Relationships between dissolved oxygen, mouth closures, and tidal mixing in the Los Peñasquitos Lagoon

Katie DuBois, September 1st 2017

Contents

Summary

Los Peñasquitos Lagoon is characterized by dynamic and, at times, extreme fluctuations in dissolved oxygen. This heterogeneity is seen at multiple time scales including: interannual, seasonal, tidal, and daily cycles (Figures 1-7). When the lagoon mouth is open, oscillations in dissolved oxygen levels appear to be primarily influence by tidal cycle and height (Figure 10). The effect of tidal mixing is modified by daily cycles in respiration and photosynthesis, which are also modified by seasonal changes in temperature and photoperiod. Annual rain events also result in more extended periods of low dissolved oxygen despite the mouth being open. When the lagoon mouth is shut, dissolved oxygen levels appear to remain high only while salinity is maintained around 30 ppt. However, after breaching freshwater from the back of the estuary flushes out of the mouth and often causes low oxygen events (Figures 9 & 10). When salinity levels drop while the lagoon is closed, dissolved oxygen can be reduced to near zero and remain low for the remainder of the closure (Figure 12). During longer closures, over wash of seawater into the lagoon during spring tide cycles can temporarily increase dissolved oxygen values (Figures 11-13). During years that unusually high volumes of sand accumulated at the mouth of Los Peñasquitos Lagoon, mechanical breaching was an essential tool that allowed for the recovery of critically low dissolved oxygen values (Figures 11 & 12).

The goals of this project were to 1) better understand the different temporal frequencies of heterogeneity in dissolved oxygen within Los Peñasquitos Lagoon, and 2) how these many factors act synergistically or antagonistically to influence dissolved oxygen within the lagoon over time.

Knowledge gained in this project will help managers better predict the circumstances that lead to low oxygen events and to decide if interventions, such as mechanical breaching of the lagoon mouth, are necessary. Additionally, this work highlights the extreme, yet natural, fluctuations in dissolved oxygen experienced within estuaries located in Mediterranean climates. It may be useful for managers to question if these fluctuations in dissolved oxygen are essential to ecological communities and to maintaining species diversity within such systems.

Data was compiled and organized in Excel by Julio Lorda.

Justin McCullough provided the data though a Dropbox folder: (https://www.dropbox.com/sh/z7zujvovgpxf53v/AAB7R-Z9Nu_okokxwlzyKfnEa?dl=0)

Katie DuBois graphed data in R Version 3.3.3. Ms. DuBois is a PhD Candidate in the Department of Evolution and Ecology at UC Davis and the Bodega Marine Laboratory. Jeff Crooks, the TRNERR Research Coordinator, and the Southwest Wetlands Interpretive Association hired Ms. DuBois as an independent contactor. Her contract was to compile and synthesize the long-term water quality data collected for Los Peñasquitos Lagoon with a focus on how these data reveal patterns in low oxygen events within the lagoon. Ms. DuBois also compiled additional information from Los Peñasquitos Lagoon Annual Reports

John Largier, Professor at UC Davis and resident at the Bodega Marine Laboratory, provided expert advice on data exploration and interpretation

This project is part of the NERRs Science Collaborative: Monitoring and Management of Lagoon Mouths in Southern California.

Table 1. Los Peñasquitos Lagoon closure events

Year	Number of Closures	Approximate Dates
2004	1	March 27-April 5
2005	1	Dec. 20 – Dec. 31
2006	2	Jan. 18 – Feb. 20 Dec. 10 – Dec. 31
2007	4	Feb. 12 – 16 March 28 – April 17 April 27 – May 15 Nov. 18 – 21
2008	3	March 16 – 25 March 27 – April 5 April 7 – May 5
2009	0	
2010	2	March 16 – April 5 July 1 – 9
2011	0	
2012	3	March 28 – April 15 April 30 – May 6 May 27 – June 3
2013	3	Feb. 25 – March 10 March 20 – May 10 May 17 – July 15
2014	4	Jan. 20 – 30 March 10 – April 9 May 07 – 12 Dec. 10 – 9
2015	2	Feb. 10 – 17 March 26 - April 9
2016	2	Jan. 29 – Feb 2 Feb 13 – April 1

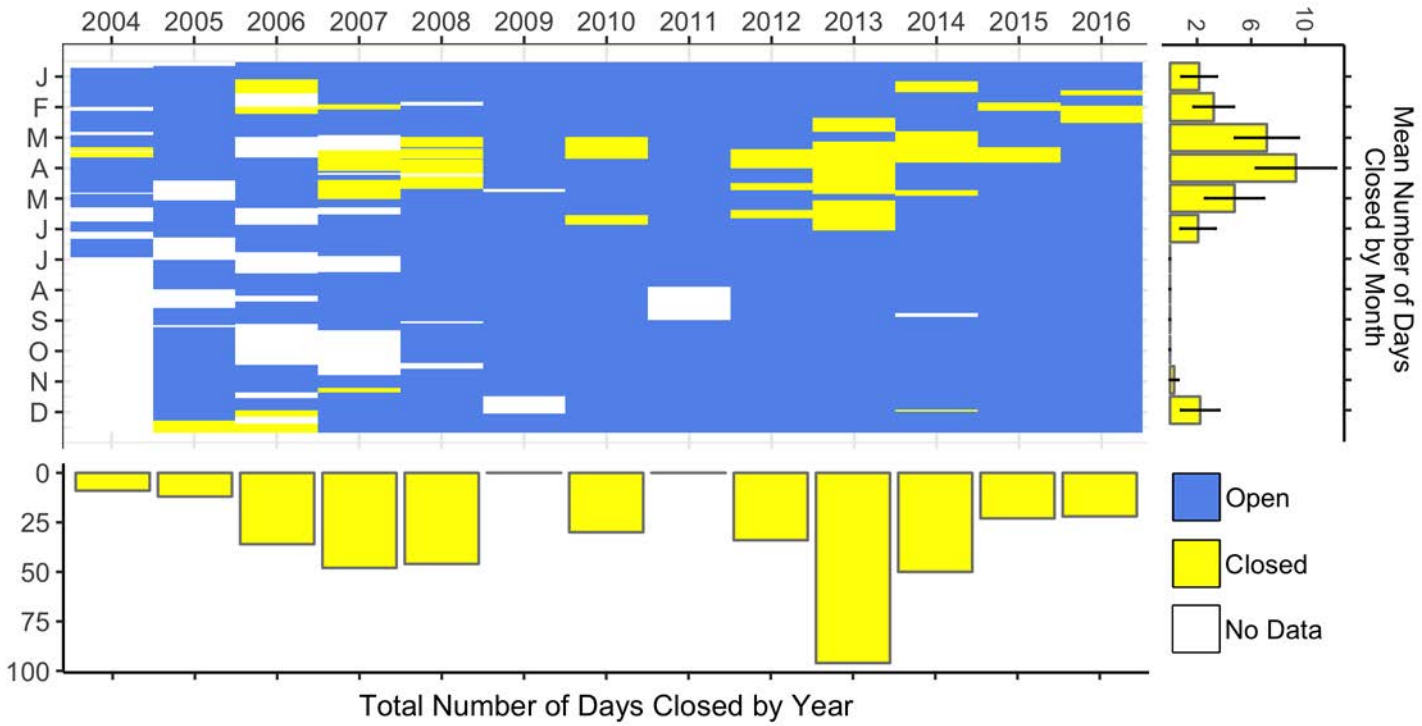

Figure 1. The mouth of Los Peñasquitos Lagoon is susceptible to closure during winter months (February – May) when storms cause the accumulation of sand and cobble berms over the estuary mouth. Almost every year, both spring tide cycles as well as mechanical breaching cause the mouth to reopen. Notable years: during 2009 and 2011 no closures occurred because mouth was dredged preemptively; 2013 experienced long periods of closure due to unusually high levels of sand from San Diego beach replenishment during 2012.

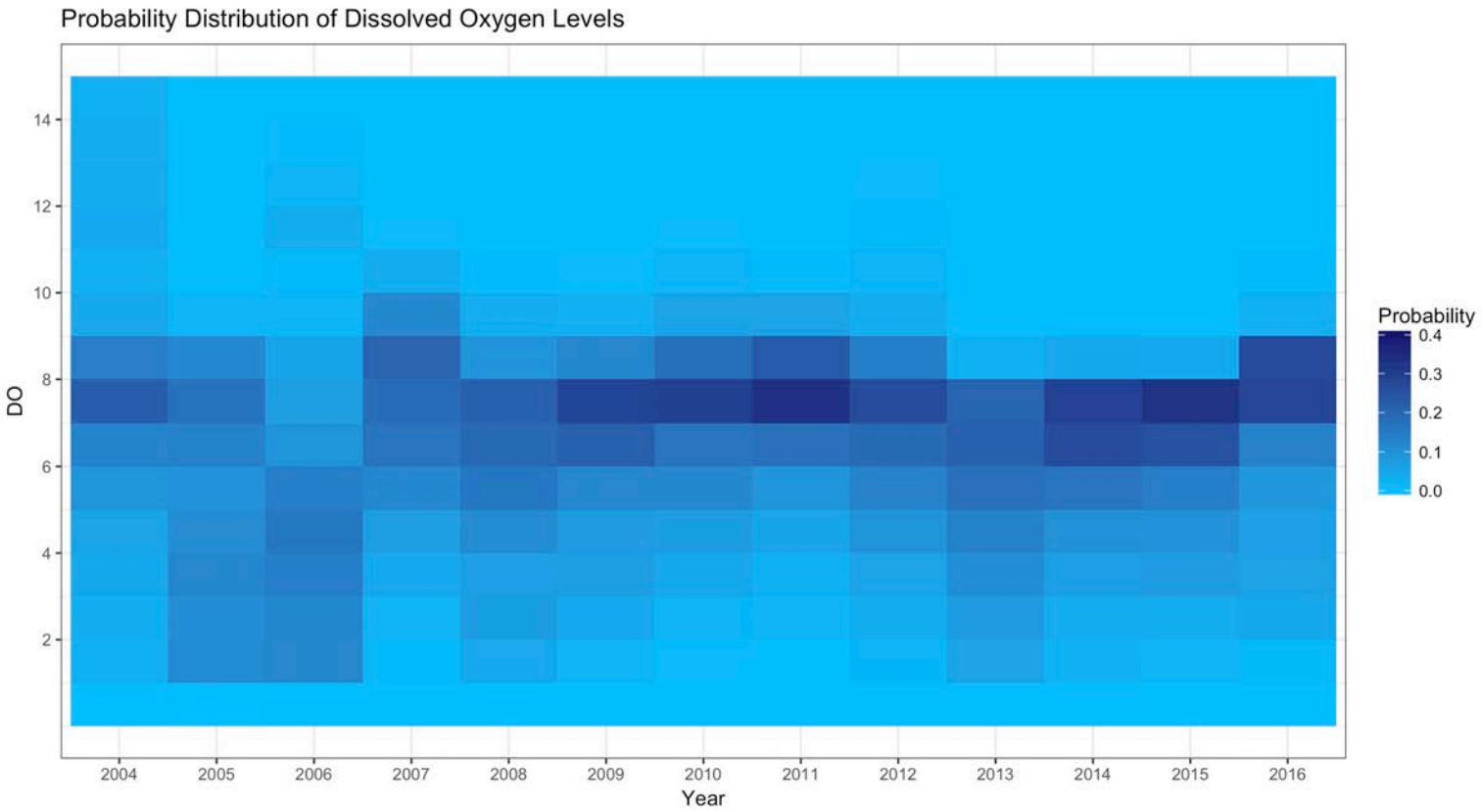

Figure 2. Across years Los Peñasquitos Lagoon dissolved oxygen levels hover around 8 mg/l with minimal variability. Notable exceptions are 2008 and 2013, when dissolved oxygen levels are skewed towards lower values. Dissolved oxygen data taken prior 2008 is not continuous and might not represent yearly averages.

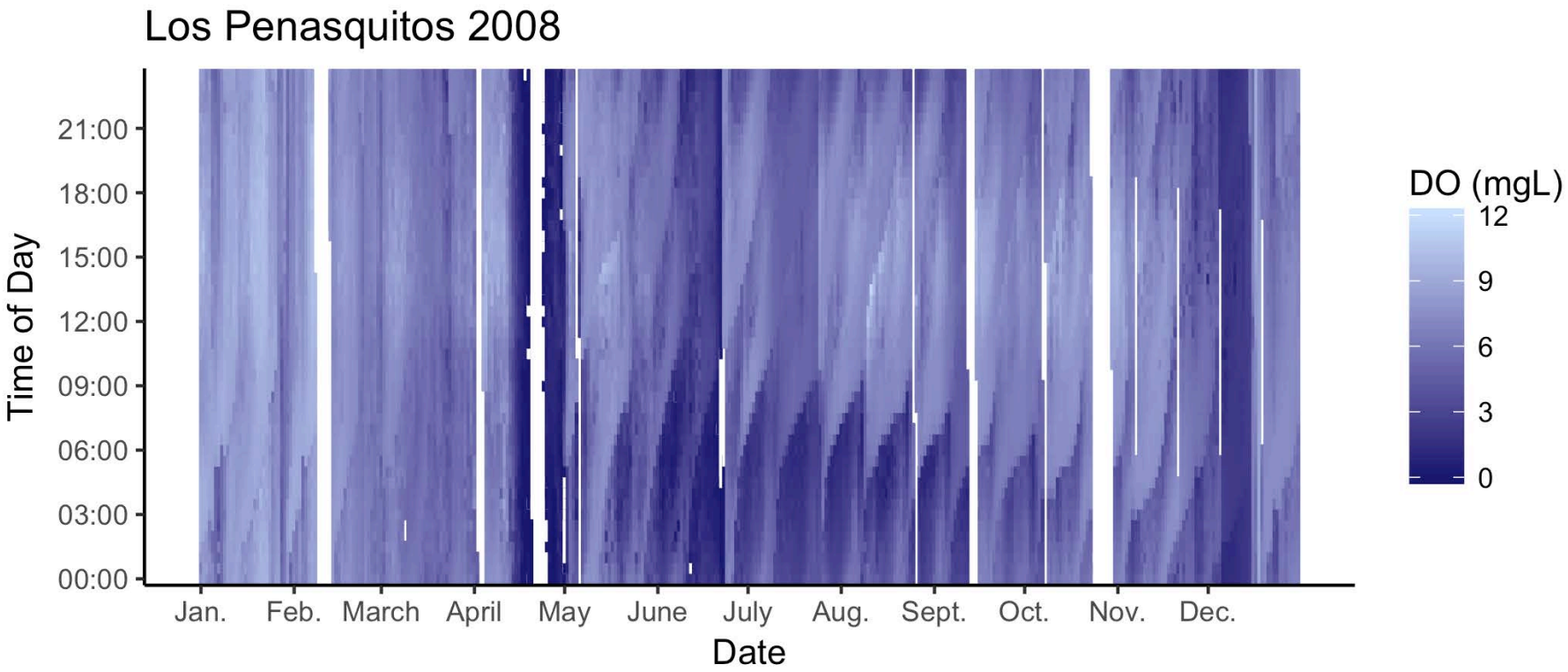

Figure 3. During 2008, a month-long closure in April led to low dissolved oxygen values that were alleviated after mechanical breaching. Daily fluctuations in dissolved oxygen became more extreme towards the end of the summer due to build up of organic matter in estuary during the summer growing season. Low dissolved oxygen values tend to be exasperated during pre-dawn hours when photosynthesis does not occurring within the water column. A low oxygen event happened in December following heavy rainfall.

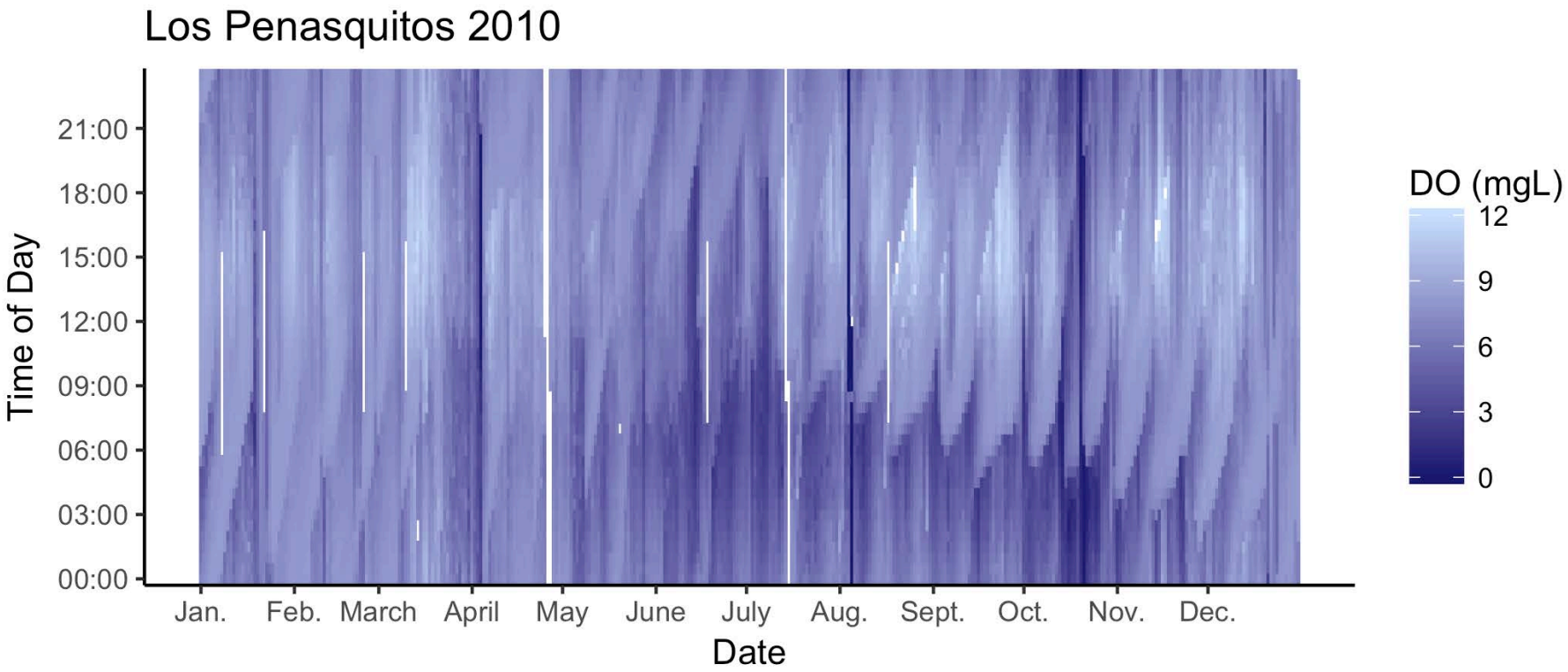

Figure 4. Water quality was generally good throughout 2010. The mouth was closed from March 16th until April 4th without a prominent decline in dissolved oxygen values. Similarly, a brief closure at the beginning of July did not lead to low dissolved oxygen. However, flooding events in October coincided with lower dissolved oxygen values. Daily fluctuations in dissolved oxygen became more extreme towards the end of the summer with build up of organic matter in estuary due to the summer growing season. Low dissolved oxygen values tend to be exacerbated during pre-dawn hours when photosynthesis is not occurring within the water column.

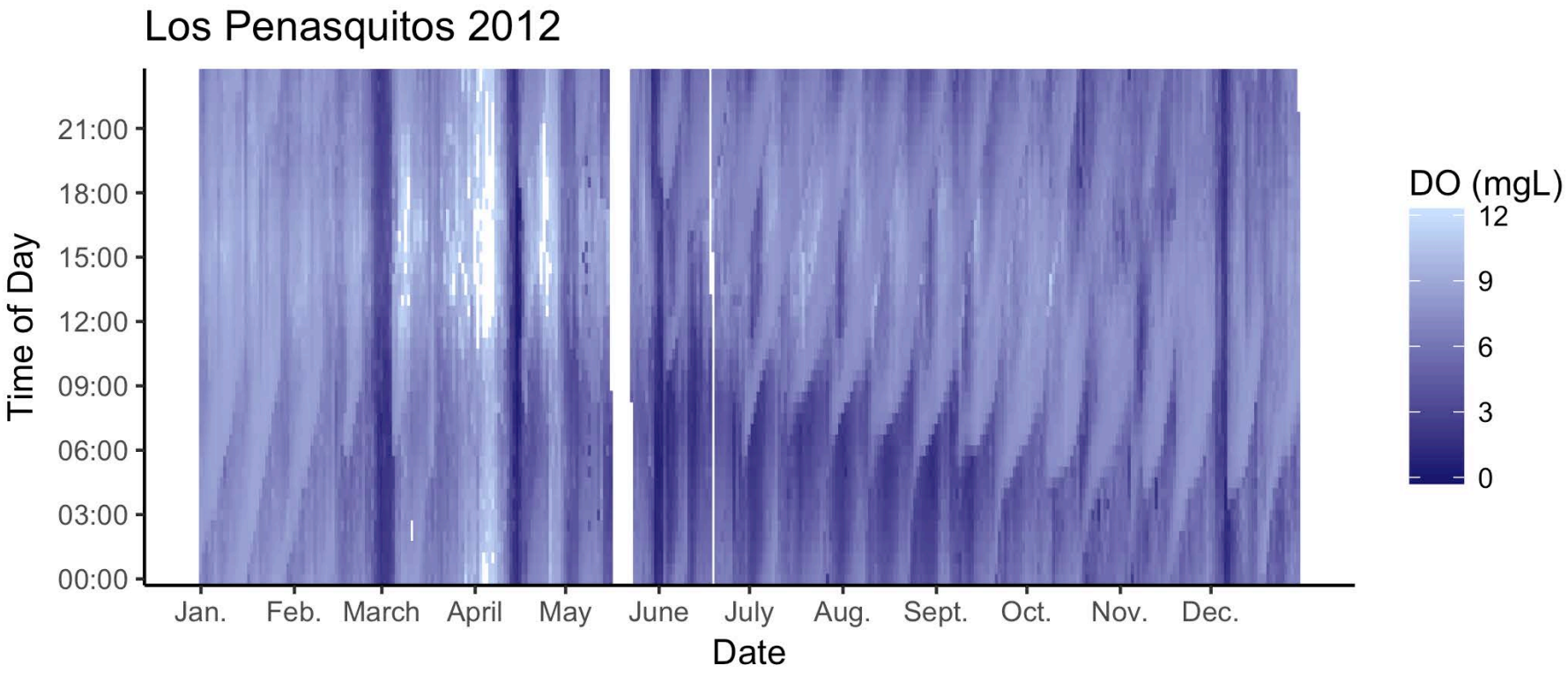

Figure 5. Closures in March, April, and May occurred during neap tides and led to brief low oxygen events. Dissolved oxygen values recovered quickly after natural breaching events due to spring tides (March and April), and after mechanical breaching (May). Daily fluctuations in dissolved oxygen became more extreme towards the end of the summer with build up of organic matter in estuary due to the summer growing season. Low dissolved oxygen values tend to be exasperated during pre-dawn hours when photosynthesis is not occurring within the water column.

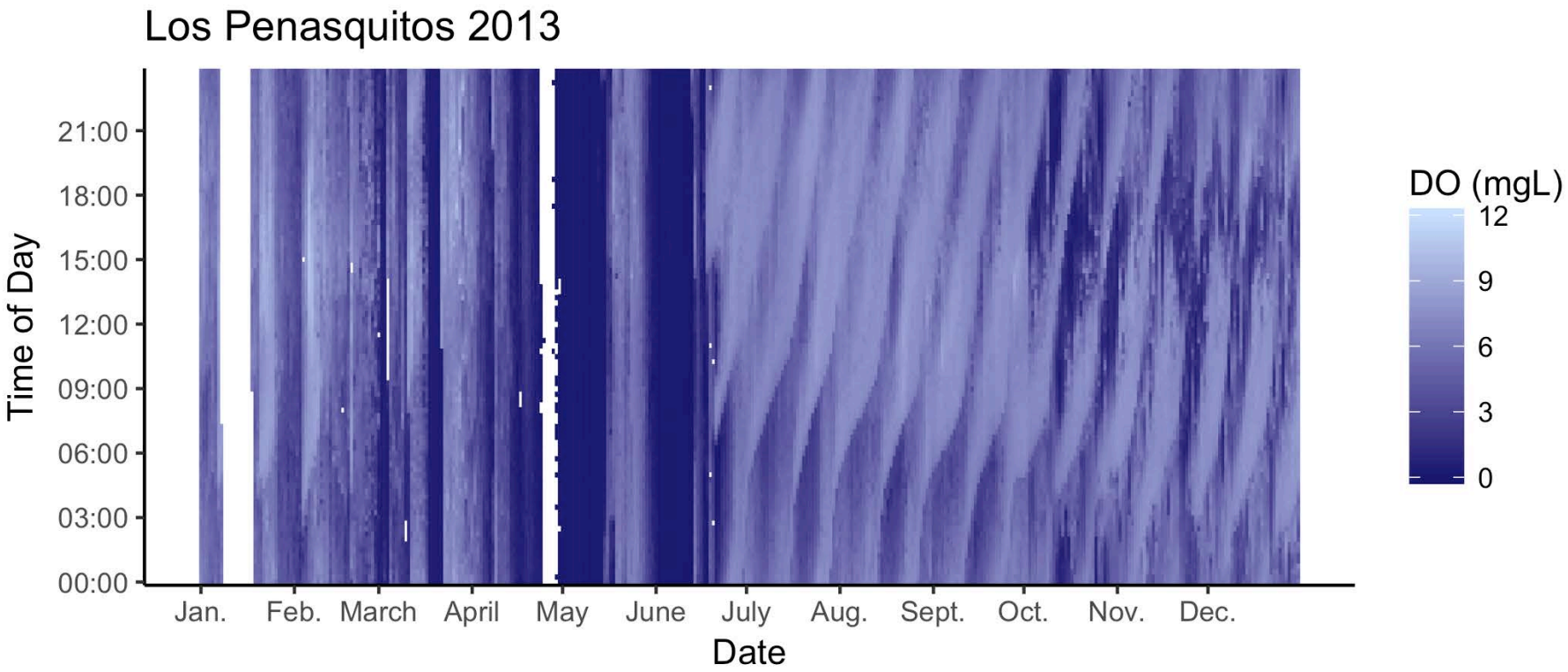

Figure 6. Unusually high levels of sand resulted in long periods of closure and low levels of dissolved oxygen during the spring of 2013. During 2012, the Regional Beach Sand Project attempted to address eroding shorelines along the San Diego coast using beach replenishment, which consisted of dredging sand from offshore deposits and then pumping it onto receiver sites (i.e., beaches). It is likely that beach replenishment efforts north of Los Peñasquitos Lagoon contributed to increased sand accretion at the estuary mouth.

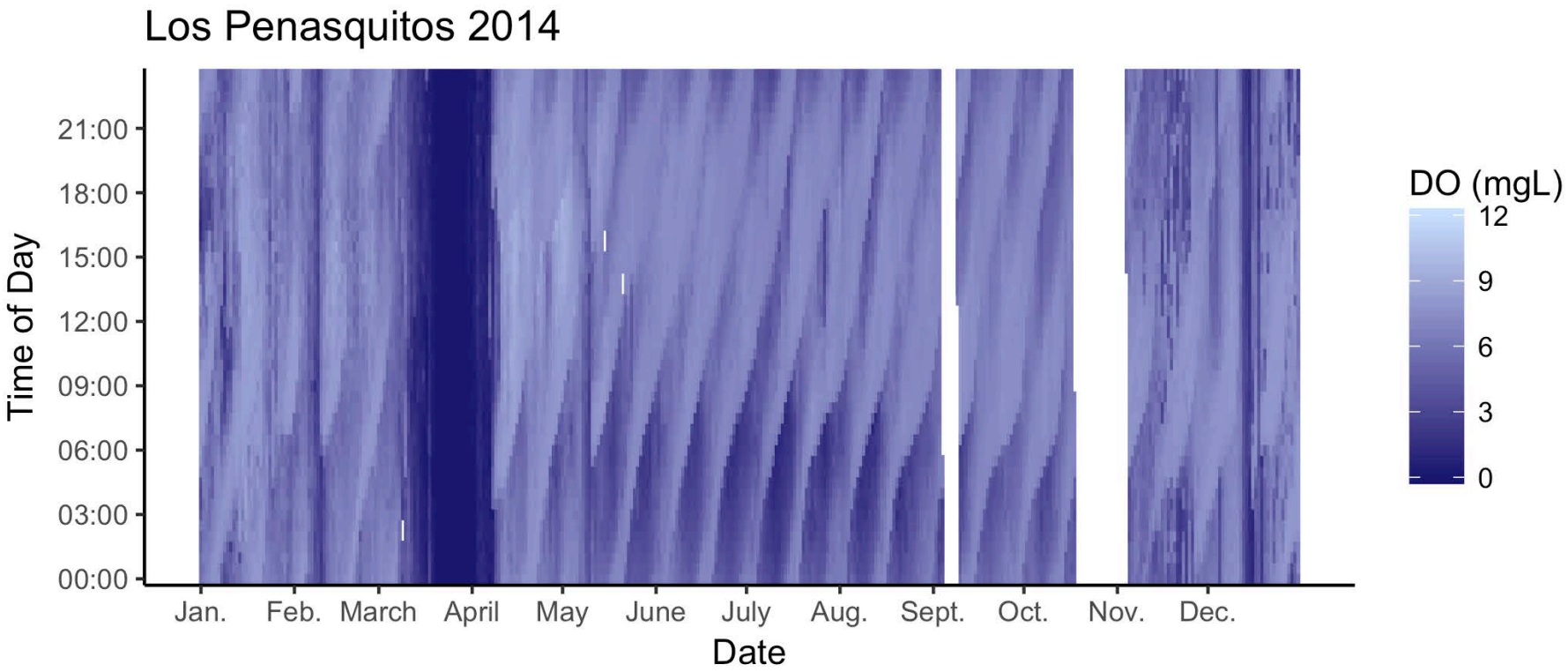

Figure 7. Dissolved oxygen levels were near zero during most of the spring closure in March and April 2014. Excavation of the mouth on April 7th led to rapid recover of oxygen levels and tidal mixing within the estuary. It is believed that beach nourishment efforts in 2013 in the Cities of Solana Beach and Encinitas likely played a role in the inlet closures at LPL by introducing more than 300,000 cubic yards of sand from offshore sand bars into the nearshore. A brief closure can also be seen in mid December.

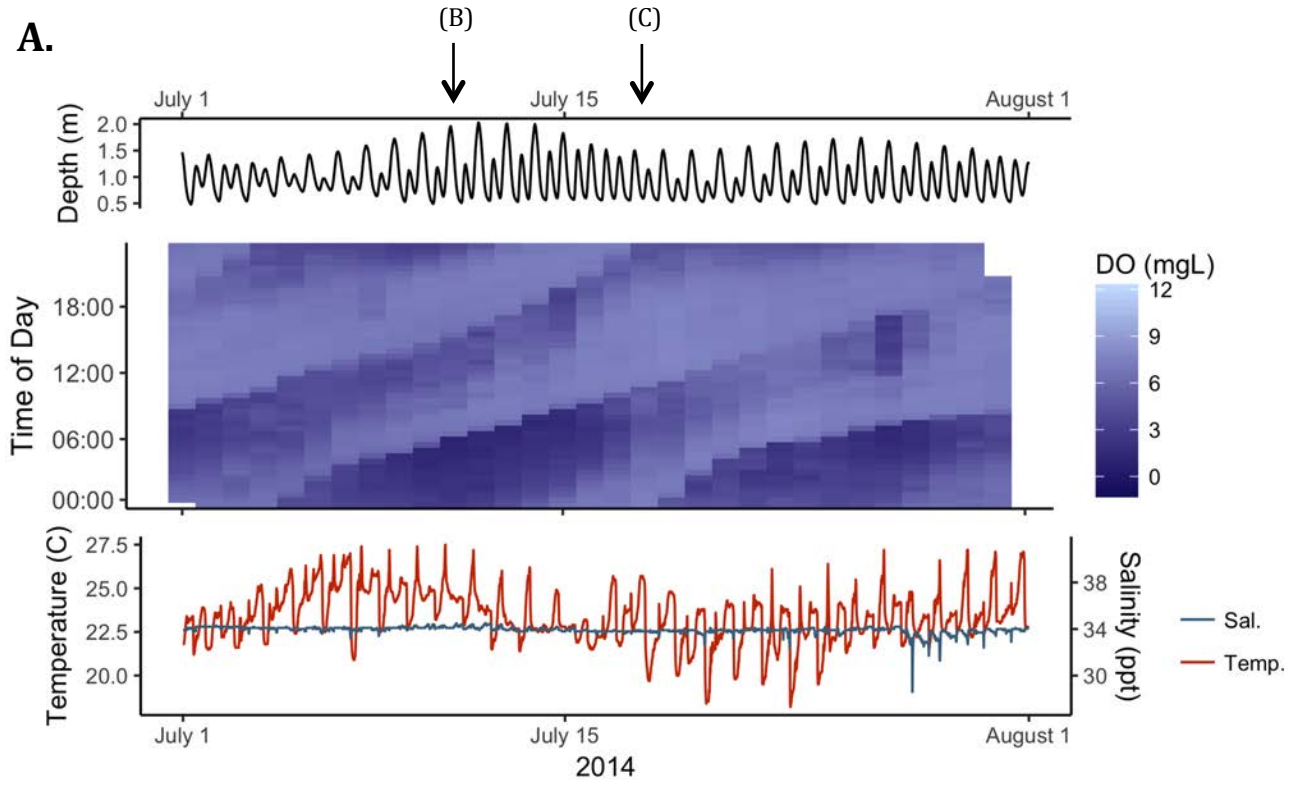

Figure 8. A. During summer months the mouth of Los Peñasquitos Lagoon is predominately open, and dissolved oxygen levels are influenced by respiration and timing of tidal flushing. The darks bands of low dissolved oxygen levels demonstrate daily shifts in the timing of low tide. Spring tide cycles lead to more extreme daily fluctuations in dissolved oxygen levels. Additionally, timing of low tide during pre-dawn hours can lead to critically low dissolved oxygen values (B.) while timing of high tide during pre-dawn hours results in high and stable dissolved oxygen values throughout the day (C.). Predawn drawdown of dissolved oxygen is cause by high respiratory demand of decomposers, plants, and animals within the water column as well as a lack of aquatic photosynthesis to replenish oxygen being consumed.

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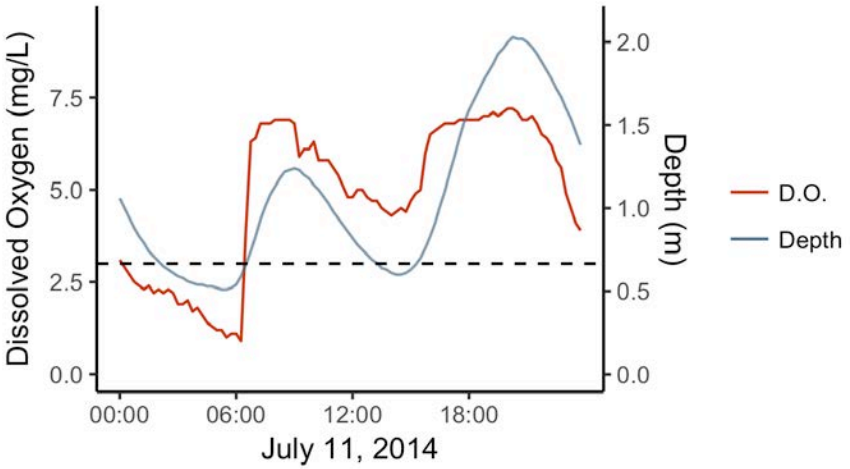

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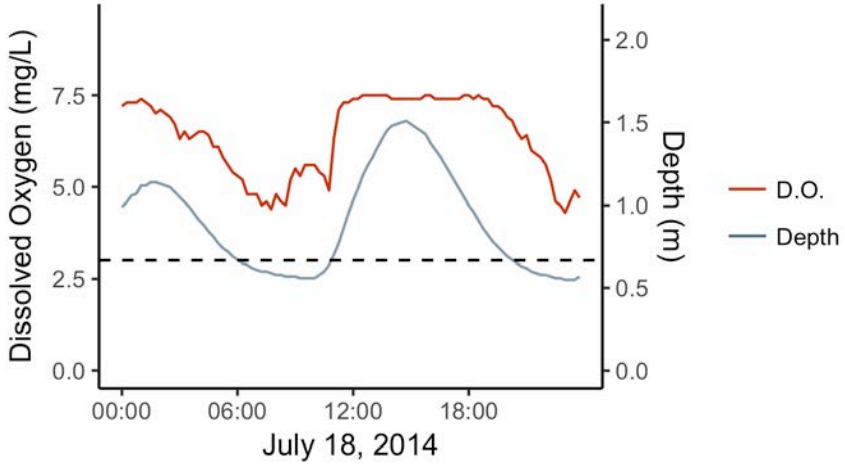


Figure 8. B. Close-up of dissolved oxygen profile during July 11th, 2014 demonstrates how pre-dawn low tide can exacerbate low dissolved oxygen levels. **C.** Close-up of dissolved oxygen profile during July 18th, 2014 demonstrates how pre-dawn high tide can stabilize dissolved oxygen levels throughout the day. Pre-dawn high tide flushes the estuary when aquatic photosynthesis is incapable of counteracting respiration within the water column. Dashed line denotes start of hypoxic conditions, where dissolved oxygen levels drop below 3 mg/l.

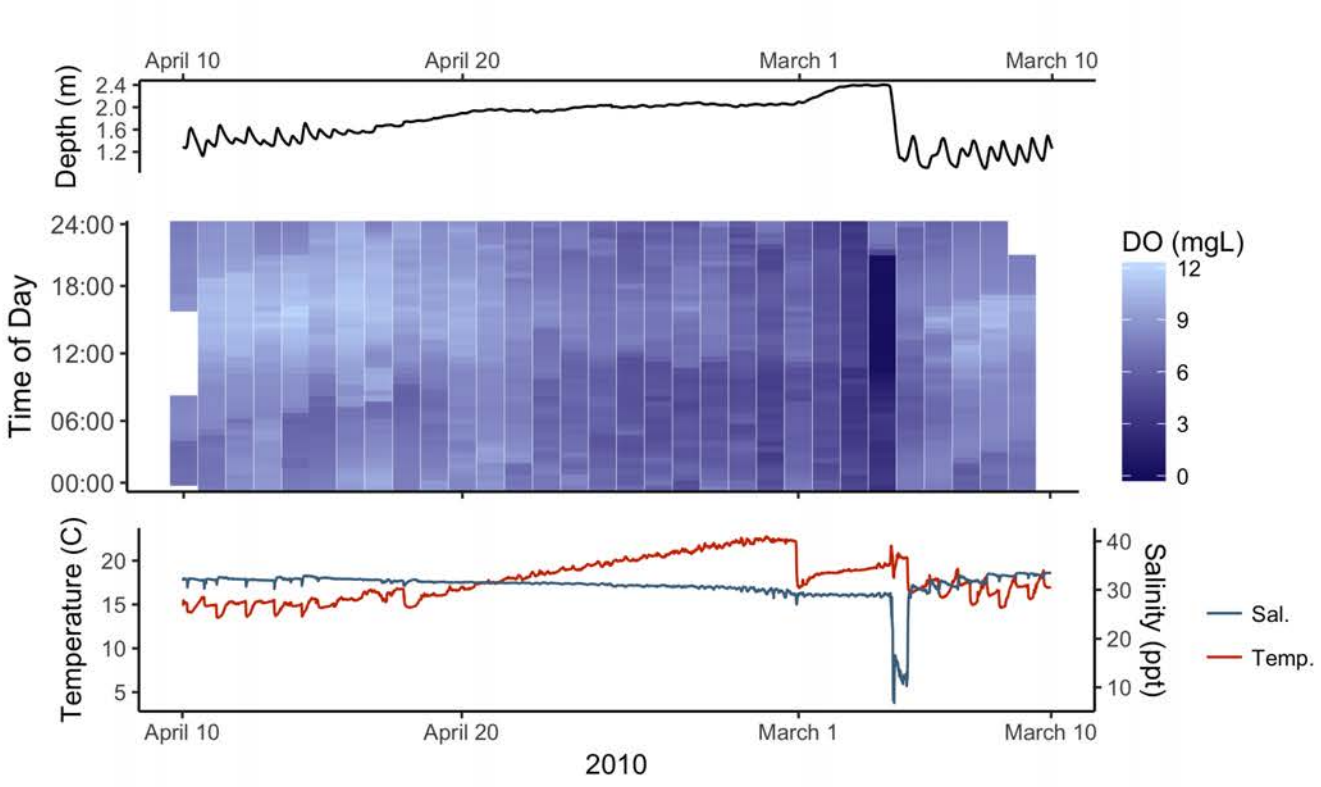


Figure 9. During April 2010, the mouth of Los Peñasquitos Lagoon was closed for one month, until it open naturally on April 4th. Dissolved oxygen levels were high and stable during this closure. However, after the mouth breached dissolved oxygen levels dropped to hypoxic levels as freshwater drained out of the estuary. Before the breaching event, salinity levels remained close to 30ppt and temperature increased by 5ºC.

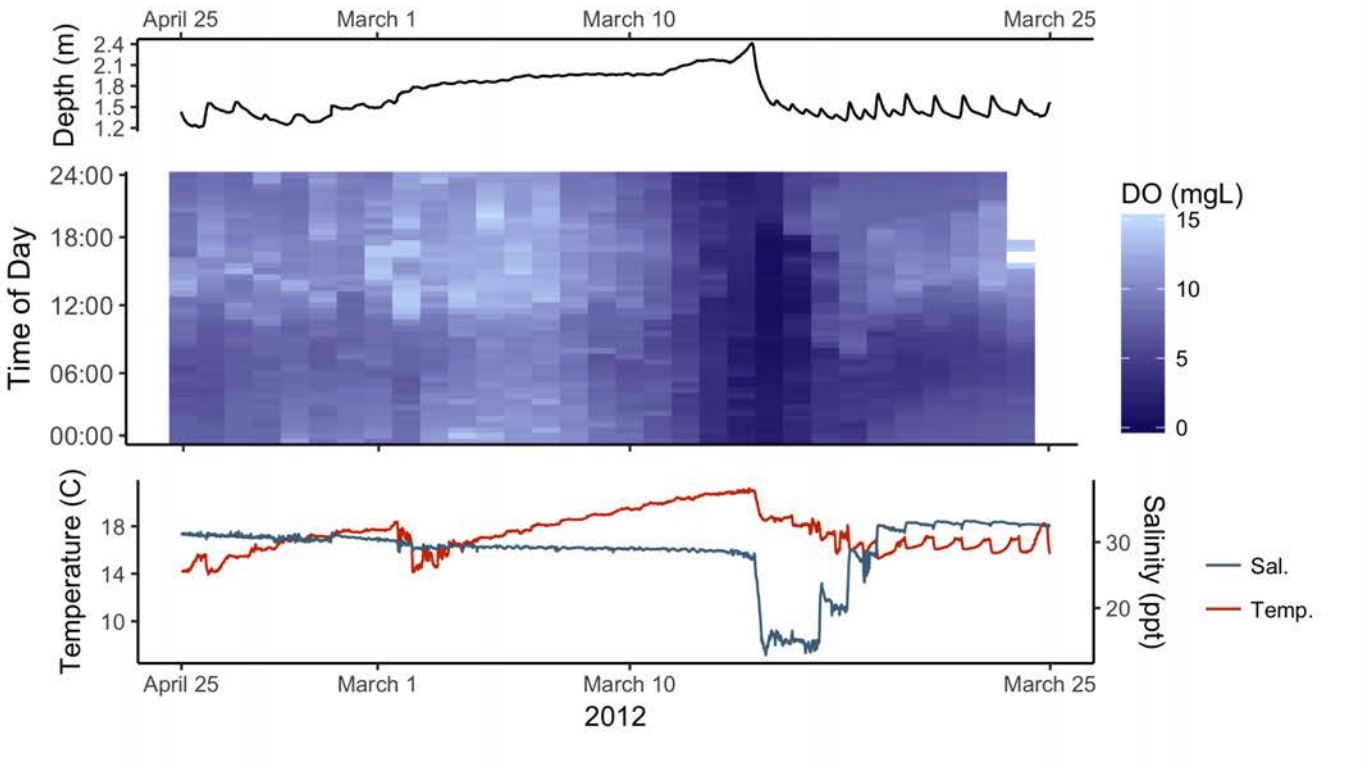


Figure 10. A brief, two-week closure occurred in Los Peñasquitos Lagoon during March 2012. Dissolved oxygen levels began to drop during final days of closure, but became critically low after natural breaching event, which led to freshwater draining out of the estuary. Dissolved oxygen levels recovered as tidal mixing was reinstated.

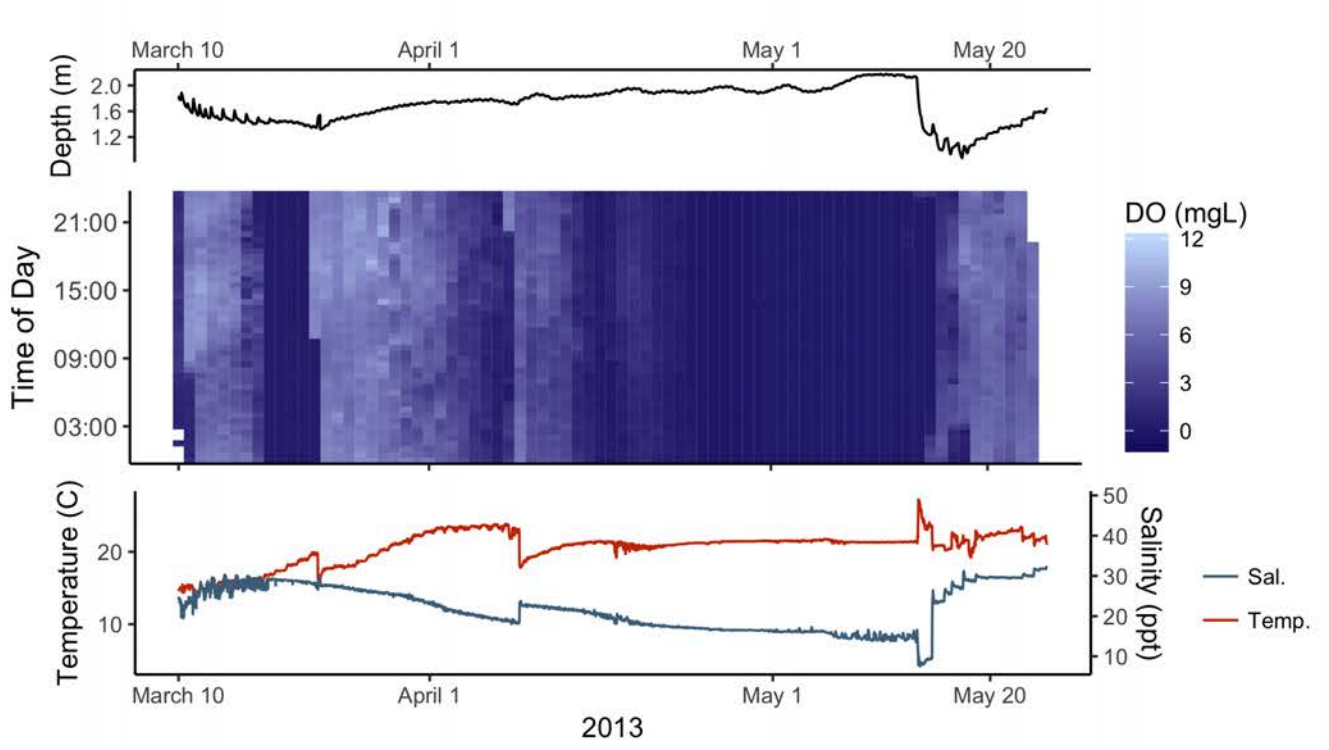


Figure 11. Dissolved oxygen levels were critically low for most of the six-week closure during Spring 2013. Dissolved oxygen levels recovered briefly when waves washed over the berm at the lagoon mouth during early April (likely during a spring tidal series). This wash-over event is denoted as a sharp drop in temperature and increase in salinity. Beach replenishment north of Los Peñasquitos Lagoon led to high levels of sand in estuary mouth and long periods of closure during 2013 and 2014. The mouth was mechanically breached on May 13th, however it reclosed within 12 hours of breaching.

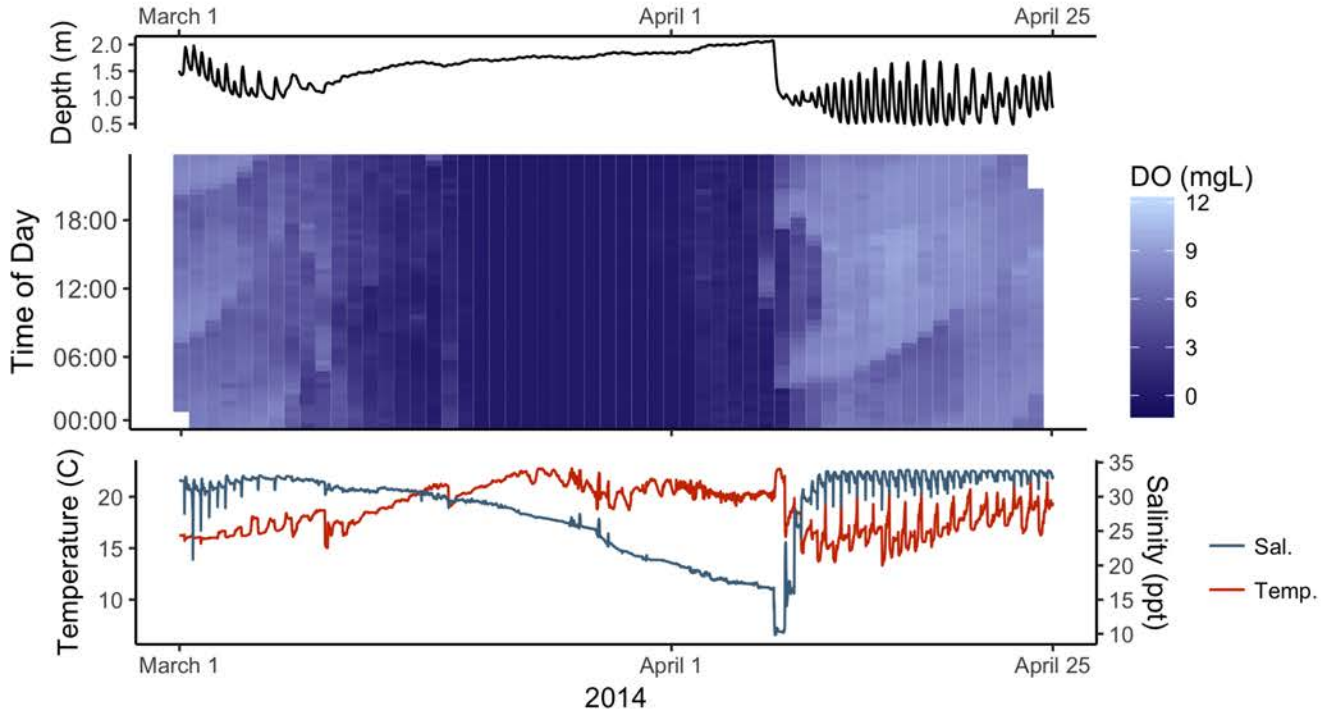


Figure 12. Dissolved oxygen levels dropped below critical levels and remained low during a month-long closure during April 2014. The drop in dissolved oxygen coincided with a steady decline in salinity. The mouth was mechanically breached on April 7th resulting in rapid tidal mixing within lagoon and recovery of dissolved oxygen. Beach replenishment north of Los Peñasquitos Lagoon led to high levels of sand in estuary mouth and long periods of closure during 2013 and 2014.

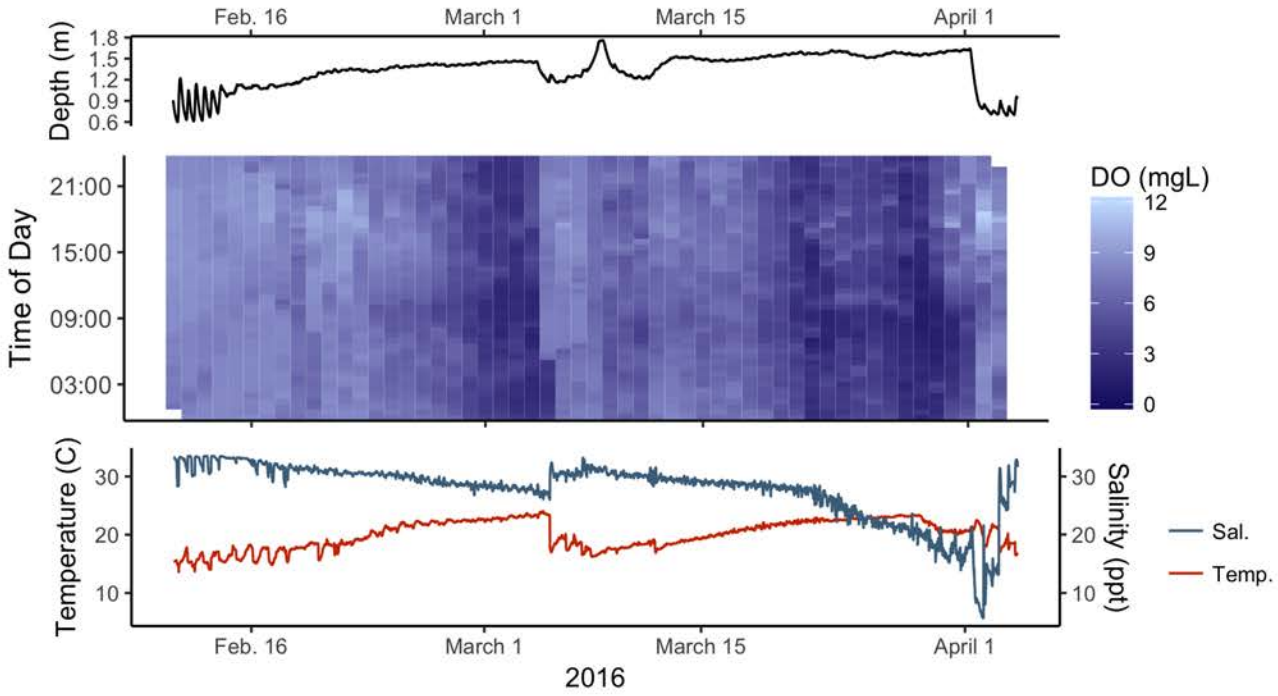
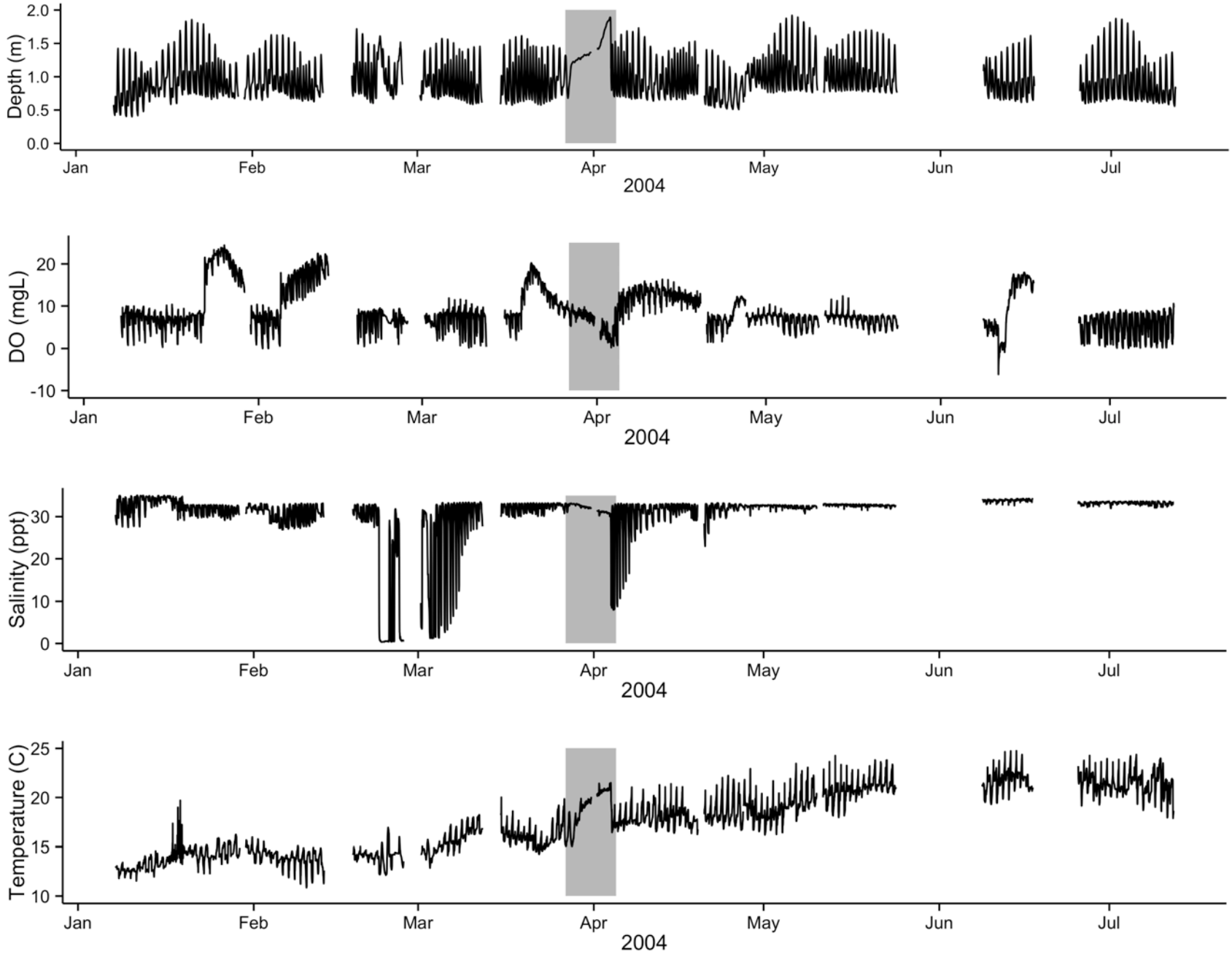


Figure 13. Los Peñasquitos Lagoon remained closed for six weeks during Spring 2016. Dissolved oxygen began to decrease to hypoxic levels as salinity declined and temperature rose. However, in early March seawater was introduced into the lagoon and dissolved oxygen levels recovered for two weeks. This wave wash-over event can be seen as a sharp change in salinity, temperature, and depth levels at the beginning of March, and likely occurring during a spring tidal cycle.

Water Quality Time Series Data by Year

On the following pages are time series figures for four water quality variables: water depth (m), dissolved oxygen (mg/l), salinity (ppt), and temperature (C) for the Los Penasquitos Lagoon. Each page represents one year of data (from 2004-2016) for all four water quality variables. Shaded regions represent possible mouth closure events (listed in Table 1 and Figure 1). Data is missing when sonde was removed for maintenance.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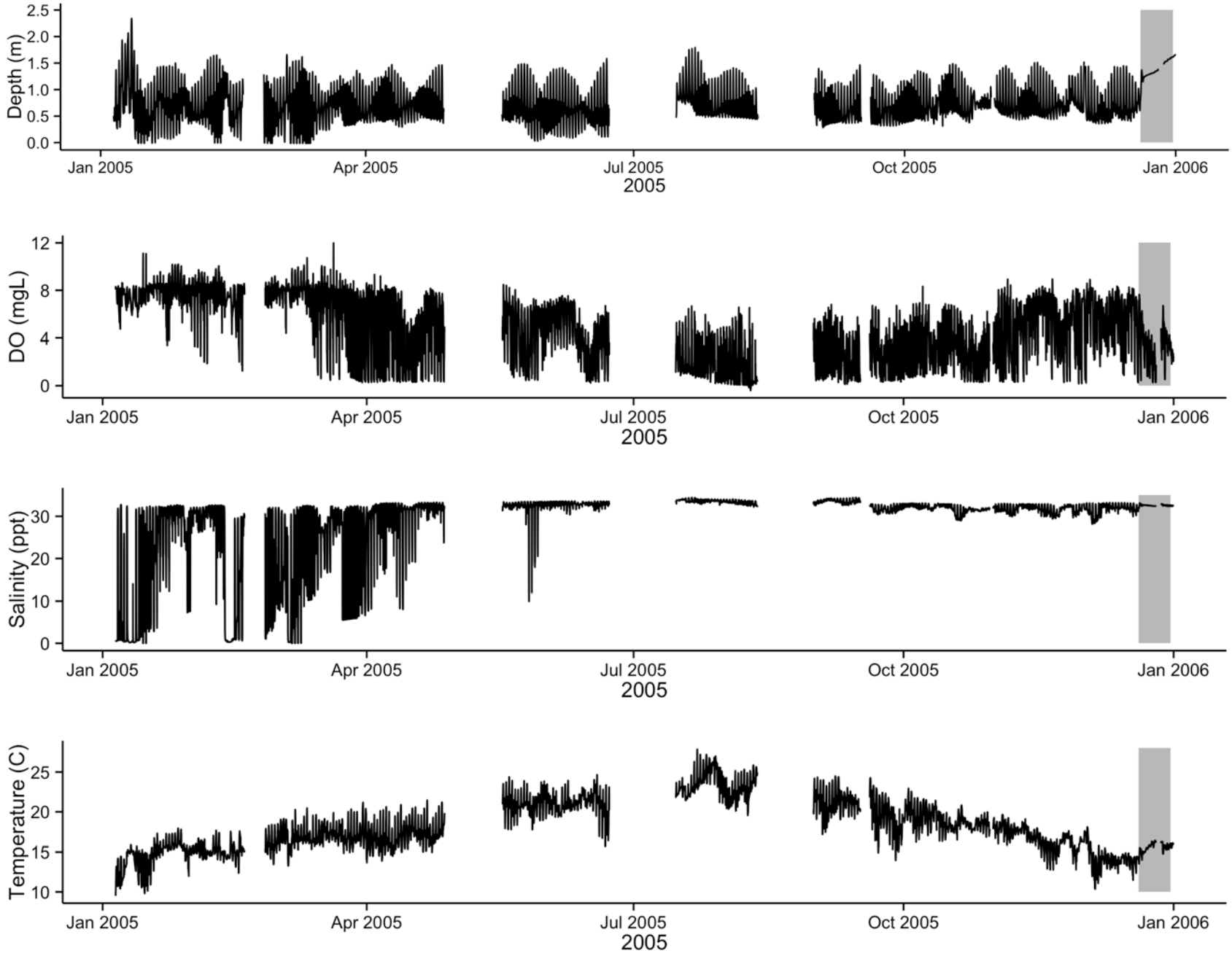
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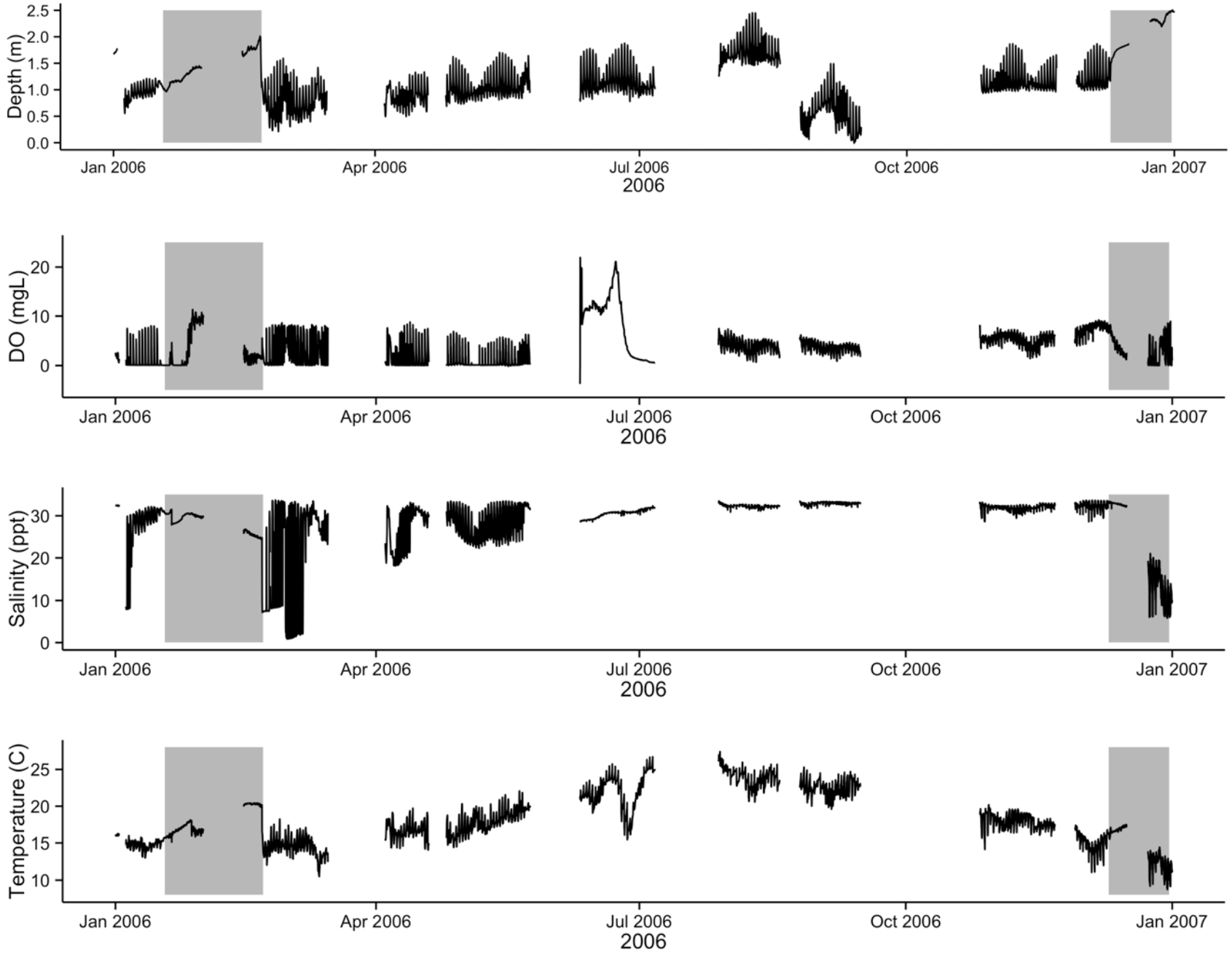
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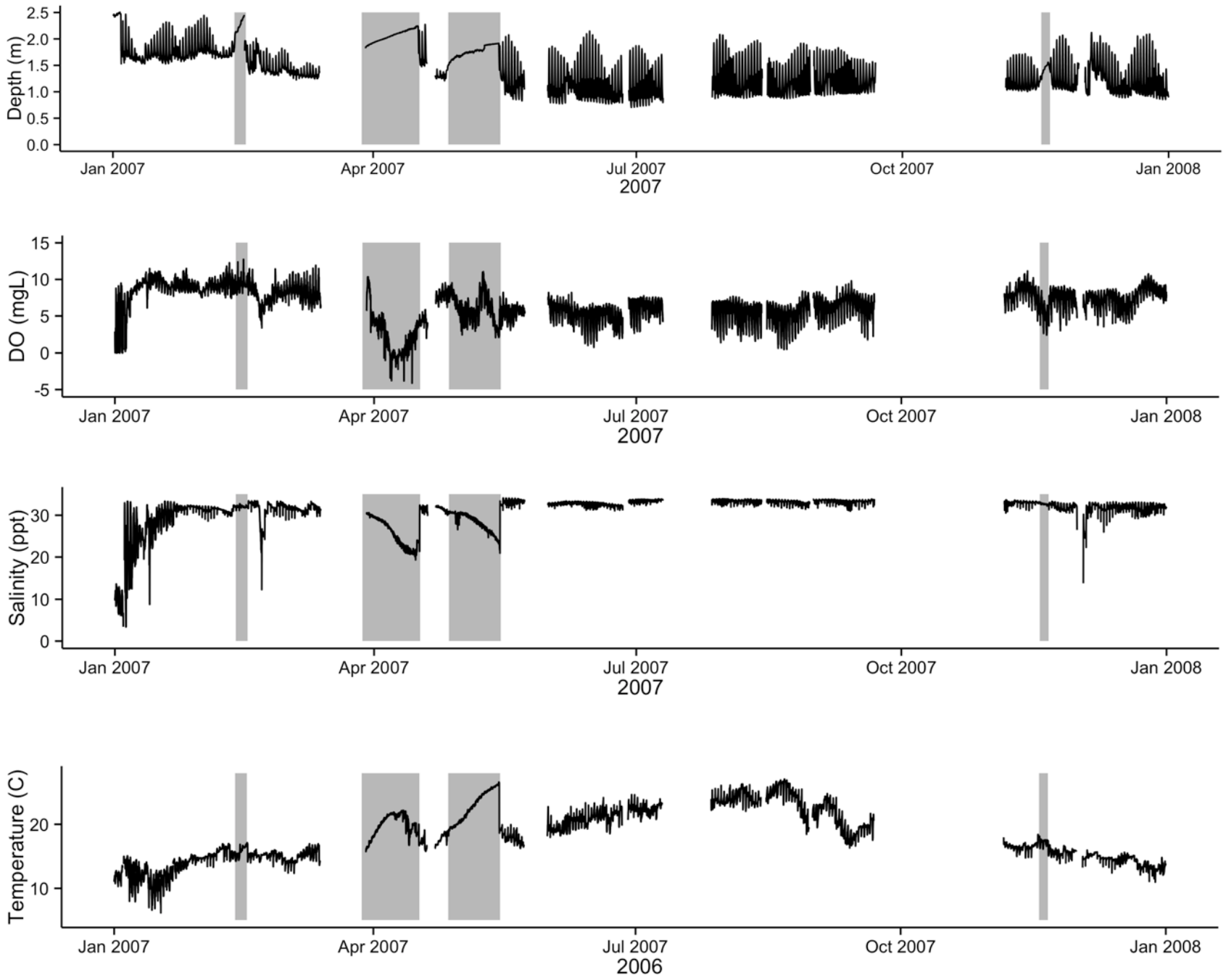
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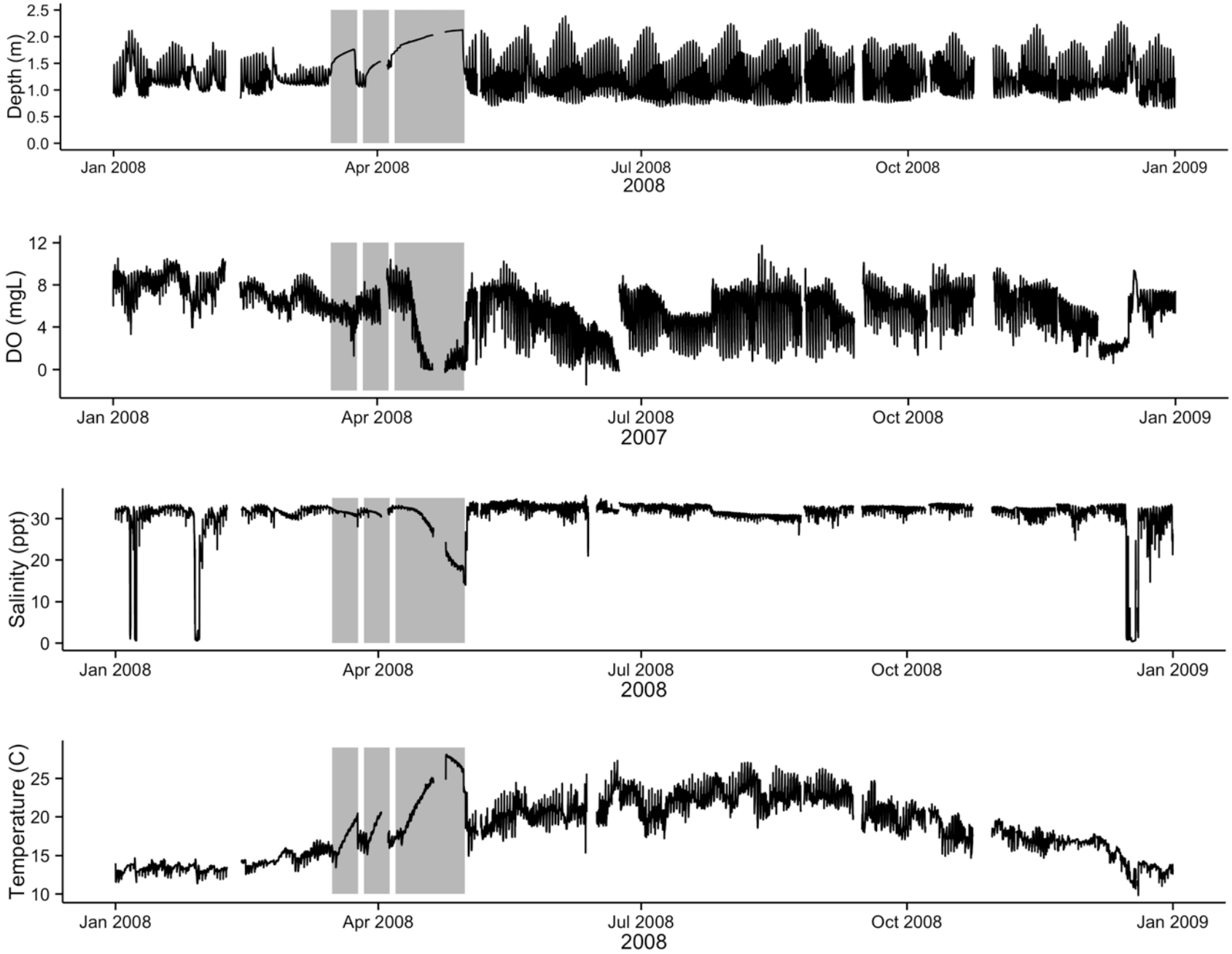
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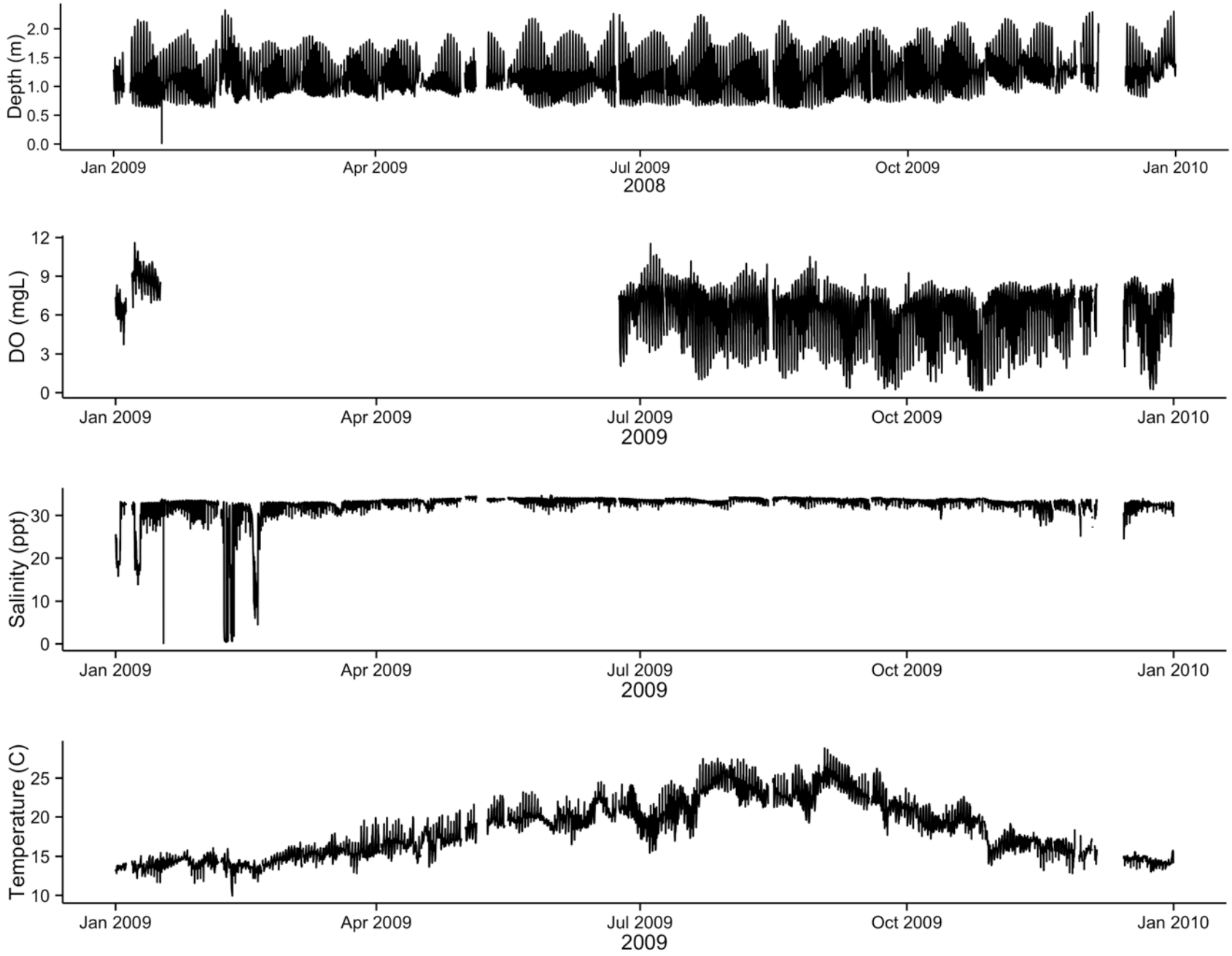
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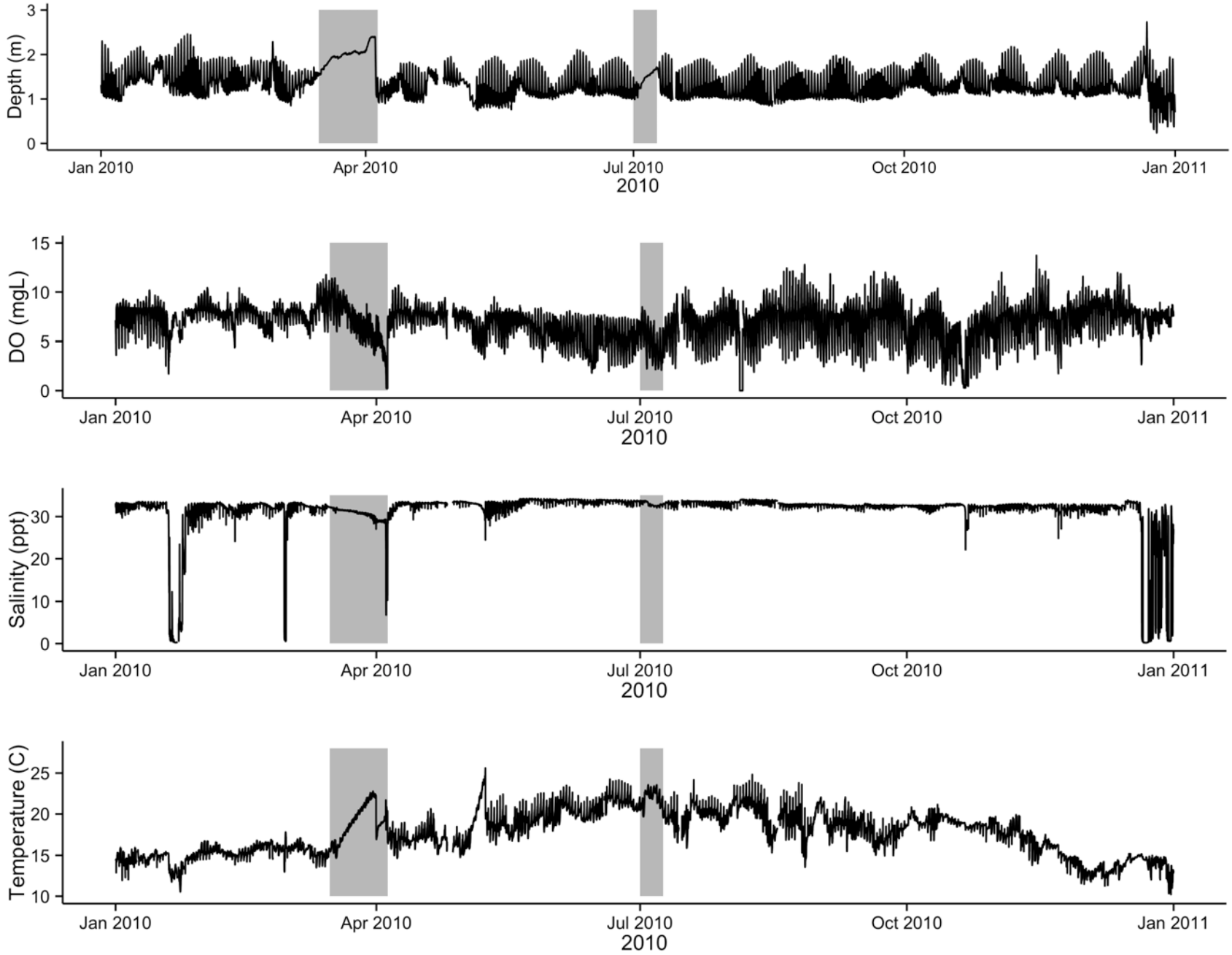
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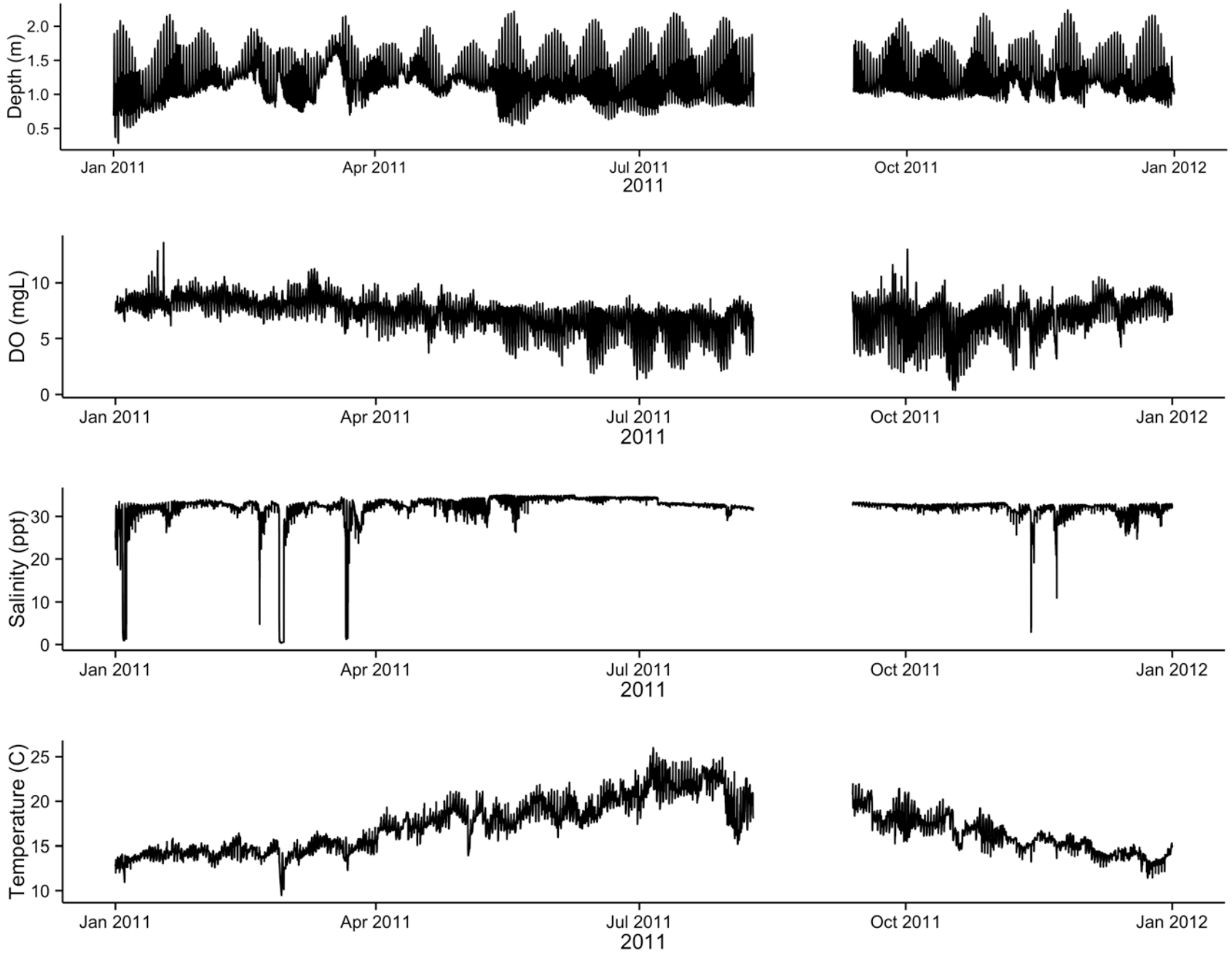
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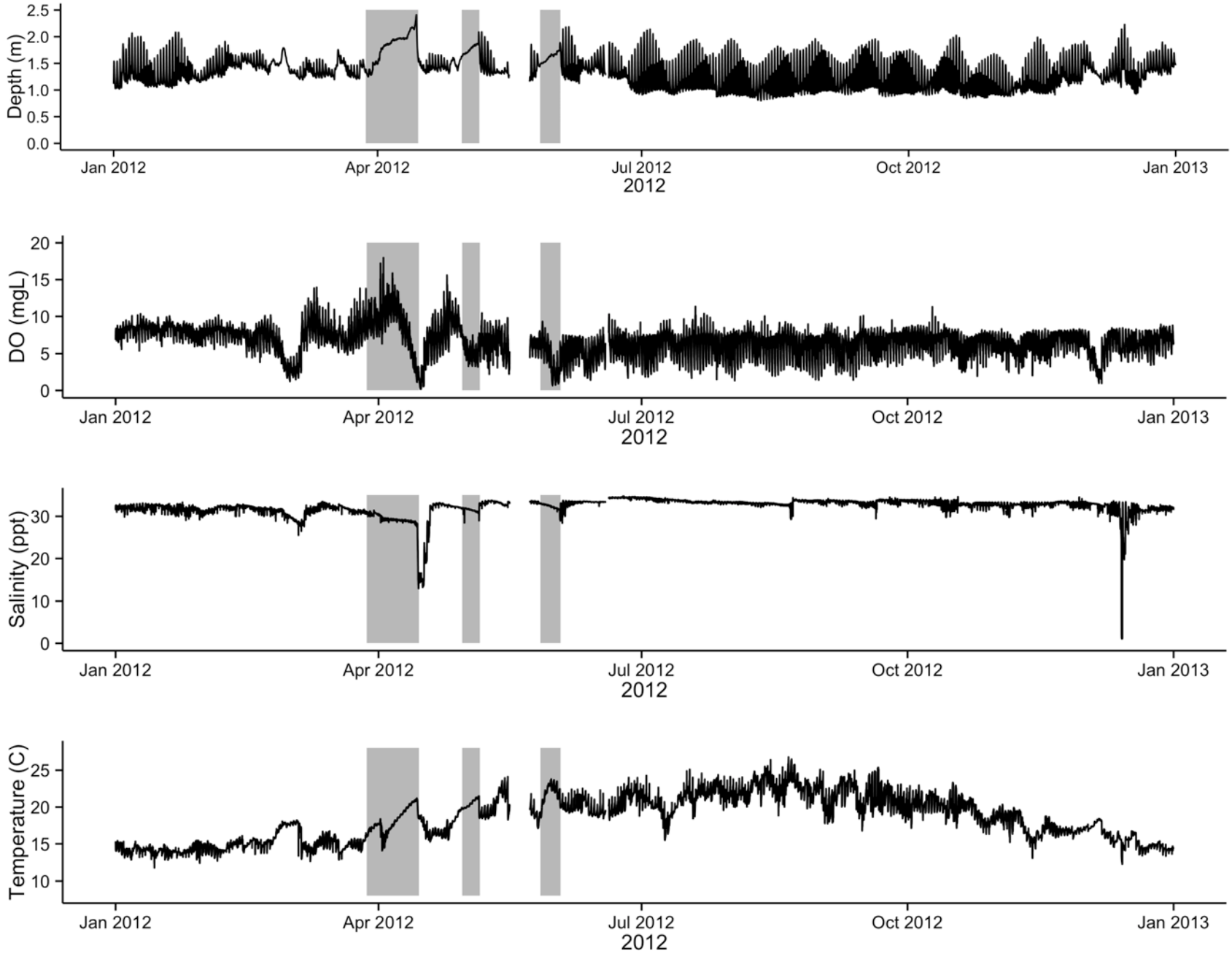
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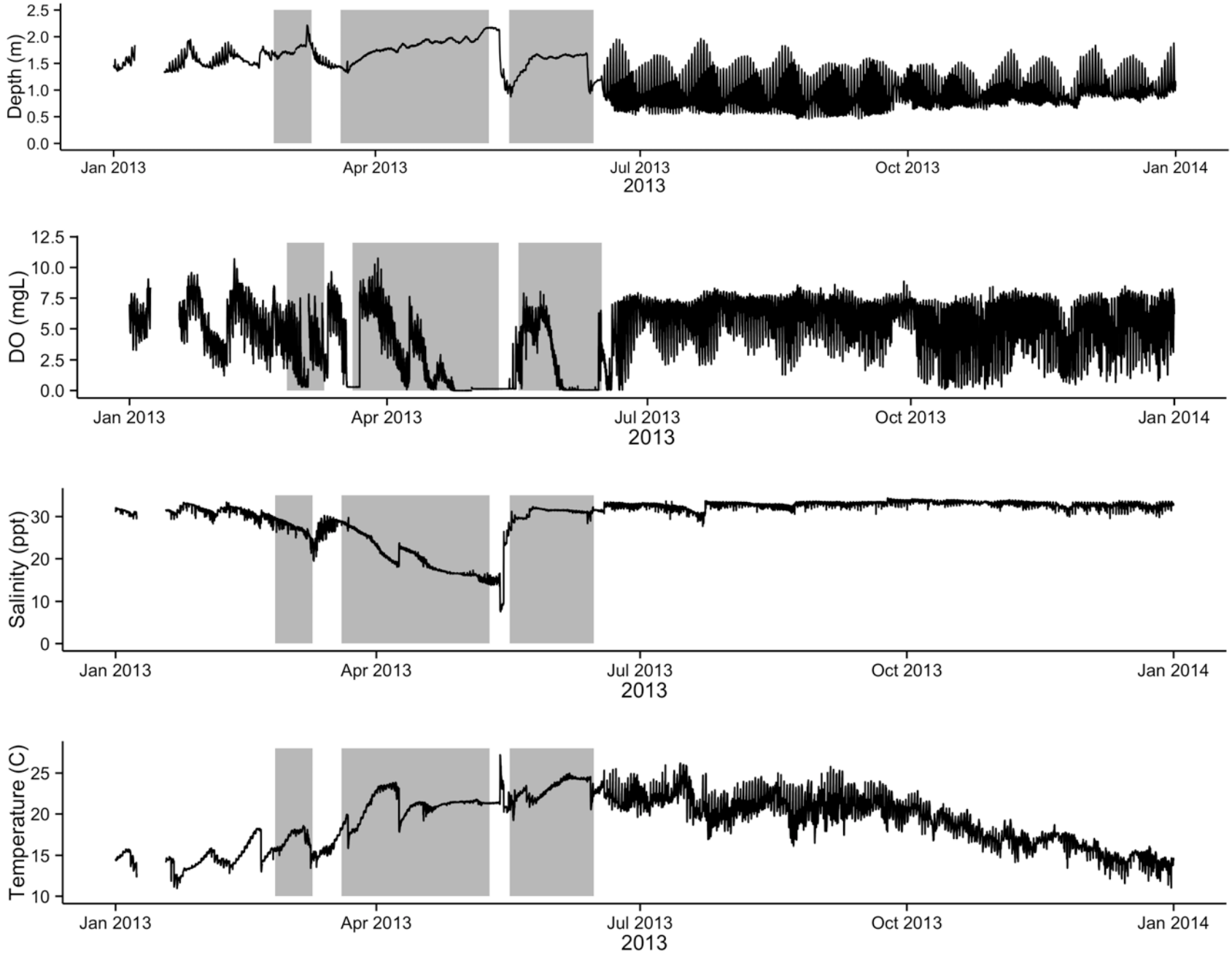
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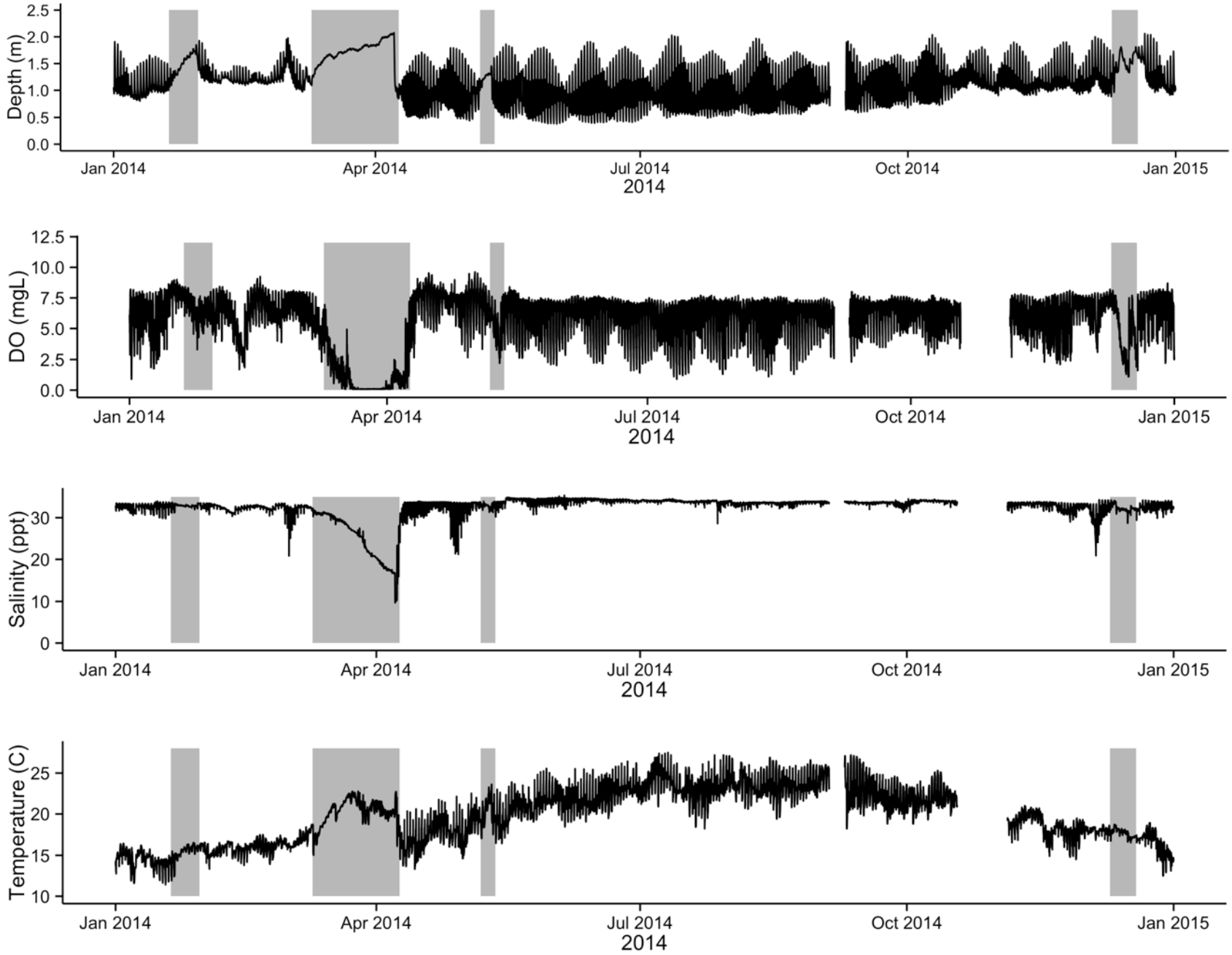
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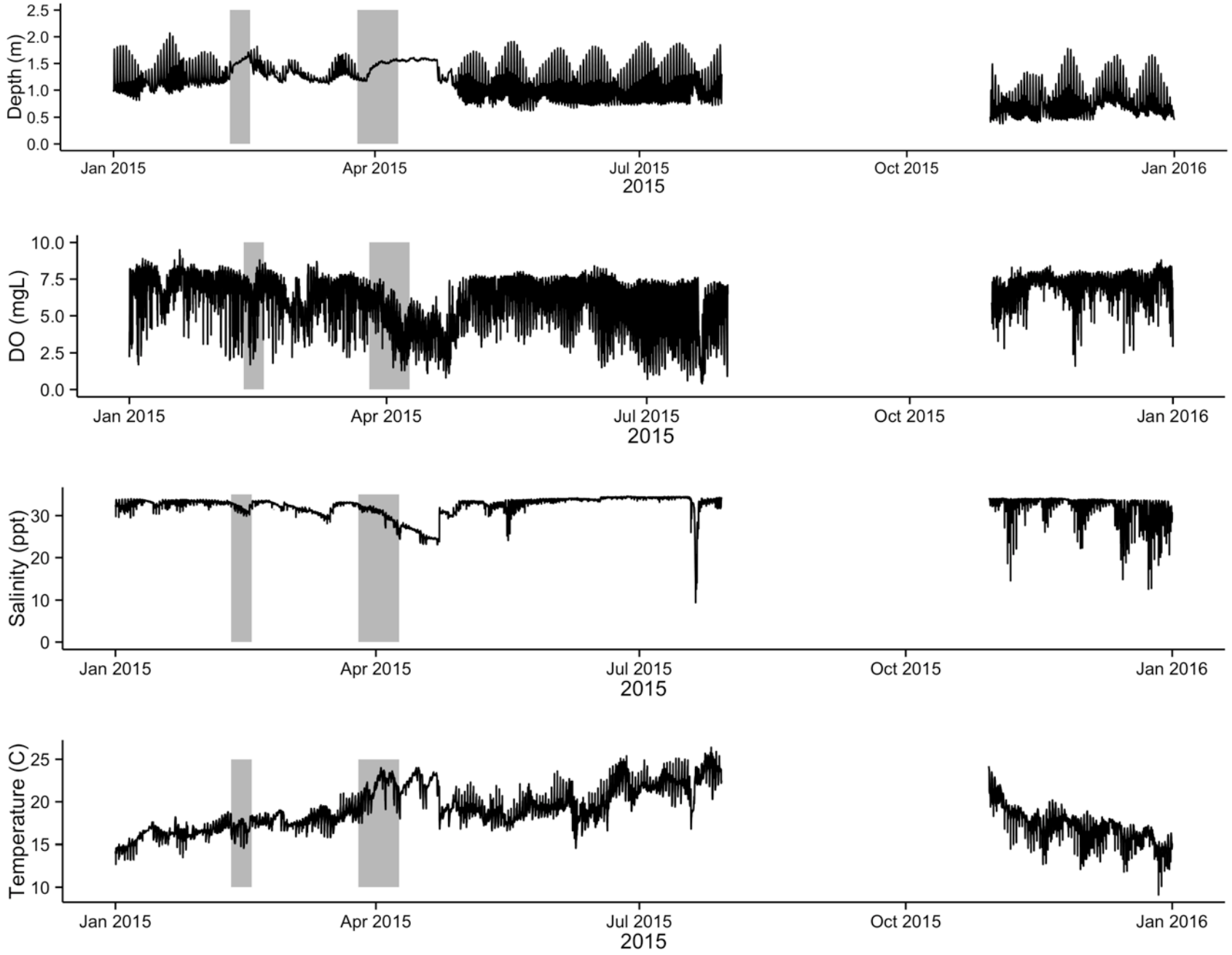
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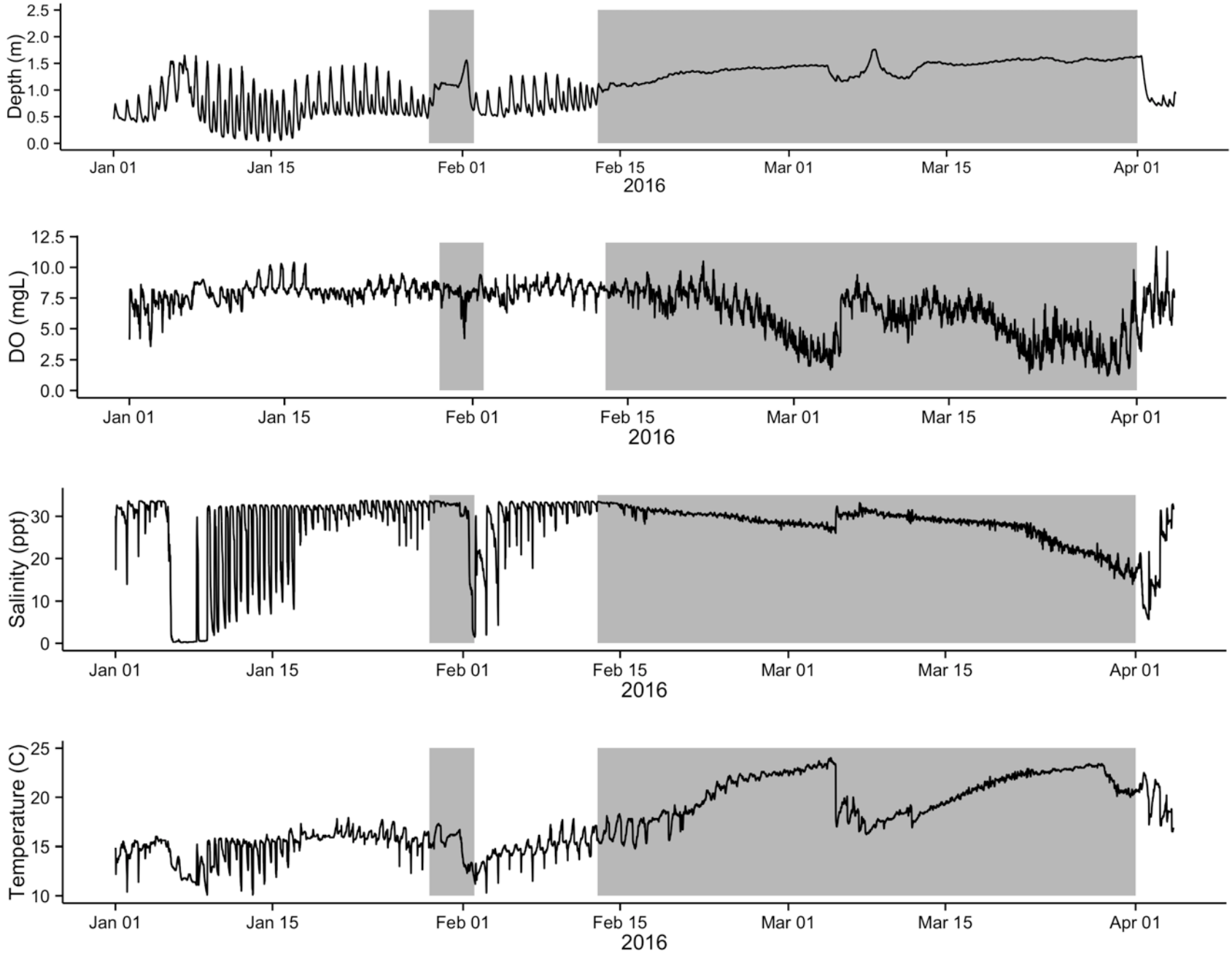
DO (mgL)
10.0
7.5
5.0
2.5
0.0
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
2015
Salinity (ppt)
30
20
10
0
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
2015
Temperature (C)
25
20
15
10
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
2015


Depth (m)
2.5
2.0
1.5
1.0
0.5
0.0
Jan 01
Jan 15
Feb 01
Feb 15
Mar 01
Mar 15
Apr 01
2016
DO (mgL)
12.5
10.0
7.5
5.0
2.5
0.0
Jan 01
Jan 15
Feb 01
Feb 15
Mar 01
Mar 15
Apr 01
2016
Salinity (ppt)
30
20
10
0
Jan 01
Jan 15
Feb 01
Feb 15
Mar 01
Mar 15
Apr 01
2016
Temperature (C)
25
20
15
10
Jan 01
Jan 15
Feb 01
Feb 15
Mar 01
Mar 15
Apr 01
2016

Conclusion and Future Directions

The Southwest Wetlands Interpretive Association and the Tijuana River National Estuarine Research Reserve have procured an invaluable dataset by maintaining the long-term monitoring of Los Peñasquitos Lagoon water quality. This document summarizes an initial exploration of these data and how these data provide understanding of dissolved oxygen levels within the lagoon at multiple timescales. With the use of multilevel mixed models it would be possible to formally quantify the effect sizes of different factors (e.g. tidal fluctuations, seasonal cycles, daily changes in temperature) on dissolved oxygen. The use of Structural Equation Modeling could be particularly useful as it allows for hierarchical analyses and can demonstrate how these factors are also related to each other (in terms of both effect size and direction). Such analysis should be preformed on data collected during both open and closed states and entirely separate projects could entail the study of the mechanisms driving dissolved oxygen levels in both states. Furthermore it might be valuable to compare low oxygen events during natural and mechanical breaching. As this data set now spans 13 years it should be possible to tease general patterns in dissolved oxygen fluctuations from interannual variability.

In the future, placing replicate sondes at multiple depths would allow researchers to understand how water masses are stratified within the lagoon. Also, deploying sondes along the length of the estuary would reveal the areal extent of low oxygen events within the lagoon. Both of these suggestions are aimed at improving the spatial understanding of low oxygen events within the lagoon as this is ecologically important. How does spatial and temporal heterogeneity in dissolved oxygen affect the ecological dynamics in Los Peñasquitos Lagoon? How often do low oxygen events at the mouth of the estuary simultaneously include high oxygen refuge at other locations or depths within the estuary? If these refuges exist, how important is it to the ecosystem to mechanically breach the estuary? Such questions are yet to be answered.

On a final note, long-term data sets will continue to become more valuable as we proceed into the 21st century and the effects of climate change become more pronounced. These data will act as a baseline characterization of oxygen heterogeneity and mouth closures in Los Peñasquitos Lagoon. Predicted future changes in precipitation, temperature, and dissolved oxygen levels within the ocean will likely alter both Los Peñasquitos Lagoon dissolved oxygen regimes and mouth state. While the oxygen regime we see now in Los Peñasquitos Lagoon might not be representative of the future, we have the opportunity to understand what mechanisms are causing the current oxygen regime to shift and how best to manage these changes.