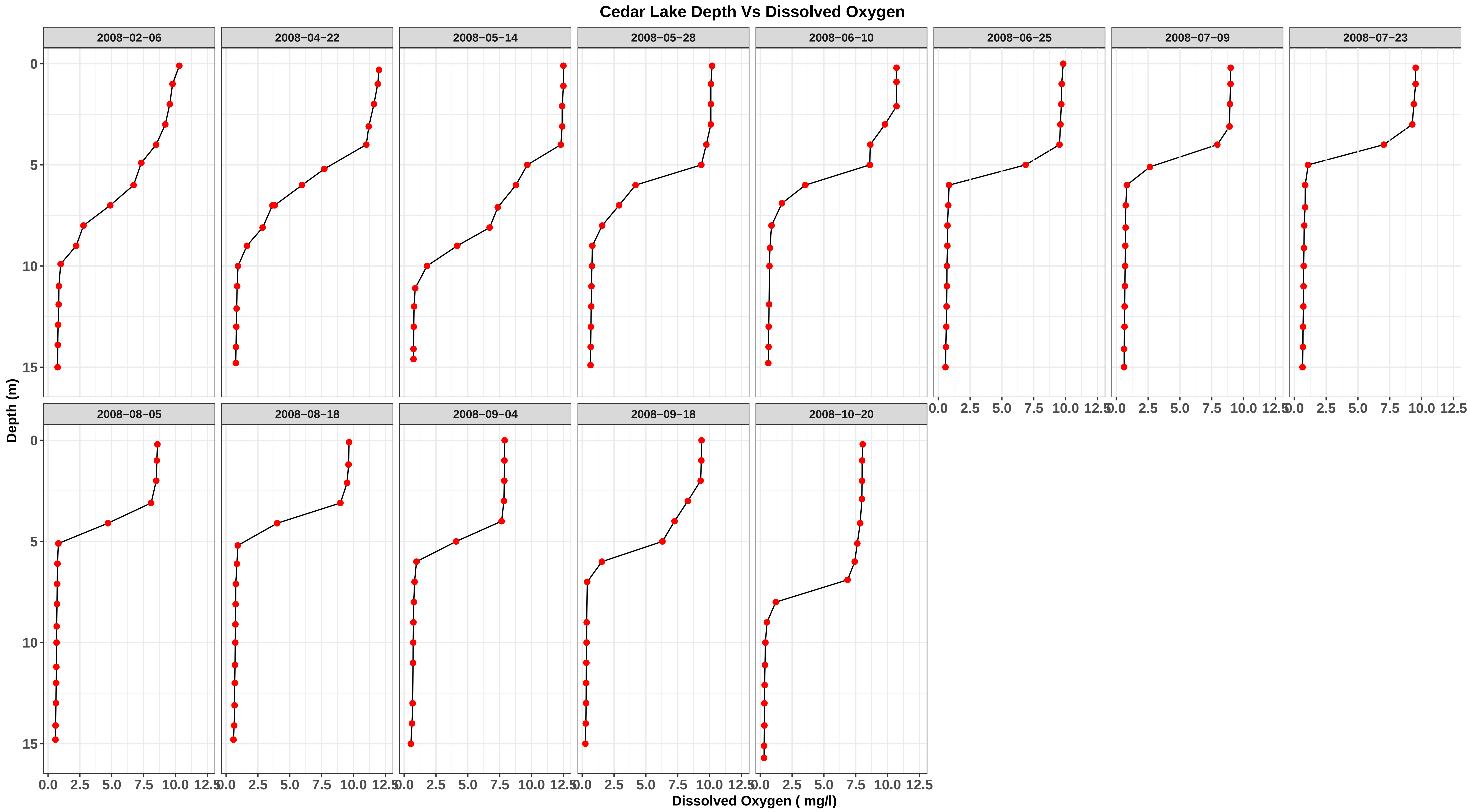

Cedar Lake Depth Vs Dissolved Oxygen
2005−02−03
2005−04−15
2005−05−10
2005−05−25
2005−06−06
2005−06−22
2005−07−06
2005−07−19
2005−08−11
2005−08−22
2005−09−09
2005−09−26
2005−10−17
Depth (m)
Dissolved Oxygen (mg/l)



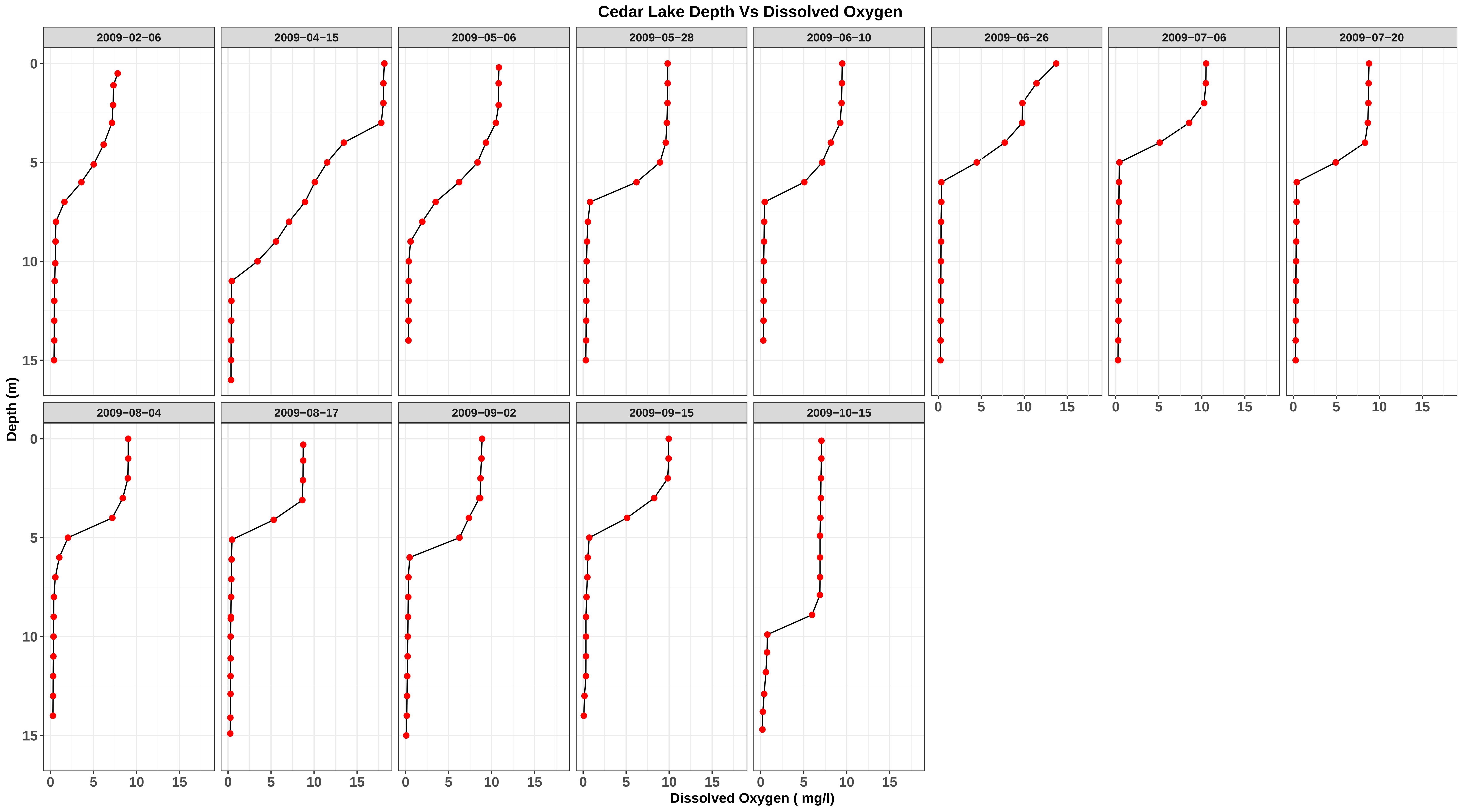
Cedar Lake Depth Vs Dissolved Oxygen
2006−04−17
2006−05−10
2006−05−22
2006−06−07
2006−06−21
2006−07−05
2006−07−21
2006−08−01
2006−08−15
2006−09−07
2006−09−26
2006−10−19
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)



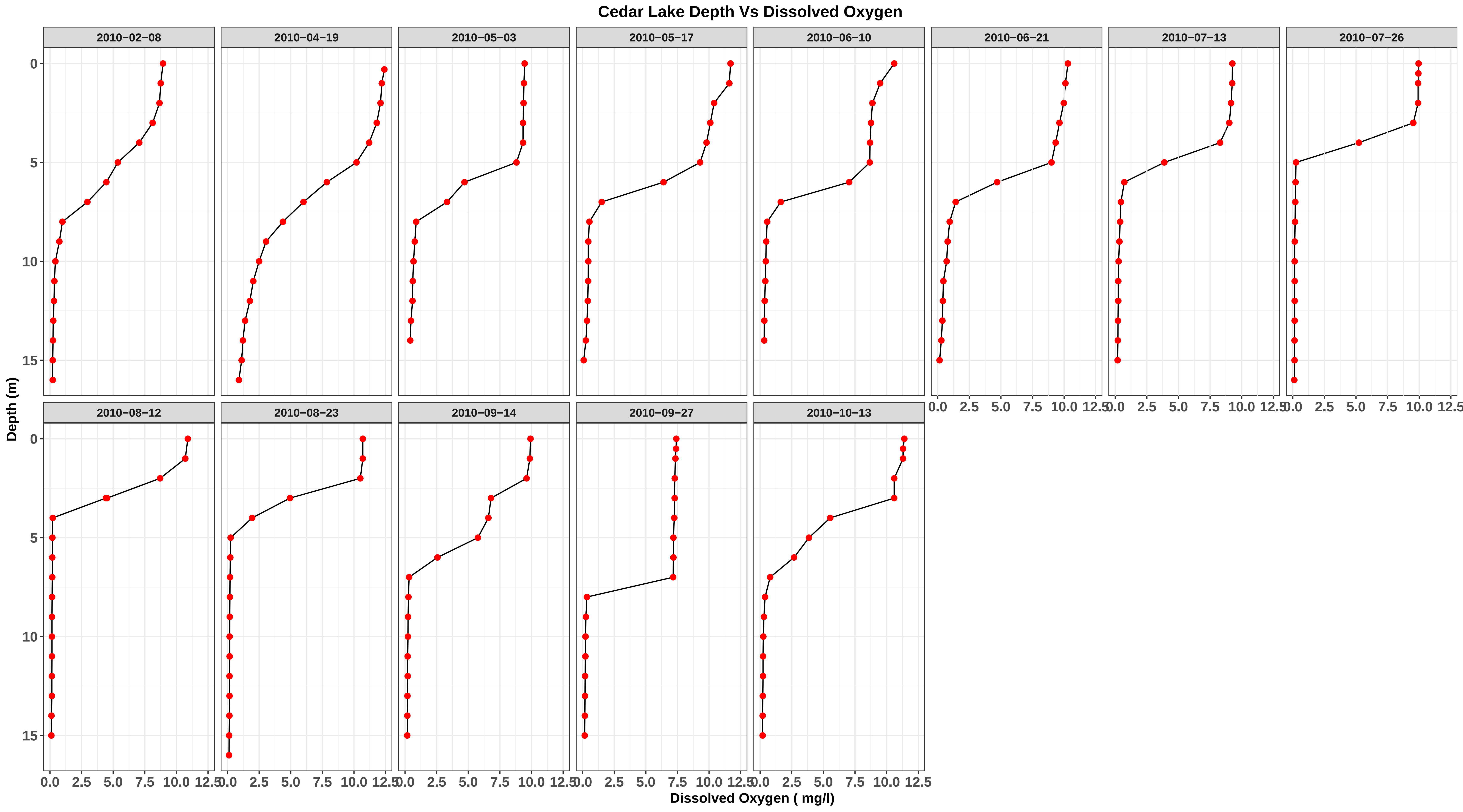
Cedar Lake Depth Vs Dissolved Oxygen
2007−01−29
2007−04−27
2007−05−10
2007−05−22
2007−06−04
2007−06−20
2007−07−11
2007−07−23
2007−08−07
2007−08−28
2007−09−10
2007−09−26
2007−10−12
Depth (m)
Dissolved Oxygen (mg/l)
0
5
10
15



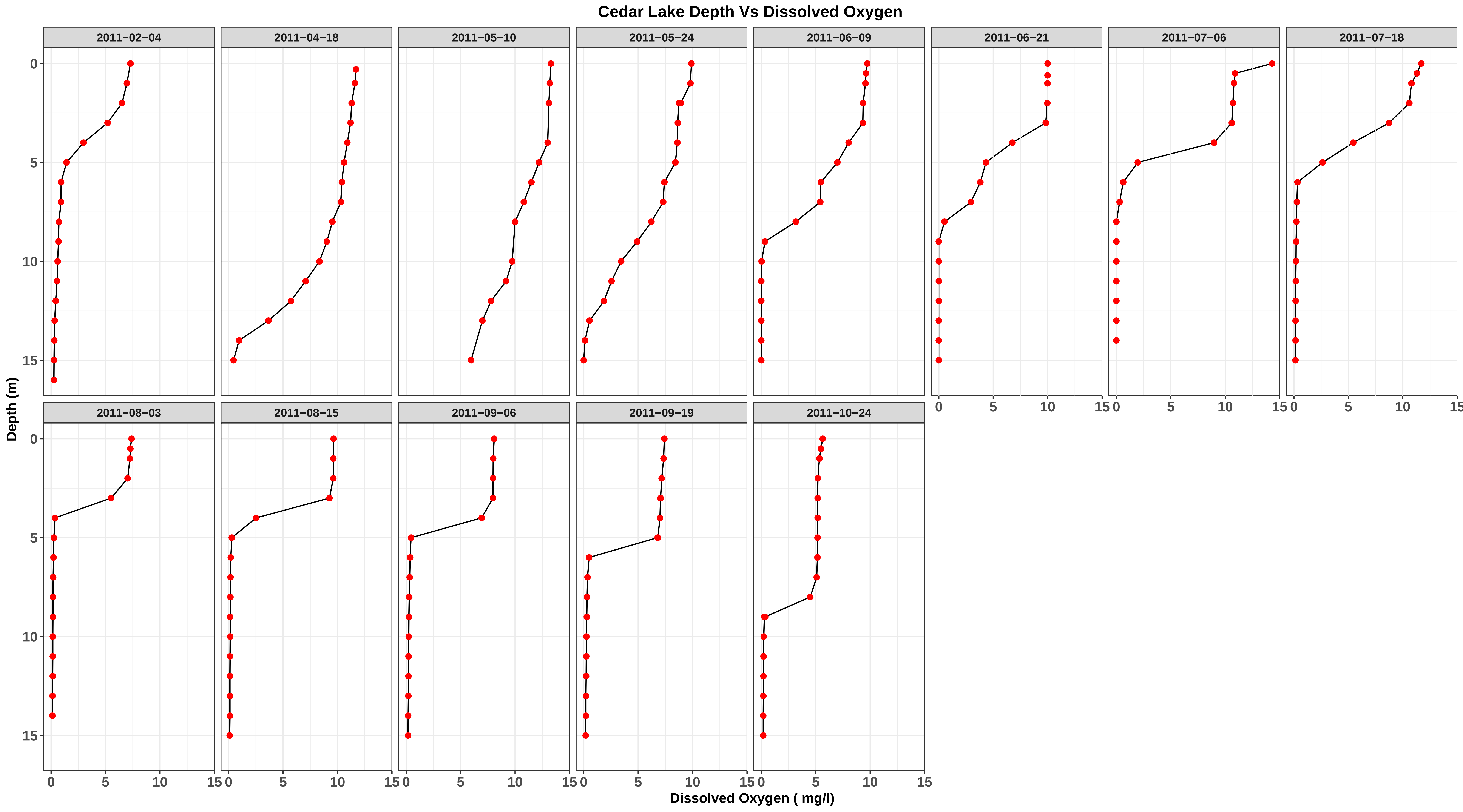
Cedar Lake Depth Vs Dissolved Oxygen
2008−02−06
2008−04−22
2008−05−14
2008−05−28
2008−06−10
2008−06−25
2008−07−09
2008−07−23
2008−08−05
2008−08−18
2008−09−04
2008−09−18
2008−10−20
Depth (m)
0
5
10
15
0.0 2.5 5.0 7.5 10.0 12.5
Dissolved Oxygen (mg/l)

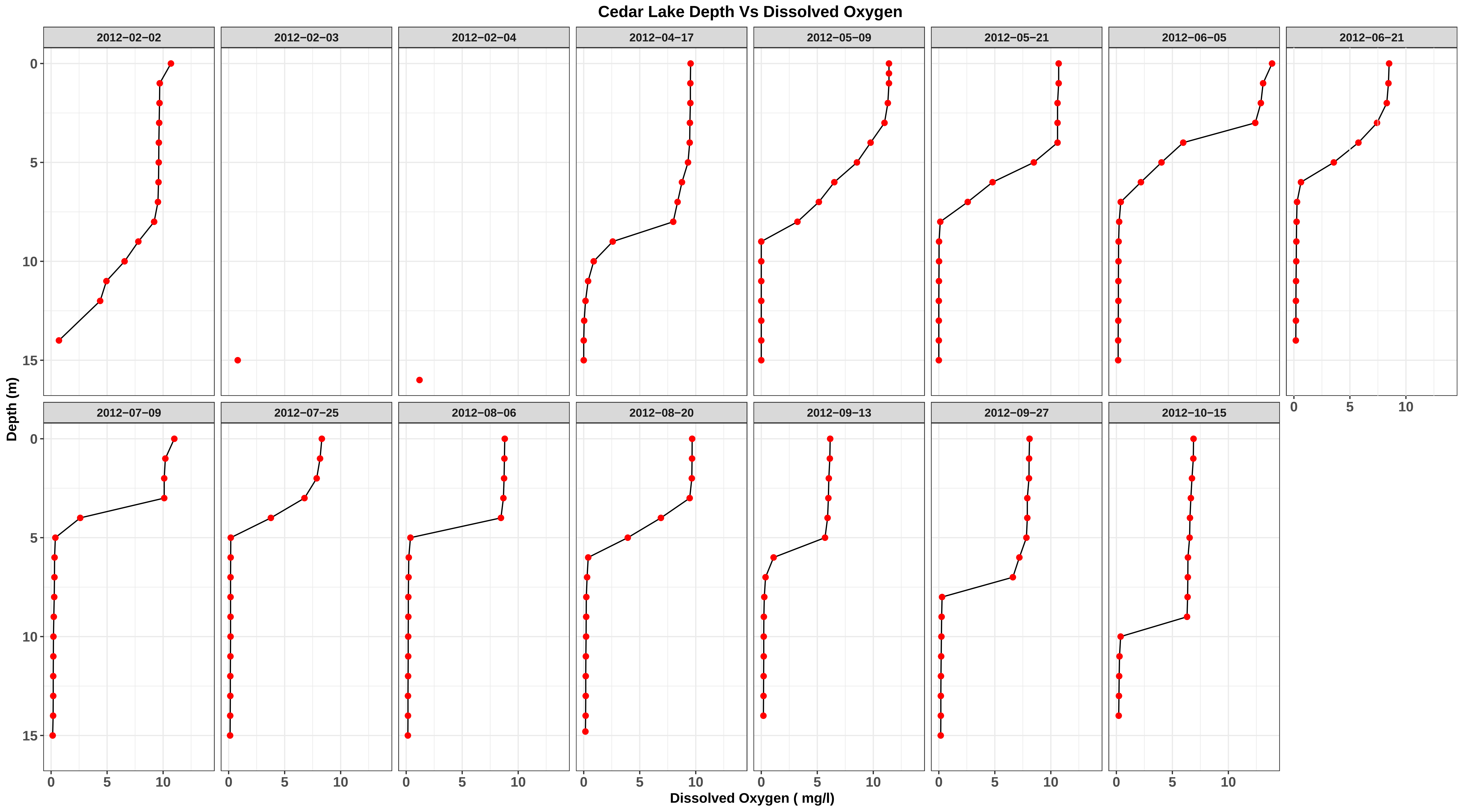


Cedar Lake Depth Vs Dissolved Oxygen
2009−02−06
2009−04−15
2009−05−06
2009−05−28
2009−06−10
2009−06−26
2009−07−06
2009−07−20
2009−08−04
2009−08−17
2009−09−02
2009−09−15
2009−10−15
Depth (m)
Dissolved Oxygen (mg/l)
0
5
10
15

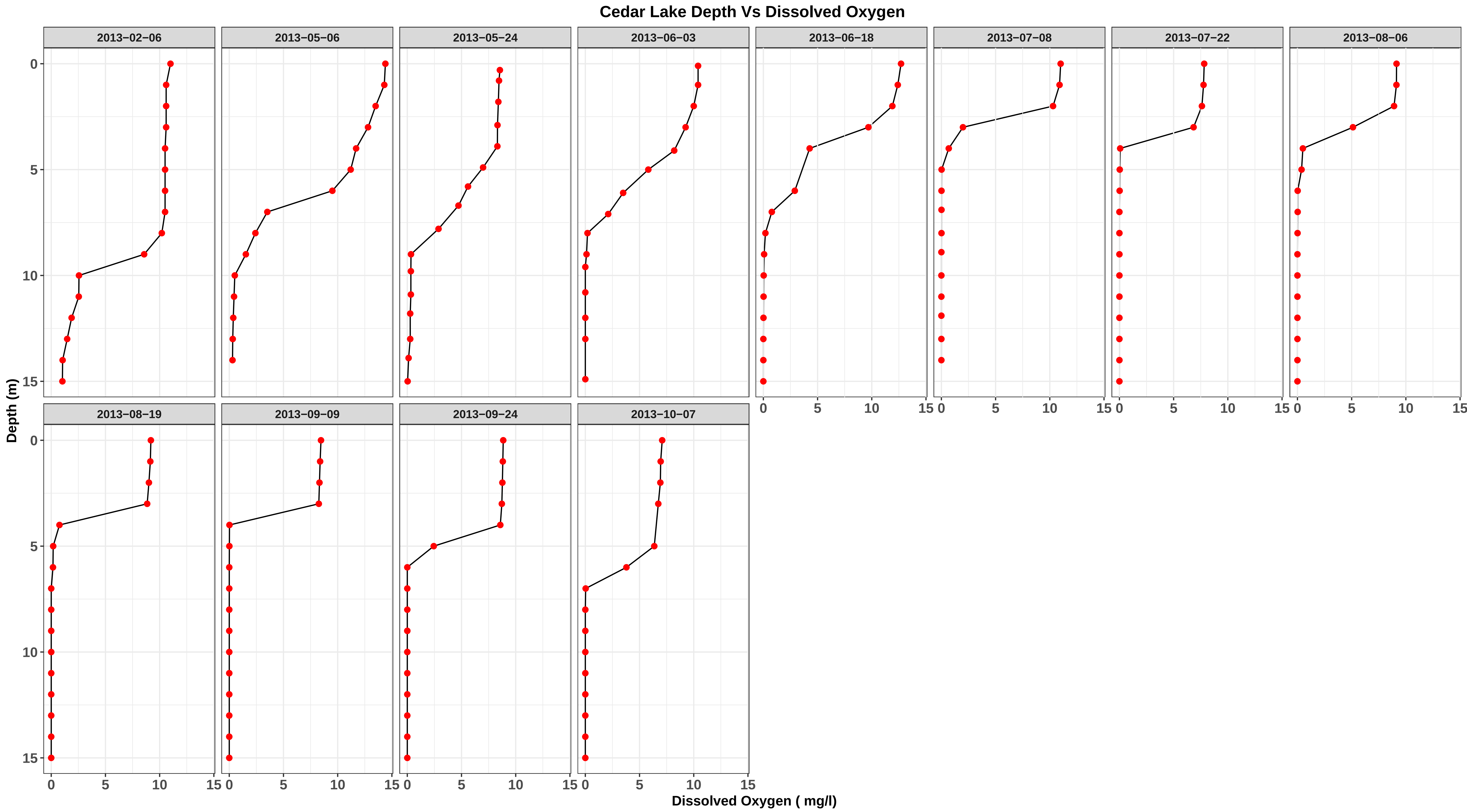


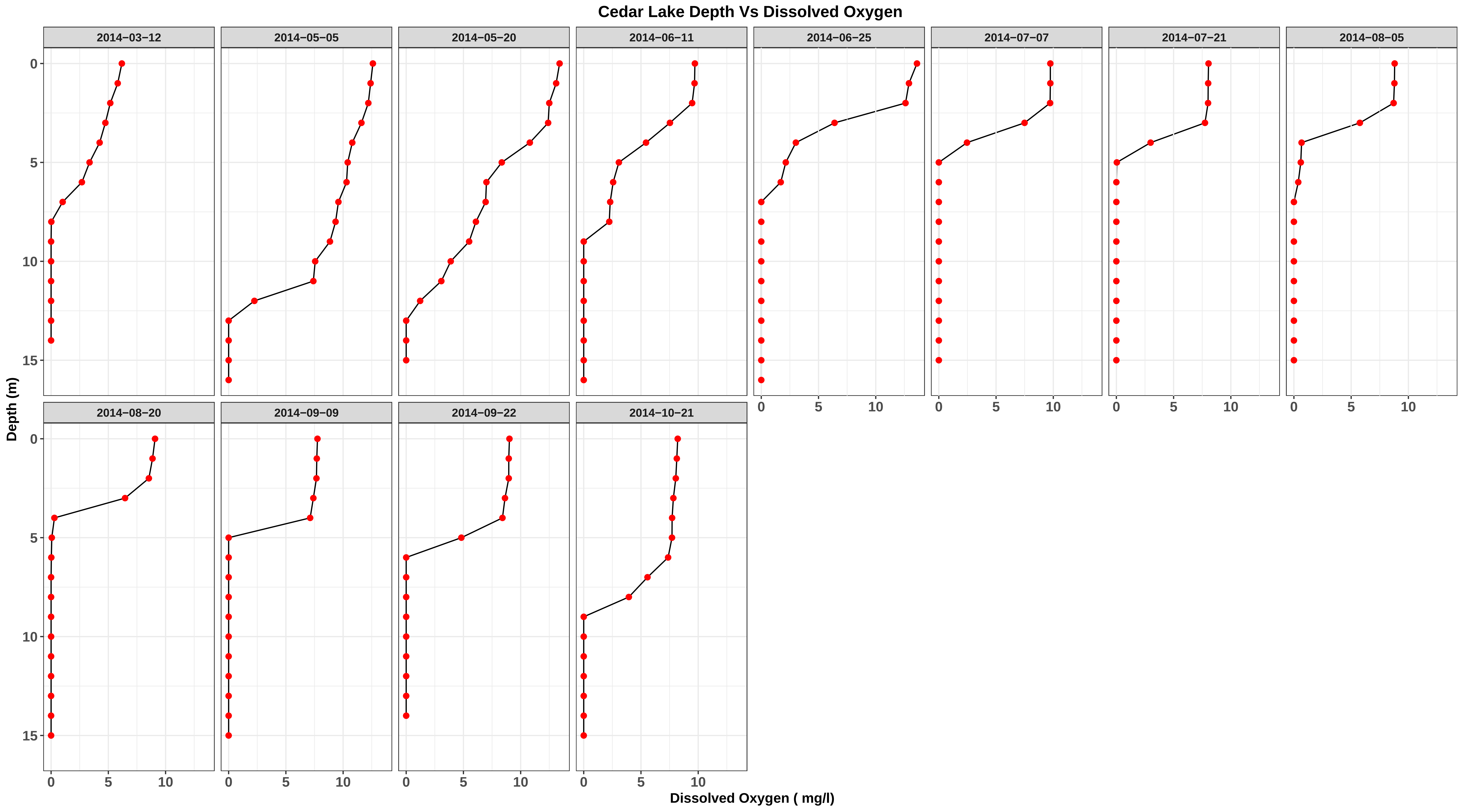
Cedar Lake Depth Vs Dissolved Oxygen
2010−02−08
2010−04−19
2010−05−03
2010−05−17
2010−06−10
2010−06−21
2010−07−13
2010−07−26
2010−08−12
2010−08−23
2010−09−14
2010−09−27
2010−10−13
Depth (m)
0
5
10
15
0.0 2.5 5.0 7.5 10.0 12.5
Dissolved Oxygen (mg/l)

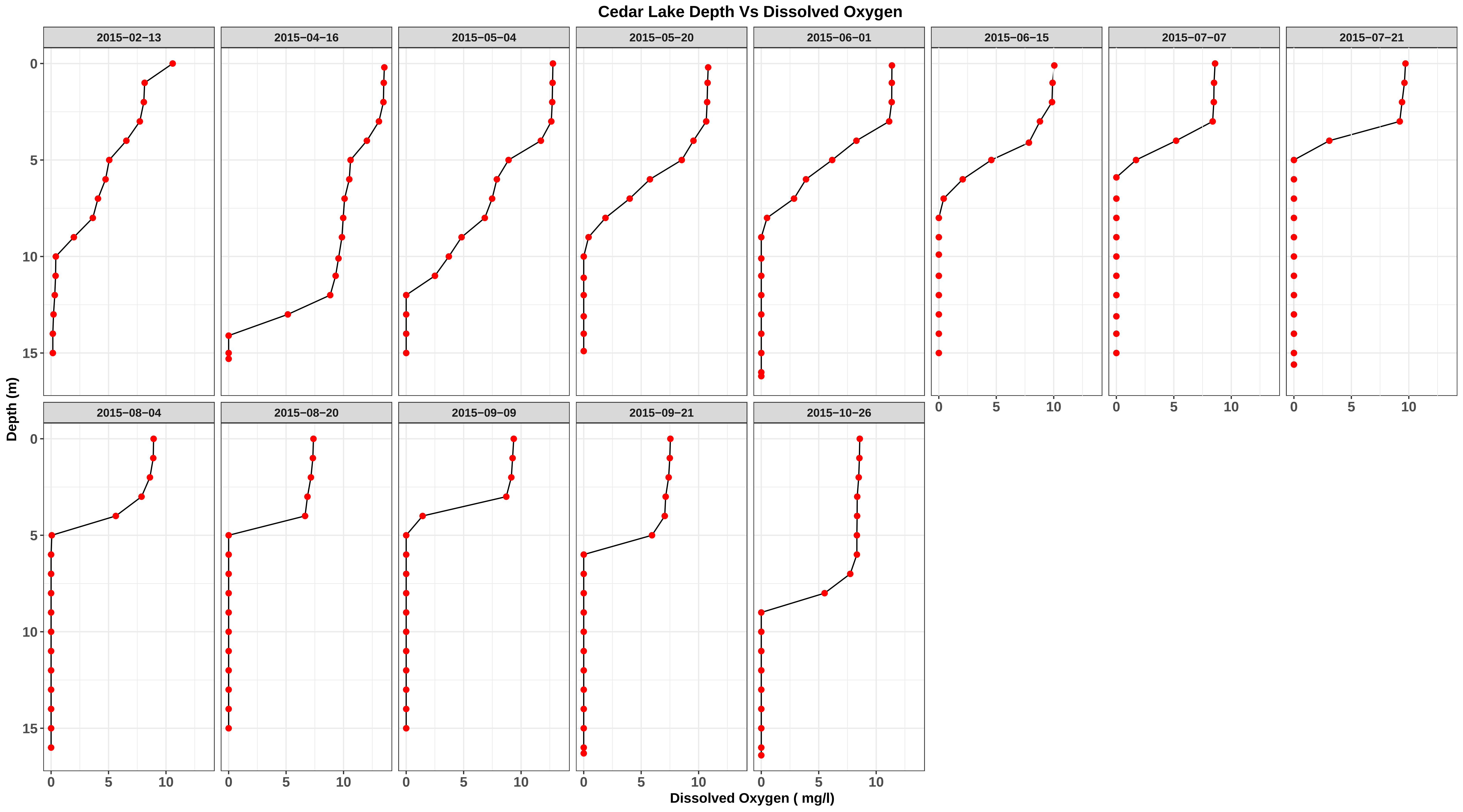

Cedar Lake Depth Vs Dissolved Oxygen
2011−02−04
2011−04−18
2011−05−10
2011−05−24
2011−06−09
2011−06−21
2011−07−06
2011−07−18
2011−08−03
2011−08−15
2011−09−06
2011−09−19
2011−10−24
Depth (m)
Dissolved Oxygen (mg/l)
0
5
10
15



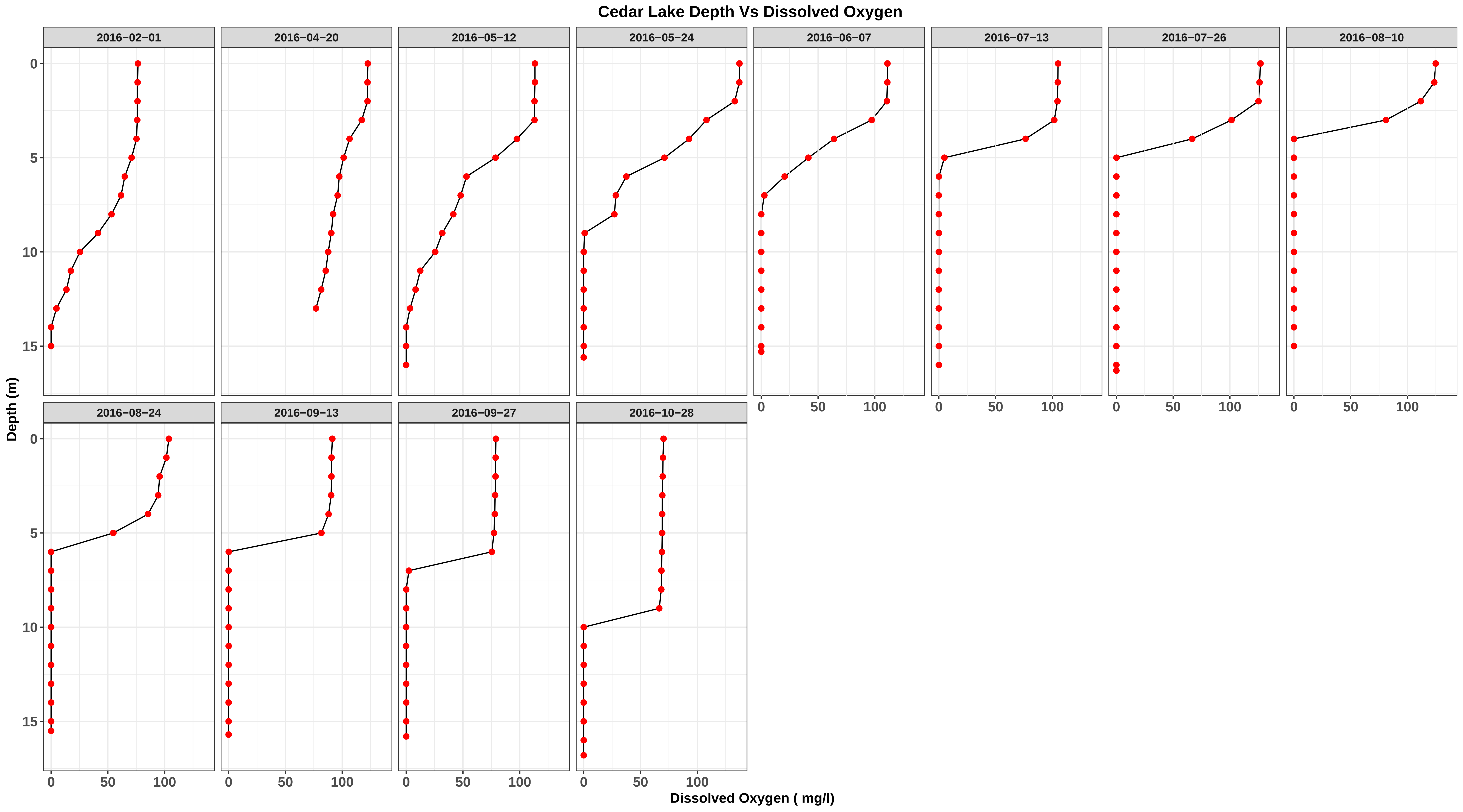
Cedar Lake Depth Vs Dissolved Oxygen
2012−02−02
2012−02−03
2012−02−04
2012−04−17
2012−05−09
2012−05−21
2012−06−05
2012−06−21
2012−07−09
2012−07−25
2012−08−06
2012−08−20
2012−09−13
2012−09−27
2012−10−15
Depth (m)
Dissolved Oxygen (mg/l)
0
5
10
15


Cedar Lake Depth Vs Dissolved Oxygen
2013−02−06
2013−05−06
2013−05−24
2013−06−03
2013−06−18
2013−07−08
2013−07−22
2013−08−06
2013−08−19
2013−09−09
2013−09−24
2013−10−07
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)

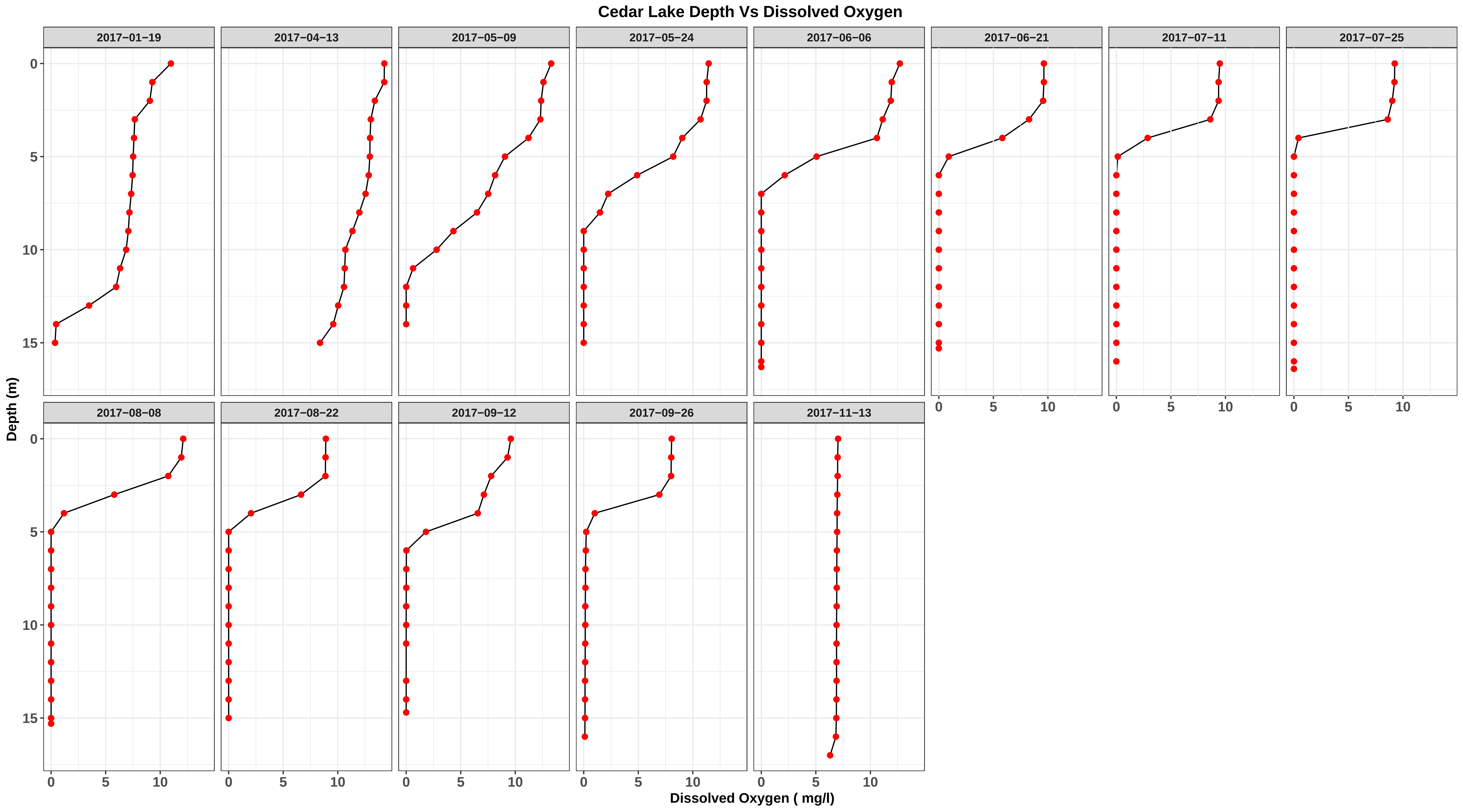

Cedar Lake Depth Vs Dissolved Oxygen
2014−03−12
2014−05−05
2014−05−20
2014−06−11
2014−06−25
2014−07−07
2014−07−21
2014−08−05
2014−08−20
2014−09−09
2014−09−22
2014−10−21
Depth (m)
Dissolved Oxygen (mg/l)
0
5
10
15

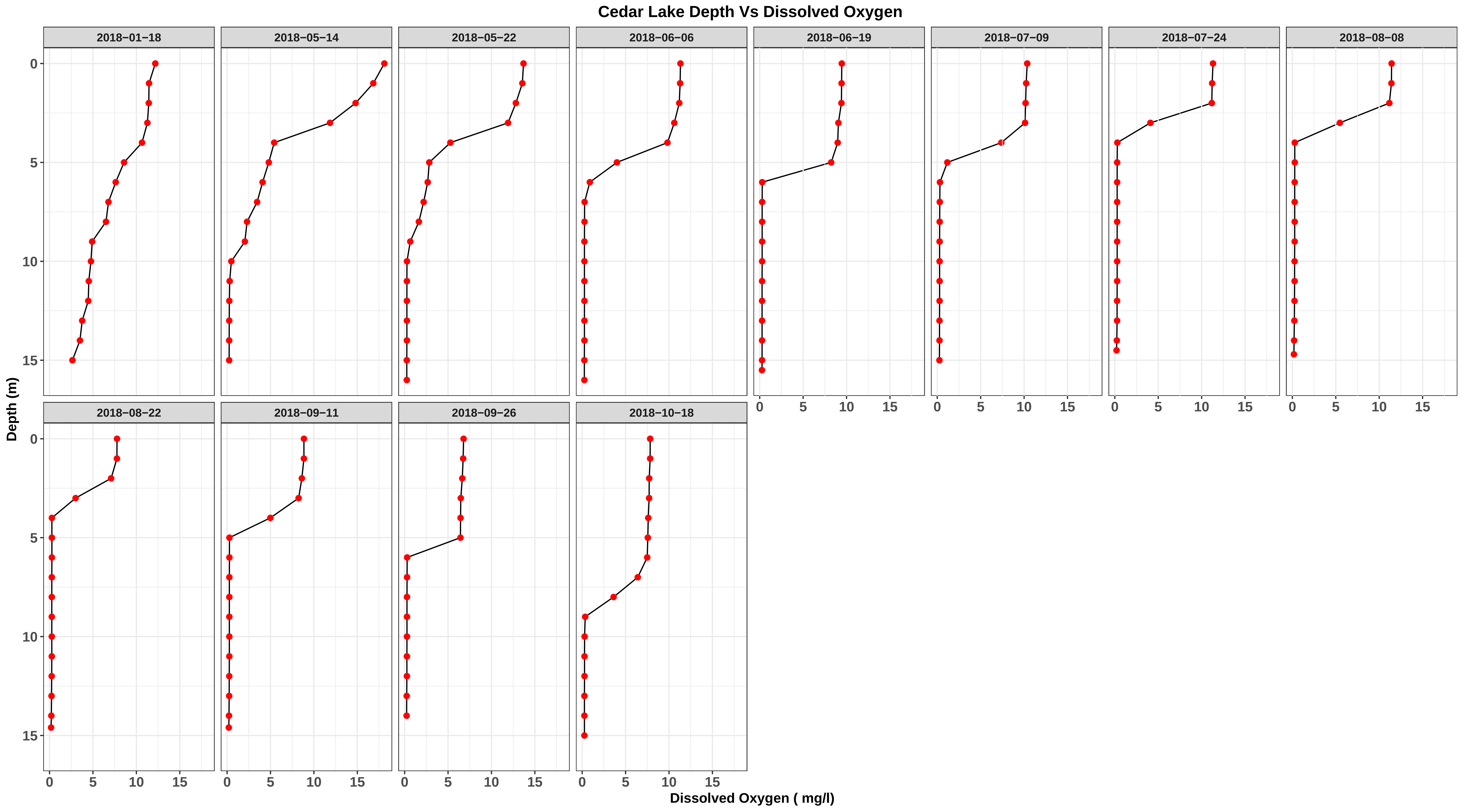


Cedar Lake Depth Vs Dissolved Oxygen
2015−02−13
2015−04−16
2015−05−04
2015−05−20
2015−06−01
2015−06−15
2015−07−07
2015−07−21
2015−08−04
2015−08−20
2015−09−09
2015−09−21
2015−10−26
Depth (m)
Dissolved Oxygen (mg/l)
0
5
10
15

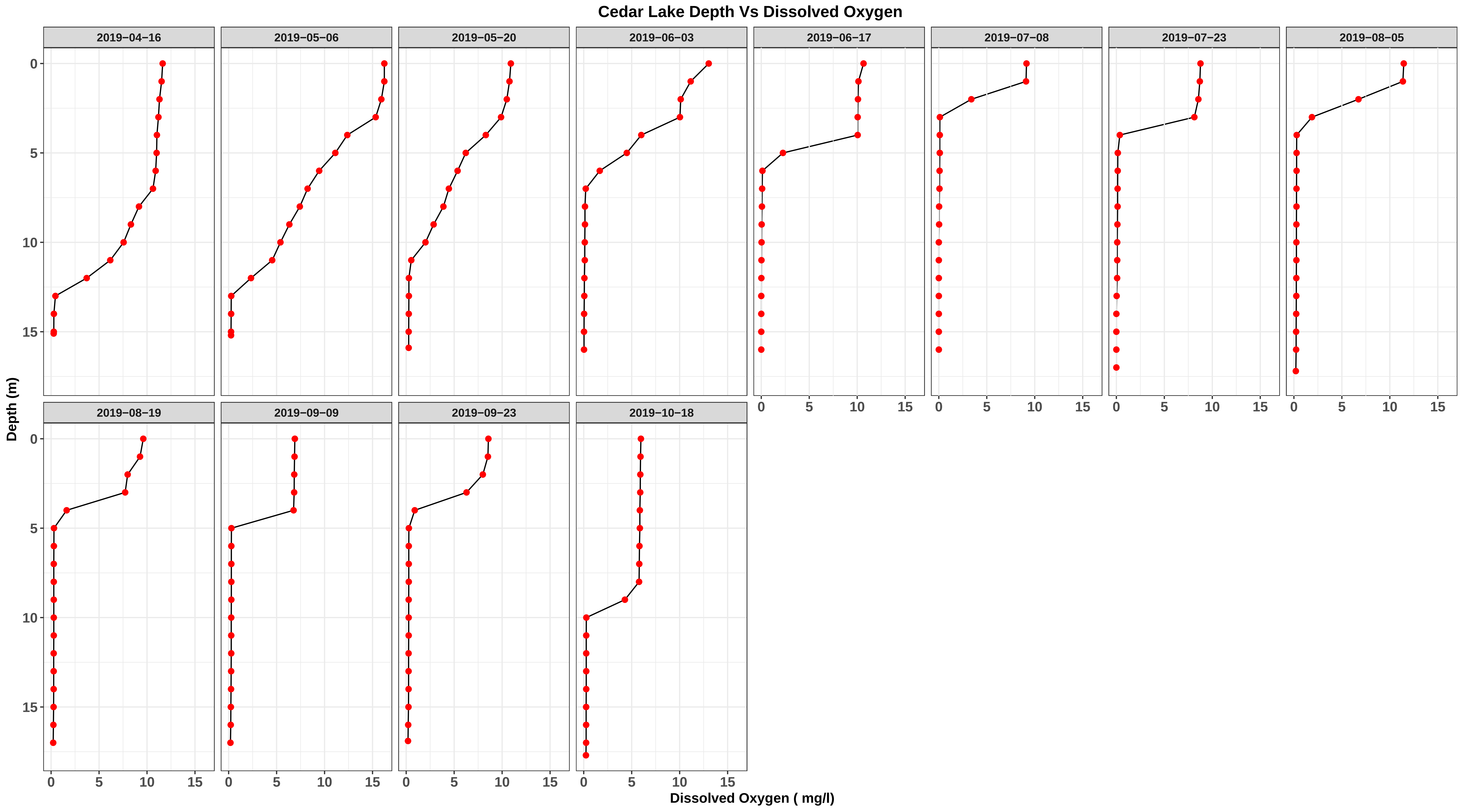


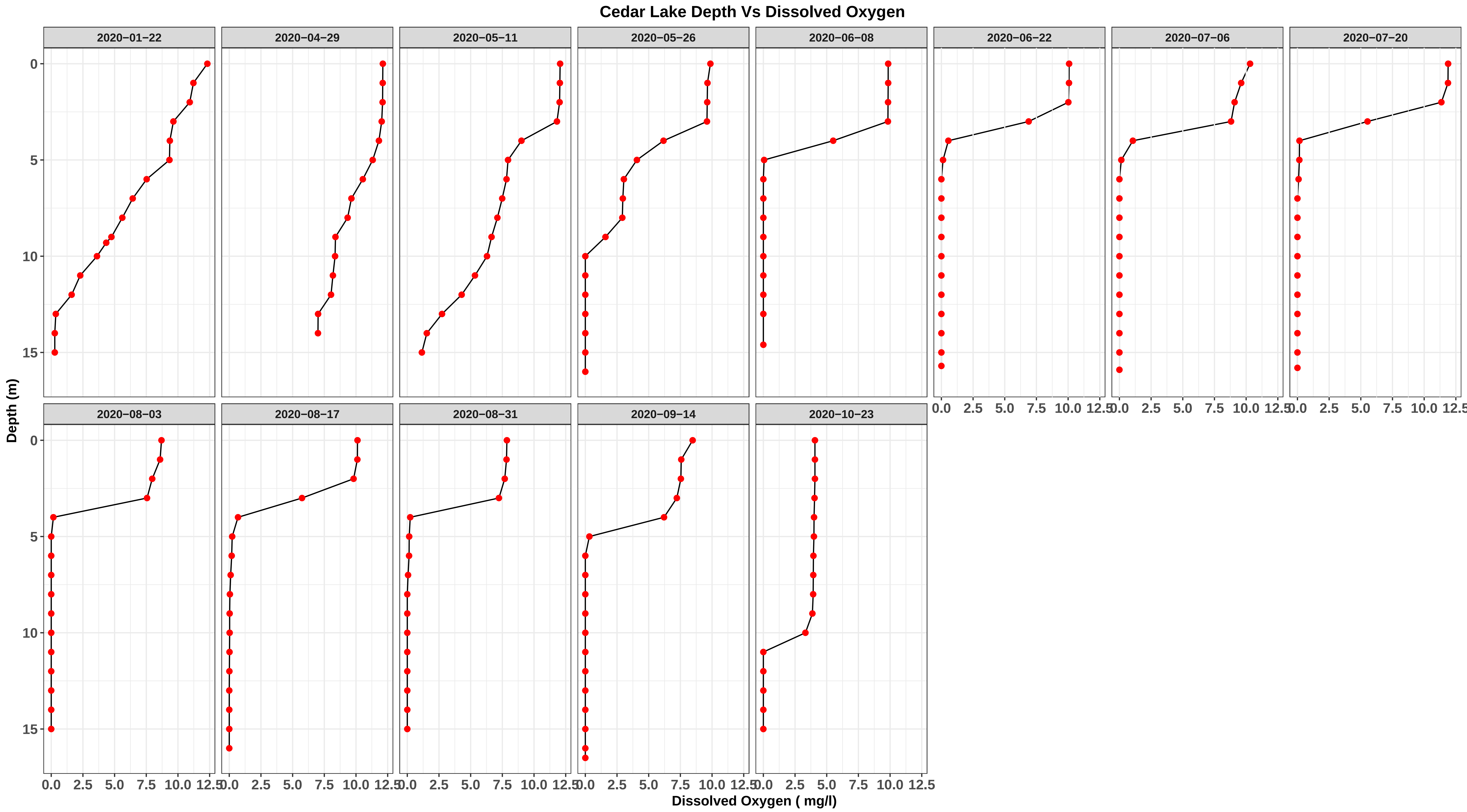
Cedar Lake Depth Vs Dissolved Oxygen
2016−02−01
2016−04−20
2016−05−12
2016−05−24
2016−06−07
2016−07−13
2016−07−26
2016−08−10
2016−08−24
2016−09−13
2016−09−27
2016−10−28
Depth (m)
0
5
10
15
0
50
100
Dissolved Oxygen (mg/l)

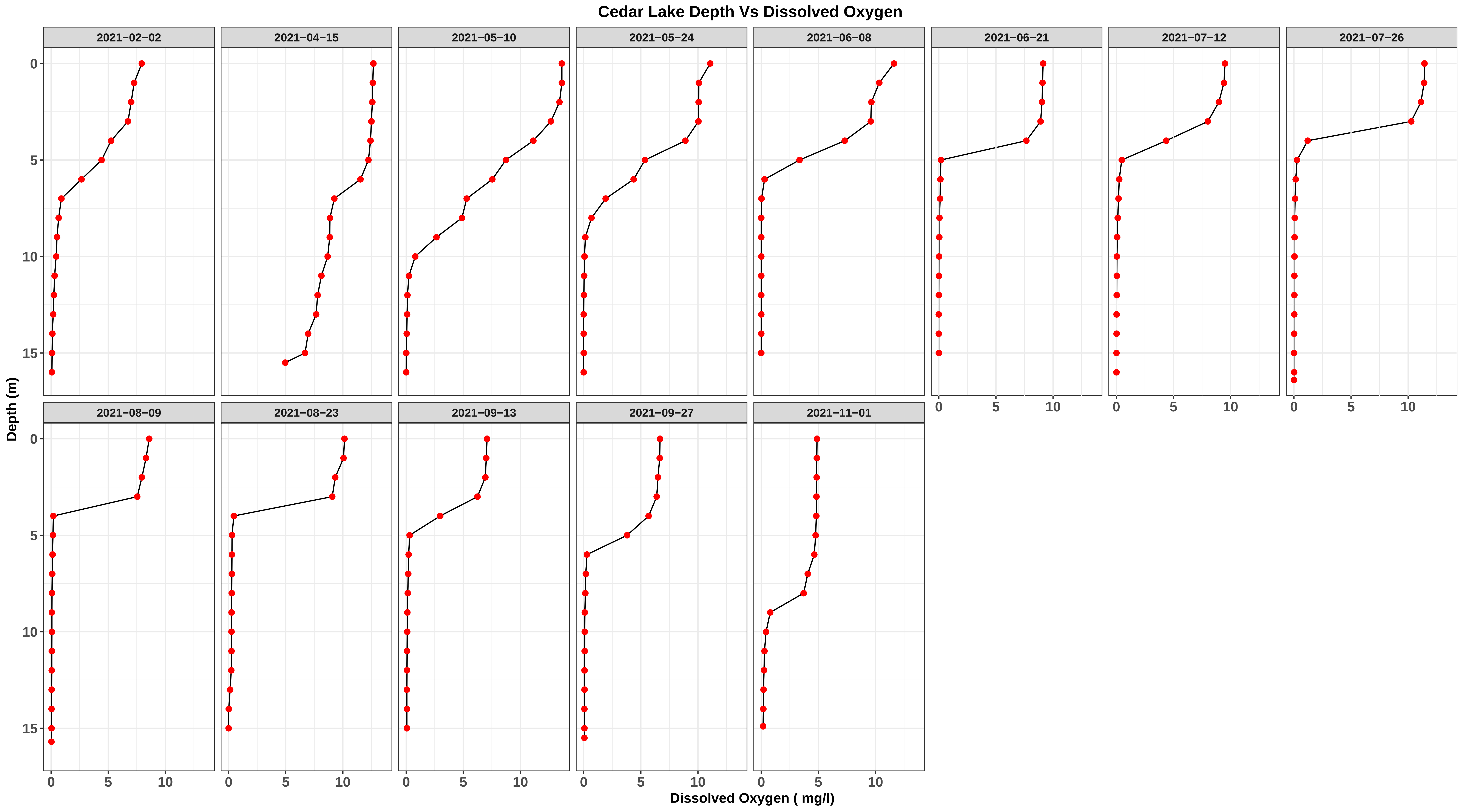

Cedar Lake Depth Vs Dissolved Oxygen
2017−01−19
2017−04−13
2017−05−09
2017−05−24
2017−06−06
2017−06−21
2017−07−11
2017−07−25
2017−08−08
2017−08−22
2017−09−12
2017−09−26
2017−11−13
Depth (m)
Dissolved Oxygen (mg/l)
0
5
10
15



Cedar Lake Depth Vs Dissolved Oxygen
2018−01−18
2018−05−14
2018−05−22
2018−06−06
2018−06−19
2018−07−09
2018−07−24
2018−08−08
2018−08−22
2018−09−11
2018−09−26
2018−10−18
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)


Cedar Lake Depth Vs Dissolved Oxygen
2019−04−16
2019−05−06
2019−05−20
2019−06−03
2019−06−17
2019−07−08
2019−07−23
2019−08−05
2019−08−19
2019−09−09
2019−09−23
2019−10−18
Depth (m)
Dissolved Oxygen (mg/l)
0
5
10
15


Cedar Lake Depth Vs Dissolved Oxygen
2020−01−22
2020−04−29
2020−05−11
2020−05−26
2020−06−08
2020−06−22
2020−07−06
2020−07−20
2020−08−03
2020−08−17
2020−08−31
2020−09−14
2020−10−23
Depth (m)
Dissolved Oxygen (mg/l)


Cedar Lake Depth Vs Dissolved Oxygen
2021−02−02
2021−04−15
2021−05−10
2021−05−24
2021−06−08
2021−06−21
2021−07−12
2021−07−26
2021−08−09
2021−08−23
2021−09−13
2021−09−27
2021−11−01
Depth (m)
Dissolved Oxygen (mg/l)
0
5
10
15