SOIL BIOLOGICAL TEMPORAL VARIABILITY AS FUNCTIONS OF PHYSIOCHEMICAL STATES AND SOIL DISTURBANCE

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ABSTRACT

Within our ecosystems, soil biota control an array of functions, such as nutrient cycling and decomposition, and have been pursued as a soil quality indicator. Though microbial communities are known to be a reflection of their environment, small scales dynamics within an agricultural system have been overlooked for many years leading to gaps when inferring on relative microbial values. To further asses our current microbial knowledge, two experiments analyzing microbial phospholipid fatty acid (PLFA) structures and enzyme activities sought out to determine temporal fluctuations, cycles, and driving force behind simulated daily microbial parameter outputs. Across both studies, temporal effects, cyclical structures, and common driving forces were recorded, but further validation and characterization is needed to solidify the temporal dynamics of the microbial community. Overall, this information serves as a valuable step towards determining the most viable tillage systems based on environmental conditions, and physical proof of small scale microbial fluctuations.

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GENERAL INTRODUCTION

Soil's functionality ranges from natural to engineering media, making soil a fundamental part in society. With an increasing need for food, feed, fiber, and fuel, a balance between sustainable soil management and consistent high yielding crops is essential. Therefore, stakeholders should take steps to reduce soil disturbance (e.g., tillage) to maintain optimum soil functionality and allow for increased crop water, light, and nutrient use efficiencies and other ecosystem services. However, knowledge of soil microbial dynamics over short periods (i.e. days, week, or months) in soil tillage systems is lacking in the scientific literature. Efforts to fill this knowledge gap are needed to help make sound management decisions for economically viable crop production while maintaining important environmental functions.

Soil biota control an array of ecosystem functions, such as nutrient cycling and decomposition. Microbial communities may also aid in soil aggregation via glomalin and glycoprotein (produced by fungal hyphae) secretions, leading to enhanced soil carbon storage over time (Rillig, 2004). Additionally, symbiotic organisms such as arbuscular mycorrhizal fungi (AMF) and rhizobacteria play prominent roles in soil health and crop production. Soil AMF at the plant and ecosystem levels can increase nutrient uptake and defend against soil-borne pathogens (Smith et al., 2016), while rhizobacteria are able to perform functions such as nitrogen fixation, hormone production, and pathogenic defense (Bloemberg and Lugtenberg, 2001). However, the microbial community's composition and functions can be moderated by the soil's physical and chemical environment (Kibblewhite et al., 2008; Degrune et al., 2017). Agricultural management practices, including conservation tillage, directly shift the soil's physical and chemical states. Knowledge of a soil microbial community's response to these shifts could enable our ability to infer subsequent consequences to crop production and ecosystem services.

Historically, plowing or tilling of the soil has been a tool for many purposes in crop lands. For instances, mechanical disturbance has been used for seedbed preparation, incorporation of fertilizers and crop residues, stimulate the release of nutrients in crop residues through decomposition, weed management, and for drying and warming the soil during cold springs (Hobbs et al., 2008). Though these effects were historically deemed beneficial for crop production, research has provided evidence of the degrading effects tillage can have on soil health. For example, O'Rourke and Petersen (2016) demonstrated that moldboard plowed field increased water erosion by 8.9 times when compared with no-till fields due to the reduction in crop residue cover at the soil surface. Additionally, long-term differences in soil physical and chemical properties between tillage systems are well known in the scientific community. Tillage decreases soil organic carbon, soil water retention, soil aggregation, and stratifies bulk densities when compared with reduced tillage or no-till systems (Gosai et al., 2009; Gottshall et al., 2017). Tillage disturbs soil structure and homogenizes soil microbial communities. In turn, this homogenization allows reduced species in the bacteria and protozoa groups to function at high levels creating an unbalanced community (Coudrain et al., 2016).

As stakeholder education increases, land managers and researchers are beginning to implement new tillage strategies to prepare fields for planting. In the past, moldboard plowing, was the primary tool for tillage. This tool inverted soil to a depth of 20-30 cm. This method then typically required an additional one to two passes with a field cultivator, disc, or harrow to smooth the soil surface for good seed depth placement; thus, leaving less than 15% crop residue on the soil surface. As society became more conscientious of soil conservation to reduce erosion, a number of reduced tilled (oftentimes referred to as conservation tillage) systems emerged from industry for crop producers. These reduced tillage systems were used to reduce environmental impact, yet sustain crop yields. The first reduced tillage tool was the chisel plow. Though termed reduced tillage, the chisel plow tills the soil to a depth of 15-20 cm with shanks followed by a secondary implement in spring; thus, leaving > 30% crop residue cover on the soil surface. In more recent years, other reduced tillage systems were designed to leave even more crop residues on the soil surface. For instances, vertical tillage lightly disturbs the top 2-10 cm of soil with wavy or straight coulters which are meant to cut crop residue into small pieces and increase their contact with the top soil for enhanced decomposition. Vertical tillage does not require a secondary tillage pass to smooth the soil for planting and typically leaves > 50% crop residue cover at the soil surface (Daigh and DeJong-Hughes, 2017). Generally, soil erosion decreases and soil water retention increases as the level of mechanical soil disturbance decreases, providing immediate benefits to rain-fed cropping systems (Bescansa et al., 2006; O'Rourke and Petersen, 2016).

Though the scientific literature has a general agreement regarding the effects of tillage on soil microbial and chemical properties, contradictions still emerge. In 2016, a literature review completed by Stacy Zuber and Maria Villamil consisted of a meta-analysis of 62 studies from around the globe used to assess the effects of tillage on microbial properties, such as microbial biomass carbon and nitrogen, and enzyme activities (Zuber and Villamil, 2016). Though major results indicated a general trend that microbial biomass and all studied enzyme activities were higher under the no-till treatments, exceptions where reverse trends occurred were noted. Additional studies have also documented mixed results where lower richness in both fungi and bacteria communities above and below the seed bed were recorded in reduced tillage systems (Degrune et al., 2016, 2017), while others have reported higher microbial diversity and abundance in reduced tillage systems (Coudrain et al., 2016; Swedrzynska & Malecka-

Jankowiak, 2017). In addition to microbial properties, tillage effects on soil chemical (i.e. P, N, C, pH) and physical properties have been noted to vary from study to study (Smith et al., 2016; Moinoddini et al., 2017). Therefore, the scientific community has struggled to infer, or predict, the subsequent effects that tillage has on soil microbial communities even though the direct effects of soil pH, water content, temperature, and soil organic carbon on microbial dynamics are well known (Bell et al., 2008; Armstrong et al., 2016; Swedrzynska and Malecka-Jankowiak, 2017).

Although previous research has focused on temporal dynamics of microbial communities under different tillage regimes at yearly to decadal scales (Coudrain et al., 2016; Degrune et al., 2017; Swedrzynska and Malecka-Jankowiak, 2017), very few have studied the soil biota at weekly to seasonal scale throughout a crop's growing season (Armstrong et al., 2016). Experiments studying tillage on a yearly basis encompass more of a snapshot at course intervals of the microbial community, as compared with high-frequency, sub-weekly or sub-seasonal surveys. Aside from soil tillage, agricultural production systems can also vary depending on crop rotation and the seedbed preparation before and during the growing season. When comparing microbial communities under the same crop phase but different crop rotations, crop rotations with legume-based crops can support higher diversity microbial communities (Lupwayi et al., 1998). Additionally, agrochemical applications, including herbicides, pesticides, nematicides, and fungicides, may cause variations in microbial community composition and function within the growing season (Engelen et al., 1998). Given our general conception on how tillage and management systems influence soil properties, we presume these conditions directly and indirectly influence soil microbial communities and dynamics.

Significance

Soil microbial communities are the backbone of ecosystem functions such as nutrient cycling, decomposition, and carbon storage. Additionally, soil biota's agricultural benefits include increased nutrient uptake, natural defense against plant pathogens, and nutrient fixation (natural fertilization). The monetary benefits that microbes provide for the environment and humans are vast and difficult for society to fully appreciate. Finding ways to manage agricultural systems to balance soil health/sustainability with crop productivity is extremely important for a growing population.

Through the research of conservation tillage practices, a connection between environmental functions, soil sustainably, and production can help agricultural managers continue to strive for the most efficient cropping systems. Here we are taking a fundamental approach in describing the temporal nature of microbial communities and their activities under two tillage systems. By coupling our new knowledge of microbial temporal patterns with prevalent soil physical and chemical knowledge, a valuable step is being made towards determining the most viable tillage systems based on environmental conditions. If the dynamics behind the microbial communities can be adequately explained, future research may allow us to manipulate the microbial communities for society's agricultural and environmental needs. Additionally, gaining new knowledge of microbial dynamics can allow us to better use these organisms as indicators of soil health conditions. Where the characterization of temporal patterns can be used to assess whether these microbial communities are relatively static or dynamic within a growing season to determine if their states can be accurately characterized with current evaluation procedures (i.e. sampling frequencies).

With a general lack of knowledge elucidating seasonal microbial dynamics, the experiments below seek to describe and compare the temporal and spatial variabilities of microbial communities and their processes among our sampling zones and tillage practices, and evaluate if microbial community structures and enzyme activities are impacted over short-scale times (i.e., days to seasons) and tillage disturbance levels. In addition, they seek to characterize temporal patterns of microbial community structures and activities for cyclical states and correlations with covariate properties and states within simulations and seasonal datasets.

References

Armstrong, A., A. Valverde, J.B. Ramond, T.P. Makhalanyane, J.K. Jansson, et al. 2016. Temporal dynamics of hot desert microbial communities reveal structural and functional responses to water input. Sci. Rep. 6: 8. doi: 10.1038/srep34434.

Bell, C., N. McIntyre, S. Cox, D. Tissue, and J. Zak. 2008. Soil microbial responses to temporal variations of moisture and temperature in a Chihuahuan Desert Grassland. Microb. Ecol. 56(1): 153–167. doi: 10.1007/s00248-007-9333-z.

Bescansa, P., M.J. Imaz, I. Virto, A. Enrique, and W.B. Hoogmoed. 2006. Soil water retention as affected by tillage and residue management in semiarid Spain. Soil Tillage Res. 87(1): 19–27. doi: 10.1016/j.still.2005.02.028.

Bloemberg, G. V, and B.J.J. Lugtenberg. 2001. Molecular basis of plant growth promotion and biocontrol by rhizobacteria. Curr. Opin. Plant Biol. 4(4): 343–350. doi: 10.1016/s1369-5266(00)00183-7.

Coudrain, V., M. Hedde, M. Chauvat, P.A. Maron, E. Bourgeois, et al. 2016. Temporal differentiation of soil communities in response to arable crop management strategies. Agric. Ecosyst. Environ. 225: 12–21. doi: 10.1016/j.agee.2016.03.029.

Daigh, A., and J. DeJong-Hughes. 2017. Upper Midwest Tillage Guide-Tillage implements : Soil management and health : Agriculture : University of Minnesota Extension. Univ.

Minnesota Ext. https://www.extension.umn.edu/agriculture/soils/tillage/tillage-guide-implements/ (accessed 6 March 2018).

Degrune, F., N. Theodorakopoulos, G. Colinet, M.P. Hiel, B. Bodson, et al. 2017. Temporal dynamics of soil microbial communities below the seedbed under two contrasting tillage regimes. Front. Microbiol. 8. doi: 10.3389/fmicb.2017.01127.

Degrune, F., N. Theodorakopoulos, M. Dufrene, G. Colinet, B. Bodson, et al. 2016. No favorable effect of reduced tillage on microbial community diversity in a silty loam soil (Belgium). Agric. Ecosyst. Environ. 224: 12–21. doi: 10.1016/j.agee.2016.03.017.

Engelen, B., K. Meinken, F. von Wintzintgerode, H. Heuer, H.P. Malkomes, et al. 1998. Monitoring impact of a pesticide treatment on bacterial soil communities by metabolic and genetic fingerprinting in addition to conventional testing procedures. Appl. Environ. Microbiol. 64(8): 2814–2821.

Gosai, K., A. Arunachalam, and B.K. Dutta. 2009. Influence of conservation tillage on soil physicochemical properties in a tropical rainfed agricultural system of northeast India. Soil Tillage Res. 105(1): 63–71. doi: 10.1016/j.still.2009.05.008.

Gottshall, C.B., M. Cooper, and S.M. Emery. 2017. Activity, diversity and function of arbuscular mycorrhizae vary with changes in agricultural management intensity. Agric. Ecosyst. Environ. 241: 142–149. doi: 10.1016/j.agee.2017.03.011.

Hobbs, P.R., K. Sayre, and R. Gupta. 2008. The role of conservation agriculture in sustainable agriculture. Philos. Trans. R. Soc. B-Biological Sci. 363(1491): 543–555. doi: 10.1098/rstb.2007.2169.

Kibblewhite, M.G., K. Ritz, and M.J. Swift. 2008. Soil health in agricultural systems. Philos. Trans. R. Soc. B-Biological Sci. 363(1492): 685–701. doi: 10.1098/rstb.2007.2178.

Lupwayi, N.Z., W.A. Rice, and G.W. Clayton. 1998. Soil microbial diversity and community structure under wheat as influenced by tillage and crop rotation. Soil Biol. Biochem. 30(13): 1733–1741. doi: 10.1016/S0038-0717(98)00025-X.

Moinoddini, S.S., A. Koocheki, M.N. Mahalati, and A. Borzooei. 2017. Tillage and N application effects on crop yield, N uptake and soil properties in a corn-based rotation. Arch. Agron. Soil Sci. 63(8): 1150–1162. doi: 10.1080/03650340.2016.1266076.

O'Rourke, M.E., and J. Petersen. 2016. reduced tillage impacts on pumpkin yield, weed pressure, soil moisture, and soil erosion. Hortscience 51(12): 1524–1528. doi: 10.21273/hortsci11226-16.

Rillig, M.C. 2004. Arbuscular mycorrhizae, glomalin, and soil aggregation. Can. J. Soil Sci. 84(4): 355–363.

Smith, C.R., P.L. Blair, C. Boyd, B. Cody, A. Hazel, et al. 2016. Microbial community responses to soil tillage and crop rotation in a corn/soybean agroecosystem. Ecol. Evol. 6(22): 8075–8084. doi: 10.1002/ece3.2553.

Swedrzynska, D., and I. Malecka-Jankowiak. 2017. The impact of tillaging spring barley on selected chemical, microbiological, and enzymatic soil properties. Polish J. Environ. Stud. 26(1): 303–313. doi: 10.15244/pjoes/64911.

Zuber, S.M., and M.B. Villamil. 2016. Meta-analysis approach to assess effect of tillage on microbial biomass and enzyme activities. Soil Biol. Biochem. 97: 176–187. doi: 10.1016/j.soilbio.2016.03.011.

CHAPTER 1. EFFECTS OF SMALL-SCALE TIME AND DISTURBANCES ON SOIL MICROBIAL COMMUNITY TEMPORAL CHARACTERISTICS

Abstract

Soil microorganisms, including bacteria, fungi, and other groups maintain many ecosystem functions including decomposition and symbiotic nutrient uptake. Prior to recent studies, small scale microbial dynamics in agricultural systems have been overlooked, leading to little understanding of sub-seasonal management impacts. Therefore, our objectives were to determine the effects and characteristics of time and soil disturbance level on six phospholipid fatty acid (PLFA) microbial groups including total microbial abundance (TMA), fungal to bacterial ratio (F:B), arbuscular mycorrhizal fungi (AMF), total fungi, actinomycetes, and total bacteria. To do so, weekly samples were acquired from planting to harvest and analyzed for soil microbial, chemical, and physical properties. A mixed linear model was used to test for time and disturbance level effects on the six PLFA microbial groups. Additionally, a Fourier analysis was used to characterize these PLFA microbial group's cyclical patterns based on their spectral densities and their cross spectral densities and phase lags with the suite of soil chemical, soil physical, and weather states. The study was conducted during two growing seasons in a corn [*Zea mays*] - soybean [*Glycine max*] - wheat [*Triticum aestivum*] rotation with two soil disturbance levels, a high disturbance (chisel plow) and low disturbance (shallow vertical till), using a randomized complete block design. The site is on a silty-clay vertisol near Mooreton, ND. The data indicated significant time and disturbance level effects and strong cyclical patterns of the PLFA microbial groups during the growing season. Cross spectral densities indicated multiple frequencies when PLFA microbial groups and soil chemical, soil physical, and/or weather states had corresponding cyclical structures. Therefore, soil microbial communities

undergo cyclical patterns over small-scale times in soil with various disturbance levels. Further temporal analyses and characterization of these microbial processess and their covariate sensitivity of lands with soil disturbance is warranted to better understand the implications of these small-scale patterns on agricultural systems and ecosystem services.

Introduction

Microbes play a multifaceted role in soils, ranging from nutrient cycling, aiding in soil structure development, to pest control (Rillig, 2004; Smith et al., 2016). Of these, microbes mediate a substantial portion of nutrient cycling in terrestrial systems via mineralization of organically bound nutrients which are made available for plants to take up and sustain plant growth and cellular function (Jacoby et al., 2017). Additionally, soil microbes are sensitive to their direct environment and have been proposed as early indicators of changes in soil quality (Zelles, 1999). However, microbial communities and their activities are expected to vary in space and time. Numerous studies on the spatial variability of soil microbes are reported in the literature (Ettema and Wardle, 2002). However, temporal variability and patterns are lacking. In past research, fluctuations in microbial community structure and functions have been recorded at relatively large time scales, such as years (Aon and Colaneri, 2001; Swedrzynska and Malecka-Jankowiak, 2017). These time scales capture a coarse snapshot of microbial states and do not provide information on sub-seasonal microbial dynamics. The characterization of sub-seasonal microbial dynamics could provide useful information for optimizing agricultural management practices, such as fertilizer timings or rates, and confirming if sampling protocols at course time intervals provide representative and reliable information for evaluating soil health. In 2016, Armstrong et al. (2016) reported that microbial community composition shifted after a large rain event, justifying small-scale temporal monitoring of microbial dynamics under natural wetting and drying cycles in agricultural systems.

Having a precise method to measure microbial community structure and size is pivotal to understanding cycling rates and covariate correlation. In the past, community level physiological profiling and quantitative polymerase chain reaction based molecular methods have been used to for evaluating soil microbial communities. These methods are used to characterize microbial population level changes in soil. In contrast, soil microbial community structure changes can be characterized by PLFA (Ramsey et al., 2006). Phospholipid fatty acids are a component of cellular membranes from both the Bacteria and Eukarya domains. Within different broad taxonomic microorganism groups, PLFA chain lengths differ ranging between 14 to 20 carbons for bacterial and fungal groups. Although, PLFA analysis cannot identify microbes to the species level, it provides an estimate of the broad taxonomic structure of the communities present (Zelles, 1999; Quideau et al., 2016). In addition, phospholipids rapidly degrade in soil, which allows us to track changes relatively soon after land management changes (Zelles, 1997).

One of the most common land management practices in agricultural cropping systems is soil tillage. Soil structure, porosity, thermal and hydrologic properties, and soil-to-residue contact ratios are directly affected by tillage (Al-Kaisi and Yin, 2005). However, new practices that reduce soil disturbance are well known to regain higher water retention capacities, higher organic matter levels, reduce erosion, and maintain heterogeneous soil properties that promote biological biomass, diversity, and function (Bescansa et al., 2006; O’Rourke and Petersen, 2016). These effects on microbial communities has been documented in multiple studies (Wang et al., 2012; Miura et al., 2016), including studies where reduced tillage practices (ridge-till/strip-till) caused equal or higher microbial biomass levels (Vargas Gil et al., 2011; Jia et al., 2016) as compared with no-till systems. Though tillage effects on microbial communities are evident, soil profile structures may reflect past management, such as moldboard plow, longer than previously thought (Frey et al., 1999).

Through the research of conservation tillage practices, a connection between environmental functions, soil sustainably, and production can help agricultural managers continue to strive for the most efficient cropping systems. In this study, we take a fundamental approach in describing the temporal dynamics of microbial communities and their activities under two tillage systems (i.e., high and low disturbance) in an agricultural field with a history of high disturbance tillage. We also aim to provide empirical evidence of these dynamics at the sub-seasonal scale and provide evidence of their temporal fluctuations with various soil physical and chemical states. By doing so, this work provides a valuable step towards enhancing our ability to evaluate and optimize agricultural cropping systems based on the soil environmental conditions. If the dynamics behind the microbial communities can be adequately explained, future research may allow us to manipulate the microbial communities for society's agricultural and environmental needs. Additionally, gaining new knowledge of microbial dynamics can allow us to better use these organisms as indicators of soil conditions, and assess whether these microbial communities are relatively static or dynamic within a growing season to determine if their states can be accurately represented with few sampling events within a year.

The objectives of this study were to 1) describe and compare the temporal and spatial variabilities of microbial communities among tillage practices, 2) evaluate if microbial community structures are impacted over short-scale times (i.e., days to seasons) and tillage disturbance level, and 3) characterize temporal patterns of microbial community structures and evaluate them for cyclical cross correlations and lag phases with physiochemical properties and states.

Materials and Methods

Brief Methods Overview

In this study, high frequency soil sampling (approximately every 3.5 days) of soil physicochemical properties and soil biota was conducted to assess the temporal dynamics of two levels of soil disturbance systems [i.e., high (HD) and low (LD) disturbance] which differ in the depth and aggressiveness of mechanical soil disturbance. The research was conducted at the Soil Health and Agricultural Research Extension (SHARE) farm located in Mooreton, ND. The SHARE farm consists of a corn-soybean-wheat rotation. This study obtained soil samples and collected data during 2017 and 2018 while soybean and wheat, respectively, were grown. An array of microbial, physical, and chemical analyses were completed on the high frequency samplings to elucidate temporal patterns and potential driving forces of the microbial community and ecosystem functions under different soil management systems. Microbial communities were assessed using PLFA. Soil chemical properties included total nitrogen (TN), nitrate – nitrogen (NO_3^--N), ammonium – nitrogen (NH_4^+-N), total organic carbon (TOC), phosphorus (P), sulfur (S), manganese (Mn), and 1:1 suspensions of pH and electrical conductivity (EC). Soil physical properties included particle size distribution, particle density, water retention curves, and thermal properties (i.e., thermal conductivity and diffusivity) whereas soil physical conditions (i.e., states) included measured *in-situ* soil moisture and temperature. Atmospheric conditions were additionally quantified (i.e., air temperature, precipitation, relatively humidity, etc.). Hydrologic modeling was used via Hydrus-1D for soil water fluxes and states to help assess if the soil microbial community temporal dynamics reflects the surrounding physical temporal dynamics of the soil environment.

Site Description

The SHARE farm is located in Richland County (46.2686° N, 96.8762° W), and is a privately owned section that has been under continuous crop production for the past century. The site is located in the 4a plant hardiness zone indicating an average annual minimum temperature of -1.7 to - 34.4 ^{o}C (PRISM Climate Group - Oregon State University, 2018). From 2015 - 2018, the mean annual precipitation was 40.8 cm (range of 35.4 to 46.5 cm) and the mean annual temperature was 6.75 ^{o}C (range of 0.5 to 13 ^{o}C) (NDAWN, 2019).

Geologically, the SHARE farm is located inside of the Red River Valley, which has an area extent of ~41,439 km^2. The Red River Valley was formed by the ancient glacial Lake Agassiz, and is now widely used for agricultural crop production due to its fertile soils (Hoffman, 1979). The dominant soil series is a Fargo silty clay (fine, smectitic, frigid Typic Epiaquert). A representative Fargo soil series' horizonation sequence is Ap-A-Bss-Bkg-Cg, with silty clay as the dominant soil texture (Soil Survey, 2017). These soils are poorly drained, and can endure overland flooding after snowmelt and high precipitation events.

Surface drainage ditches have historically been used at this site to aid in the removal of flood waters. However, subsurface drainage was also installed in 2013 on the northern half of the SHARE farm. Drains were deployed at a depth of 1.1 m with a spacing of 12.1 m between lateral lines to alleviate excessive soil water. The SHARE farm has a saline seep at the western edge. The present study was carried out in the NE portion of the farm where subsurface drain is installed and the soil is non-saline to avoid confounding effects to plant production and microbial composition.

Experimental Design and Site Management

The site has historically been chisel plowed and field cultivated with a soybean-wheat rotation, while corn has been included in the rotation in recent years. Prior to chisel plowing, the field was prairie and was most likely moldboard plowed annually after it was put into agricultural crop production. The region has been in agricultural production for the past one to two centuries, and this is assumed to be similar for the SHARE farm.

In the fall of 2015, reduced tillage plots [i.e., chisel plow, vertical till, and strip till (note: strip till plots were not used in this present study)] were initiated in production-scale replicated strips along the whole field. Tillage treatments were implemented using full-sized equipment (12.2 m wide), arranged in a randomized complete block design with three replicates (Figure 1). Vertical tillage was performed to a depth of 2-8 cm while the chisel plowing was performed to a depth of 18-20 cm. Vertical till plots receive a tillage pass in both the fall and spring before planting. The vertical tillage equipment had front and rear gangs of fluted coulters spaced 15 cm apart, pitched at a 3-4^{o}, and with a rear rolling basket. Chisel plow plots received one pass in the fall followed by field cultivation in spring before planting. Due to tillage implement availability, the vertical till plots did not receive a tillage pass during the spring of 2018. When referring to these tillage plots, they will be referred to as the high disturbance (HD – chisel plow) and low disturbance (LD – vertical till) treatments. Soybeans (Alligent 08L82 08 maturity) were planted at 76 cm row spacing on 16 May 2017, and wheat at 19 cm row spacing on 6 May 2018. Wheat received broadcasted synthetic fertilizers (140-40-10; N-P-K) prior to planting that was incorporated via field cultivation and drill sowing for the HD and LD plots, respectively. Herbicide and pesticide applications were performed by the farmer, as needed, and based on regional guidelines. Applications were made perpendicular to plant rows; therefore, all treatments receive similar wheel traffic patterns. A linear transect for soil sampling was established across the treatments and parallel with the subsurface drainage laterals. Soil sensors were deployed between the 6th and 7th soybean rows of each plot.

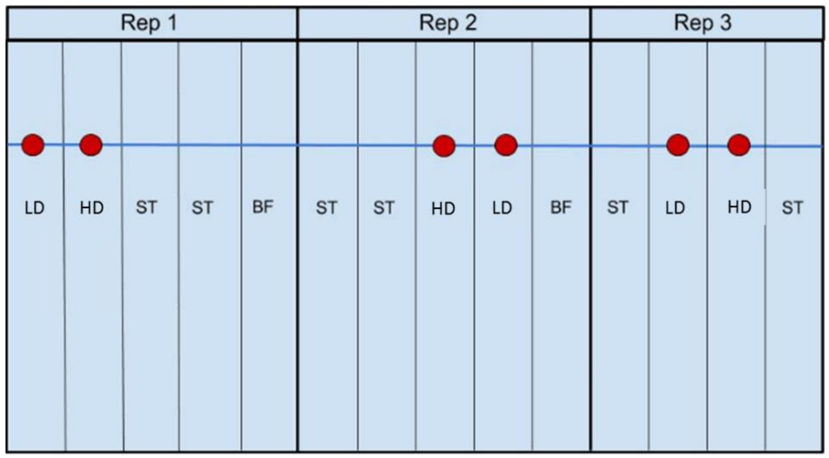

Figure 1: Representation of field scale treatment (12.2 m x 500 m) set up. Treatments systems being studied include high disturbance (HD) and low disturbance (LD) plots; Strip till (ST) treatments and buffer (BF) zones are not included in the present study. Blue line indicates placement of transect across treatments and replications, with red circles indicating sensor placement and soil sampling locations.

Soil Sampling Procedure

During the 2017 and 2018 growing seasons, soil samples were collected every Monday and Friday (approximately every 3.5 days). Soil samples were taken from the quarter row position between plants to a depth of 15 cm using a bucket auger. Two auger samples were taken immediately next to each other in each plot and composited for laboratory analysis. Soil samples were then split up into two subsamples for storage and analyses: 1) fresh, field moist soil sample placed in a -15 ^{o}C freezer for up to three weeks before being shipped to Microbial ID Laboratories, where samples were freeze dried for PLFA analysis, and 2) air-dried, ground, and sieved for physical and chemical analyses. In addition to the high frequency sampling, stratified bulk density and composite samples of 0-5, 5-10, and 10-15 cm where taken periodically for more intensive profile description and data collection.

Crop parameters and *in situ* field conditions were monitored throughout the growing season. From vegetative emergence, soybean and spring wheat growth stage and height were collected approximately every 3.5 days until harvest. Ten observations for plant height and stage were taken in each plot and averaged. Em50 and Em60 data loggers with 5TM soil moisture and temperature sensors (METER, Inc., Pullman, WA) at depths of 5, 10, 15, and 20 cm were deployed in each plot to record soil conditions at 30 minute intervals throughout the year. In 2018, Em60 data loggers were additionally used so that MPS-6 soil matric potential sensors could be deployed at the 5 and 20 cm depths along with the 5TM sensors. A North Dakota Agricultural Weather Network (NDAWN) weather station was located approximately 200 m away from sampling locations.

PLFA Analysis

Due to their short degradation period after the death of the organism (King et al., 1977; Zelles, 1997), phospholipids can be used as reliable biomarkers for microbial community shifts. Phospholipid fatty acid analysis is completed through a series of extractions, separations, transesterification, and gas chromatography described by Buyer and Sasser (2012). The standard methods now include a four-step process for the quantification of microbial community structure: 1) a single phase chloroform mixture is used to extract lipids from soil samples, 2) fractionation to isolate phospholipids from other lipids using solid phase extraction columns, 3) production of fatty acid methyl esters through methanolysis, and 4) fatty acid methyl ester analysis by gas chromatography with flame ionization detector. By using a high PLFA extraction method coupled with MIDI Inc.'s Sherlock PLFA Analysis Software, Microbial ID was able to create a highly sensitive, automated process that creates easy to use data with reduced error from human performance. The Sherlock system uses a peak naming table to identify peaks into microbial groups, and the total abundance was calculated as the sum of all biomarkers identified within a sample. For fungal to bacterial concentrations and ratios, summed biomarkers listed in Figure A1 will be used for both fungi and bacteria. All high-frequency soil samples were sent to Microbial ID, Inc. in Delaware, USA for PLFA analysis.

Soil Chemical Analysis

For each soil sample collected, an array of chemical properties were measured. Measurements on pH (1:1 suspension), EC (1:1 suspension), and TOC were completed in lab with a HACH sens-ion378 EC electrode, an Accumet Basic pH electrode, and a Primacs^{SLC} TOC analyzer. Air-dried soil samples were sent to the NDSU Soil Testing lab for the following analyses as described in Grafton (2012). These analyses included NO_3^--N (trans-nitration of salicylic acid method), NH_4^+-N (Berthelot Reaction/ Indophenol Reaction), TN (Vario Macro Cube CHNOS analyzer), extractable Mn (DPTA .033 M H3PO4 extraction), extractable S (monocalcium phosphate extraction), and available P (Olsen Method).

Soil Physical Analysis and Water Flux Simulations

Soil bulk densities were determined at two depths periodically within both growing season using Uhland core samples (7.6 by 7.6 cm dimensions). Static soil physical properties (i.e., particle density and size distribution) were performed on soil samples during 2017 and 2018, and used to detrend the PLFA data for innate spatial variations within the plot sampling areas and as initial parameters during physical state modeling (see section below). Soil particle size distribution were completed using the pipette method with a heated 30% hydrogen peroxide pretreatment (Gee et al., 1986). While particle density was assessed using the water pycnometer method (Blake et al., 1986). In addition to spatial variability, additional measures were taken to correct for site specific condition before physical state modeling.

A soil specific calibration was performed for the 5TM soil moisture sensors due to high smectite content (i.e., high surface area and quantity of electrically charged sites that can cause electrical dispersion) of the field's soil. To remove the factory calibration the raw data is converted back into the dielectric permittivity (*DP*) values using:

$$DP = 105.25x^3 - 14.53x^2 + 34.256x + 1.9761 \qquad \text{(Eq. 1)}$$

where *x* is the sensor's raw factory soil water content output. The soil specific calibration equation was then applied to the *DP* values using:

$$\theta = 0.0002DP^2 + 0.0229DP - 0.0502 \qquad \text{(Eq. 2)}$$

Where θ is the calibrated volumetric water content used for further analysis and modeling. Water retention was determined for all 2017 and 2018 soil samples using the pressure plate method at seven matric potentials (10, 33, 100, 300, 500, 800, and 1,500 kPa) and converted to volumetric water content using the soil bulk density. However, the smectitic soil also has a high shrink swell capability. Bulk density samples are always obtained when soils are relatively dry (i.e., somewhat shrunken compared with saturated conditions) and therefore their measured, unsaturated bulk densities will always underestimate the soil's total porosity (i.e., equal to the soil's saturated water content) when saturated. Therefore, the saturated bulk densities [$\rho_b(\theta_{sat})$] were calculated by inverting the product of the measured bulk density at field moist conditions [$\rho_b(\theta)$] and the Groenevelt and Grant (2001) soil shrinkage characteristic model using model parameters obtained by Klopp et al. (2018) for the Fargo soil series:

$$\rho_b(\theta_{sat}) = \rho_b(\theta)\frac{1}{0.9676+(0.395-0.265598)e\hat{}(-\frac{0.55}{\theta})} \qquad \text{(Eq. 3)}$$

where θ is the volumetric water content at the time of soil sampling.

For simulating water fluxes from the soil profile, particle densities obtained during 2017 and 2018 were averaged at the plot scale before use. Additionally, measured water retention obtained during 2017 and 2018, along with saturation-corrected total porosity, were used with the RETC software program (citation or source) to obtain parameters of the Mualem (1976) and van Genuchten (1980) models as the initial starting points for the Hydrus-1D iterative inverse modeling using the in-field soil moisture sensors and weather station data.

$$\theta(\varphi_m) = \theta_r + (\theta_{sat} - \theta_r)\frac{1}{\left[1+\left(\frac{1}{AEP}|\varphi_m|\right)^n\right]^{1-1/n}} \quad \text{(Eq. 4)}$$

Where φ_m is the matric potential energy, θ_r is the residual water content, AEP is the air entry matric potential, and n is the slope factor based on the pore size distribution (van Genuchten, 1980).

$$K(\theta) = K_{sat}\sqrt{S_e}\left[1-\left(1-S_e^{\ 1/m}\right)^m\right]^2 \quad \text{(Eq. 5)}$$

where $K(\theta)$ is the hydraulic conductivity as a function of water content, K_{sat} is the saturated hydraulic conductivity, S_e is the relative water content between 0 and 1, and m = 1-1/n. The RETC program and Hydrus-1D uses weighted least-squares to minimize the objective function via the Marquardt's maximum likelihood method (Marquardt, 1963).

Once soil hydraulic parameters were inversely fitted in Hydrus-1D using in-situ soil moisture data, additional weather and soil data were used to simulate surface water fluxes and deep percolation fluxes over time. Hydrus-1D numerically solves Richard's equations for one dimensional problems:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}\left[K(\varphi)\frac{\partial\varphi}{\partial x} + 1\right] \quad \text{(Eq. 6)}$$

Statistical Analysis

As a preliminary assessment of the microbial community structure to indicate if data variations tended to be more strongly associated with spatial or temporal processes, we graphed the spatial (i.e., across replicates for each sample date) and temporal (i.e., across time within a plot) coefficient of variations (sd/mean) for each PLFA biomarker category. These six PLFA biomarker categories included total microbial abundance (TMA), arbuscular mycorrhizal fungi (AMF), bacteria, fungi, fungal to bacterial ratio (F:B), and actinomycetes.

Then, to evaluate if there is evidence that PLFA biomarker categories are affected by time within the season-long sampling period, we performed a repeated measures mixed linear model for effects of time, tillage disturbance levels, and their interaction for each year separately. Time and tillage disturbance levels were set as fixed effects with block as random. The covariate structure of the repeated factor was determined as a heterogeneous first-order auto regressive function based on smallest Akaike information criterion value. Mean separations were performed using Tukey's Honest Significant Differences (THSD) tests at an alpha level of 0.05. These analyses were performed in SAS version 9.4.

Graphs of the repeated measures linear mixed model showed what appears to be cyclical structure across time. Therefore, we then performed a spectral analysis using PROC Spectra in SAS on the PLFA biomarker categories to test if temporal variations contained cyclical structures at distinct frequencies or were white noise using Bartlett's Kolmogorov-Smirnov statistic (Bartlett, 1966). The spectrum is calculated using a finite Fourier transform and then smoothed by a moving average to estimate the spectral densities. The input data for the spectral analysis was first spatially detrended and made stationary using static variables (i.e. total carbon or particle density). This was done by calculating the population mean of the raw data and then subtracting by the error of a fitted linear regression for the PLFA data and the static variable. Then near continuous simulations of biological (as well as the chemical and physical where needed) states, across the season-long sampling period, were splined to daily intervals. The spectral analysis involves decomposing the data into the sums of sine and cosine waves of differing amplitudes and wavelengths by:

$$A_t = \frac{\alpha_0}{2} + \sum_{k=1}^{m-1} f_k(\alpha_k \cos \omega_k t + \ b_k \sin \omega_k t) \qquad \text{(Eq. 7)}$$

where A_t is the equally spaced soil state of interest, and t is the point in time of A, α_0 is $2\bar{u}$, $\bar{u}$ is the mean, m is the number of frequencies [$m = (n+2)/2$ if n is even, $m = (n-2)/2$ if n is odd), n is the number of sample points, k is the frequency 0, 1, 2, …, m-1, α_k are cosine coefficients, b_k are sine coefficients, and ωk are Fourier frequencies = $(2\pi k)/n$. This reduces into:

$$r(h) = \frac{cov[A_i(t), A_i(t+h)]}{\sqrt{var[A_i(t)]}\sqrt{var[A_i(t+h)]}} \qquad \text{(Eq. 8)}$$

$$r_c(h) = \frac{cov[A_i(t), B_i(t+h)]}{\sqrt{var[A_i(t)]}\sqrt{var[B_i(t+h)]}} \qquad \text{(Eq. 9)}$$

$$S(f) = 2\int_0^{\infty} r(h)\cos(2\pi f h)\,\partial h \qquad \text{(Eq. 10)}$$

$$Co(f) = 2\int_0^{\infty} r_c(h)\cos(2\pi f h)\partial h \qquad \text{(Eq. 11)}$$

$$Q(f) = 2\int_0^{\infty} r_c'(h)\sin(2\pi f h)\,\partial h \qquad \text{(Eq. 12)}$$

$$h_{\emptyset}(f) = \frac{1}{2\pi f} tan^{-1}[\frac{Q(f)}{Co(f)}] \qquad \text{(Eq. 13)}$$

where $r(h)$ and $r_c(h)$ are the temporal autocorrelation and cross-correlation functions, respectively, cov and var are the covariance and variance, respectively, A_i and B_i are the soil properties or states of interest, h is the time lag, $S(f)$ and $Co(f)$ are the spectrum and cross spectrums of the auto- or cross-correlations, respectively, f is the frequency, $Q(f)$ is the quadrature spectrum for the lag between sets that are correlated at the same f, and $h_{\emptyset}(f)$ is the phase lag between oscillations as a function of f.

When the spectral analysis passed the white noise test (i.e., reject the null hypothesis that the time series is noise), then 95% confidence intervals (CI) were determined to indicate the frequencies with the strongest spectral densities that differ from white noise. Then, a cross spectral analysis was performed on the PLFA data with each chemical and physical properties and states listed in the previous sections. This evaluates if strong cyclical patterns among the PLFA and chemical/physical properties and states occur at the same frequencies when densities also occur beyond a 95% CI. The cross spectral densities above 95% CI were considered as only meaningful for frequencies where the PLFA spectral densities also indicated strong signals that differed from white noise. When such cross spectral densities were detected, we then extracted the phase lag between oscillations for those frequencies. For ease of visualization, all spectral densities are presented using the period and frequency for ease of interpretation.

We observed considerably more time series, than originally expected, that passed the white noise test and frequencies with spectral densities which indicated cyclical patterns. This is the reason we decided to focus our discussion on the frequencies with the strongest signals. To do so, we choose spectral densities above a 95% CI as a convenient (but arbitrary) way of isolating such frequencies. We further isolated the frequencies by focusing on those with spectral densities >95% CI which were observed at all moments in spaces (i.e., reps). These conditions for isolating a subset of the strongest signals likely ignores some important information about temporary processes occurring in the soil. However, this also allows us to focus on the most dominate temporal structures that appear to be generalized with space.

Results and Discussion

Spatial and Temporal Coefficient of Variations

In general, most spatial CV's (i.e., calculated across replicates for each sample date) tended to be similar or below the temporal CV's (i.e., calculated across sample dates for each replicate) (Figure 2, Figure A2 & A3). For example, the ranges of temporal CV's for each plot as seen in the 2017 TMA are higher than a majority of the spatial CV's (Figure 2). This may indicate that TMA has a greater temporal variation than spatial variation within the dataset at these scales. Similarly, this same trend can be observed in components of the microbial community structure, as seen in 2017 AMF (Figure 2). However, some components of the microbial community structure indicated varying degrees of variability across temporal sampling events. From the 2017 analysis, five out of the six CV graphs (TMA, bacteria, fungi, F:B, and actinomycetes) suggests a greater microbial temporal variation over the course of the season compared to its spatial counterpart. Additionally, in 2017 AMF in the HD plots tended to show higher temporal variability as compared to the LD plots; although, this trend was not as clearly observed in the other PLFA biomarkers graphs. In 2018, four out of the six CV graphs (TMA, bacteria, F:B, and actinomycetes) indicated a somewhat higher temporal variability over spatial (Figure A2 & A3). Similar to 2017, AMF CV's (as well as fungi) suggested that spatial vs temporal variability may vary between HD and LD. Overall, these results suggest that many microbial community structure components may vary more through time, rather than across small spatial scales, with few apparent influences from soil disturbance levels.

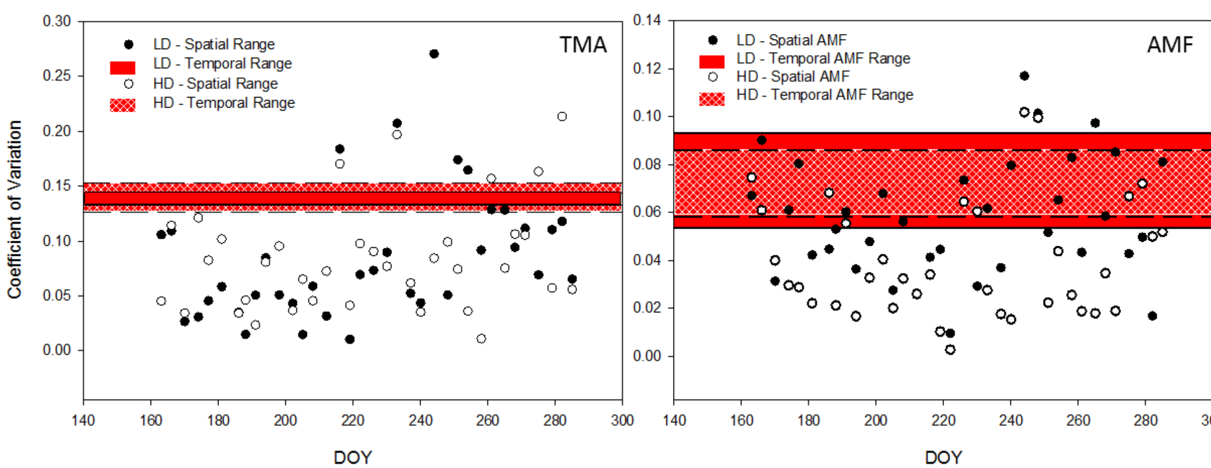

Figure 2: 2017 Total Microbial Abundance (TMA), left, and Arbuscular Mycorrhizal Fungi (AMF), (right), coefficient of variation diagrams. Individual dots represent spatial variability for individual dates and treatments [High Disturbance (HD), and Low Disturbance (LD)], while horizontal bars represent temporal treatment variability ranges.

Repeated Measures Analysis

The preliminary data assessment above provides some evidence that temporal processes may vary substantially at small time scales. That assessment thus justifies to proceed to an *F*-test to evaluate potential effects of time, tillage disturbance level, and their interactions on the soil microbial groups. In 2017, both TMA and AMF had significant differences by date (Table 1). These data and the date effects are shown in Figure A4 where they can be seen with physical conditions (i.e. precipitation and soil temperature) and plant growth stages. A significant tillage disturbance level effect was detected for both fungi and F:B. Total fungi means were 2.73 and 2.10% of total abundance and F:B means were 0.08 and 0.07 in the high and low disturbance levels, respectively, where means were calculated across all dates sampled. No interactions between date and tillage disturbance levels were detected for any biomarkers in 2017 (Table 1).

Table 1: 2017 p-values for six PLFA biomarkers across date, tillage, and date by tillage interaction effects.

Effect	TMA†	AMF	Fungi	Bacteria	F:B	Actinomycetes
Date	**0.001****	**0.001****	0.243	0.254	0.113	0.080
Tillage	0.648	0.732	**0.002****	0.566	**0.004****	0.529
Date*Tillage	0.289	0.072	0.649	0.967	0.632	0.716

*Significant at $P < 0.05$
**Significant at $P < 0.01$
***Significant at $P < 0.001$
† TMA: total microbial abundance, AMF: arbuscular mycorrhizal fungi, Fungi: total fungi, Bacteria: total bacteria, F:B: fungal to bacterial ratio, Actinomycetes: total actinomycetes.

In 2018, TMA and bacteria were significantly different through time (Table 2). These data and the date effects are shown in Figure A5 where they can be seen with physical conditions (i.e. precipitation and soil temperature) and plant growth stages. No tillage disturbance level effects or interactions between date and tillage disturbance levels were detected for all biomarkers in 2018 (Table 2).

Table 2: 2018 p-values for six PLFA biomarkers across date, tillage, and date by tillage interaction effects.

Effect	TMA†	AMF	Fungi	Bacteria	F:B	Actinomycetes
Date	**0.0001*** **	0.064	0.563	**0.022***	0.503	0.250
Tillage	0.061	0.630	0.540	0.078	0.650	0.086
Date*Tillage	0.170	0.872	0.316	0.962	0.294	0.175

*Significant at $P < 0.05$
**Significant at $P < 0.01$
***Significant at $P < 0.001$
† TMA: total microbial abundance, AMF: arbuscular mycorrhizal fungi, Fungi: total fungi, Bacteria: total bacteria, F:B: fungal to bacterial ratio, Actinomycetes: total actinomycetes.

Compared to the scientific literature, our results demonstrating microbial response to tillage effects were inconsistent with the general literature conclusion that reduced tillage systems will lead to increased microbial community abundance and structure (Wang et al., 2012; Mathew et al., 2012). Our results indicated a minimal disturbance effect across both years, where the only significant difference occurred under the total fungi and F:B PLFA categories. When this distinction occurred, the high disturbance treatment produced higher fungal concentrations than the low disturbance treatment. Under the fungal categories, this is not an uncommon phenomena (Shi et al., 2013; Sun et al., 2016), and can possibly be a reflection of long versus short term study durations. Though tillage treatments can strongly influence soil microorganisms, differences between experiments, including study duration, as mentioned above (Frey et al., 1999), and initial soil organic carbon and matter concentrations (Bergstrom et al., 1998) can lead to discrepancies between final study conclusions. Ultimately leaving us with little information on why differences were or were not noticed between tillage systems. Comparatively, the temporal results consistently indicated that soil microbial community structures can significantly change in time within an season-long cropping season, agreeing with some of the few sub-seasonal studies in the literature (Armstrong et al., 2016; Sun et al., 2016). Our results specifically provide some of the first results explicitly identifying small scale shifts (i.e. days and weeks) of temporal processes observed within the field. With this information, we can begin to infer on using PLFA as a way to characterize sub-seasonal microbial dynamics for soil quality indicators and confirming sampling protocols for representative and reliable information for evaluating soil health. Additionally, with continued research, this information could lead to the optimization of agricultural management practices, such as fertilizer timings and rates, for increased efficiency and sustainable farming practices.

PLFA Spectral Analysis

Since the previous analyses indicate that the microbial community structures do change within the time scales of this study, the spectral analysis elucidates if these community shifts have a cyclical structure that repeats at one or more frequencies. From the frequency analysis, inferences on sampling frequencies for soil health evaluation may be concluded. The cross spectral densities and phase lags help identify potential contributing or correlated chemical and physical properties or states that also have temporal structure at those same frequencies, where we can begin to infer on what may be driving or influencing microbial properties. By doing so, these analyses should support why small time scale shifts in the microbial groups are occurring. The frequencies with spectral densities above the 95% CI (i.e. not white noise) for 2017 and 2018 are shown in figures 3 & 4 as heat maps. If a frequency had a spectral density above the 95% CI, the individual block is filled with color. Note that frequencies/periods, where all three replications had spectral densities above the 95% CI, are outlined in thick boxes to indicate consistency among replicates in a tillage disturbance level treatment. Restricting major comparison to boxed frequencies allowed us to generalize this information across space more efficiently in years where an extensive number of strong spectral density signals occurred.

In 2017, spectral densities revealed common trends across both PLFA biomarkers and tillage disturbance levels (Figure 3). Within the 12 to 15 day periods, HD had consistent temporal cycles for TMA, F:B, and fungi; while, LD only had similar temporal cycles for AMF. Additionally, at the 26 day period, the LD had temporal cycles the same four biomarkers (TMA, F:B, AMF, and Fungi); while, HD only had similar temporal cycles for fungi. This possibly indicates a tillage disturbance level influence on cyclical states of fungal dynamics since these four PLFA biomarkers include a fungal growth form. On the other hand, actinomycetes and bacteria had similar cycles during 17 to 21 and 35 to 51 days, indicating a less pronounced effect of tillage disturbance level influence on bacterial groups. Periods at or longer than 53 days show consistent larger scale cycles for all PLFA categories.

In 2018, the occurrence of cyclical patterns across PLFA categories and tillage disturbance levels were much fewer than those observed in 2017. Within the fungal categories, AMF showed consistent cycles between periods of 12 and 28 days; while, both F:B and fungi did not show any consistent evidence of cycles at periods of 85 and up (Figure 4). Though fewer consistent cycles occurred in the fungal categories, actinomycetes and bacteria still had some similar cycles as the fungal categories in 2017 in regards to LD producing consistent cycles at longer periods, while HD produced faster cycles in 12 to 14 day range.

Similar to the repeated measures *F*-test, the spectral analysis provided the first evidence in the scientific literature that these temporal dynamics are occurring in cycles at distinct and consistent frequencies. Temporally, low disturbance systems may produce cycles at longer periods due to their resilience to rapid changes in environmental conditions (i.e. thermal and hydraulic conditions) as compared with higher disturbance systems. From this, we can begin to infer that sampling for soil health assessments may require variable sampling dates dependent on disturbance levels and PLFA groups being studied.

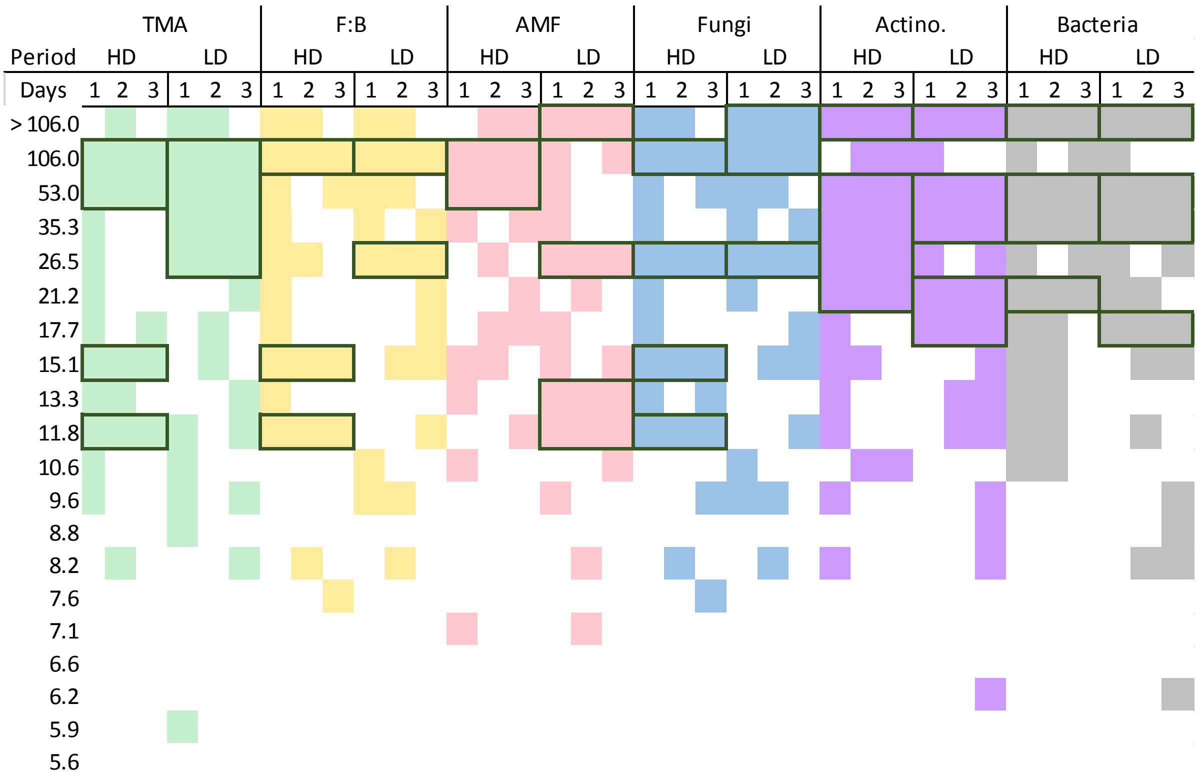

Figure 3: Heat map analysis of 2017 PLFA group spectral densities. Total Microbial Abundance (TMA), Fungal to Bacterial Ratio (F:B), Arbuscular Mycorrhizal Fungi (AMF), Actinomycetes (Actino.), High Disturbance (HD), Low Disturbance (LD). Colored boxes indicate frequencies above the 95% CI, and boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

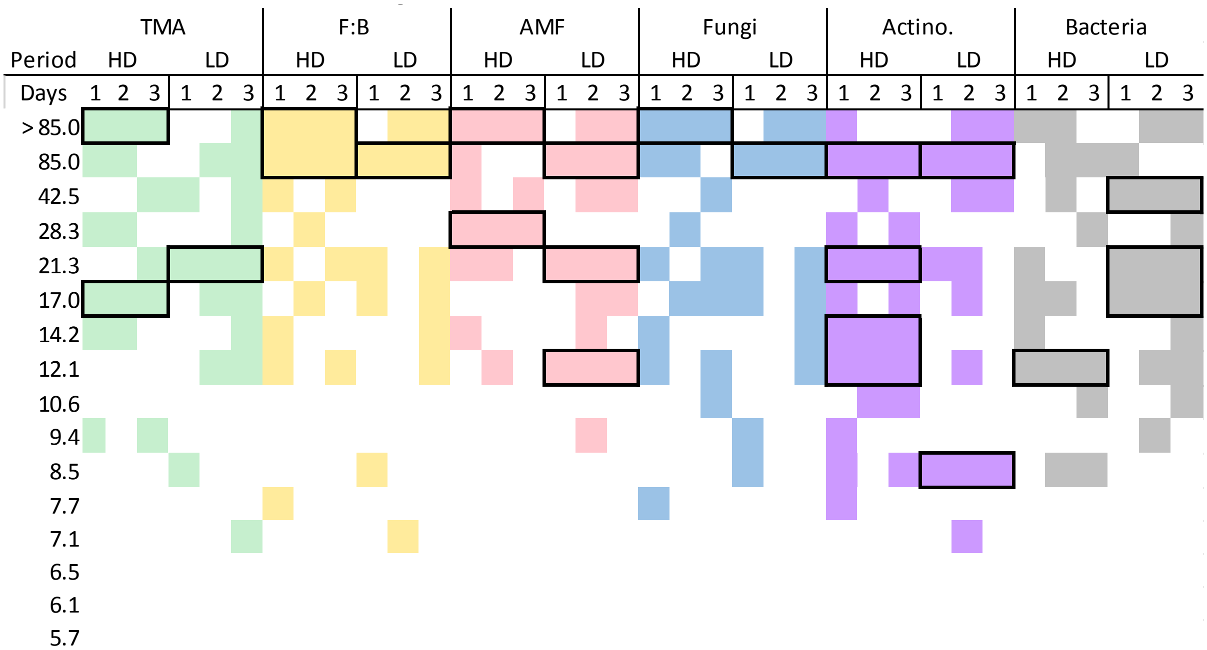

Figure 4: Heat map analysis of 2018 PLFA biomarker spectral densities. Total Microbial Abundance (TMA), Fungal to Bacterial Ratio (F:B), Arbuscular Mycorrhizal Fungi (AMF), Actinomycetes (Actino.), High Disturbance (HD), Low Disturbance (LD).Colored boxes indicate frequencies above the 95% CI, and boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

PLFA Cross Spectral Analysis

With distinct and consistent spectral density frequencies indicating cyclical patterns within the PLFA structures over time, cross spectral analysis aimed to identify potential contributing or correlated chemical and physical properties or states that also have temporal structure at those same frequencies. Similar to the spectral density analysis above, cross spectral analysis revealed considerably more frequencies above the 95% CI than originally expected in both years. The cross spectral densities above 95% CI, and pass replication consistency restrictions as noted in the spectral analysis section above, are only meaningful for frequencies where strong PLFA spectral density signals also occurred. The conceptual model below represents the process indicated above for the refinement and generalization of spectral and cross spectral analyses (Figure 5).

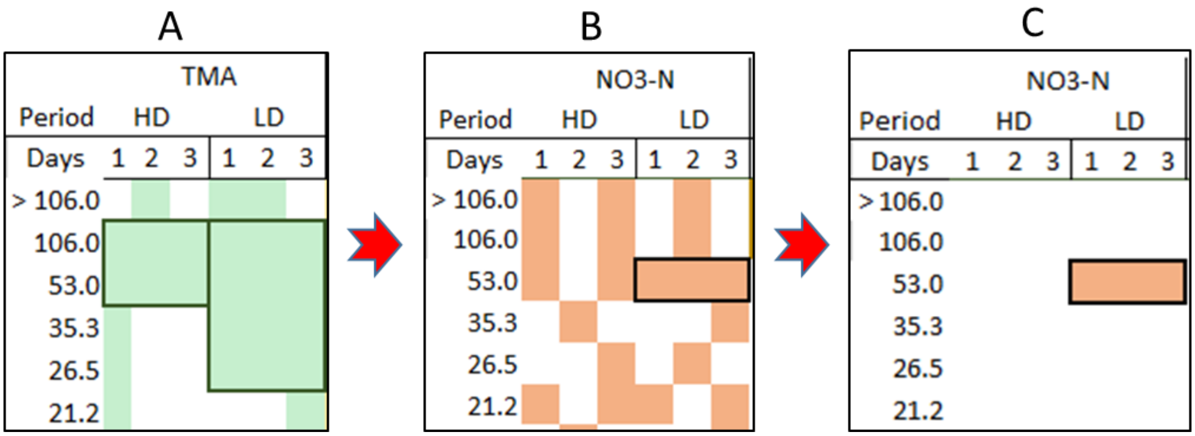

Figure 5: Representation of cross spectral density refinement. A) Initial spectral density analysis where complete replication consistency is boxed in under both high disturbance (HD) and low disturbance (LD) systems. B) Initial cross spectral density analysis between microbial abundance and NO_3^--N, where complete replication consistency boxed in under both HD and LD systems. C) Refined cross spectral density analysis where boxed areas must fall within the original spectral density boxed areas.

In 2017, the cross spectral analysis across soil chemical properties, physical conditions, and weather conditions revealed a considerable range of frequencies above the 95% CI (Figure A6-A23). Though similar to PLFA category spectral density analyses, plot consistency restrictions considerably reduced the number of cross spectral periods and regions that were used to assess PLFA and covariate trends. With the initial assessment, it was noted that a majority of the strong cross spectral signals occurred within a range of 35 – 106 day cycling periods (i.e. season-long, bimonthly, and monthly periods), while there were also notable areas of sub-monthly cycling between 12 – 27 days (i.e. AMF, actinomycete, and bacteria). At the monthly to season-long time scale, PLFA categories with a fungal biomarker component, including TMA, F:B, AMF, and fungi, expressed longer cross spectral signals as compared to their bacterial counterparts, actinomycetes and bacteria, which had consistent strong cross spectral signals at the sub-monthly periods. Though the 2017 spectral density analysis (Figure 3) revealed strong cycles between 12 – 16 days across the fungal biomarker categories and treatments, the cross spectral analysis found few instances of cycling with the soil chemical, soil physics, and weather covariates, except for AMF in the LD treatment. When considering the bacterial and fungal categories, bacterial species are known to conform under both r and K reproductive strategies, where r-strategist have a high growth rate with low survivability, while K-strategists have a low growth rate with high survivability. Overall, allowing bacterial shifts to be characterized at both short and long cycles as seen in Figure A18 – A23. These results are in agreement with current knowledge that fungal turnover rates are magnitudes slower than bacterial turnover rates (Rousk and Bååth, 2007). Comparatively, multi-celled oligotrophic soil fungi generally consolidated to the K reproductive strategy, where slower growing organisms would limit reflections in community level shifts, as seen in the fungi and F:B cross spectral analysis (Figure A9 – A16 & A15– A17) (Ho et al., 2017; Simonin et al., 2017; Borowik et al., 2017). Though the general fungi categories showed minimal cyclical structure at the sub-monthly level, the AMF cross spectral analysis indicated cycles occurring at sub-monthly to season-long periods, 12 – 106 days, which could be due to AMF group's ability to undergo both r and K reproductive strategies similar to bacterial species (IJdo et al., 2010). We presume that effects on sub-groups, such as actinomycetes and AMF, may be diluted out during the analysis of the general categories, such as TMA or F:B ratio. Therefore, the more generalized a microbial community category, the fewer inferences may be concluded on causation of their cyclical temporal dynamics.

Within the six PLFA categories, unique cross cyclical structures with covariates and soil disturbance levels became apparent. For instance, actinomycetes showed consistent trends in regards of soil disturbance levels to both chemical and physical conditions. Within the chemical cross spectral densities (Figure A18), the HD treatment consistently cycled at periods with MN, TN, and TC properties that were almost two fold longer on average when compared with the LD treatment. Comparatively, the physical cross spectral densities (Figure A19) had similar, but opposite trends where HD treatments cycled at shorter periods than LD treatments with soil VWC, temperature gradient, and water storage states. Physically, this effect could be a representation of higher microbial community resistance to environmental conditions [e.g., soil moisture and heat transfer (Daigh and DeJong-Hughes, 2017)], under lower disturbance systems. In contrast to actinomycetes, no strong bacteria cycles were associated with soil chemical properties. However, consistent strong signals near the 53 day period in HD, and 53 and >106 day periods in LD, were observed for soil physical states and weather conditions (Figure A22 & A23).

Therefore, soil physical states and weather condition show to be a more related to bacterial PLFA categories within field conditions as compared with soil chemical properties or nutrient availability. However, this appears to be in contrast with fungal dynamics. The fungal categories F:B, AMF, and fungi, showed strong cross spectral densities at the season-long scales with TN, TC, and pH, which is in general agreement with the scientific knowledge of fungal communities (Yang et al., 2011). The AMF did have some cross spectral densities with soil physical states and weather conditions that were similar to the bacterial categories mentioned above.

Overall, in 2017 we saw many trends across periods, PLFA categories, covariates, and soil disturbance level treatments. Some of the most important included soil chemical properties tend to cycle at longer periods at the season-long to bimonthly scale, and possess strong relationships with fungal dynamics. Where a strong correlation between fungal communities and chemical pools, such as total nitrogen and soil organic carbon, is well known (Dang et al., 2018). Additionally, for the soil physical states and weather conditions, we commonly saw strong cyclical trends between the bi-monthly and sub-monthly intervals that aligned with actinomycete dynamics. This was similar for bacterial categories, but at longer periods. From this, we can begin to derive further information on how our management practices can directly and indirectly influence the microbial community and their processes. Where our direct influences on chemical pools through fertilization and residue incorporation, may influence fungal structures and ecosystem functions, such as nutrient fixation and decomposition. Alternatively, bacterial community shifts in agricultural soils were closely tied to environmental conditions, where our tillage treatments may indirectly affect the soil thermal and hydraulic gradients that bacteria fluctuate with. Lastly, in 2017, the cross spectral analyses for the most generalized PLFA categories (i.e., bacteria and fungi) tended to show more mixed dynamics among periods with strong cyclical signals and covariate relationships, where these categories may be best suited for assessments of fertilizer timings and rates, or sampling procedure evaluations. In contrast, less generalized sub-groups (i.e., AMF and actinomycetes) tended to show more consistent temporal dynamics among soil disturbance level treatments, allowing us assess the impacts of our management systems on microbes with known agricultural benefits.

Similar to 2017, the cross spectral analyses in 2018 resulted in an abundance of strong cross spectral signals above the 95% CI. Though similar to PLFA category spectral density analyses (Figure 4), plot consistency restrictions considerably reduced the number of cross spectral periods and regions that were used to assess PLFA and covariate trends (Figure A24 – A41). Unlike 2017, the refined cross spectral densities left few or no frequencies to infer on. The PLFA categories TMA, F:B, AMF, and fungi had strong cross spectra signal only at the ≥85 days period. This could either be an artifact of spring wheat having a shorter growing season as compared with soybeans in 2017, or the change in crop and/or weather patterns caused actinomycetes and bacteria to cycle at shorter periods than the fungal categories, which is the opposite of the results in 2017.

In 2018, differences between soil disturbance levels were evident. The vast majority of all strong signals in the cross spectral analysis occurred in the HD treatment for TMA, F:B, AMF, fungi, and actinomycetes. In contrast, all strong signals within the bacteria category occurred in the LD treatment. With relatively consistent weather conditions occurring throughout the year in 2018, the LD plots may have not been influenced as much by physical and environmental weather conditions (Daigh and DeJong-Hughes, 2017), as noted above during 2017. Whereas, the HD plots may have produced more dramatic shifts in physical and chemical properties leading to higher cyclical pattern correlations.

Among 2017 and 2018, the most notable similarities included 1) shorter cycles with relationships stemming between soil physical states and weather conditions for actinomycete and Bacteria PLFA categories, and 2) longer cycles with relationships stemming between from soil chemical properties for TMA, F:B, AMF, and fungi PLFA categories. However, as mentioned previously, notable and opposite trends occurred among the two years. In addition to differences in weather patterns, the crops were rotated from soybean in 2017 to spring wheat in 2018. During the spring wheat phase, soils received nitrogen fertilization, while no fertilization occurred during the 2017 soybean growing season. In agreement with our results, others have reported that inorganic nitrogen inputs can depress soil microbial respiration rates and total microbial biomass by shifting the metabolic capabilities of the microbial communities (Ramirez et al., 2012). Additionally, N nitrogen fertilization has been noted to decrease in AMF colonization rates due to the higher concentration of plant available nitrogen, and the symbiotic relationship is not needed (Blanke et al., 2004). This may also support our observation of strong bacteria signals under LD, where fertilizer incorporation into the soil was more limited in the HD treatment.

PLFA Phase Lag Analysis

In addition to cross spectral densities described above, phase lag analysis allowed us to supplementary infer on the sensitivity of the relationships between the microbial community and their chemical, physical, and weather covariates cross. As indicated in Table A1-A10, phase lags are calculated in terms of π (i.e., -3.14 to 3.14), which signifies the offset or shift between the wave periods. When a value is negative, the associated covariate cycle is initiated before the PLFA microbial group's cycle. These phase lags could likely imply a "causation" of the covariate on the microbial dynamics. In contrast, when a value is positive, the associated covariate cycle is initiated after the PLFA microbial group's cycle. These phase lags could likely imply a limited correlation for covariates such as weather conditions, since the soil microbial community does not cause weather shifts at these time scales. Additionally, phase lags with a value of 0, or near $\pm \pi$, indicate that the PLFA microbial group and the covariate cycles exactly at the same time.

When assessing phase lags in both 2017 and 2018, the season-long period intervals revealed consistent values of 0 and 3.1, indicating no lags between the variables. Aside from consistent season-long phase lags, no clear trends could be deciphered from the phase lag analysis. However, the phase lag analysis revealed a consistent trend across our replicate sets, even though we had spatially detrended the data with static soil properties prior to the spectral analysis to gain stationary data. In the HD treatments, a consistent gradient of increasing phase lag was observed from replicate 1 to 3 for all PLFA categories in both years. In contrast, in the LD treatments, a consistent gradient of decreasing phase lags was observed from replicate 1 to 3 for all PLFA categories in both years. This is likely due to the slight microtopography in the field, which we anecdotally observed with slightly wetter and denser soils near replicates 3 (i.e., block 3). Although we spatially detrended with data with static soil properties, these landscape characteristics in this relatively flat and clayey field would not have been captured in detrending. From these observations, we can infer that not only do cyclical temporal structure exists, but that their timings associated or correlated with chemical, physical, and weather conditions are strongly tied to variable properties.

Conclusions

Our objectives were to assess the temporal variability across time and soil disturbance levels, and characterize the temporal patterns of microbial community at short time scales over the course of the growing season. In summary, the coefficient of variation analyses revealed an equal or higher variability of microbial community groups over time as compared with spatial replicates. Repeated measure mixed linear model analysis detected significant differences within some of the studied PLFA categories over time, providing some of the first evidence of microbial fluctuations at short time intervals. Finally, the spectral analyses uncovered that not only do patterns of abundance in microbial communities shift throughout the growing season, but they display cyclic patterns at various frequencies with chemical, physical, and environmental covariates. Most notably, bacteria cycle at shorter periods and are primarily associated with weather conditions, whereas the fungal categories cycle over longer periods and are primarily associated with chemical properties. Additionally, it was speculated that fertilization in the second year of the study may have caused substantial changes in the microbial community's temporal characteristics. With this information we can gain new insight on the use of PLFA analyses as a soil health indicator and our current assessment methods of the microbial community. Additionally, this information serves as a valuable step towards determining the role of soil disturbances (i.e. tillage) have on the soil microbial communities. If the dynamics behind the microbial communities can be adequately explained, future research may allow us to manipulate the microbial communities for society's agricultural and environmental needs.

Further analysis and interpretation of this data should include characterizing the cyclical amplitude heights and wave period lengths to help determine soil microbial community sensitivities to soil chemical properties, soil physical states, and weather conditions. In addition to these further characterizations, future research could include green house or growth chamber studies to validate our in-field observation and to further isolate covariates for their causalities versus correlations with microbial community temporal dynamics.

References

Al-Kaisi, M.M., and X. Yin. 2005. Tillage and crop residue effects on soil carbon and carbon dioxide emission in corn–soybean rotations. https://pdfs.semanticscholar.org/4a9f/018f5a6b838c826638e80158742f90cd04ff.pdf (accessed 26 April 2018).

Aon, M.A., and A.C. Colaneri. 2001. II. Temporal and spatial evolution of enzymatic activities and physico-chemical properties in an agricultural soil. Appl. Soil Ecol. 18(3): 255–270. doi: 10.1016/s0929-1393(01)00161-5.

Armstrong, A., A. Valverde, J.B. Ramond, T.P. Makhalanyane, J.K. Jansson, et al. 2016. Temporal dynamics of hot desert microbial communities reveal structural and functional responses to water input. Sci. Rep. 6: 8. doi: 10.1038/srep34434.

Bergstrom, D.W., C.M. Monreal, and D.J. King. 1998. sensitivity of soil enzyme activities to conservation practices. Soil Sci. Soc. Am. J. 62(5): 1286. doi: 10.2136/sssaj1998.03615995006200050020x.

Bescansa, P., M.J. Imaz, I. Virto, A. Enrique, and W.B. Hoogmoed. 2006. Soil water retention as affected by tillage and residue management in semiarid Spain. Soil Tillage Res. 87(1): 19–27. doi: 10.1016/j.still.2005.02.028.

Blake, G.R., and K.H. Hartge. 1986. Particle Density. In A. Klute (ed) ASA monograph No. 9, Part 1, p. 377-382.

Blanke, V., C. Renker, M. Wagner, K. Füllner, M. Held, et al. Nitrogen supply affects arbuscular mycorrhizal colonization of Artemisia vulgaris in a phosphate-polluted field site. doi: 10.1111/j.1469-8137.2005.01374.x.

Borowik, A., J. Wyszkowska, and K. Oszust. 2017. Functional diversity of fungal communities in soil contaminated with diesel oil. Front. Microbiol. 8: 1862. doi: 10.3389/FMICB.2017.01862.

Buyer, J.S., and M. Sasser. 2012. High throughput phospholipid fatty acid analysis of soils. Appl. Soil Ecol. 61: 127–130. doi: 10.1016/J.APSOIL.2012.06.005.

Daigh, A., and J. DeJong-Hughes. 2017. Upper Midwest Tillage Guide-Tillage implements : Soil management and health : Agriculture : University of Minnesota Extension. Univ. Minnesota Ext. https://www.extension.umn.edu/agriculture/soils/tillage/tillage-guide-implements/ (accessed 6 March 2018).

Dang, P., N.H. Vu, Z. Shen, J. Liu, F. Zhao, et al. 2018. Changes in soil fungal communities and vegetation following afforestation with Pinus tabulaeformis on the Loess Plateau. Ecosphere 9(8): e02401. doi: 10.1002/ecs2.2401.

Ettema, C., and D.A. Wardle. 2002. Spatial soil ecology. Trends Ecol. Evol. 17(4): 177–183. doi: 10.1016/S0169-5347(02)02496-5.

Frey, S.., E.. Elliott, and K. Paustian. 1999. Bacterial and fungal abundance and biomass in conventional and no-tillage agroecosystems along two climatic gradients. Soil Biol. Biochem. 31(4): 573–585. doi: 10.1016/S0038-0717(98)00161-8.

Gee, G.W. and J.W. Bauder. 1986. Particle-size analysis. In A. Klute (ed) Methods of Soil Analysis. ASA monograph No. 9, Part 1, p. 383-411.

Grafton, K., et al. 2012. Recommended Chemical Soil Test Procedures for the North Central Region.

Groenevelt, P.H. and C.D. Grant. 2006. Analysis of soil shrinkage data. Soil and Tillage Research. 79: 71-77.

Ho, A., D.P. Di Lonardo, and P.L.E. Bodelier. 2017. Revisiting life strategy concepts in environmental microbial ecology. FEMS Microbiol. Ecol. 93(3): fix006. doi: 10.1093/femsec/fix006.

Hoffman, W. 1979. Ancient Lake Agassiz and the Red River Valley. https://www.mbbnet.umn.edu/hoff/hoff_agassiz.html (accessed 17 April 2019).

IJdo, M., N. Schtickzelle, S. Cranenbrouck, and S. Declerck. 2010. Do arbuscular mycorrhizal fungi with contrasting life-history strategies differ in their responses to repeated defoliation? FEMS Microbiol. Ecol. 72(1): 114–122. doi: 10.1111/j.1574-6941.2009.00829.x.

Jacoby, R., M. Peukert, A. Succurro, A. Koprivova, and S. Kopriva. 2017. The role of soil microorganisms in plant mineral nutrition-current knowledge and future directions. Front. Plant Sci. 8: 1617. doi: 10.3389/fpls.2017.01617.

Jia, S., X. Zhang, X. Chen, N.B. McLaughlin, S. Zhang, et al. 2016. Long-term conservation tillage influences the soil microbial community and its contribution to soil CO2 emissions in a Mollisol in Northeast China. J. Soils Sediments 16(1): 1–12. doi: 10.1007/s11368-015-1158-7.

King, J.D., D.C. White, and C.W. Taylor. 1977. Use of lipid composition and metabolism to examine structure and activity of estuarine detrital microflora. Appl. Environ. Microbiol. 33(5): 1177–83. http://www.ncbi.nlm.nih.gov/pubmed/16345244 (accessed 22 April 2019).

Klopp, H.W., A.L.M. Daigh, and T. DeSutter. 2018. Soil shrinkage characteristics as affected by solution composition and mineral contents. Commun. Soil Sci. Plant Anal. 49(2): 170–180Available at https://www.tandfonline.com/doi/full/10.1080/00103624.2017.1421646 (verified 7 March 2018).

Marquardt, D.W. 1963. An algoritm for least-squares estimation of nonlinear parameters. J. Soc. Ind. Appl. Math. 11: 431-441.

Mathew, R.P., Y. Feng, L. Githinji, R. Ankumah, and K.S. Balkcom. 2012. impact of no-tillage and conventional tillage systems on soil microbial communities. Appl. Environ. Soil Sci. 2012: 1–10. doi: 10.1155/2012/548620.

Miura, T., A. Niswati, I.G. Swibawa, S. Haryani, H. Gunito, et al. 2016. Shifts in the composition and potential functions of soil microbial communities responding to a no-tillage practice and bagasse mulching on a sugarcane plantation. Biol. Fertil. Soils 52(3): 307–322. doi: 10.1007/s00374-015-1077-1.

Mualem, Y. 1976. A new model for predicting the hydraulic conductivity of unsaturated porous media. Water Resour. Res. 12: 513-522.

North Dakota Agricultural Weather Network (NDAWN). 2019. NDAWN Station: Wahpeton, ND. Available online at https://ndawn.ndsu.nodak.edu/station-info.html?station=63 (Accessed 3 March 2019).

O'Rourke, M.E., and J. Petersen. 2016. Reduced tillage impacts on pumpkin yield, weed pressure, soil moisture, and soil erosion. Hortscience 51(12): 1524–1528. doi: 10.21273/hortsci11226-16.

PRISM Climate Group - Oregon State University. USDA Plant Hardiness Zone Map. USDA Agric. Res. Serv. http://planthardiness.ars.usda.gov/PHZMWeb/ (accessed 6 March 2018).

Quideau, S.A., A.C.S. McIntosh, C.E. Norris, E. Lloret, M.J.B. Swallow, et al. 2016. Extraction and analysis of microbial phospholipid fatty acids in soils. J. Vis. Exp. (114). doi: 10.3791/54360.

Ramirez, K.S., J.M. Craine, and N. Fierer. 2012. Consistent effects of nitrogen amendments on soil microbial communities and processes across biomes. Glob. Chang. Biol. 18(6): 1918–1927. doi: 10.1111/j.1365-2486.2012.02639.x.

Ramsey, P.W., M.C. Rillig, K.P. Feris, W.E. Holben, and J.E. Gannon. 2006. Choice of methods for soil microbial community analysis: PLFA maximizes power compared to CLPP and PCR-based approaches. Pedobiologia (Jena). 50(3): 275–280. doi: 10.1016/J.PEDOBI.2006.03.003.

Rillig, M.C. 2004. Arbuscular mycorrhizae, glomalin, and soil aggregation. Can. J. Soil Sci. 84(4): 355–363.

Rousk, J., and E. Bååth. 2007. Fungal biomass production and turnover in soil estimated using the acetate-in-ergosterol technique. Soil Biol. Biochem. 39(8): 2173–2177. doi: 10.1016/J.SOILBIO.2007.03.023.

Shi, Y., R. Lalande, C. Hamel, N. Ziadi, B. Gagnon, et al. 2013. Seasonal variation of microbial biomass, activity, and community structure in soil under different tillage and phosphorus management practices. Biol. Fertil. Soils 49(7): 803–818. doi: 10.1007/s00374-013-0773-y.

Simonin, M., N. Nunan, J.M.G. Bloor, V. Pouteau, and A. Niboyet. 2017. Short-term responses and resistance of soil microbial community structure to elevated CO2 and N addition in grassland mesocosms. FEMS Microbiol. Lett. 364(9). doi: 10.1093/femsle/fnx077.

Smith, C.R., P.L. Blair, C. Boyd, B. Cody, A. Hazel, et al. 2016. Microbial community responses to soil tillage and crop rotation in a corn/soybean agroecosystem. Ecol. Evol. 6(22): 8075–8084. doi: 10.1002/ece3.2553.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at the following link: https://websoilsurvey.sc.egov.usda.gov/.

Sun, B.J., S.X. Jia, S.X. Zhang, N.B. McLaughlin, X.P. Zhang, et al. 2016. Tillage, seasonal and depths effects on soil microbial properties in black soil of Northeast China. Soil Tillage Res. 155: 421–428. doi: 10.1016/j.still.2015.09.014.

Swedrzynska, D., and I. Malecka-Jankowiak. 2017. The Impact of tillaging spring barley on selected chemical, microbiological, and enzymatic soil properties. Polish J. Environ. Stud. 26(1): 303–313. doi: 10.15244/pjoes/64911.

van Genuchten, M.Th. 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J. 44: 892-898.

Vargas Gil, S., J. Meriles, C. Conforto, M. Basanta, V. Radl, et al. 2011. Response of soil microbial communities to different management practices in surface soils of a soybean agroecosystem in Argentina. Eur. J. Soil Biol. 47(1): 55–60. doi: 10.1016/J.EJSOBI.2010.11.006.

Wang, J.J., X.Y. Li, A.N. Zhu, X.K. Zhang, H.W. Zhang, et al. 2012. Effects of tillage and residue management on soil microbial communities in North China. Plant Soil Environ. 58(1): 28–33.

Yang, H., Q. Zhang, J. Tang, Y. Yuan, Y. Liu, et al. 2011. Changes in soil organic carbon, total nitrogen, and abundance of arbuscular mycorrhizal fungi along a large-scale aridity gradient. Catena 87: 70–77. doi: 10.1016/j.catena.2011.05.009.

Zelles, L. 1997. Phospholipid fatty acid profiles in selected members of soil microbial communities. Chemosphere 35(1–2): 275–294. doi: 10.1016/S0045-6535(97)00155-0.

Zelles, L. 1999. Fatty acid patterns of phospholipids and lipopolysaccharides in the characterisation of microbial communities in soil: a review. Springer-Verlag.

CHAPTER 2. SEASONAL SOIL MICROBIAL ENZYME ACTIVITIES UNDER HIGH AND LOW DISTURBANCE MANAGEMENT PRACTICES

Abstract

Soil microbial communities are a collection of microorganisms, including bacteria and fungi, which play an extensive role in the moderation of soil physical and chemical properties. Through the production of enzymes, soil microbes ultimately regulate the fate of plant growth, which is dependent on available nutrients in the soil. During the process of soil tillage, soil structure, porosity, thermal and hydrologic properties, and soil:residue contact ratios can be altered (Al-Kaisi and Yin, 2005), possibly leading to fluctuations in microbial enzyme concentrations and dynamics. Historically, microbial dynamics have been studied at large time scales, such as years or decades, overlooking small scales dynamics within an agricultural system. Therefore, our objectives were to determine both soil disturbance level and time effects on nitrate reductase, ammonium oxidation, and β-glucosidase enzyme activities, and additionally infer on seasonal enzyme dynamics during two growing seasons as a results of reduced tillage practices. The study was conducted with two tillage practices, a high disturbance (chisel plow) and low disturbance (shallow vertical till), using a randomized complete block design within the growing season of a northern corn [*Zea mays*] - soybean [*Glycine max*] - wheat [*Triticum aestivum*] rotation on a silty-clay vertisol near Mooreton, North Dakota. Seasonal enzyme activities and soil physiochemical states were analyzed using repeated measures means seperations, covariate dependency, and enzyme simulation temporal autocorrelations and spectral densities. Results showed there were no significant differences between enzyme activities across soil disturbance levels or dates. Though differences in enzyme activities between disturbance levels were not apparent, covariate analysis revealed relationships with

environmental covariates. Lastly, temporal analyses on enzyme simulations revealed consistent cyclical trends over the season, but further validation is needed to conclude on current testing methods and the use of enzymes as soil quality indicators.

Introduction

In soil, enzymes released by soil biota regulate the rate at which plant residues are decomposed and ultimately release plant available nutrients (Soil Quality, 2011). Enzyme activities can be defined in terms of moles of substrate converted per unit time. This allows us to quantify the concentration of a known enzyme within a specified range of conditions. By understanding the community's production of enzymes, we may relate them to microbial function and composition, and use them as a soil quality indicator under different environmental conditions (Doran et al., 1994). Though soil enzymes have been studied since the early 1980's, our continuous advancements in enzyme methodology, statistics, and knowledge have allowed us to understand their functions and stability in response to changes in land management practices. With these opportunities, researchers are conducting both methodological and experimental studies on microbial communities and developing ways in which we can efficiently study them.

In the past, soil microbial communities and activities have commonly been approached similar to other aspects of agriculture (such as yield), where systematic study designs (such as randomized complete block or strip trial designs), are used to assess treatment effects. Over decades of research, many studies have concluded that soil enzyme activities increase with reduced tillage practices in both long and short term trials (Melero et al., 2009), as well as diverse crop rotations (Bolton Jr et al., 1985). With treatment effects on enzyme activity becoming apparent, research has taken a turn to focus on studying microbial enzyme variability across both space and time, to better understand how we can use microbial dynamics as indicators or for applied management.

Spatial approaches seek to explain patterns of soil change and behavior across geographical ranges, both horizontally and vertically (Ettema and Wardle, 2002). When considering past research on spatial variability, studies were commonly assembled using multiple treatment sites, addressing broad spatial variability, capturing ecosystem, landscape, or management shifts. Results from these studies commonly observed significant variability across ecosystems and management due to wide variability in soil ecosystems (Bergstrom et al., 1998; Wallenius et al., 2011). In addition to broad spatial analyses, studies have continued to increase the spatial resolution as precision agriculture continues to push the efficiencies of farm operations. Considering both horizontal and vertical (i.e. 0-20 cm) components, enzyme variability within the plot-scale (i.e. 150 x 90 m) has been evident in studies using spatial analyses. Taking a geostatistic and block-kriging approach in 2006, Aşkın et al. (date) observed significant relationships between three enzyme activity spatial patterns and physiochemical properties (particle size distribution, organic matter, pH, CEC, and lime content). Vertically, enzyme activities similarly correlate with physiochemical properties in relation to nutrient stratification due to management practices on site (Swedrzynska and Malecka-Jankowiak, 2017), strengthening the justification that enzymes can be used as a soil quality indicator across a landscape.

Temporally, analyses seek to examine and model the behavior of a variable over an allotted time series. Similar to spatial studies, temporal studies have been restricted to broad temporal scales such as years and decades, and have examined temporal dynamics at monthly or smaller intervals. At large temporal scales, enzyme activities have been noted to fluctuate as a function of time and management systems (Kandeler et al., 1999; Emmerling et al., 2001). With studies continuing to refine their scope of interest, conclusions on enzyme activity response over time are variable or contradicting as studies try to elude spatial and methodological variability within and between studies (Bolton Jr et al., 1985; Aon and Colaneri, 2001; Swedrzynska and Malecka-Jankowiak, 2017). As our basic understanding of enzyme activity variability across landscapes and physiochemical gradients grows, temporal variability remains a challenge for understanding soil microbial dynamics as soil quality indicators. With continued research on temporal enzyme activities, the influence of microbial processes on nutrient cycling and dynamics may also lead to more efficient fertility management and nutrient availability for sustainable crop production.

During the preparation of land for the upcoming growing season, land managers commonly use tillage, described as the mechanical disturbance of the upper soil profile, to prep seed beds, incorporate fertilizer and crop residues, manage weeds, and accelerate drying and warming of the soil during cold springs (Hobbs et al., 2008). Moving away from intensive conventional practice like moldboard plow, which inverted soil to a depth of 20-30 cm, reduced tillage implements like chisel plow, vertical till, and strip till, aim to reduce soil disturbance and leave more crop residue on the soil surface (Daigh and DeJong-Hughes, 2017). During the conversion of natural systems, such as forests or grasslands, to cultivated lands, it is well known that the production of enzymes significantly decreases (Salam et al., 1997; Follett and Schimel, 1989). Though degradation of soil functionality is inevitable with an increase in tillage system intensity, the use of reduced tillage systems, such as no-till, and strip-till, can increase enzyme activity levels closer to natural states, when compared to conventional tillage systems, such as moldboard plow (Deng and Tabatabai, 1997; Bergstrom et al., 1998; Kandeler et al., 1999).

However, it has been noted that agricultural soils with high carbon (>3.5% TC) see less of an effect between tillage implements on enzyme activity concentrations, where site characteristics (i.e. topography and soil texture) may concluded to be larger driving forces than tillage (Bergstrom et al., 1998). The upper Midwest US hosts high carbon, poorly drained fine textured soils, which may exhibit this level of soil resiliency, with respect to enzyme response to tillage treatments.

Over the course of this experiment, our objectives included 1) determine both soil disturbance level and time effects on nitrate reductase (NR), ammonium oxidation (AO), and β-glucosidase (BG) enzyme actvities., 2) determine best fit predictive covariates for empirical enzyme models using multiple linear regression models, 3) produce full season simulations of microbial enzyme activity, and 4) analyze enzyme activity simulations for repeated shifts, or stability, in the seasonal enzyme activity outputs. Completing these objectives allowed us to not only infer on microbial activity and dynamics under different disturbance levels, but also new approaches to evaluating soil health and our current testing procedures.

Materials and Methods

Site Description

This study was conducted at the Soil Health and Agricultural Research Extension (SHARE) farm located in Mooreton, ND (46.2686° N, 96.8762° W), which has been in continuous crop production for several decades. From 2015 - 2018, the mean annual precipitation was 40.8 cm with a range of 35.4 to 46.5 cm. The mean annual temperature was 6.75 ^{o}C with a mean minimum and maximum temperatures from 0.5 to 13 ^{o}C, respectively (NDAWN, 2019). Weather condition data, dating back to 2015, was gathered from the in-situ North Dakota Agricultural Weather Network (NDAWN) weather station that is located on the SHARE farm. Corresponding with the weather conditions, the site is located in the 4a plant hardiness zone indicating an average annual minimum temperature of -1.7 to - 34.4 ^{o}C (PRISM Climate Group - Oregon State University, 2018).

Soils within the Red River Valley and field site consist of a Fargo silty clay soil series (fine, smectitic, frigid Typic Epiaquert). A representative Fargo soil series' horizonation sequence is Ap-A-Bss-Bkg-Cg, with silty clay as the dominant soil texture (Soil Survey, 2019). The formation of this soil series occurred from the settling of glacial sediment within Ancient Lake Agassiz, which occupied an area of 41,439 square kilometers forming the flat Red River Valley. With high clay contents in the soil series, the area commonly endures flooding after large rain events or snowmelts, but is widely used for agricultural crop production due to its fertile soils (Hoffman, 1979).

With the short growing season, and frequently saturated soils, surface drainage systems are commonly used in the region for the removal of excess surface water. In addition to excess soil moisture, the SHARE farm also has salinity seep present on the western edge of the field boundary. To investigate the effectiveness of drainage infrastructure on soil properties, subsurface drainage was installed on the north half of the field in 2013 at a depth of 1.1 meters with a spacing of 12.1 meters between lateral lines. When implementing field scale tillage plots for this study, drained soils with non-saline conditions were chosen to reduce sources of variability in soil properties due to management practices extraneous to our objectives.

Experimental Design and Site Management

Before agriculture practices became a dominant industry in the Red River Valley, a prairie ecosystem covered the landscape creating fertile soils with high organic matter content. Over the course of two centuries, moldboard plow was annually used to convert and manage the prairie soils for agricultural production. Switching to less aggressive tillage in 2015, chisel plowing and field cultivation became the dominant management practices within the Red River Valley and SHARE farm for corn, soybean, and wheat production. Of interest in the region are tillage systems that further reduce soil disturbance, such as vertical tillage, strip tillage, and no-till (Daigh, et al., 2019). The SHARE farm provides an opportunity to examine these practices in typical Red River Valley soils.

After the implementation of subsurface drainage systems in 2013, three replications of randomized complete block design tillage treatments were implemented at production scale (12.2 m x 500 m) in the fall of 2015 (Chapter 1: Figure 1). Of the four reduced tillage treatments implemented (i.e. chisel plow, vertical till, spring and fall strip till), this study focused only on chisel plow and vertical till. During annual management and implementation, chisel plow plots endured one pass, at a depth of 18-20 cm, in the fall after harvest, and were additionally field cultivated in spring before planting. Over the first three years of the four year tillage study, vertical tillage was performed in both the fall and spring to a depth of 2-8 cm. The vertical tillage equipment had front and rear gangs of fluted coulters spaced 15 cm apart, pitched at a 3-4^{o}, coupled with a rear rolling basket. Due to tillage implement availability, the vertical till plots did not receive tillage during the spring of 2018. When referring to these tillage plot, they will be referred to as the high disturbance (HD – chisel plow) and low disturbance (LD – vertical/no-till) treatments.

On 16 May 2017, soybeans (Alligent 08L82 08 maturity) were planted at 76 cm row spacing. Common with soybean management, no additional fertilizers were used during the course of the season. On 6 May 2018, spring wheat (Prosper) was planted via grain drill at 19 cm row spacing. Prior to planting in 2018, synthetic fertilizer (140-40-10; N-P-K) was broadcasted and incorporated by means of field cultivation in HD plots, and grain drill in the LD plots. To reduce variability within plots and reduced wheel traffic, applications of herbicides and pesticides were applied in perpendicular patterns to planted rows. All field operations were performed by the landowner based on university extension recommendations for the region.

In both 2017 and 2018, a linear transect for soil sampling was established across the treatments and parallel to the subsurface drainage laterals. Within soil sampling locations, data loggers (2017: Decagon Em50; 2018: METER Em60) and Decagon 5TM soil moisture and temperature sensors were deployed between the 6^{th} and 7^{th} soybean rows (i.e., center of plot) for each experimental plot.

Soil Sampling Procedure and Selection

In 2017 and 2018, soil samples were collected each Monday and Friday (at approximately 3.5 day intervals) throughout the growing season (i.e., 39 and 32 sample dates in 2017 and 2018, respectively). Soil samples were taken from the quarter row position between plants to a depth of 15 cm using a bucket auger. Two auger samples were taken in close proximity in each plot and composited for laboratory analysis. Collected samples were then split into two subsamples for storage and analyses: 1) fresh, field moist sample placed in -4 ^{o}C freezer for enzyme analysis; and 2) air-dried, ground, and sieved for chemical analyses.

Chemical analyses were performed on all soil samples collected in 2017 (n = 234) and 2018 (n = 192). Though an equivalent amount of fresh soil samples were frozen for enzyme analyses, only a subset of sampling dates were analyzed for enzyme activities due to lab and time constraints. The designated dates used for enzyme analysis (Table B1 & B2) were selected based on capturing a range of soil moisture as well as before and after precipitation events.

Enzyme Activity/Biochemical Analysis

Thawed field-moist soils were analyzed for BG, AO, and NR enzyme activity. BG was used to assess processing of carbon-based biochemicals due to its higher abundance compared with alternative carbon-acting enzymes β and α galactosidase. BG main functions serves to catalyze the enzymatic hydrolysis of polysaccharides, where the hydrolysis product of glucosidase has been noted to be an important energy source for soil biota and can be sensitive to soil management practices (Doran et al., 1994; Tabatabai et al., 2003). Procedures for enzyme activity analysis were performed according to (Dick and Al-Amoodi, 2011). Triplicates of 1g field moist soil were analyzed for each selected sample. Analyses required one-hour incubations to measure colorimetric properties (absorbance level of 410nm) based off p-Nitrophenol release by BG expressed in µg p-Nitrophenol - g^{-1} h^{-1}. All colorimetric analyses were performed using a spectrophotometer (ThermoSpectronic 20D+, model 333183, Franklin, MA).

Since nitrogen is the second most limiting nutrient behind water for terrestrial plants, nitrogen cycle enzyme activities were assessed using AO and NR. Both AO and NR were measured to factor in the total plant available nitrogen pool in soil. Where, NR catalyzes the reduction of NO_3^- to NO_2^-, and AO catalyzes the oxidation of NH_4^+ to NO_2^{-}. Procedures defined by (Dick and Al-Amoodi, 2011) were used to measure both AO and NR. For two of the three AO triplicates, 5g of field moist soil was incubated for 5 h at 25°C, filtered, and tested for NO_2^- using a colorimetric test at an absorbance level of 520 nm. The third triplicate was kept at -20°C and treated as a control for comparisons and calculations. A similar process was used for the NR procedure, but 5g triplicates of field moist soil underwent 24 h incubations at 25° C and -20° C. Nitrite concentrations were measured by absorbance levels of 520 nm. AO activity will be expressed as µg NO_2^-, - N g^{-1} 5 h^{-1}, while NR activity will be expressed in µg NO_2 - N g^{-1} 24 h^{-1}.

Physiochemical Explanatory Variables

For further comparisons between enzyme activities and studied explanatory variables, enzyme activities were aggregated to tillage treatment block (HD-1 etc.) and sampling dates (DOY). Tillage block enzyme activity averages were then compiled with corresponding abiotic and biotic variables across sampling dates (Table B1 & B2). The selected explanatory biotic and abiotic variables were selected based on the knowledge of microbial sensitivity to nutrient availability, and thermal and moisture regimes (Debosz et al., 1999). Soil nutrients used for modeling assessment where analyzed by the NDSU testing lab and followed procedure described by Grafton et. al (2012). Tests included: nitrate – nitrogen (NO_3^--N) (trans-nitration of salicylic acid method), phosphorus (P) (Olsen Method), extractable sulfur (S) (Monocalcium phosphate extraction), extractable manganese (Mn) (DPTA .033 M H_3PO_4 extraction), ammonium (NH_4^+-N) (Berthelot Reaction/ Indophenol Reaction), total nitrogen (Vario Macro Cube CHNOS analyzer), and total organic carbon (TOC) (Primacs^{SLC} TOC analyzer).

In addition to the soil nutrient pools, abiotic variables were used to describe the thermal and moisture regimes within the studied soil profile zone (0-15 cm). Em50/Em60 data logger with 5TM soil moisture and temperature sensors (METER, Inc., Pullman, WA) at depths of 5, 10, 15, and 20 cm were deployed in each plot to record soil conditions at 30 minute intervals throughout the year. From the collected sensor data, soil profile averages from 0-15 cm were calculated at half hour intervals. From these records, abiotic properties were extracted for enzyme sample dates, including daily maximum temperature (DailyMax), daily average temperature (DailyTemp), preceding weekly average temperature (WeeklyTemp), daily average moisture (DailyMoist), and preceding weekly average moisture (WeeklyMoist). Daily maximums and averages were calculated on the date respective soil samples were taken for both soil nutrient and enzyme analysis. Weekly averages were calculated based on the previous seven days corresponding to the sampling date.

Statistical and Modeling Validation/Analysis

We were interested in comparing mean enzyme activities across tillage systems within sample date, as well as through time. We were also interested in exploring the relationships between enzyme activities and auxiliary soil variables, in effort to better understand temporal drivers of enzyme activities.

For mean separations in both 2017 and 2018, treatment replicates were averaged at the treatment level for means comparison between the high and low disturbance systems. Due to low number of replicates (n=3) and sample date frequencies (2017: n=8; 2018: n=6), the Friedman test, a non-parametric analysis for treatment comparison on repeated measures, was used to compare mean enzyme activities across treatments and sample dates. Statistical significance was set at $\alpha \leq 0.05$.

To further investigate how seasonal soil microbial enzyme activities related to soil properties, we fit multiple linear regression models, where the enzyme was the response variable and chemical pool and abiotic properties were the predictor variables. Initial models were first constructed by including all explanatory covariates, and followed up with an automated stepwise variable selection function (stepAIC) to retain lowest AIC model, and select for the best fit model predictors for each treatment and enzyme. Selected best fit variables were then analyzed using a stepwise ANOVA to indicate significance levels within specified models at *** ($\alpha \leq 0.001$), ** ($\alpha \leq 0.01$), and * ($\alpha \leq 0.05$), and additionally indicate adjusted R^2 values of the working models. Both Friedman mean comparisons and regression model fitting were completed in R (R Core Team, 2019) with ‘plyr’ (Wickham, 2011) and ‘MASS’ (Venables and Ripley, 2002) packages for data manipulation, visualization, and analysis.

Before using the generated enzyme activity models for full season simulations, we assessed model accuracy using a leave-one-out cross-validation in R. Leave-one-out cross-validations are commonly used on models where limited data samples, replication, or consistency occur in an experiment. This validation process was completed by cycling through the dataset, leaving each observation out, one at a time, and predicting the withheld value using the fitted model. Model observed and predicted values were then analyzed for fit statistic variables that included root mean square error (RMSE) and R-squared values. Root mean square error values served as an interpretation of the standard deviation of the unexplained variance, where lower values express a better fit model. Model validation R-squared values that were considerably lower than adjusted R-squared values, from model calibration, indicated that the model was over-fit.

By producing best fit empirical models for the three enzyme activities in both 2017 and 2018, full season simulations proctored a way for us to visually and statistically analyze high frequency data for cyclical patterns within the dynamics of the enzyme activities. Taking this first step into modeling microbial activity, we were able to infer on sampling frequency intervals, methodological approaches, and relative significance of short time scales at the microbial level. To produce daily enzyme activity outputs, the initial high frequency datasets, including all explanatory variables at roughly 3.5 day periods, were interpolated to produce full season, daily interval datasets. The interpolation was conducted using a 2-D smoothing analysis (loess function) in Sigma Plot 12.5. With full season, daily datasets built, the finalized best fit empirical models were implemented, simulating enzyme activities at daily intervals over the course of the sampling periods. The enzyme simulations were then evaluated for temporal autocorrelations and spectral densities for cyclic states using JMP version 13 as described in the previous chapter.

$$r(h) = \frac{cov[A_i(t), A_i(t+h)]}{\sqrt{var[A_i(t)]}\sqrt{var[A_i(t+h)]}} \quad \text{(Eq. 8)}$$

$$S(f) = 2\int_0^{\infty} r(h)\cos(2\pi f h)\,\partial h \quad \text{(Eq. 9)}$$

where r(h) is the temporal autocorrelation function in which cov and var are the covariance and variance, respectively, A_i is the soil property or state of interest, t is the point in time of A_i, and h is the time lag. S(f) is the spectrum of the auto-correlations, where f is the frequency. For visualization, all spectrum plots will be presented using the period instead of the frequency for ease of interpretation.

Results and Discussion

Tillage and Date Mean Separations

Soil microbial enzyme activities are dependent on their surrounding environment (Debosz et al., 1999; Aon and Colaneri, 2001), and have been considered reliable indicators of soil microbial community functionality (Doran et al., 1994 ; Soil Quality, 2010). Our goal was to understand temporal patterns of soil enzyme activites under moderated treatments and time intervals, and infer if cyclical patterns exist at short time scales within the studied parameters. When considering enzyme activities at short time scales within a growing season, the Friedman test results from 2017 and 2018 revealed no significant differences between either treatment or date (Table 3 & 4). On the treatment side, these results coincide with Aon and Colaneri (2001), where enzyme activities had no dependence with tillage treatments. However, that study observed that enzyme activities significantly differed with dates, which is not consistent with our results. Though significant differences were not found by date, some enzyme activity trends (i.e. NR-17, BG-17, and BG-18) agree with Aon et al. (2001) and Swedrzynska et al. (2017) where peak enzyme activities occurred closely peak vegetative growth (early anthesis) (Figure 6). Where soybean antheiss started 7 August 2017, and wheat antheiss started 29 June 2018. Concerning BG directly, noted trends could additionally be an artifact of crop residue decomposition over the course of the years, where BG has been viewed as a possible indicator of crop residue and soil carbon turnover (Zhang et al., 2011). With more exhaustive sampling, BG could serve as a quality indicator of disturbance, and the nutrient composition of previous crop residues.

When assessing management effects on microbial enzyme activities, differences due to soil properties and study design have caused difficult interpretations of results both within and between studies as mentioned above (Doran et al., 1994). Comparing studies from the literature, contradictions in comparisons, interpretations, and conclusions stem largely between studies with differing study designs. Sampling procedures alone varied by: profile zone (heterogeneous or homogenous), sampling zone (in row or between row), sampling frequency (day or month intervals), and sampling replication within plot for reduced variability. In addition, studied enzyme activities, planted crop/cropping system, and climate conditions also varied between studies creating challenging conditions to make strong conclusion (Aon & Colaneri, 2001; Bolton Jr et al., 1985; Martens, Johanson, & Frankenberger, 1992; Swedrzynska & Malecka-Jankowiak, 2017) .

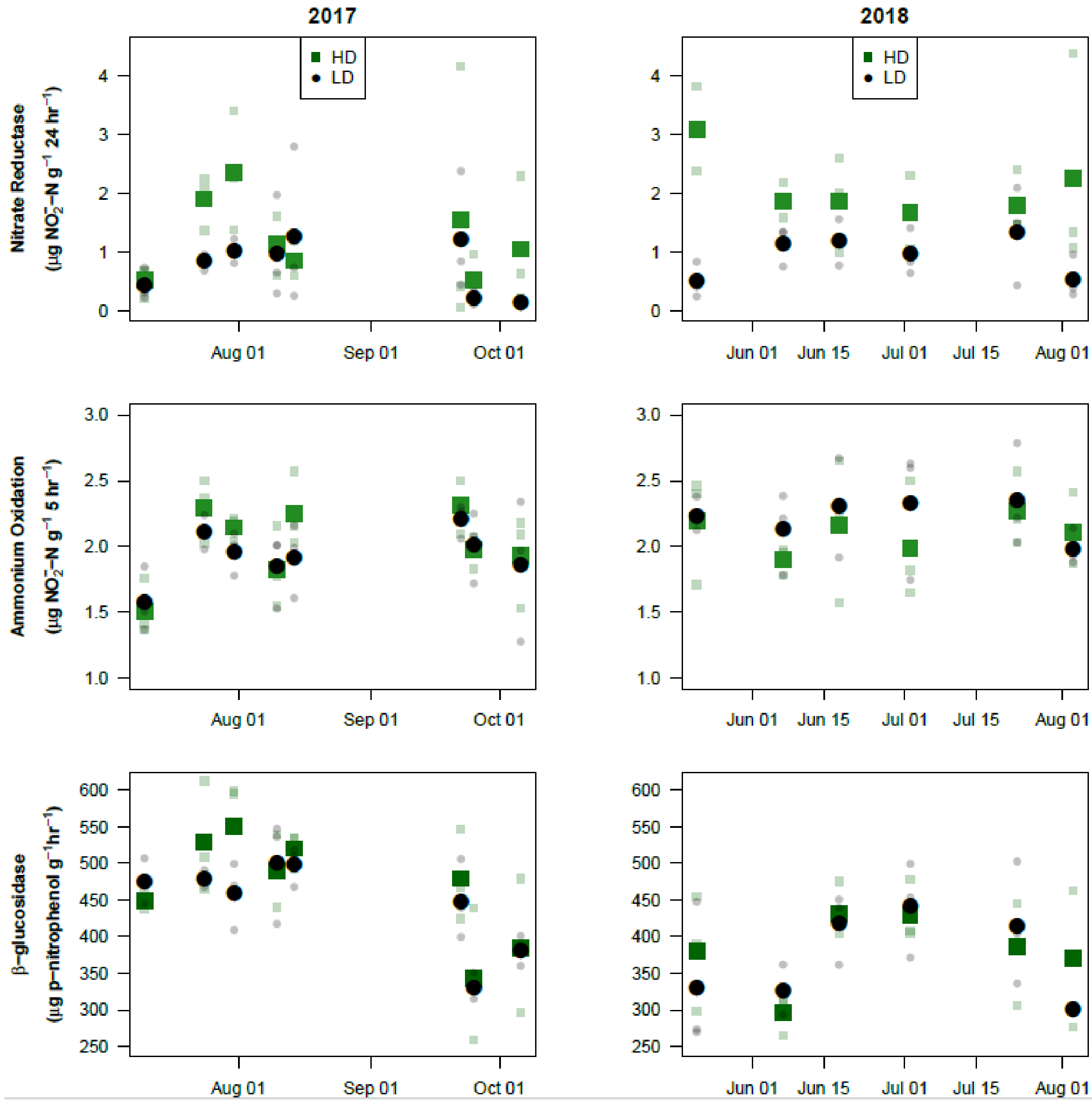

Figure 6: Nitrate Reductase, Ammonium Oxidation, and β-glucosidase enzyme activities across selected dates. Disturbance levels are represented with treatment means (bolded) and plot replications (faded).

Table 3: 2017 Friedman non-parametric repeated measures results.

Effects	Variable	AO†	NR	BG
Treatment	DOY‡	µg NO_2^- - N g^{-1} $5h^{-1}$	µg NO_2^- - N g^{-1} 24 h^{-1}	µg p-Nitrophenol - g^{-1} 1 h^{-1}
HD§	191	1.51 (0.18)	0.52 (0.22)	448.6 (10.2)
LD	191	1.58 (0.20)	0.42 (0.22)	475.8 (25.4)
	Pr > F	N/A	1	0.4
HD	205	2.30 (0.20)	1.90 (0.38)	528.6 (62.0)
LD	205	2.12 (0.11)	0.84 (0.12)	478.5 (25.4)
	Pr > F	0.4	0.1	0.7
HD	212	2.15 (0.08)	2.35 (0.83)	551.0 (64.7)
LD	212	1.96 (0.13)	1.02 (0.17	459.3 (37.6)
	Pr > F	0.2	0.1	0.4
HD	222	1.83 (0.25)	1.13 (0.41)	489.6 (40.5)
LD	222	1.85 (0.23)	0.97 (0.72)	500.3 (58.8)
	Pr > F	N/A	1	1
HD	226	2.25 (0.23)	0.85 (0.25)	520.3 (19.7)
LD	226	1.92 (0.23)	1.26 (1.11)	498.6 (22.0)
	Pr > F	0.4	1	0.4
HD	265	2.31 (0.16)	1.54 (1.86)	479.3 (51.0)
LD	265	2.21 (.011)	1.22 (0.84)	448.2 (43.9)
	Pr > F	0.4	0.7	0.7
HD	268	1.98 (0.11)	0.51 (0.34)	343.9 (73.9)
LD	268	2.02 (0.22)	0.20 (0.09)	330.8 (14.8)
	Pr > F	0.7	0.4	1
HD	279	1.93 (0.29)	1.05 (0.90)	348.7 (74.8)
LD	279	1.86 (0.44)	0.14 (0.06)	381.3 (16.7)
	Pr > F	1	0.1	1
Treatment x DOY	Pr > F	0.06439	0.1982	0.1247

*Significant at $P < 0.05$
**Significant at $P < 0.01$
***Significant at $P < 0.001$
N/A: cannot compute exact p-values with ties
† Ammonium Oxidation (AO); Nitrate Reductase (NR); β-glucosidase (BG)
‡ Day of Year (DOY)
§ HD: High Disturbance; LD: Low Disturbance

Table 4: 2018 Friedman non-parametric repeated measures results.

Effects	Variable	AO†	NR	BG
Treatment	DOY‡	µg NO_2^- - N g^{-1} $5h^{-1}$	µg NO_2^- - N g^{-1} 24 h^{-1}	µg p-Nitrophenol - g^{-1} 1 h^{-1}
HD§	141	2.19 (0.34)	3.09 (0.59)	380.5 (64.2)
LD	141	2.23 (0.11)	0.49 (0.25)	330.2 (83.0)
	Pr > F	0.7	0.1	0.4
HD	158	1.91 (0.09)	1.87 (0.25)	296.2 (22.2)
LD	158	2.13 (0.25)	1.14 (0.28)	326.6 (28.0)
	Pr > F	0.4	0.1	0.4
HD	169	2.16 (0.45)	1.87 (0.66)	431.7 (31.3)
LD	169	2.31 (0.31)	1.18 (0.32)	417.2 (39.7)
	Pr > F	0.7	0.4	1
HD	183	1.99 (0.37)	1.67 (0.51)	430.1 (33.8)
LD	183	2.33 (0.41)	0.96 (0.33)	441.5 (52.9)
	Pr > F	0.4	0.2	1
HD	204	2.27 (0.22)	1.78 (0.44)	386.7 (59.1)
LD	204	2.35 (0.32)	1.34 (0.69)	414.2 (68.4)
	Pr > F	1	1	1
HD	214	2.11 (0.23)	2.27 (1.51)	370.6 (76.0)
LD	214	1.98 (0.11)	0.54 (0.30)	300.2 (1.1)
	Pr > F	1	0.1	0.7
Treatment x DOY	Pr > F	0.1907	0.8871	0.09314

*Significant at $P < 0.05$
**Significant at $P < 0.01$
***Significant at $P < 0.001$
N/A: cannot compute exact p-values with ties
† Ammonium Oxidation (AO); Nitrate Reductase (NR); β-glucosidase (BG)
‡ Day of Year (DOY)
§ HD: High Disturbance; LD: Low Disturbance

Explanatory Variable Selection

In 2017, the HD enzyme model adjusted R-squares were 0.58, .045, and 0.52 in the NR, AO, and BG models, respectively. Comparatively, the LD enzyme models produced adjusted R-squared values of 0.35, 0.39, and 0.74 in the NR, AO, and BG models, respectively (Table 5). Among the two disturbance level models, similar environmental covariates were used, but the degree of power in which the covariates contributed in their corresponding models differed. Across all six models, there was a general consistency in the use of DailyMax, DailyTemp, and

DailyMoist regardless of enzyme or disturbance level. The role of chemical covariates in the models was much less powerful and consistent compared with physical states such as temperature and moisture regimes, but an interesting trend in the use of chemical covariates was observed. When a chemical covariate was used in a treatment model, it was never used in the model of the alternative treatment option, except for one occasion in which both NR models used TC as a significant covariate.

Table 5: 2017 covariate summaries of seasonal enzyme empirical models.

		NO_3^-N	**P**	**SO_4^{2-}**	**Mn^{2+}**	**NH_4^+**	**TN**	**TC**	**DailyMax**	**DailyTemp**	**WeeklyTemp**	**DailyMoist**	**WeeklyMoist**	**Model**
Enzymes	**Trt**	lbs/acre	ppm	lbs/acre	ppm	ppm	%	%	°C	°C	°C	cm³/cm³	cm³/cm³	Adj-R^2
NR†	**HD‡**	X	***				X	*	**		X	*	X	0.58
	LD			X	X	X		X	**	**	*	*		0.35
AO	**HD**					X	**		X	X			**	0.45
	LD				X			X	**	**	*	*		0.39
BG	**HD**	*					X		*	*		**	X	0.52
	LD			X	***	*			X	X	X	***	*	0.74

*Significant at $P < 0.05$
**Significant at $P < 0.01$
***Significant at $P < 0.001$
X $P > .05$
† Ammonium Oxidation (AO); Nitrate Reductase (NR); β-glucosidase (BG)
‡ High Disturbance (HD); Low Disturbance (LD)

In 2018, the HD enzyme model adjusted R^2 values were 0.59, 0.35, and 0.72 in the NR, AO, and BG models, respectively. Comparatively, the LD enzyme models produced adjusted R^2 values of 0.52, 0.36, and 0.40 in the NR, AO, and BG models, respectively (Table 6). Compared with 2017 covariate results, more chemical and environmental covariates were used. Additionally, variables such as NO_3^--N, P, TN, DailyMax, DailyTemp, and DailyMoist, were consistently used across disturbance levels and enzymes, but abiotic physical states (DailyMax etc.) seemed to play a larger role in predicting and modeling enzyme dynamics over the course of the season, similar to 2017. Overall, prior to simulation analysis, the raw models have helped us distinguish differences between driving factors from year to year, and also infer on why some covariates seem to play a minimal role in corresponding models. Particularly studying carbon and nitrogen pool enzymes, NO_3^--N, NH_4^+-N, and TC did not play a major role in their corresponding NR, AO, and BG models Reasoning behind this may be due to the carbon and nutrient enriched soils from decades of agricultural practices (Bergstrom et al., 1998), or static traits as seen in TC levels over time, deeming other covariates to be responsible for enzyme activity fluctuations.

Table 6: 2018 covariate summaries of seasonal enzyme empirical models.

		NO_3^-N	**P**	**SO_4^{2-}**	**Mn^{2+}**	**NH_4^+**	**TN**	**TC**	**DailyMax**	**DailyTemp**	**WeeklyTemp**	**DailyMoist**	**WeeklyMoist**	**Model**
Enzymes	**Trt**	lbs/acre	ppm	lbs/acre	ppm	ppm	%	%	°C	°C	°C	cm³/cm³	cm³/cm³	Adj-R^2
NR†	**HD‡**	X	X				***		*					0.59
	LD		*		X		*	X		X	X	*	X	0.52
AO	**HD**	*		X	X		*			*	*			0.35
	LD	*	*	X	X	*	*	X	*	*	*	*	*	0.36
BG	**HD**	*	**	X	X	*	*		**	**	X	**		0.72
	LD	X	X			X	X		*	*	X	X	X	0.40

*Significant at $P < 0.05$
**Significant at $P < 0.01$
***Significant at $P < 0.001$
X $P > .05$
† Ammonium Oxidation (AO); Nitrate Reductase (NR); β-glucosidase (BG)
‡ High Disturbance (HD); Low Disturbance (LD)

Enzyme Model Validation

From the leave-one-out cross-validation assessments, initial observed enzyme activity values were regenerated producing sets of observed and predicted values for each model as seen in Figure 7. All models were individually assessed and plotted, and can be seen in Figure B & B2.

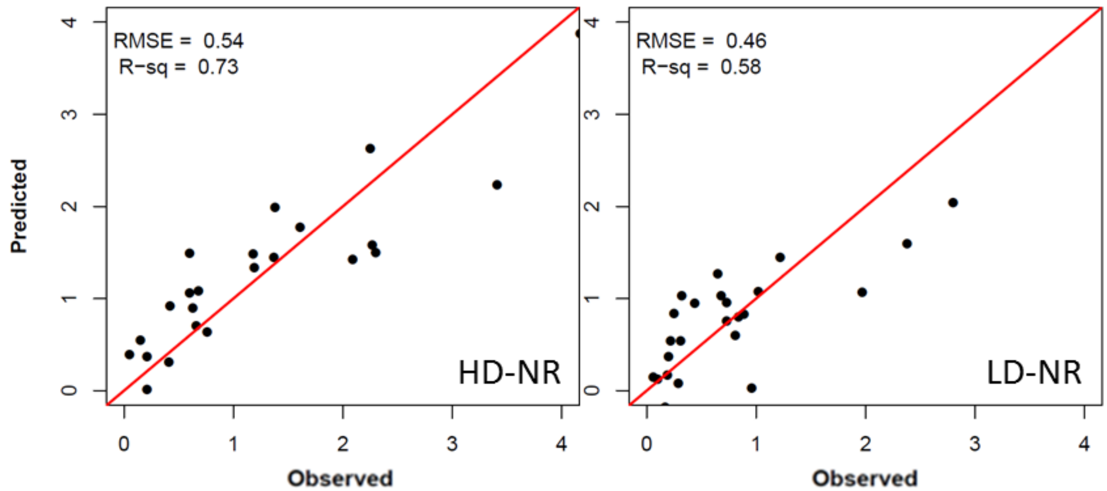

Figure 7: Leave-one-out cross-validation scatter plots for 2017 Nitrate Reductase (µg NO_2 - N g^{-1} 24 h^{-1}) High and Low disturbance systems.

With the model validation observed and predicted values, both RMSE and R-squared fit statistics were used to assess the accuracy of the models. In 2017, R-squared values ranged from 0.55 – 0.73, while 2018 model R-squares ranged from 0.02 – 0.46 (Table 7). For comparisons of RMSE fit statistics, values were reported as a percentage of the maximum observed value for each enzyme model. In 2017, RMSE percent variation ranged from 12.9 – 16.4, 8.2 – 8.6, and 6.9 – 8.5% between NR, AO, and BG enzyme models, respectively. Comparatively, 2018 RMSE percent variation ranged from 16.4 – 20.6, 12.1 – 60.2, and 20.4 – 36.4% between NR, AO, and BG enzyme models, respectively. For consideration, 10% RMSE percent variation and under can be considered a good level of prediction accuracy. Reasoning behind less accurate models in 2018 may be due to the higher dependence on the five weather condition variables in 2017, and the variable weather conditions that occurred throughout the year. Ranging from drought to flood conditions, the wider range of variable values collected may have led to improved calibration of the 2017 initial models. In 2018, consistent weather conditions may have led to an increased use of chemical properties as explanatory variables, which may be more subject to variability and stratification within the studied profile (Swedrzynska and Malecka-Jankowiak, 2017), ultimately leading to poorer calibrated enzyme models. Though higher RMSE and lower R-squared values occurred in 2018 due to a few observations that were not accurately predicted, Figure B2 shows similar trends to 2017, leading us to argue that the enzyme activity models and simulations can methodically be used to infer on microbial enzyme activity dynamics over the course of the season.

Table 7: Leave-one-out cross-validation fit statistics across all years, enzymes, and treatments.

2017				2018			
Enzyme	Treatment	RMSE†	R^2	Enzyme	Treatment	RMSE†	R^2
NR‡	HD§	0.54	0.73	NR‡	HD§	0.72	0.46
	LD	0.46	0.58		LD	0.43	0.42
AO	HD	0.21	0.57	AO	HD	0.32	0.32
	LD	0.20	0.55		LD	1.68	0.22
BG	HD	52.02	0.64	BG	HD	173.82	0.02
	LD	37.56	0.67		LD	102.48	0.27

† Root Mean Square Error (RMSE)
‡ Nitrate Reductase (NR); Ammonium Oxidation (AO); and β-glucosidase (BG)
§ High Disturbance (HD); Low Disturbance (LD)

Enzyme Simulations

With the selected explanatory covariates, empirical enzyme activity models were generated to produce full season biological simulations based on daily datasets, produced from high frequency sampling and 2D - spline interpolation functions (Figure 8 & 9). Across both years, seasonal variations and cyclical dynamics were distinguished, but further calibration is needed to produce more reliable outputs. As seen in both 2017 and 2018 outputs (Figures 8 & 9), enzyme activities can breach the negative threshold, which is a theoretical impossibility. In 2017 and 2018, simulated enzyme values fell outside of the calibration ranges a majority of the time, ranging from 7.22 – 74.23% in 2017 and 48.72 – 94.87% in 2018 (Table 8). This issue is due to limited selected training dates, and the failure to capture the minimum and maximum thresholds to ensure reasonable output limits.

Table 8: Proportion of simulated values that fell outside of the enzyme model calibration range in all years and treatments.

Year	Treatment	NR†	AO	BG
2017	HD‡	28.87%	7.22%	39.18%
	LD	74.23%	62.89%	48.45%
2018	HD	48.72%	60.26%	60.26%
	LD	61.54%	94.87%	71.79%

† Nitrate Reductase (NR); Ammonium Oxidation (AO); and β-glucosidase (BG)
‡ High Disturbance (HD); Low Disturbance (LD)

Further analysis of the daily enzyme outputs revealed a trend of diverging model outputs during extended periods of time between selected training dates. As seen in 2017, between DOY 225 and 265, large gaps and poorer calibrated models can lead to accumulated errors within the short time series intervals. A solution to this may be more equivalent time slots allocated to the seasonal training dates, as seen in the 2018 models, leading to less deviation from the true value. Also, from the analysis of the generated enzyme simulations, a minimum recommended sampling time interval of 20 days should be set to reduce major deviations between calibration data. In addition to seasonal trends, lower disturbance tillage systems were observed to have exaggerated dynamic fluxes from day to day intervals, as seen in both Table 8 and Figures 8 & 9. This phenomenon could be an expression of more heterogeneous soil profile, and indicate higher variability within collected soil samples than the high disturbance, homogenous systems. Especially in cases where consistent weather condition occurred throughout the season.

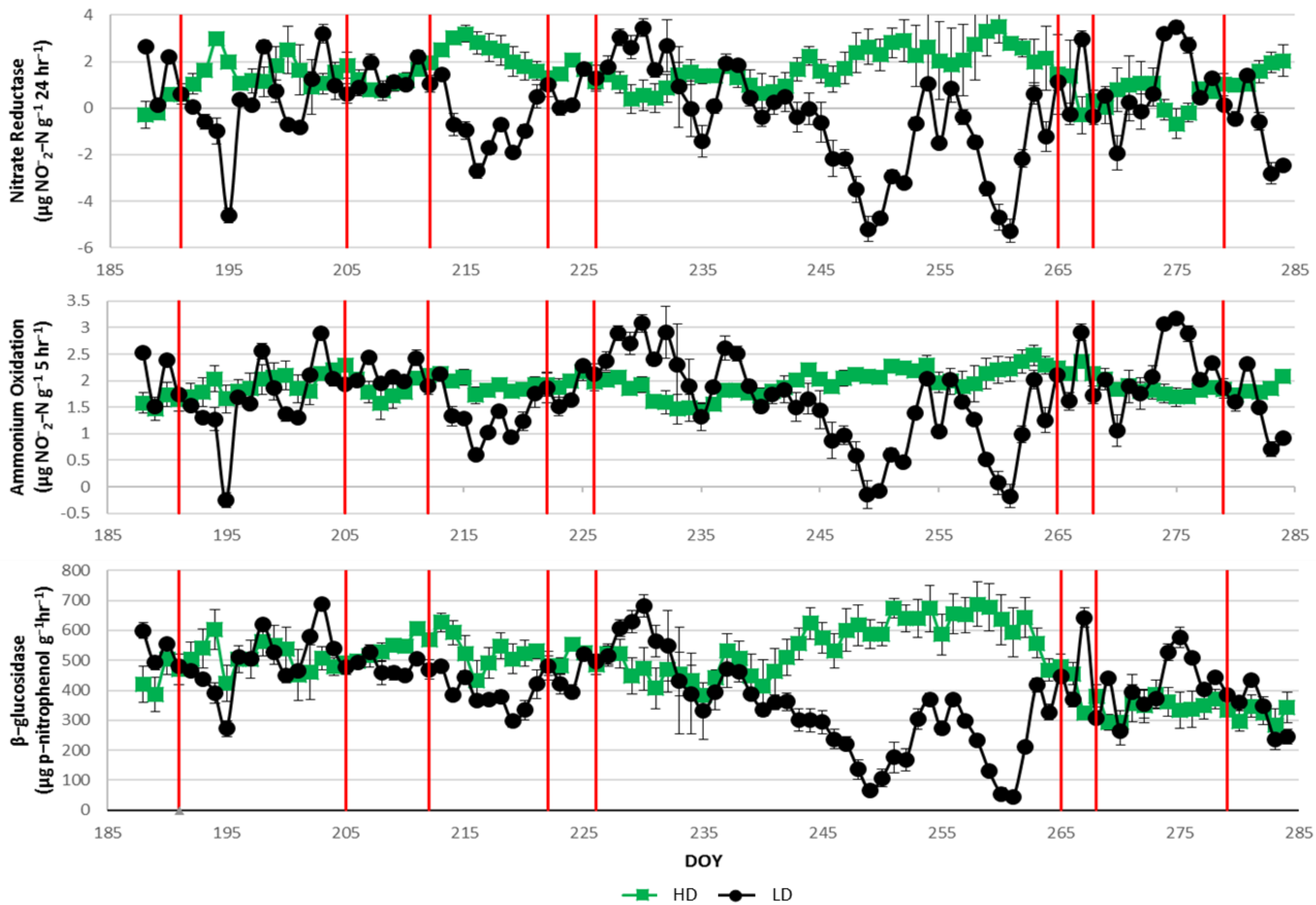

Figure 8: 2017 full season soil enzyme simulations based on models generated from initial training sets. Red lines indicate enzyme sampling dates. Error bars are represented by standard deviations (n = 3 replicates per treatment per sample date). Note: Different scaling among graphs.

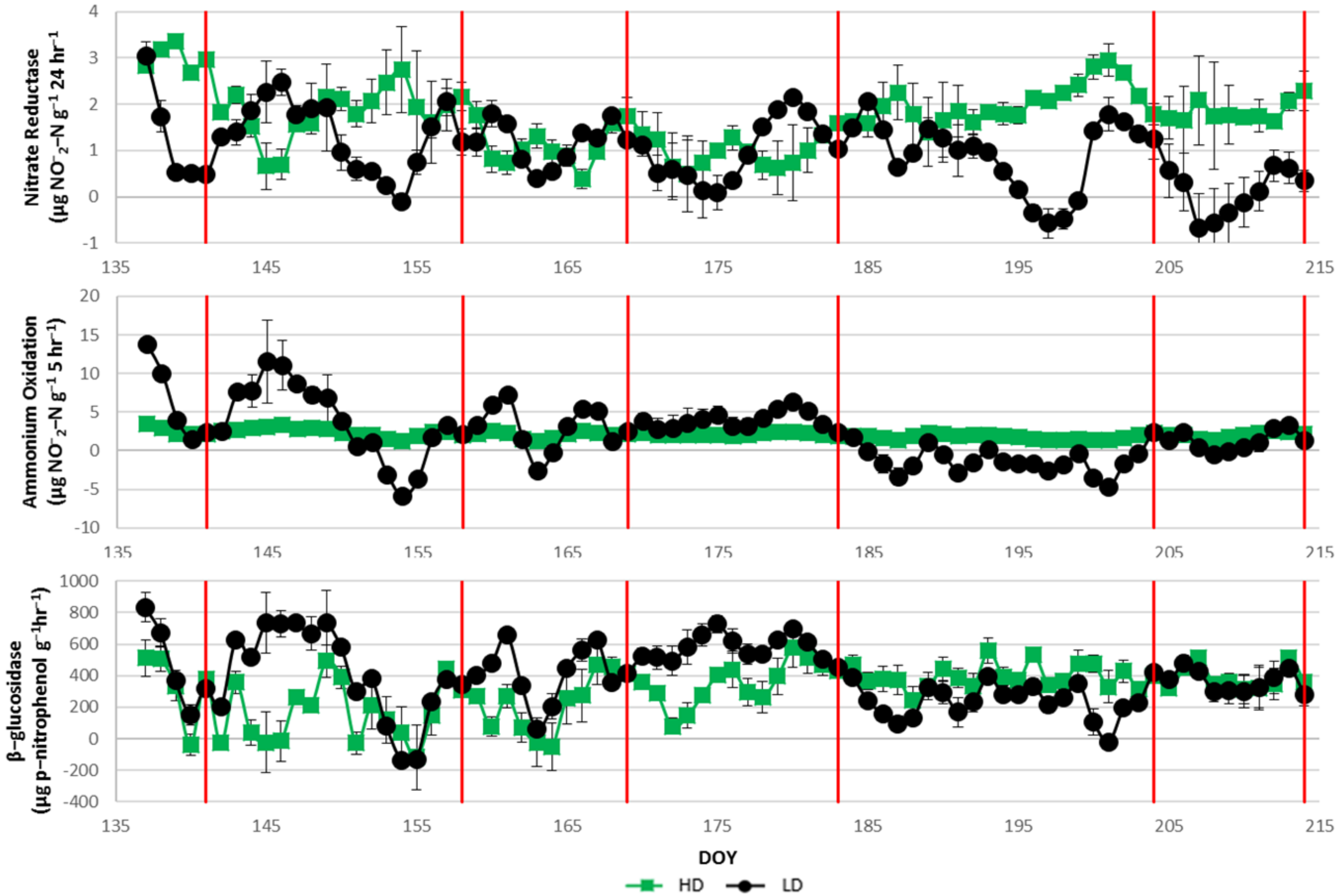

Figure 9: 2018 full season soil enzyme simulations based on models generated from initial training sets. Red lines indicate enzyme sampling dates. Error bars are represented by standard deviations (n = 3 replicates per treatment per sample date). Note: Different scaling among graphs.

Enzyme Model Spectral Density Analysis

From the 12 enzyme model outputs from 2017 and 2018, spectral density analyses were run creating 12 periodograms, allowing us to begin to infer on any possible cyclical dynamics within the model enzyme activities (Figure 10). All model outputs were assessed and plotted individually, and can be seen in Figure B3 & B4. Across all treatments and years, spectral density spikes, breaching the 95% confidence interval, consistently appeared between the ranges of 10 -15 day forecasting periods, indicating repeated shifts in the seasonal enzyme activity at those time intervals. In addition to the first initial spikes, periodograms with increasing trends past the 25 day period interval indicates that there may be larger cyclical patterns within the temporal dataset. Though the spectral densities seemingly reveal consistent results, the initial models need to be further calibrated and validated with broad spectrum datasets and real phenomenon. At the same time, larger time intervals between sampling can also lead to error accumulation over time in the enzyme model outputs. Alternatively, even with imperfectly calibrated initial models, the results shown in the periodograms below provide more justification that there is a reason to study microbial enzyme activities at small time scales. In addition, we can further infer that the spikes we are seeing are not artifacts of the sampling frequencies during data collection, due to the fact that whether training date frequencies were mixed, like in 2017, or stratified evenly throughout the year in 2018, we saw consistent results across both years in the periodograms.

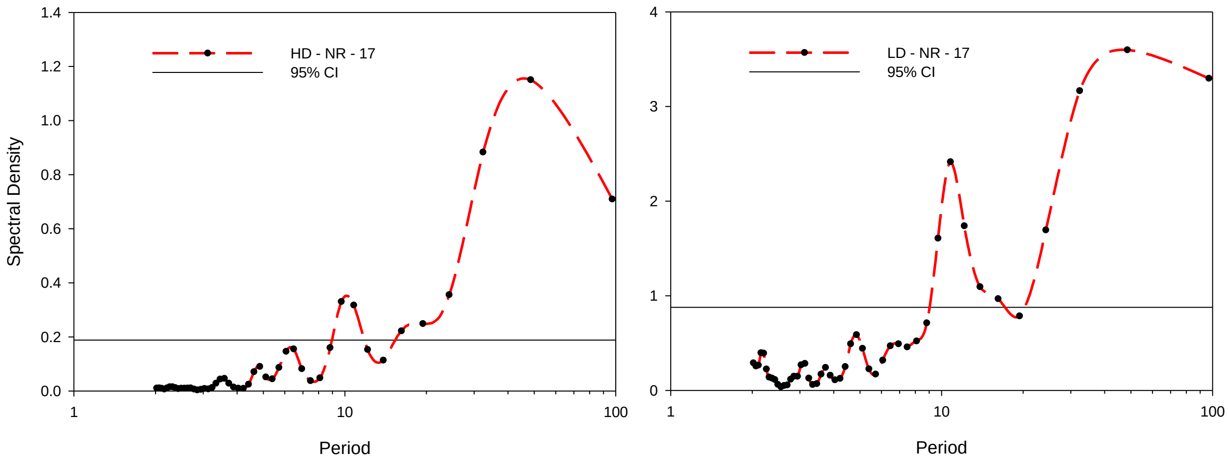

Figure 10: Spectral density periodograms of 2017 empirical enzyme activity models across both treatments and years. High Disturbance (HD) Low Disturbance (LD), Nitrate Reductase (NR), Ammonium Oxidation (AO), β-glucosidase (BG), 2017 (17), and 2018 (18).

Conclusion

Over the course of the study above, main objectives covering the effect of treatment and time, and the generation of enzyme simulations from empirical models gave us new insight on the testing and use of soil microbial enzyme activities as possible soil quality indicators. In summary, there were no significant differences between enzyme activities across both treatment and date effects. Though trends appeared, high variability and low sample sizes pose challenges for conducting confident means separation tests. During the assessment of explanatory covariates for generating empirical models, a greater dependency on environmental covariates, such as daily maximum and daily average temperatures, was observed in both 2017 and 2018, where chemical explanatory variables, limited to the nitrogen pools and phosphorus, were only reliable indicators in 2018. From the explanatory variable assessment and model generation, spectral density analysis revealed consistent cyclical trends across all treatments and years. Though convincing results appeared, the relative values within the models and spectral densities can only be used as a justification that there is reason to study the microbial community at short time scales, but cannot be proven until further calibration and validation is pursued. If soil enzyme activities can be appropriately screened for seasonal variability, and characterized based on site specific conditions, their use as soil quality indices can be further explored. Based on our enzyme activity analyses, protocols should include multiple sampling observations throughout the year to provide insight on nutrient cycling and fixation processes, and our management effects within season (i.e. disturbance levels) and between seasons (i.e. crop phase).

References

Al-Kaisi, M.M., and X. Yin. Tillage and crop residue effects on soil carbon and carbon dioxide emission in corn–soybean rotations. https://pdfs.semanticscholar.org/4a9f/018f5a6b838c826638e80158742f90cd04ff.pdf (accessed 26 April 2018).

Aon, M.A., and A.C. Colaneri. 2001. II. Temporal and spatial evolution of enzymatic activities and physico-chemical properties in an agricultural soil. Appl. Soil Ecol. 18(3): 255–270. doi: 10.1016/s0929-1393(01)00161-5.

Aşkın, T., and R. Kızılkaya. 2006. Assessing spatial variability of soil enzyme activities in pasture topsoils using geostatistics. Eur. J. Soil Biol. 42(4): 230–237. doi: 10.1016/J.EJSOBI.2006.02.002.

Bergstrom, D.W., C.M. Monreal, and D.J. King. 1998. sensitivity of soil enzyme activities to conservation practices. Soil Sci. Soc. Am. J. 62(5): 1286. doi: 10.2136/sssaj1998.03615995006200050020x.

Bolton Jr, H., L.F. Elliott, R.I. Papendick, and D.F. Bezdicek. 1985. Soil microbial biomass and selected soil enzyme activities: effect of fertilization and cropping practices.

Daigh, A., and J. DeJong-Hughes. 2017. Upper Midwest Tillage Guide-Tillage implements : Soil management and health : Agriculture : University of Minnesota Extension. Univ. Minnesota Ext. https://www.extension.umn.edu/agriculture/soils/tillage/tillage-guide-implements/ (accessed 6 March 2018).

Daigh, A, J. DeJong-Hughes, D. Gatchell, N. Derby, R. Alghamdi, Z. Leitner et al. 2019. Crop and Soil Responses to On-farm Conservation Tillage Practices in the Upper Midwest. J. Agricultural and Environmental Letters. doi: 10.2134/ael2019.03.0012.

Debosz, K., P.H. Rasmussen, and A.R. Pedersen. 1999. Temporal variations in microbial biomass C and cellulolytic enzyme activity in arable soils: effects of organic matter input. Appl. Soil Ecol. 13(3): 209–218. doi: 10.1016/s0929-1393(99)00034-7.

Deng, S.P., and M.A. Tabatabai. 1997. Effect of tillage and residue management on enzyme activities in soils: III. Phosphatases and arylsulfatase. Biol. Fertil. Soils 24(2): 141–146. doi: 10.1007/s003740050222.

Dick, R.P., and L. Al-Amoodi. 2011. Methods of Soil Enzymology.

Doran, J.W., D.C. Coleman, D.F. Bezdicek, B.A. Stewart, and R.P. Dick. 1994. Soil enzyme activities as indicators of soil quality. Defining soil quality for a sustainable environment. Soil Science Society of America and American Society of Agronomy. p. 107–124

Emmerling, C., T. Udelhoven, and D. Schröder. 2001. Response of soil microbial biomass and activity to agricultural de-intensification over a 10 year period. Soil Biol. Biochem. 33(15): 2105–2114. doi: 10.1016/S0038-0717(01)00143-2.

Follett, R.F., and D.S. Schimel. 1989. Effect of tillage practices on microbial biomass dynamics. Soil Sci. Soc. Am. J. 53(4): 1091–1096.

Grafton, K., et al. 2012. Recommended Chemical Soil Test Procedures for the North Central Region.

Hobbs, P.R., K. Sayre, and R. Gupta. 2008. The role of conservation agriculture in sustainable agriculture. Philos. Trans. R. Soc. B-Biological Sci. 363(1491): 543–555. doi: 10.1098/rstb.2007.2169.

Hoffman, W. 1979. Ancient Lake Agassiz and the Red River Valley. https://www.mbbnet.umn.edu/hoff/hoff_agassiz.html (accessed 17 April 2019).

Kandeler, E., D. Tscherko, and H. Spiegel. 1999. Long-term monitoring of microbial biomass, N mineralisation and enzyme activities of a Chernozem under different tillage management. Springer-Verlag.

Martens, D.A., J.B. Johanson, and W.T. Frankenberger. 1992. Production and persistence of soil enzymes with repeated addition of organic residues. soil sci. 153(1): 53–61. doi: 10.1097/00010694-199201000-00008.

Melero, S., R. López-Garrido, J.M. Murillo, and F. Moreno. 2009. Conservation tillage: Short- and long-term effects on soil carbon fractions and enzymatic activities under Mediterranean conditions. Soil Tillage Res. 104(2): 292–298. doi: 10.1016/J.STILL.2009.04.001.

North Dakota Agricultural Weather Network (NDAWN). 2019. NDAWN Station: Wahpeton, ND. Available online at https://ndawn.ndsu.nodak.edu/station-info.html?station=63 (Accessed 3 March 2019).

PRISM Climate Group - Oregon State University. USDA Plant Hardiness Zone Map. USDA Agric. Res. Serv. http://planthardiness.ars.usda.gov/PHZMWeb/ (accessed 6 March 2018).

R Core Team, 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/

Salam, A.K., A. Katayama, and M. Kimura. Soil Science and Plant Nutrition Activities of some soil enzymes in different land use systems after deforestation in hilly areas of West Lampung, South Sumatra, Indonesia. doi: 10.1080/00380768.1998.10414429.

Soil Quality: Indicators: Soil Enzymes. 2011. http://soilquality.org/indicators/soil_enzymes.html (accessed 17 April 2019).

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at the following link: https://websoilsurvey.sc.egov.usda.gov/.

Swedrzynska, D., and I. Malecka-Jankowiak. 2017. The impact of tillaging spring barley on selected chemical, microbiological, and enzymatic soil properties. Polish J. Environ. Stud. 26(1): 303–313. doi: 10.15244/pjoes/64911.

Tabatabai, M.A., Tabatabai, and M. Ali. 2003. Soil Enzymes. Encyclopedia of Environmental Microbiology. John Wiley & Sons, Inc., Hoboken, NJ, USA

Venables, W.N., Ripley, B.D., n.d. Modern Applied Statistics with S. Fourth Edition. Springer, New York, NY, USA.

Wallenius, K., H. Rita, A. Mikkonen, K. Lappi, K. Lindström, et al. 2011. Effects of land use on the level, variation and spatial structure of soil enzyme activities and bacterial communities. Soil Biol. Biochem. 43(7): 1464–1473. doi:10.1016/J.SOILBIO. 2011.03.018.

Wickham, H., 2011. The split-apply-combine strategy for data analysis. J. Stat. Softw. 40, 1–29.

Zhang, Y., L. Chen, Z. Wu, and C. Sun. 2011. Kinetic parameters of soil β-glucosidase response to environmental temperature and moisture regimes. Rev. Bras. Ciência do Solo 35(4): 1285–1291. doi: 10.1590/S0100-06832011000400022.

GENERAL CONCLUSIONS

The general goal of this research was to determine temporal fluctuations, cycles, and driving forces behind empirical and simulated microbial parameter outputs. Where our assessments allowed us to speculate on how microbial communities and there ecosystems functions react to soil disturbance, soil physiochemical states, and weather conditions over the course of a growing season. Additionally, allowing us to infer on whether current microbial sampling procedures are able to accurately assess microbial community concentrations with a yearly sampling protocols, or if high frequency sampling (i.e. sub-monthly) is required to accurately assess soil microbial communities as soil quality indicators. From the analyses in the chapters above, significant seasonal microbial fluctuations were identified and characterized at the sub-seasonal time scale. Strong cyclical characteristic were evident within both PLFA and enzyme analyses, where both physiochemical and weather condition covariates indicated major relationships with microbial dynamics. Among 2017 and 2018 PLFA results, the most notable outcomes included shorter cycles with major relationships with soil physical states and weather conditions for Actinomycetes and Bacteria PLFA categories, where more frequent sampling (i.e. bi-weekly to monthly) may be required for temporal characterization. Fungal categories including, TMA, F:B, AMF, and Fungi, shifted at longer cycles with relationships tied to soil chemical properties, where sampling frequencies for temporal characterization can be less frequent (i.e. bi-monthly). Additional trends where major and minor PLFA groups (i.e. Total Bacteria vs. Actinomycetes) indicated varying levels of application when evaluating levels of management effects on soil health, such as tillage treatments or crop rotation. Comparatively, seasonal enzyme activity analysis revealed a broader application of assessing ecosystem functions and possible community interactions with developing crops or seasonal management shifts. Sampling should take place intermittently over the course of the season where evident fertilizer, crop, and weather patterns exist.

As a whole, continued research, and further calibration and validation of microbial assessment will advance our insight on the use of PLFA and enzyme activities as quality soil health indicators. Moving forward, using PLFA indices to conclude on direct and indirect management effects on community fluctuations, and enzyme activities to monitor broad scale microbial ecosystem functions will continually advance our efforts to produce management systems where high production and soil sustainability are achievable.

APPENDIX A. CHAPTER 1

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Category        Index   Multiplier      Peaks   Microbial Types General Soil for PLFAD2 v2.00 2/17/2017
Non FAME        0       1       Phthalate 1     Phthalate 2
General FAME    0       1       10:0    11:0    12:0    13:0    15:0 aldehyde
                        14:0    16:1 w9c aldehyde       16:0 aldehyde
                        15:0    16:1 w7c alcohol        16:0 N alcohol  16:0    17:0
                        18:0    19:0    20:0    21:0    22:0    23:0    24:0
AM Fungi        1       1       16:1 w5c
Gram Negative   1       1       10:0 2OH        10:0 3OH        12:1 w8c        12:1 w5c
                        13:1 w5c        13:1 w4c        13:1 w3c        12:0 2OH
                        14:1 w9c        14:1 w8c        14:1 w7c        14:1 w5c
                        15:1 w9c        15:1 w8c        15:1 w7c        15:1 w6c
                        15:1 w5c        14:0 2OH        16:1 w9c        16:1 w7c        14:0 3OH
                        16:1 w6c        16:1 w4c        16:1 w3c        17:1 w9c        17:1 w8c
                        17:1 w7c        17:1 w6c        17:0 cyclo w7c  17:1 w5c
                        17:1 w4c        17:1 w3c        16:0 2OH        18:0 cyclo w6c
                        18:1 w8c        18:1 w7c        18:1 w6c        18:1 w5c
                        18:1 w3c        19:1 w9c        19:1 w8c        19:1 w7c
                        19:1 w6c        19:0 cyclo w7c  19:0 cyclo w6c
                        20:1 w9c        20:1 w8c        20:1 w6c
                        20:1 w4c        20:0 cyclo w6c  21:1 w9c        21:1 w8c
                        21:1 w6c        21:1 w5c        21:1 w4c        21:1 w3c
                        22:1 w9c        22:1 w8c        22:1 w6c        22:1 w5c
                        22:1 w3c        22:0 cyclo w6c  24:1 w9c        24:1 w7c
                        11:0 iso 3OH    14:0 iso 3OH    17:0 iso 3OH
Methanotroph    1       1       16:1 w8c
Eukaryote       1       1       15:4 w3c        15:3 w3c        16:4 w3c        16:3 w6c
                        18:3 w6c        19:4 w6c        19:3 w6c        19:3 w3c
                        20:4 w6c        20:5 w3c        20:3 w6c        20:2 w6c
                        21:3 w6c        21:3 w3c        22:5 w6c        22:6 w3c
                        22:4 w6c        22:5 w3c        22:2 w6c        23:4 w6c
                        23:3 w6c        23:3 w3c        23:1 w5c        23:1 w4c
                        24:4 w6c        24:3 w6c        24:3 w3c        24:1 w3c
                        18:4 w3c
Fungi   1       1       18:2 w6c
Gram Positive   1       1       11:0 iso        11:0 anteiso    12:0 iso        12:0 anteiso
                        13:0 iso        13:0 anteiso    14:1 iso w7c    14:0 iso
                        14:0 anteiso    15:1 iso w9c    15:1 iso w6c    15:1 anteiso w9c
                        15:0 iso        15:0 anteiso    16:0 iso        16:0 anteiso
                        17:1 iso w9c    17:0 iso        17:0 anteiso    18:0 iso
                        17:1 anteiso w9c        17:1 iso w10c   17:1 anteiso w7c
                        18:1 w9c        19:0 cyclo w9c
                        19:0 iso        19:0 anteiso    20:0 iso        22:0 iso
Actinomycetes   1       1       16:0 10-methyl  17:1 w7c 10-methyl      17:0 10-methyl  22:0 10-methyl
                        18:1 w7c 10-methyl      18:0 10-methyl  19:1 w7c 10-methyl      20:0 10-methyl
```

Figure A1: List of fungal and bacterial biomarkers used for characterization of general PLFA categories.

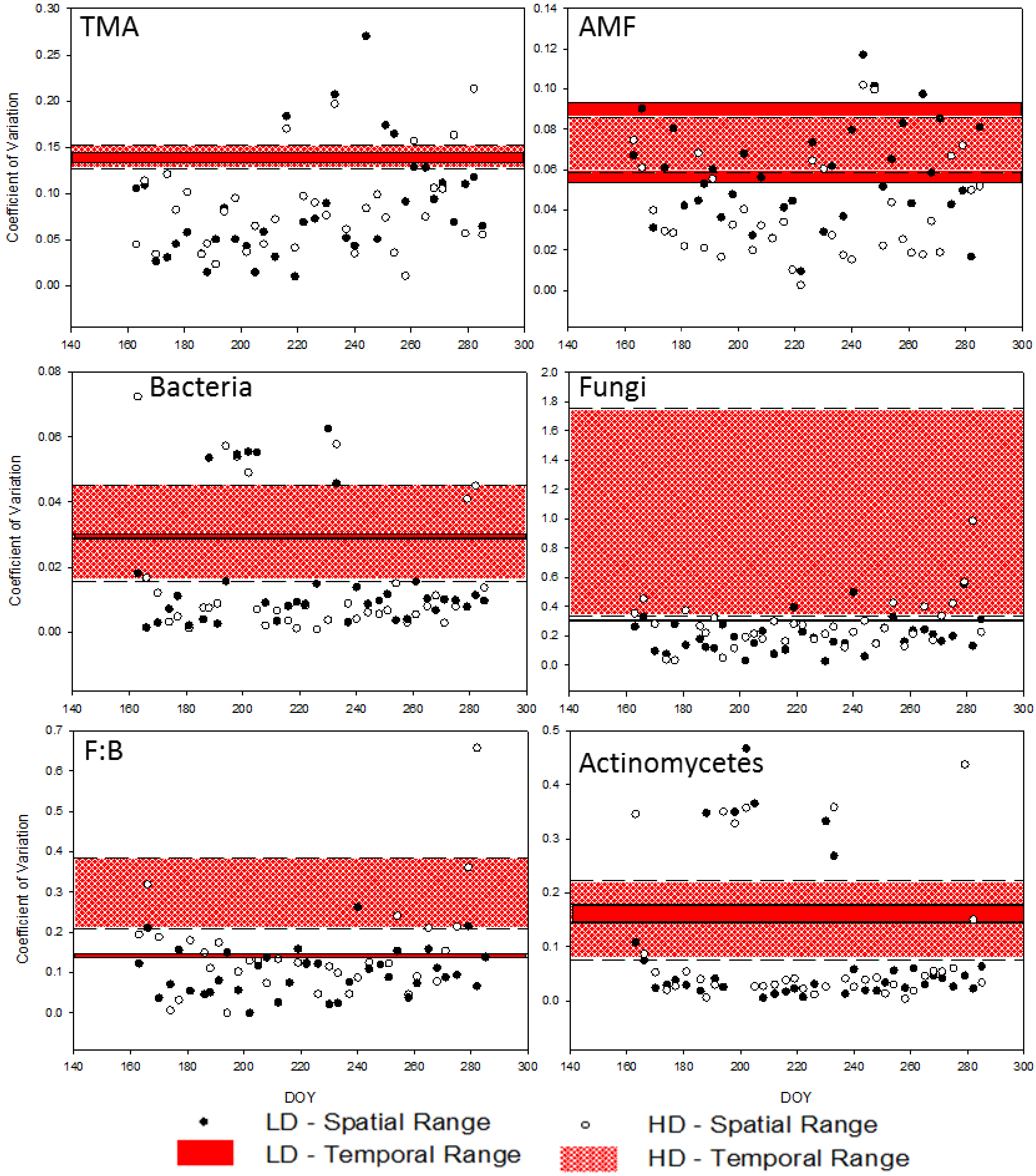

Figure A2: 2017 Total Microbial Abundance (TMA), left, and Arbuscular Mycorrhizal Fungi (AMF), (right), coefficient of variation diagrams. Individual dots represent spatial variability for individual dates and treatments [High Disturbance (HD, and Low Disturbance (LD)], while horizontal bars represent temporal treatment variability ranges.

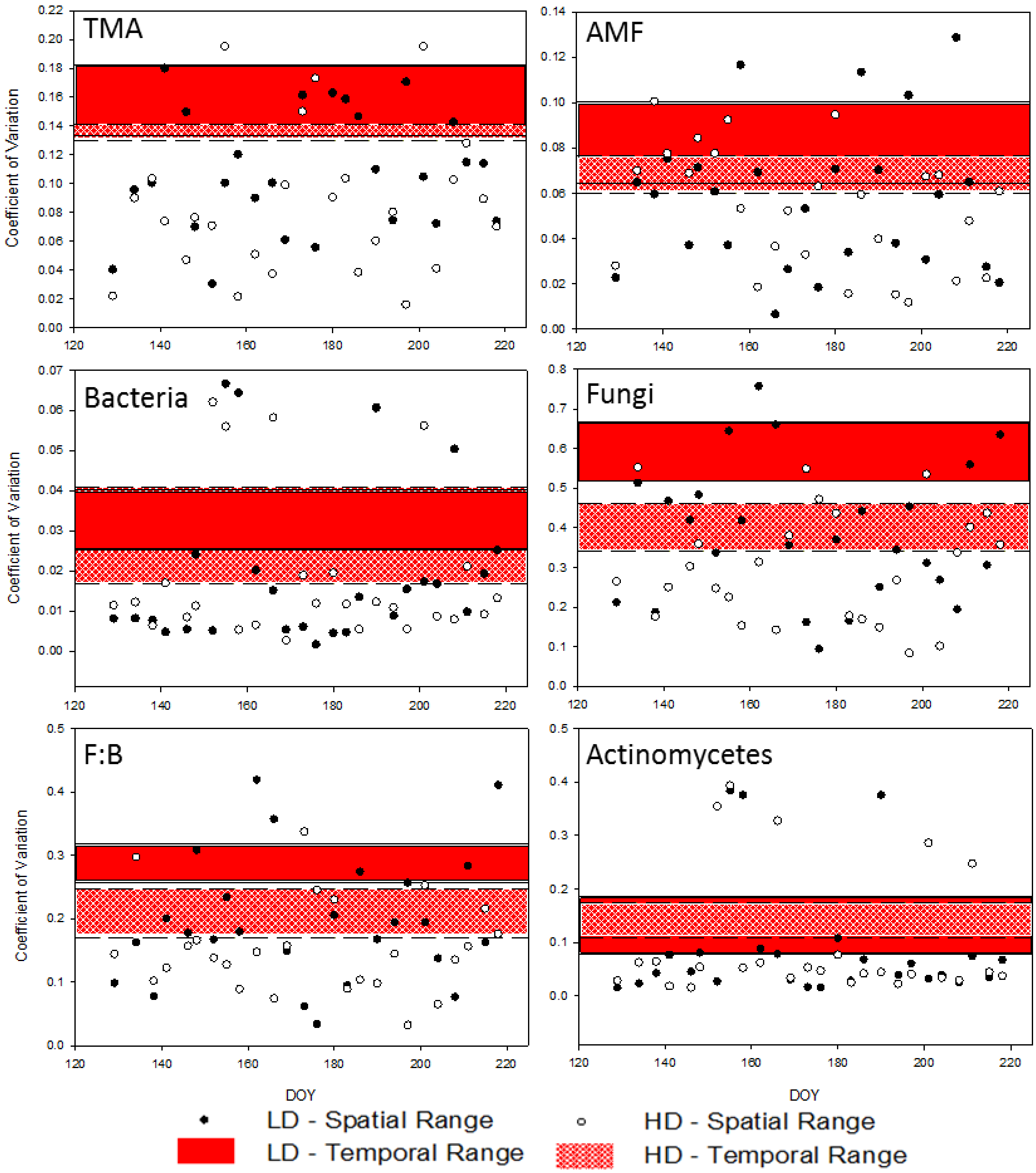

Figure A3: 2018 Total Microbial Abundance (TMA), left, and Arbuscular Mycorrhizal Fungi (AMF), (right), coefficient of variation diagrams. Individual dots represent spatial variability for individual dates and treatments [High Disturbance (HD, and Low Disturbance (LD)], while horizontal bars represent temporal treatment variability ranges.

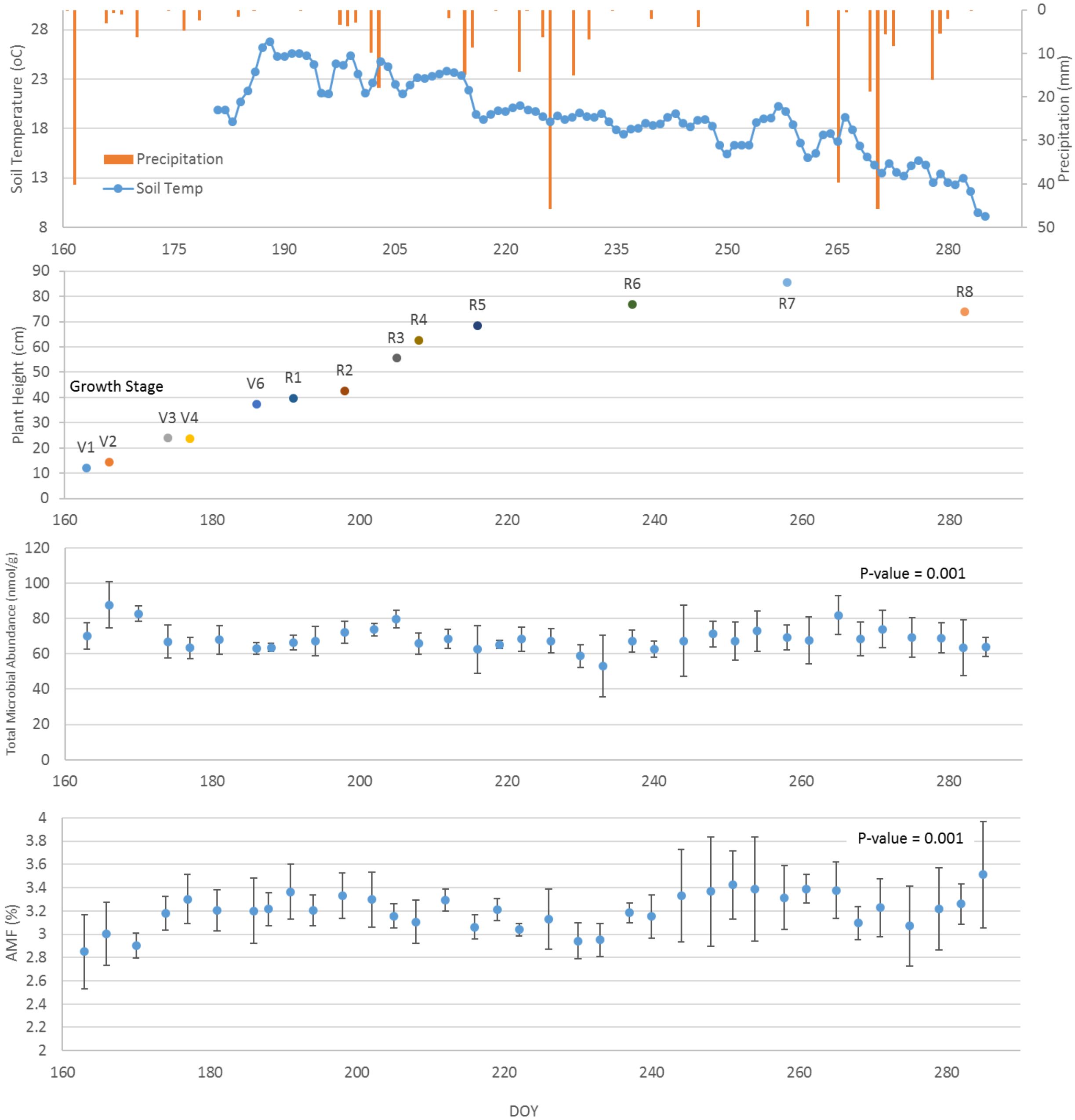

Figure A4: Representation of 2017 Total Microbial Abundance (TMA) and Arbuscular Mycorrhizal Fungi (AMF) seasonal means plotted with physical conditions (i.e. precipitation and soil temperature) and plant growth stages. Error bars represent standard deviations (n = 6).

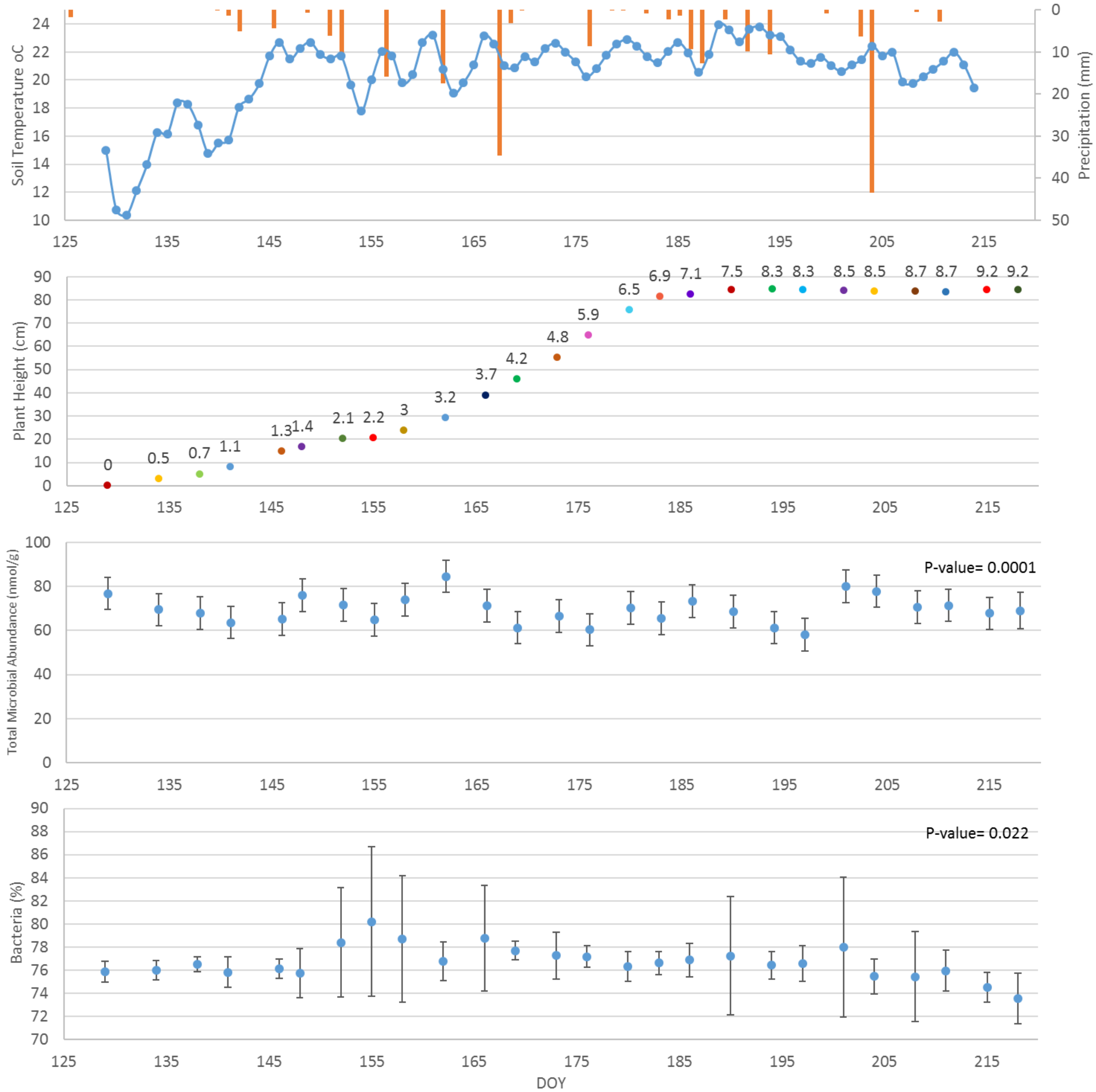

Figure A5: Representation of 2018 Total Microbial Abundance (TMA) and Bacteria seasonal means plotted with physical conditions (i.e. precipitation and soil temperature) and plant growth stages. Error bars represent standard deviations (n = 6).

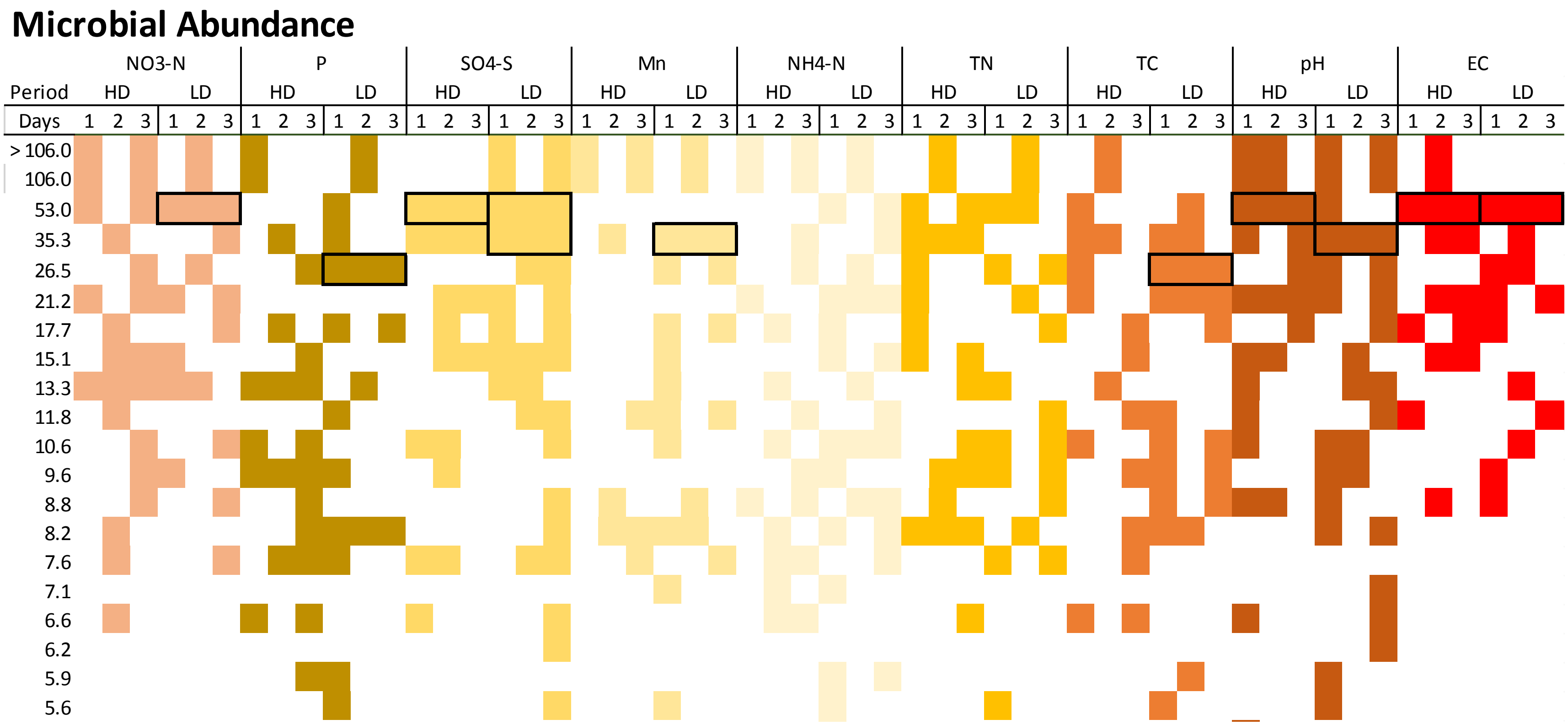

Figure A6: 2017 TMA and chemical covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

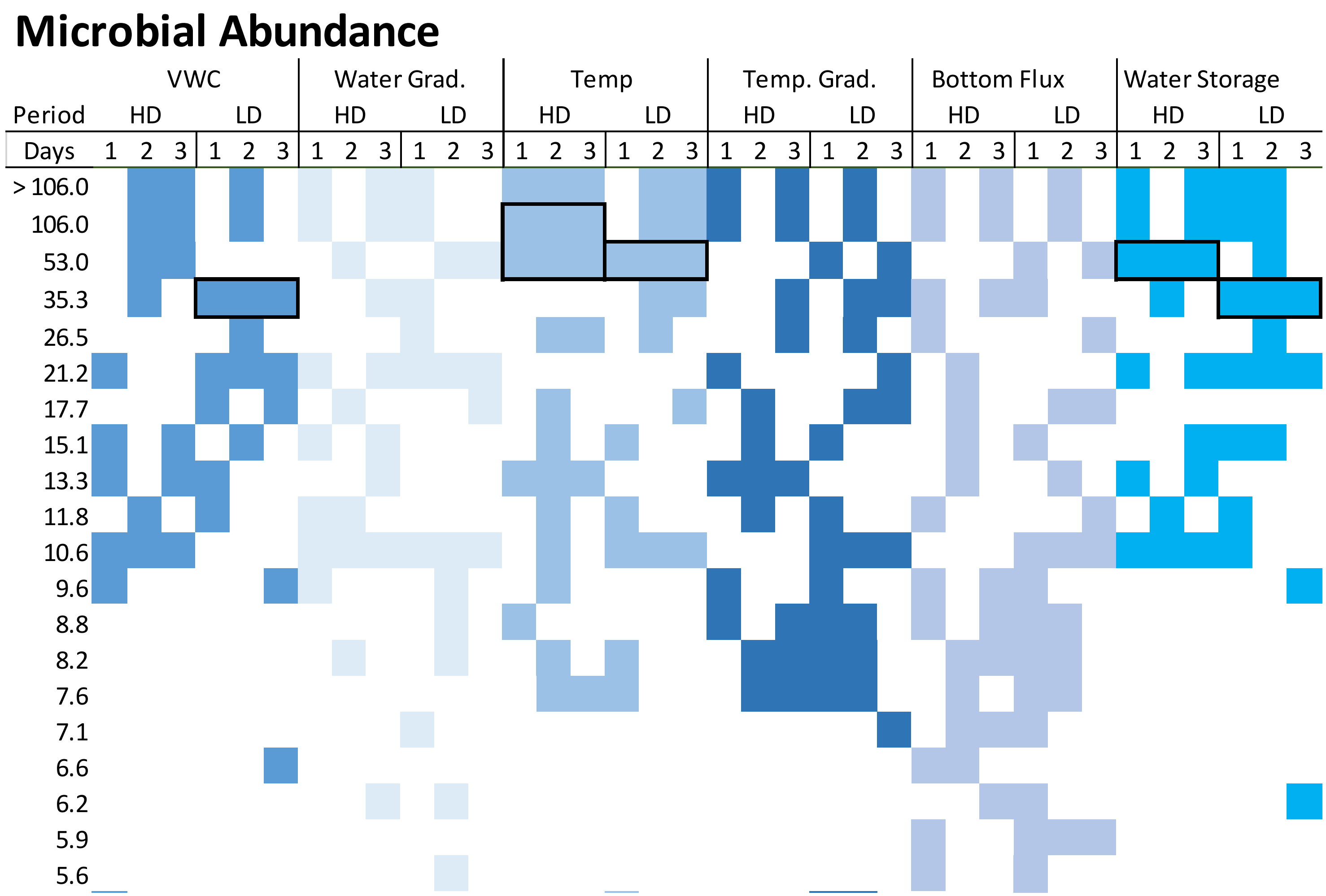

Figure A7: 2017 TMA and physical conditions covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

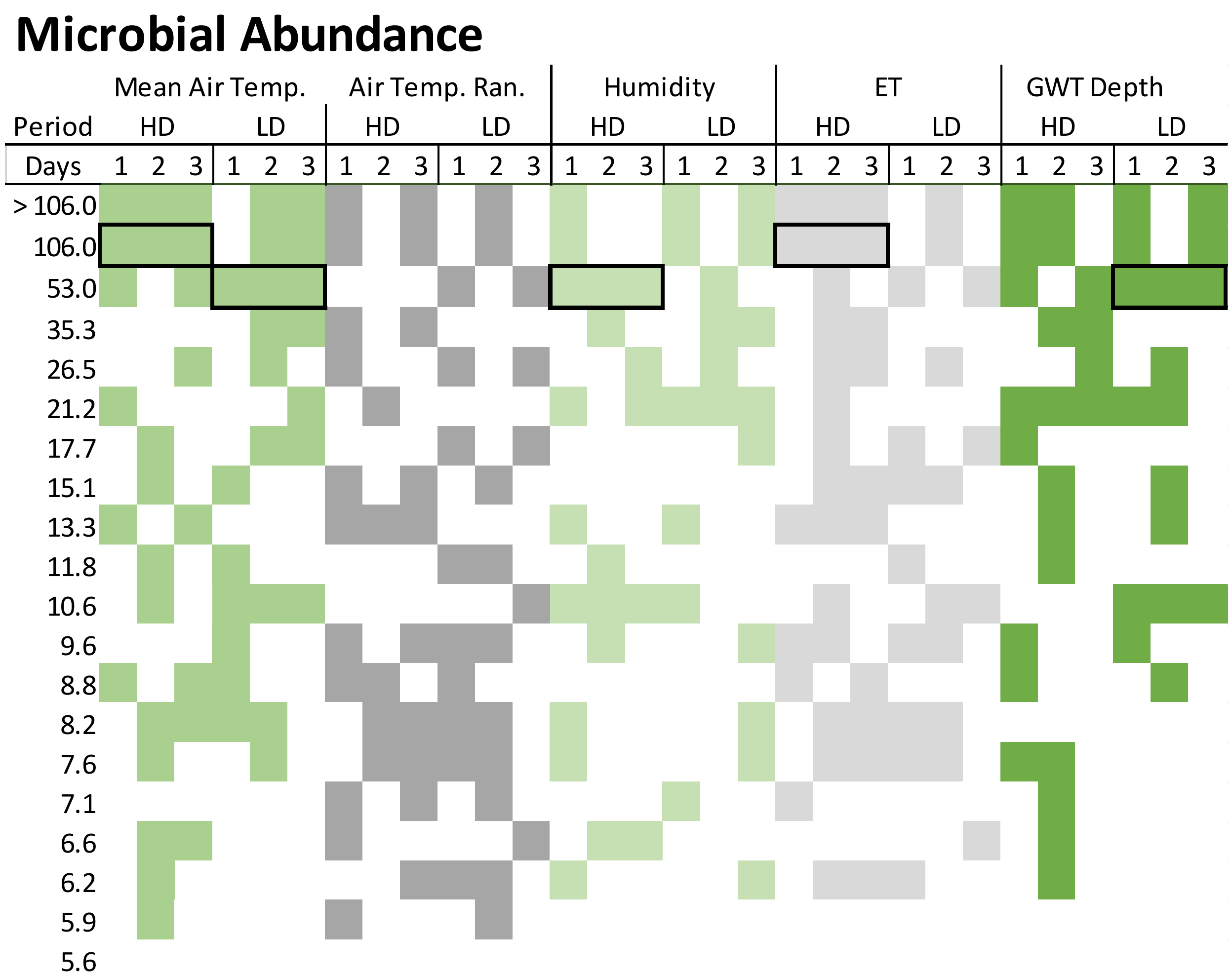

Figure A8: 2017 TMA and weather condition covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

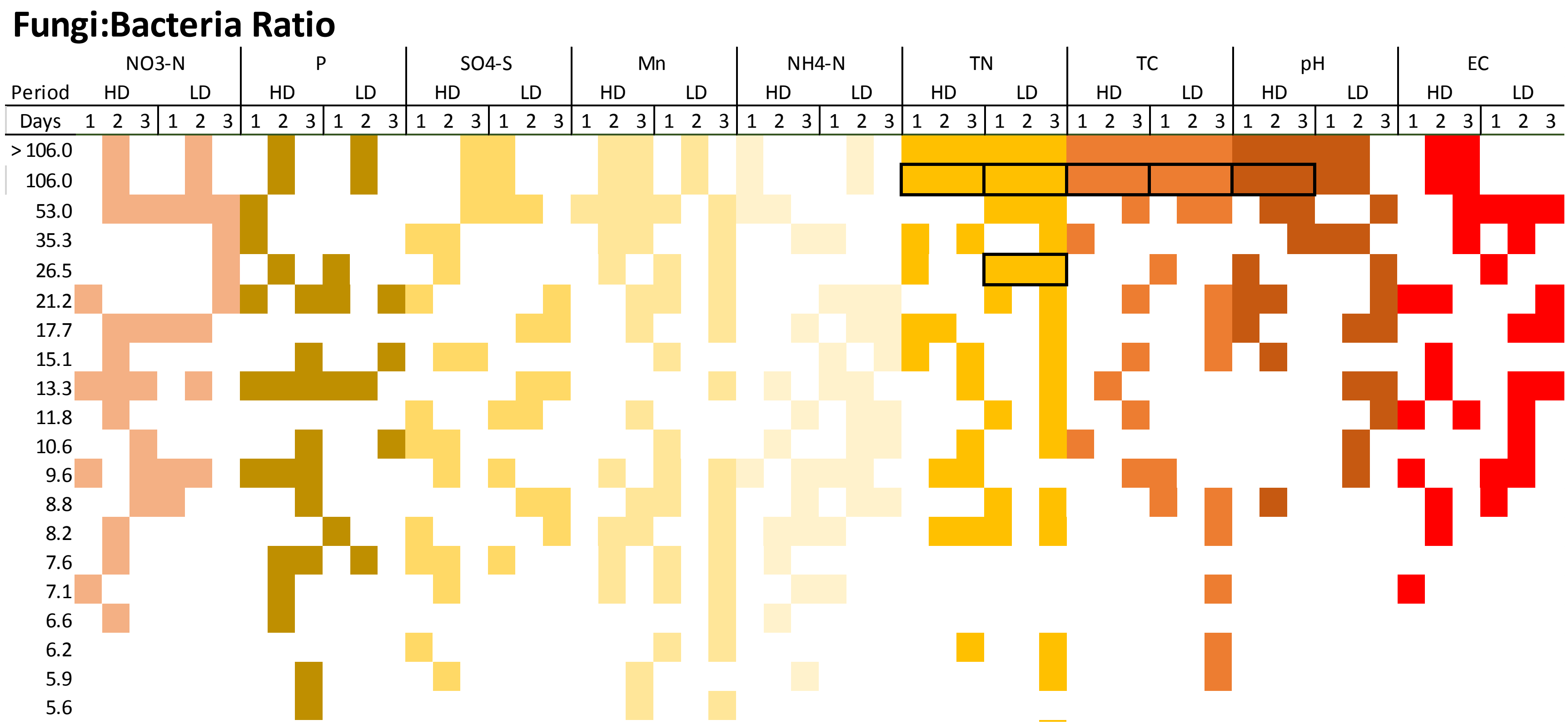

Figure A9: 2017 F:B and chemical covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

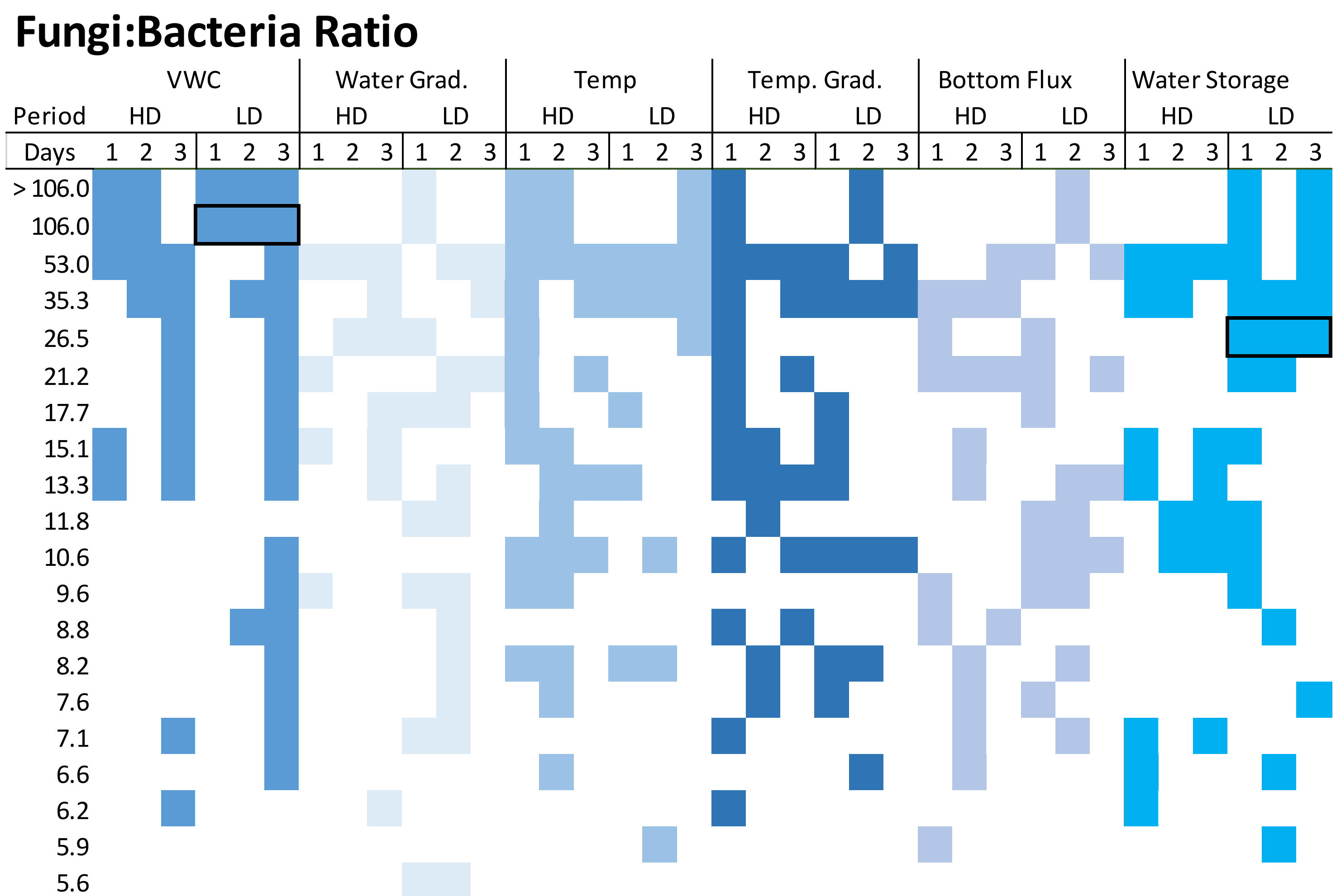

Figure A10: 2017 F:B and physical conditions covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

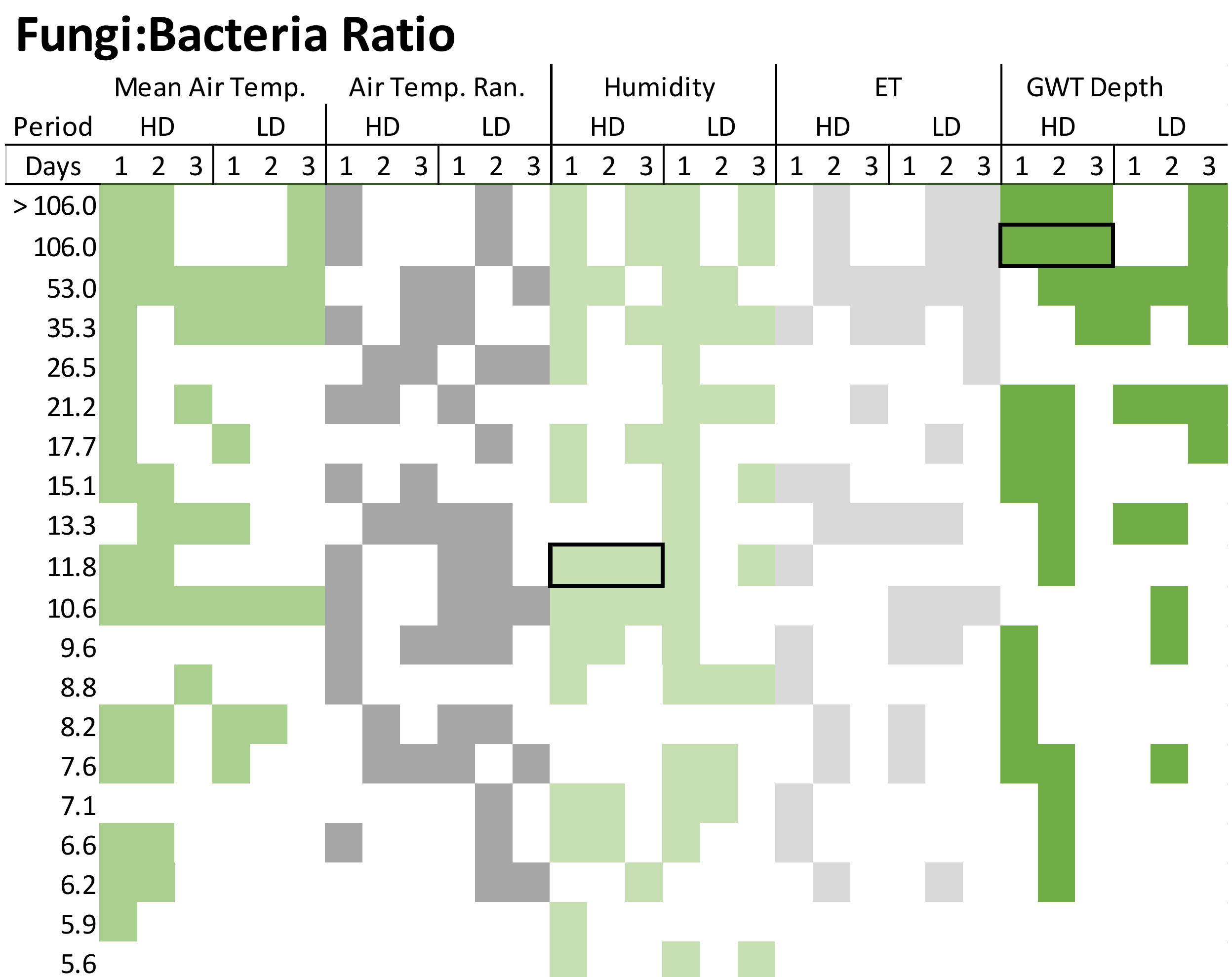

Figure A11: 2017 F:B and weather condition covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

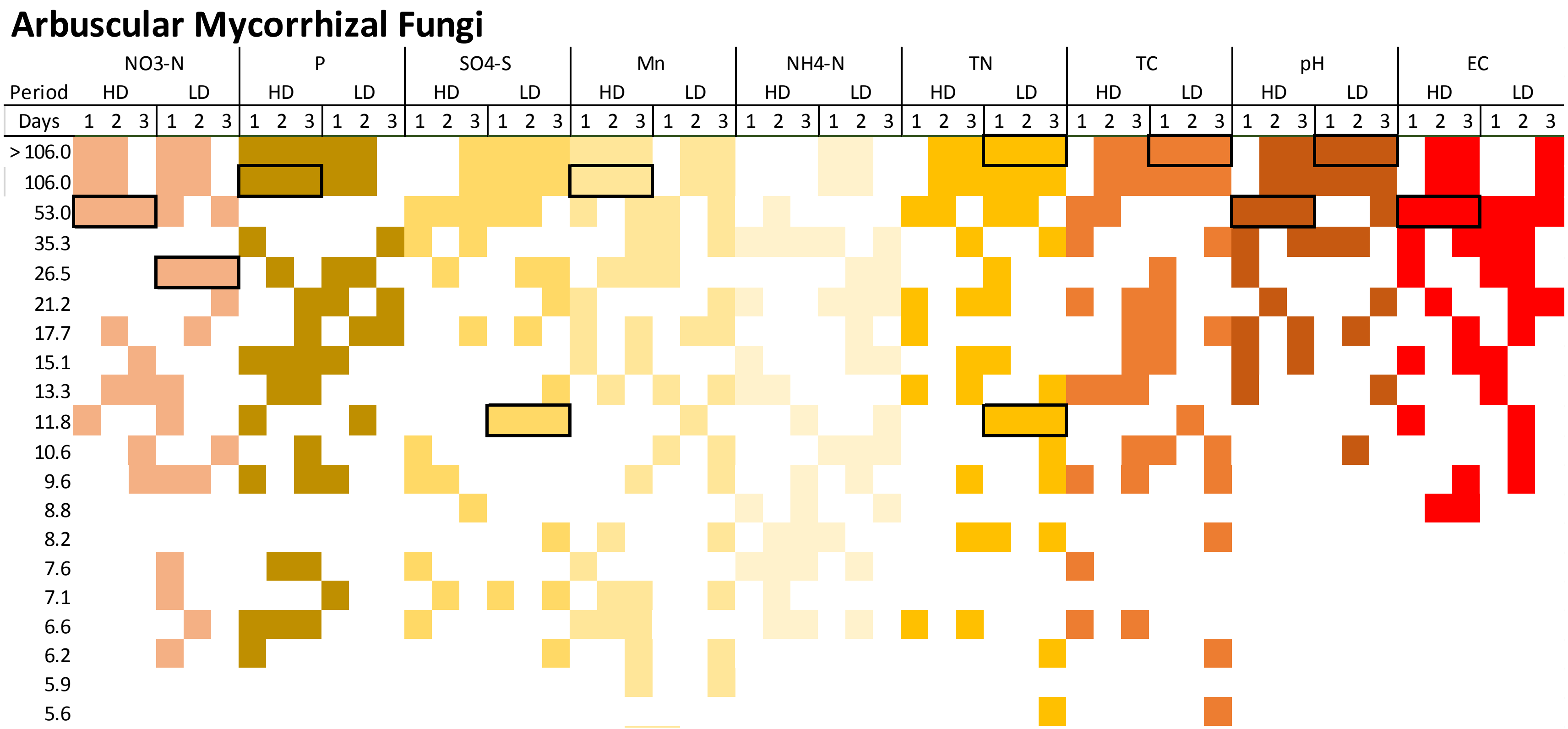

Figure A12: 2017 AMF and chemical covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

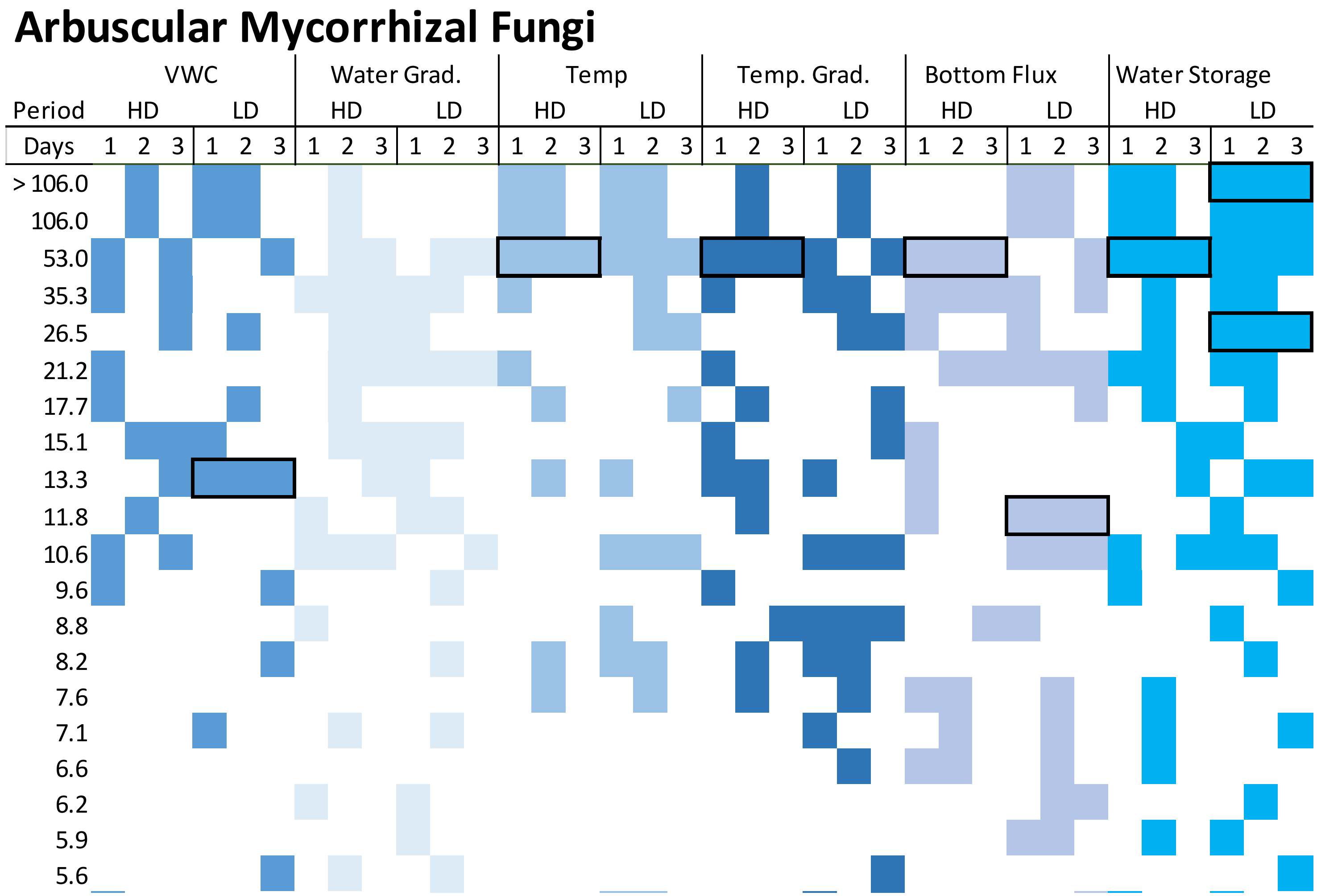

Figure A13: 2017 AMF and physical conditions covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

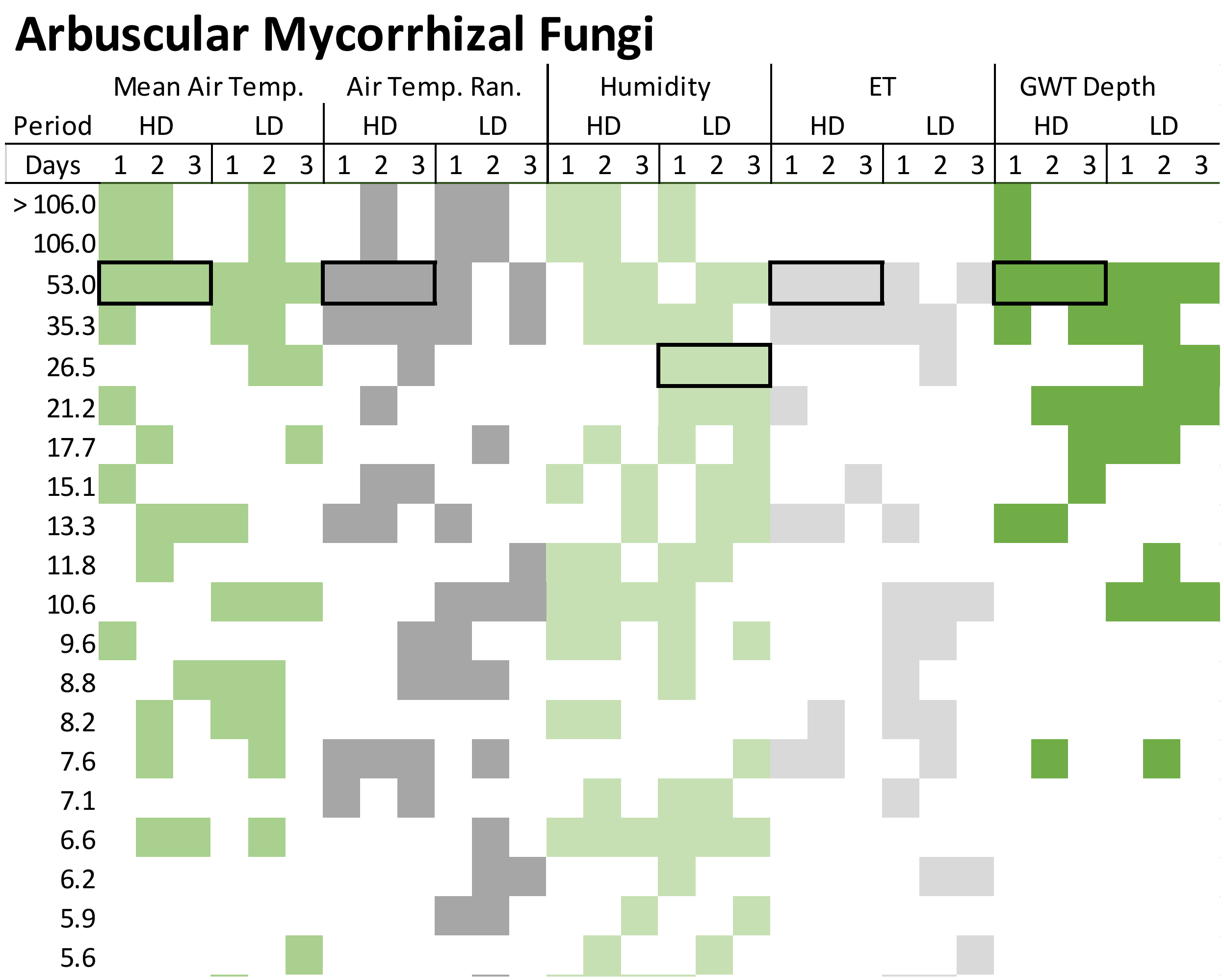

Figure A14: 2017 AMF and weather condition covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

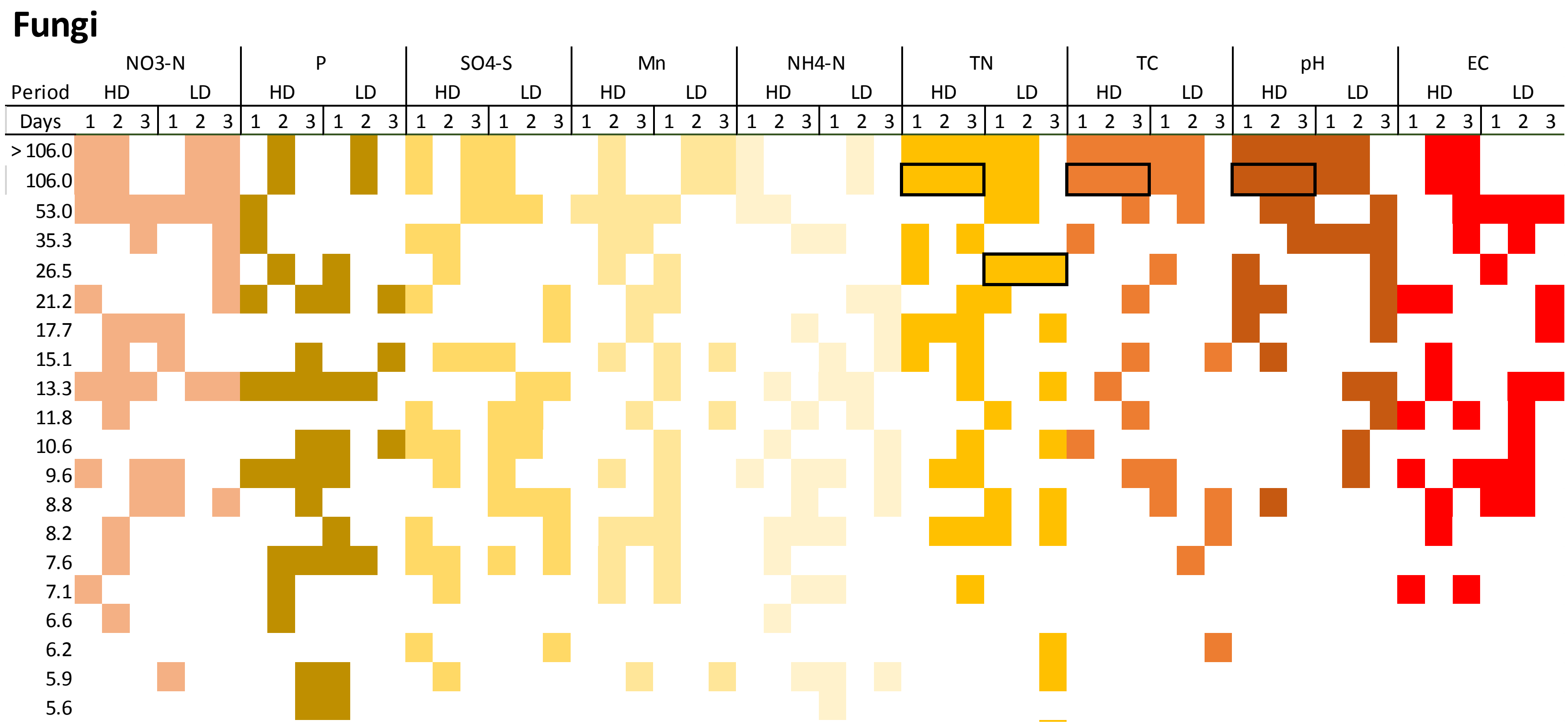

Figure A15: 2017 Fungi and chemical covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

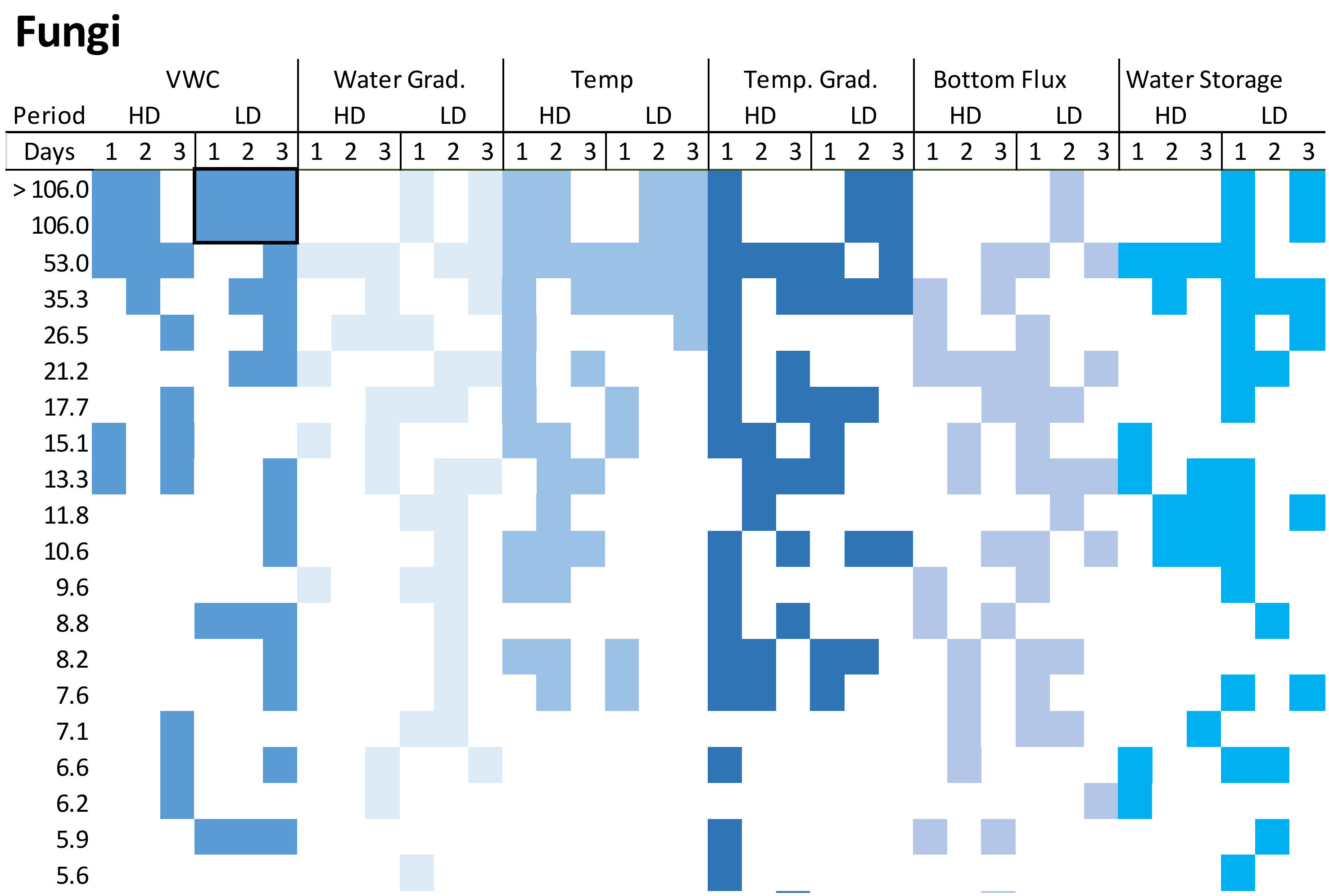

Figure A16: 2017 Fungi and physical conditions covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

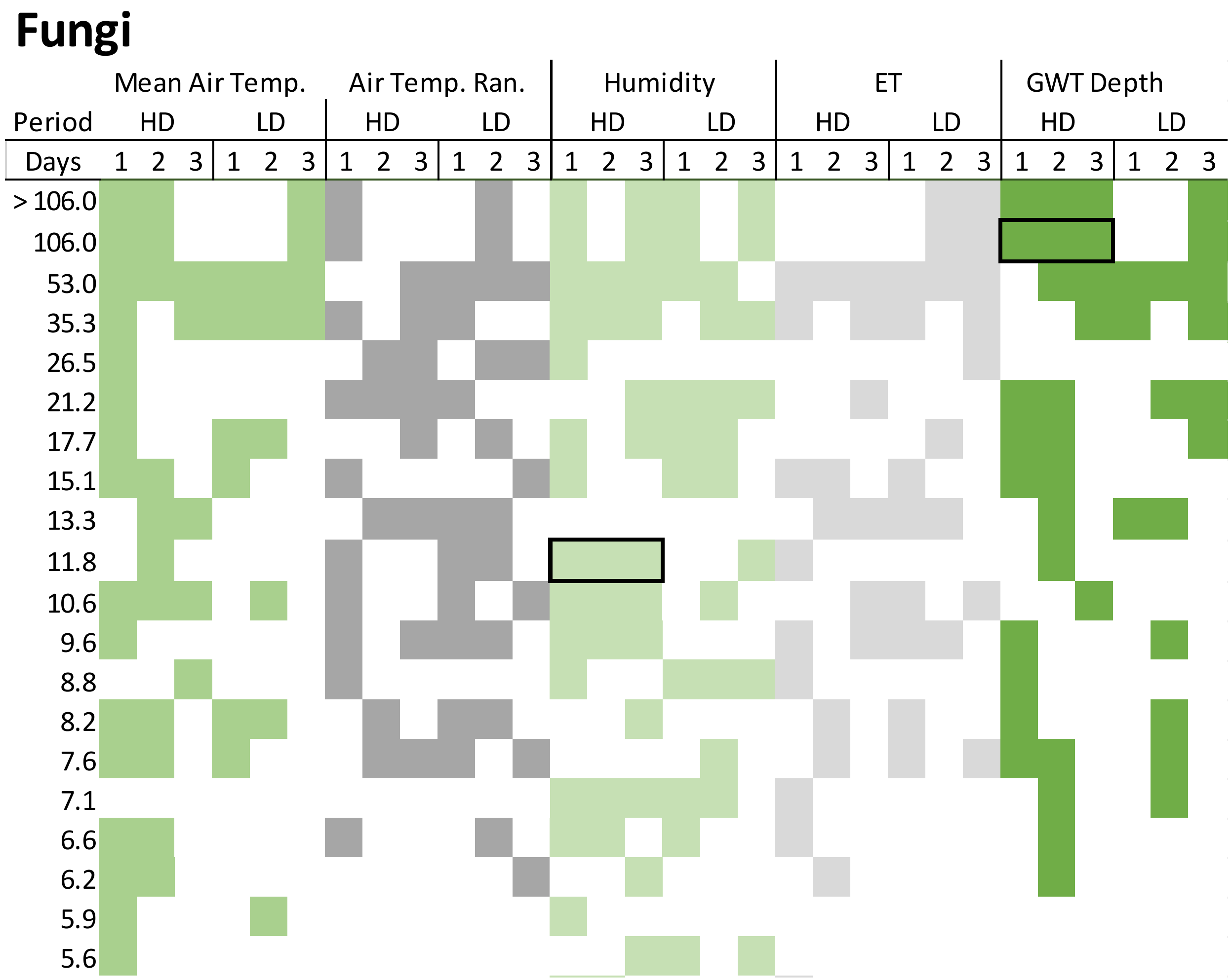

Figure A17: 2017 Fungi and weather condition covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

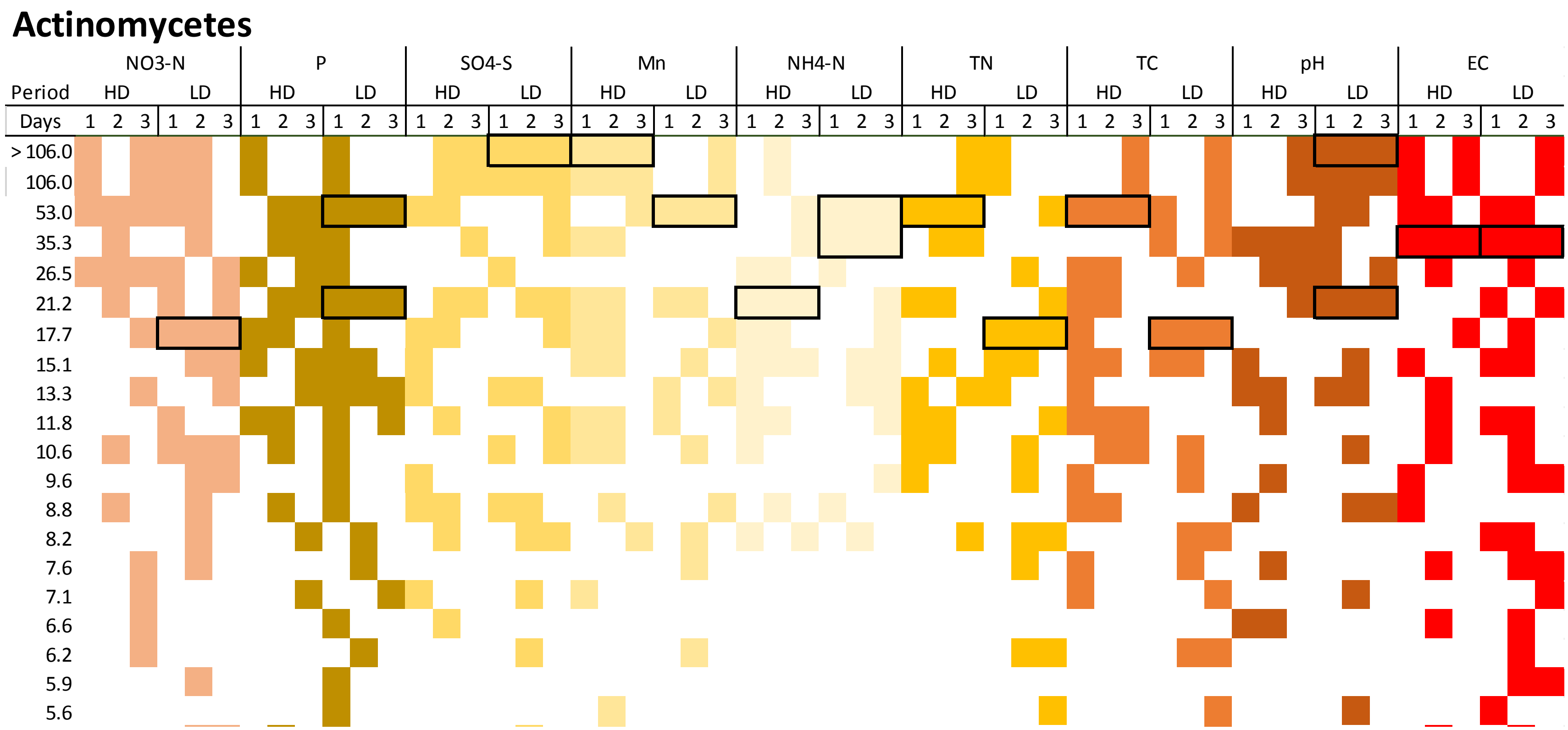

Figure A18: 2017 Actinomycete and chemical covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Actinomycetes

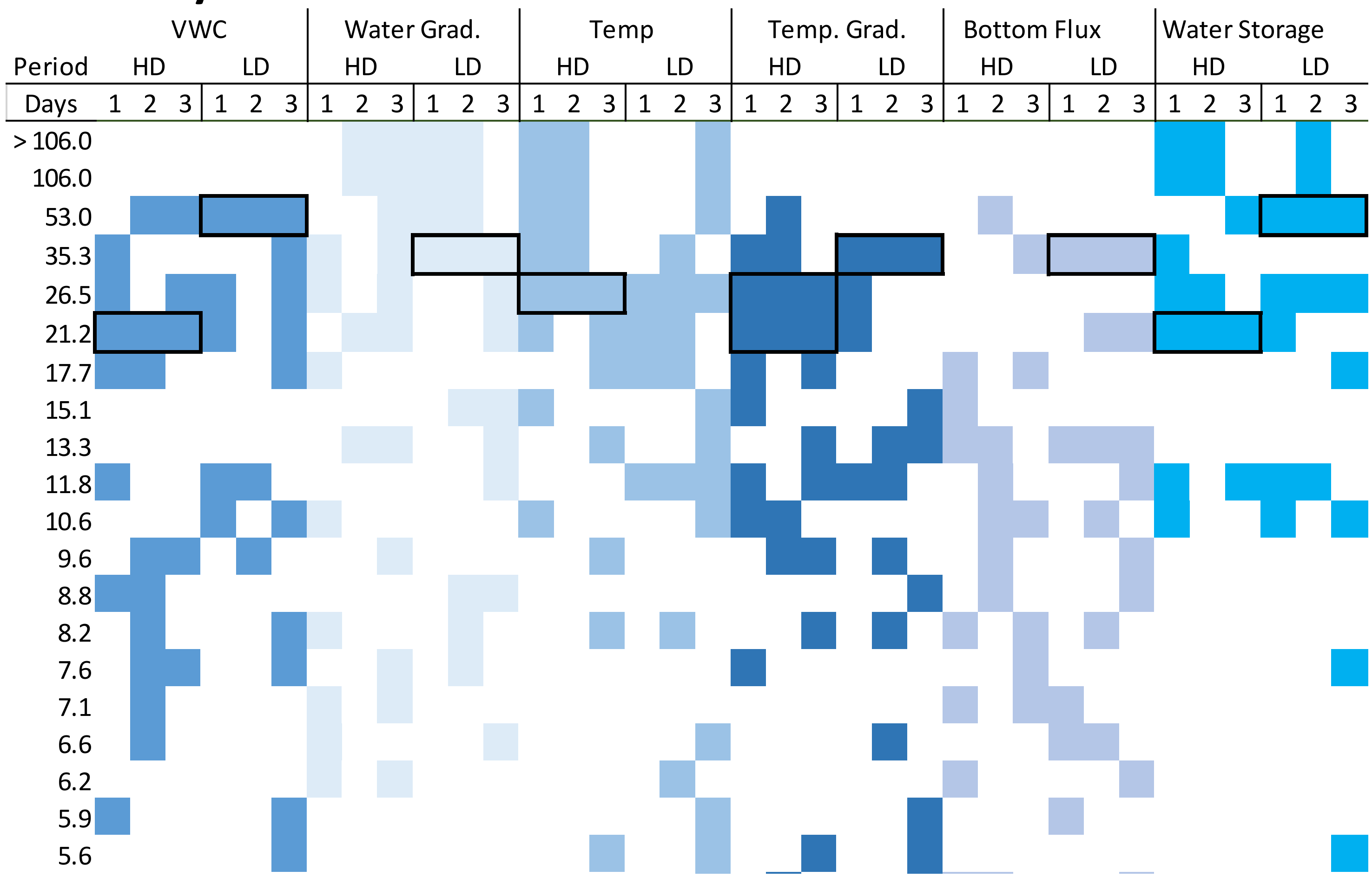

Figure A19: 2017 Actinomycete and physical conditions covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

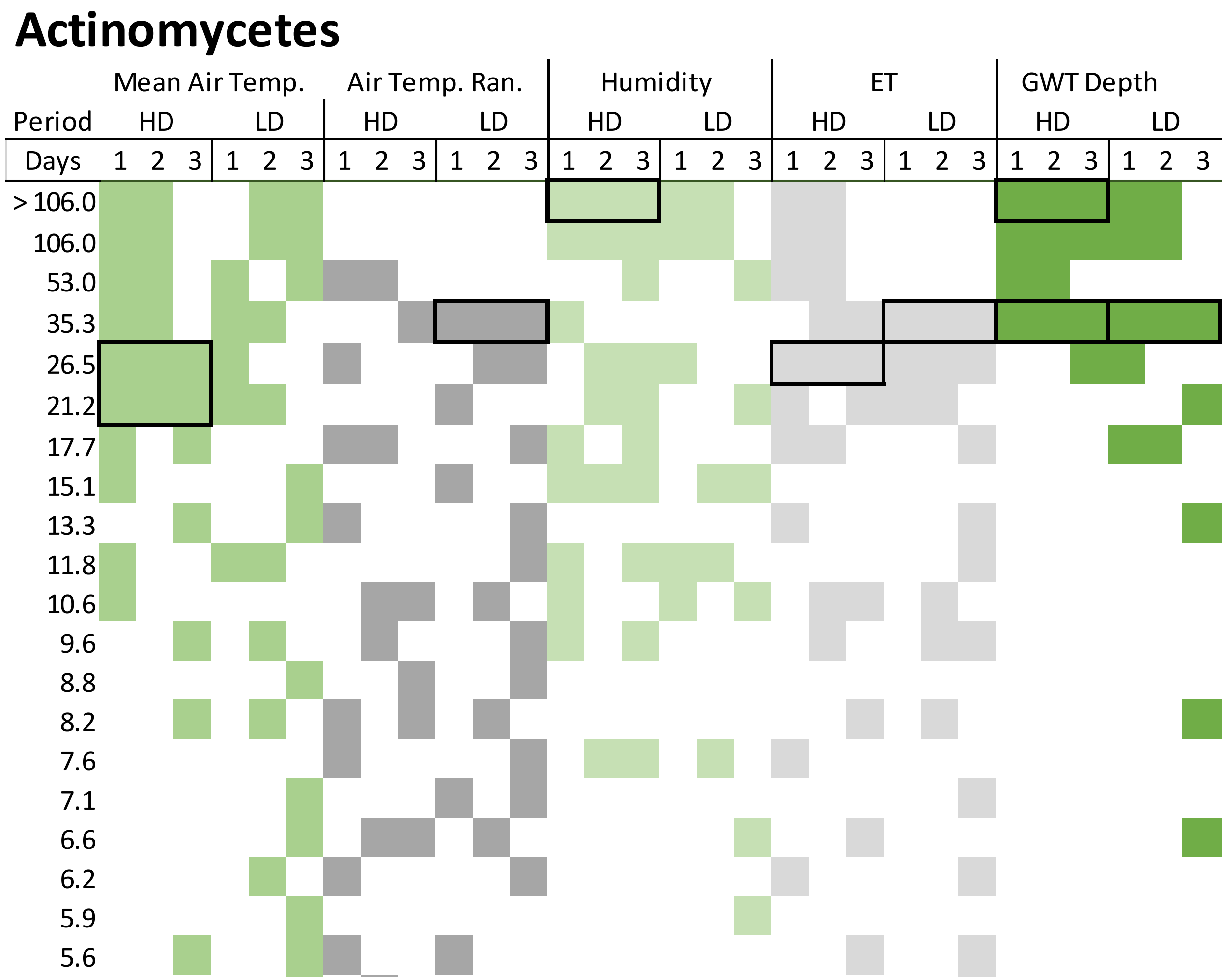

Figure A20: 2017 Actinomycete and weather condition covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

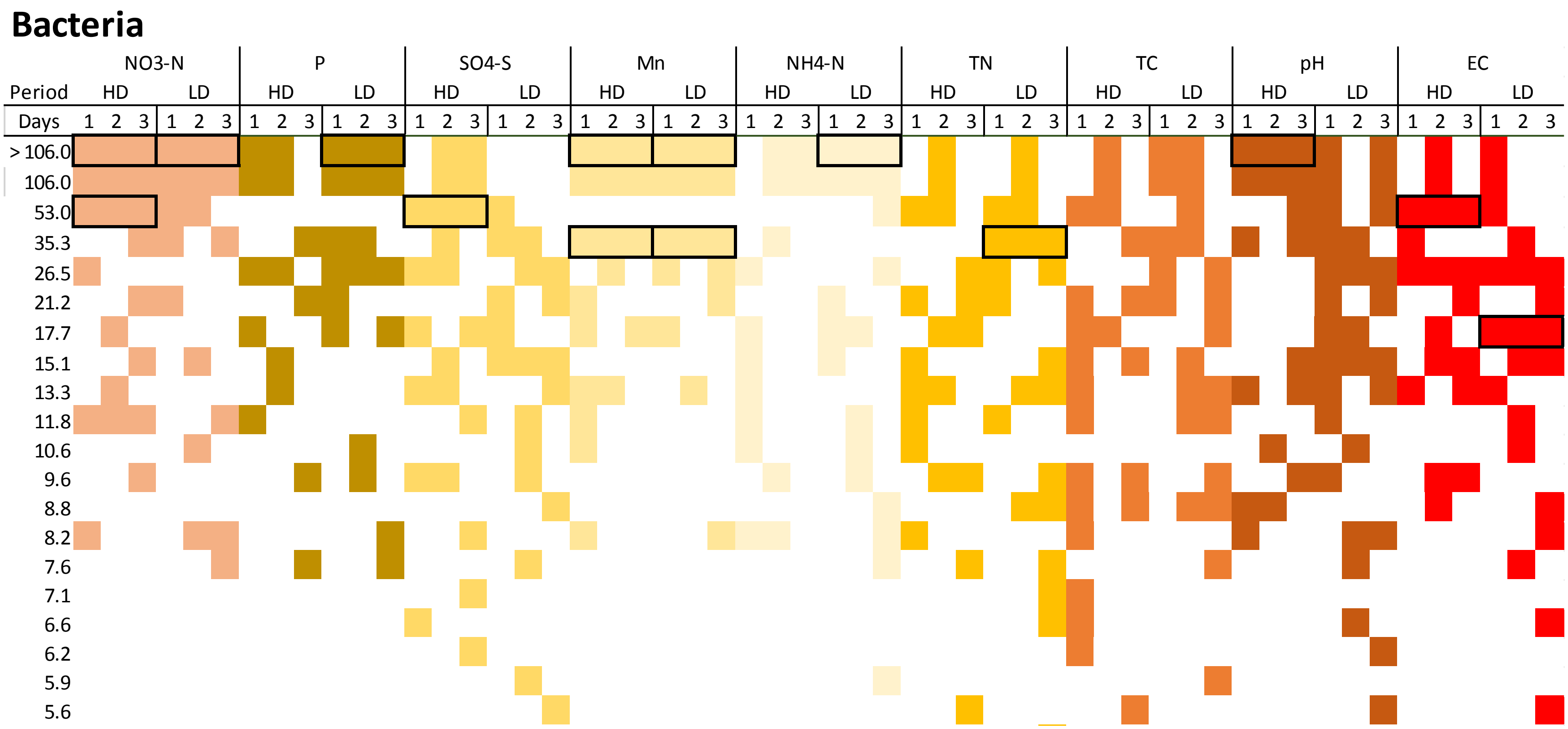

Figure A21: 2017 Bacteria and chemical covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

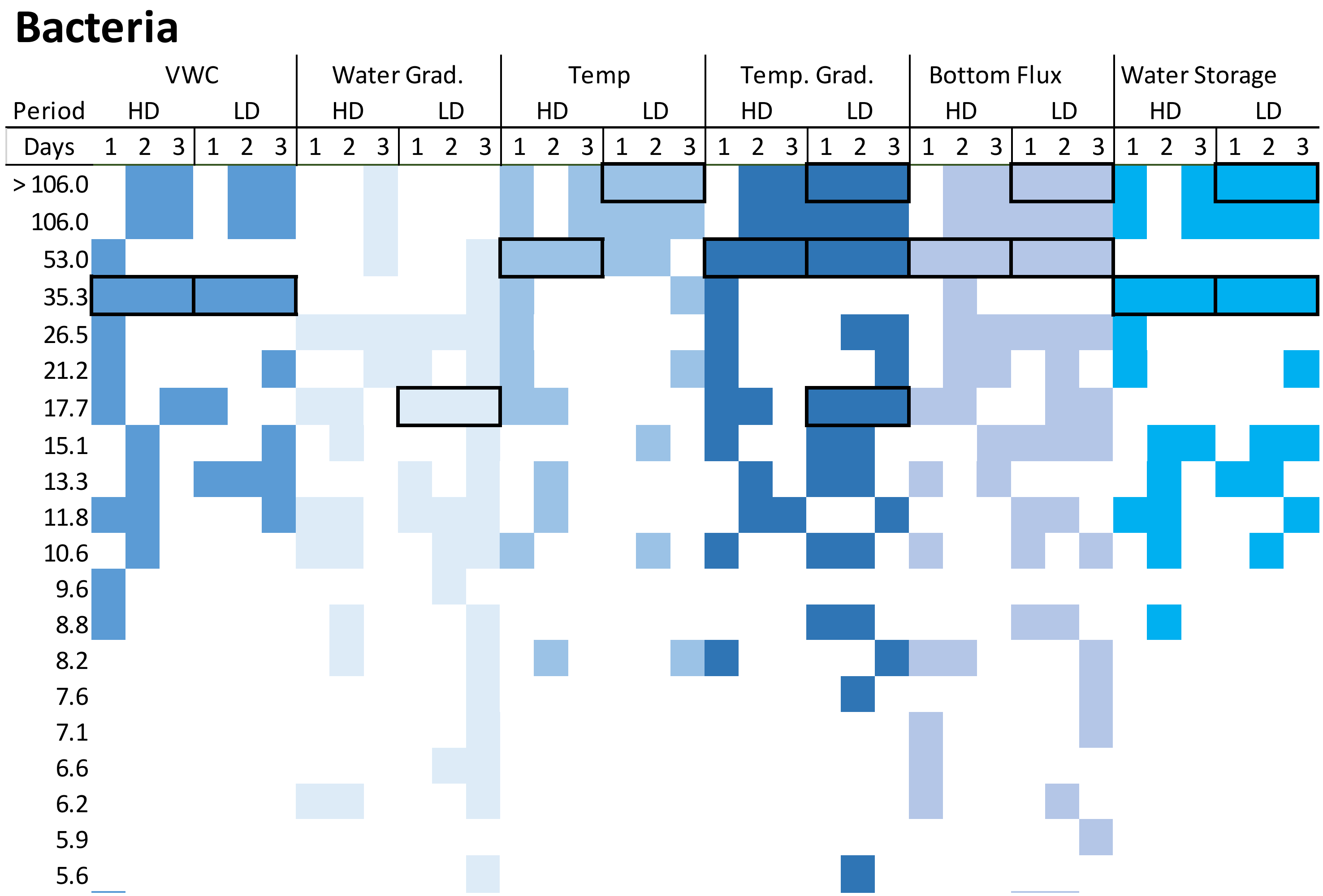

Figure A22: 2017 Bacteria and physical conditions covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

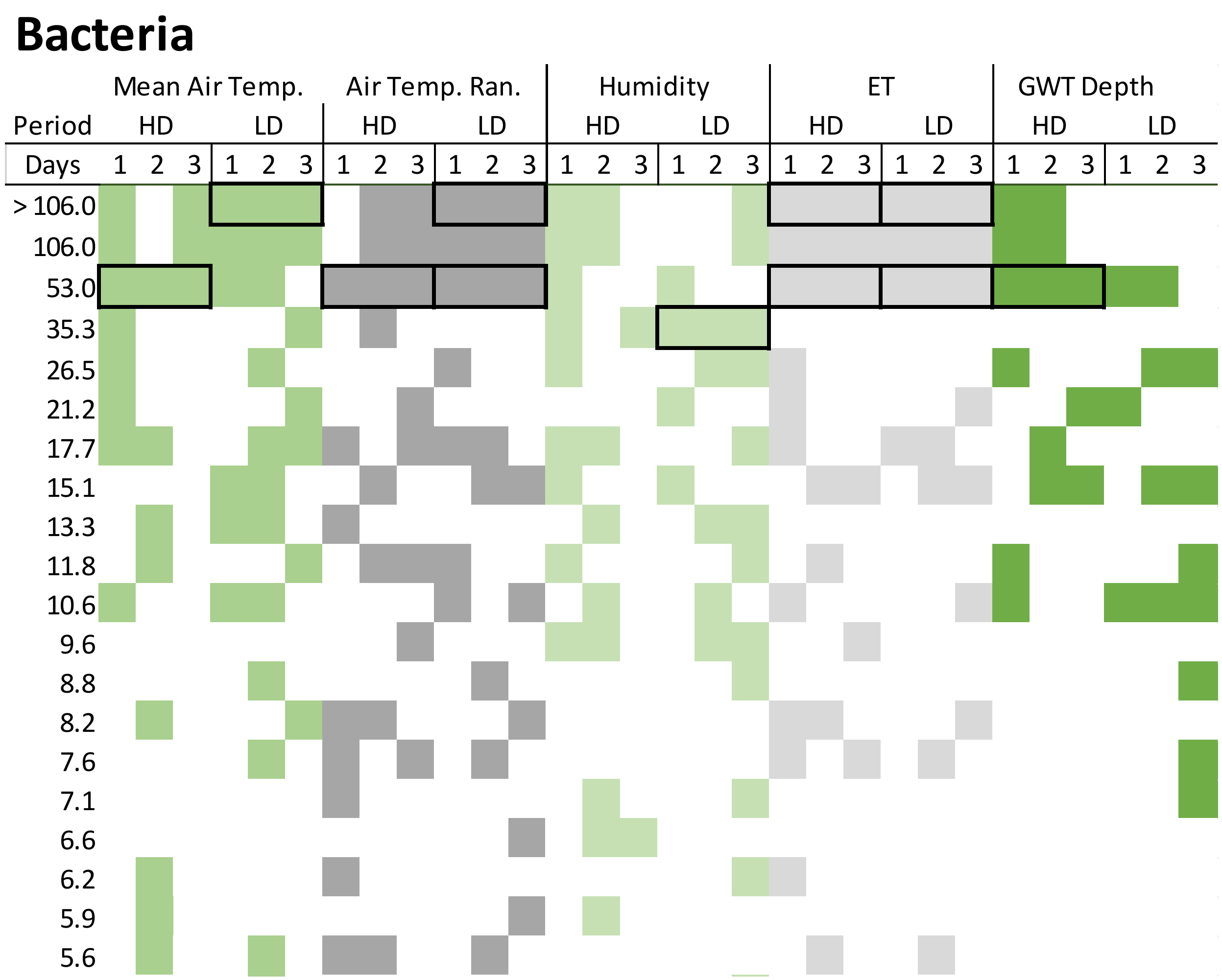

Figure A23: 2017 Bacteria and weather condition covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

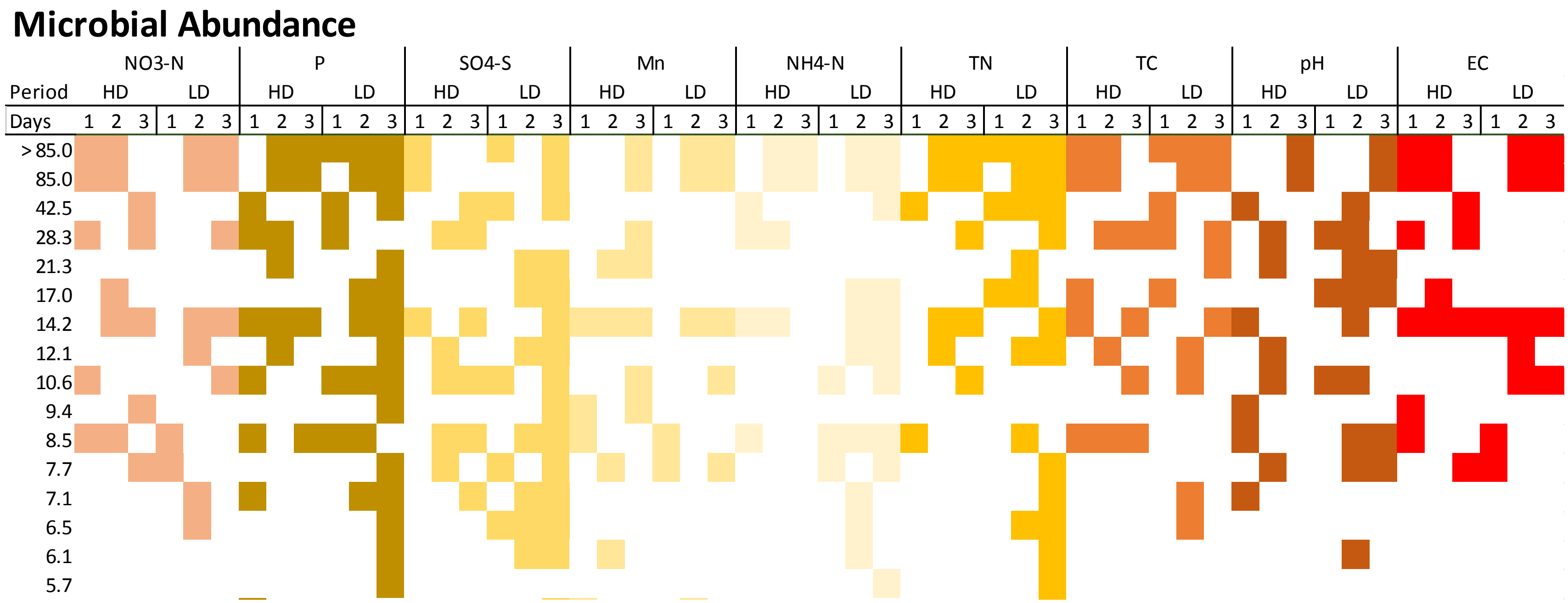

Figure A24: 2018 TMA and chemical covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

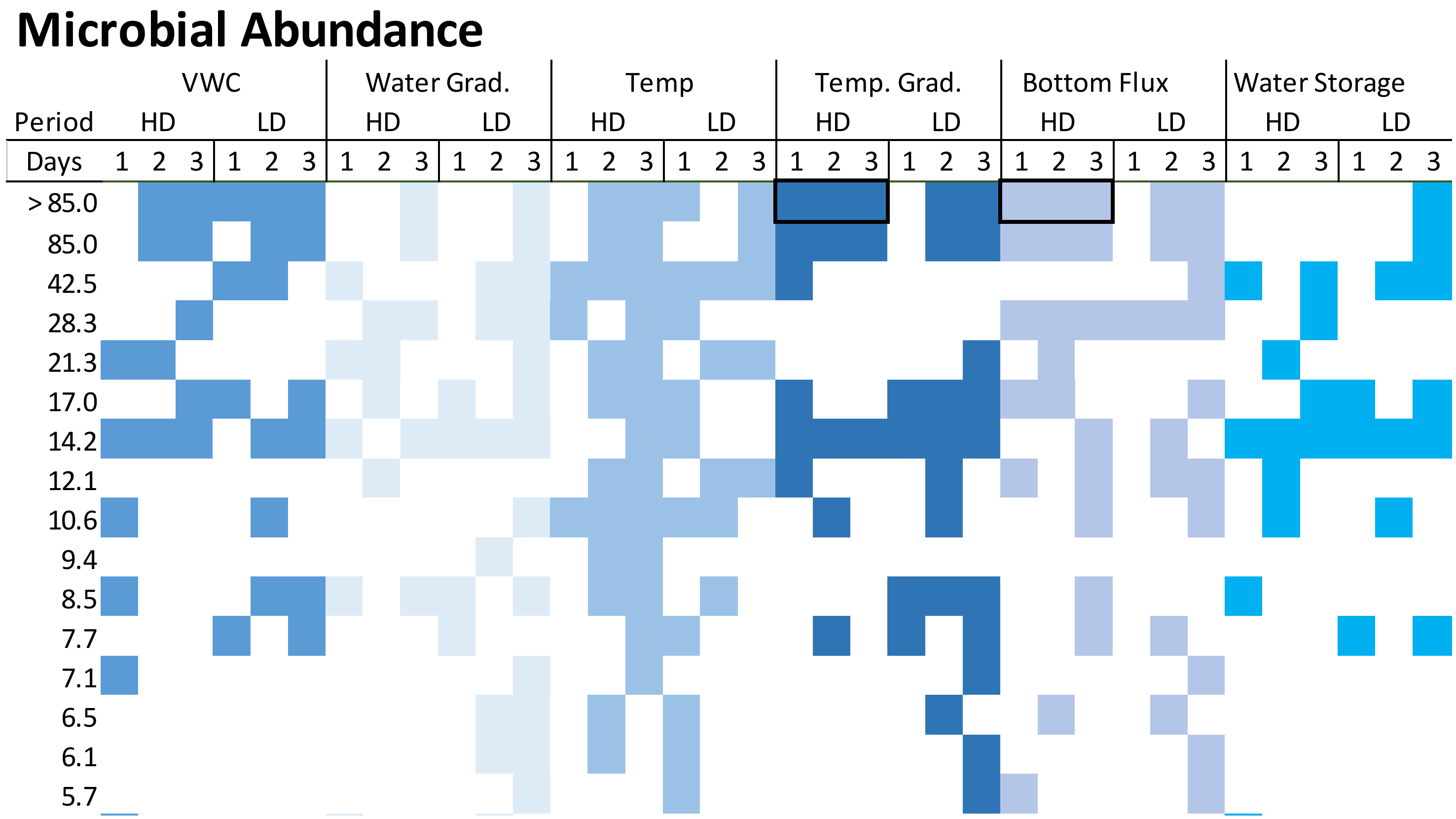

Figure A25: 2018 TMA and physical conditions covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

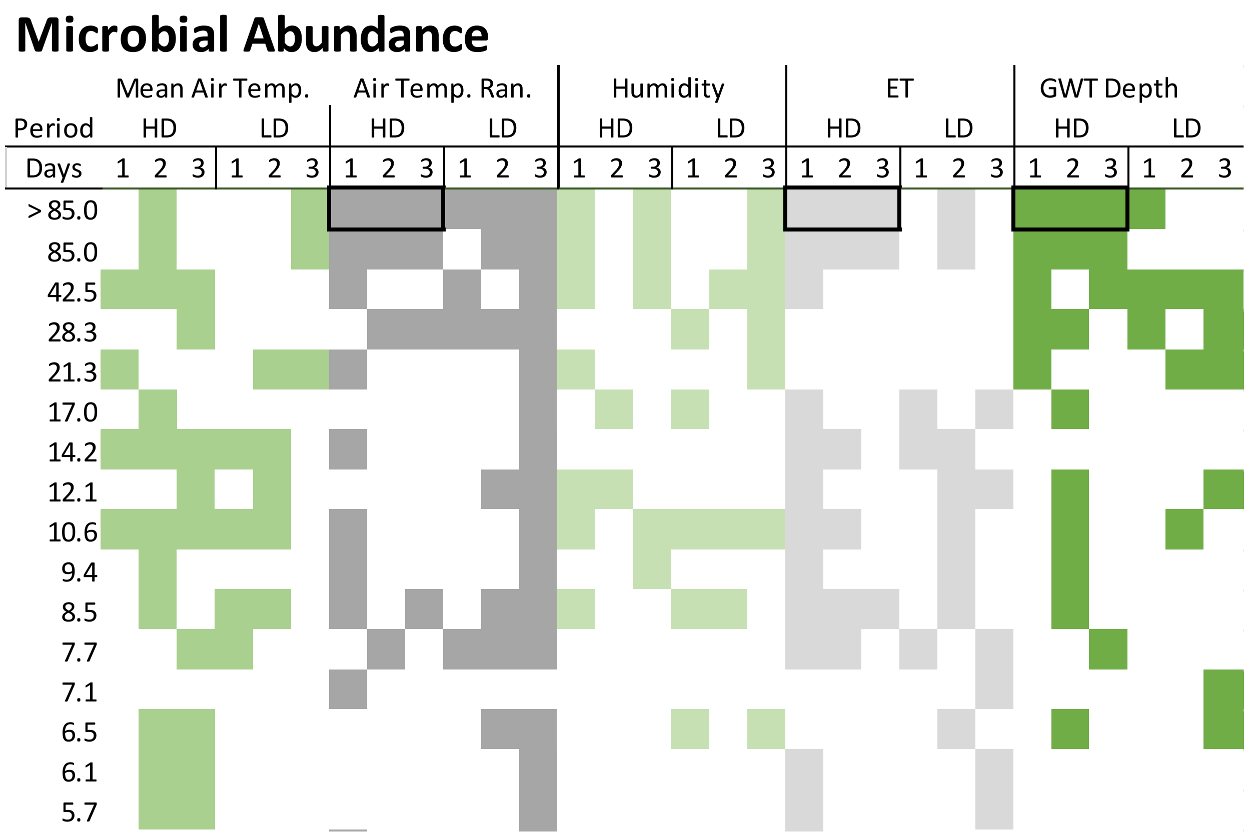

Figure A26: 2018 TMA and weather condition covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

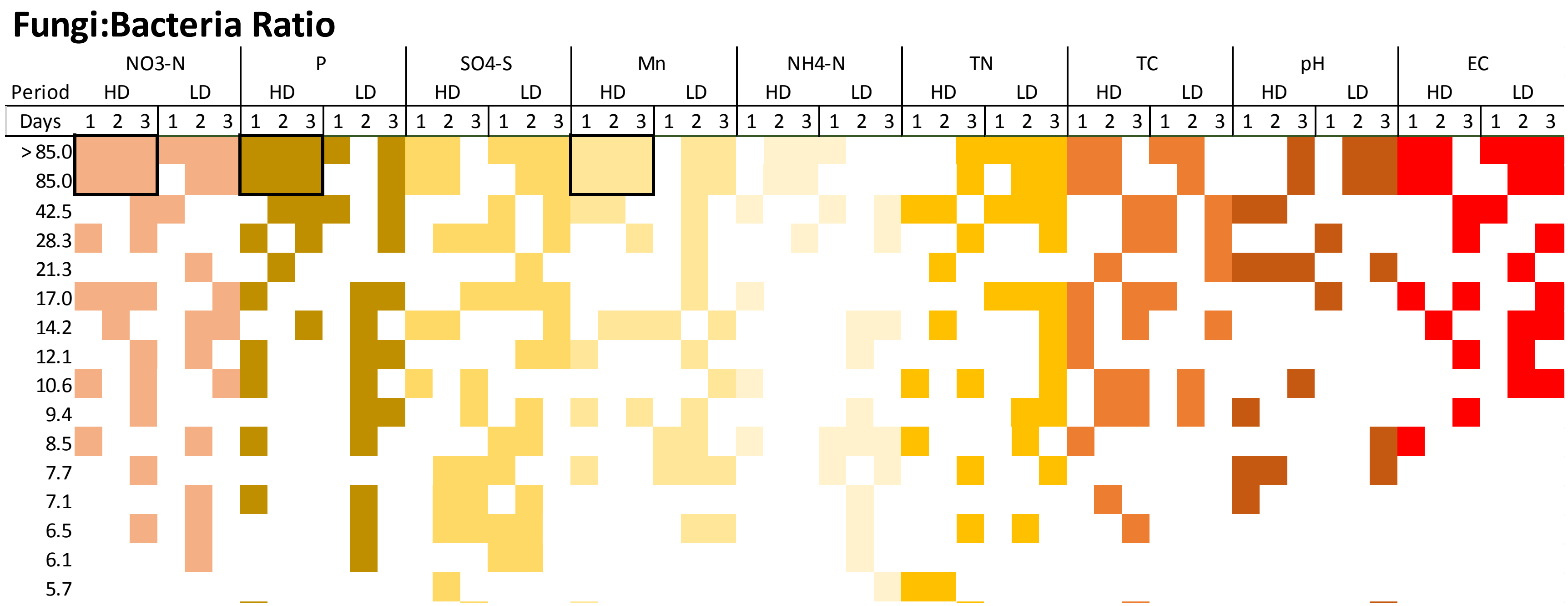

Figure A27: 2018 F:B and chemical covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

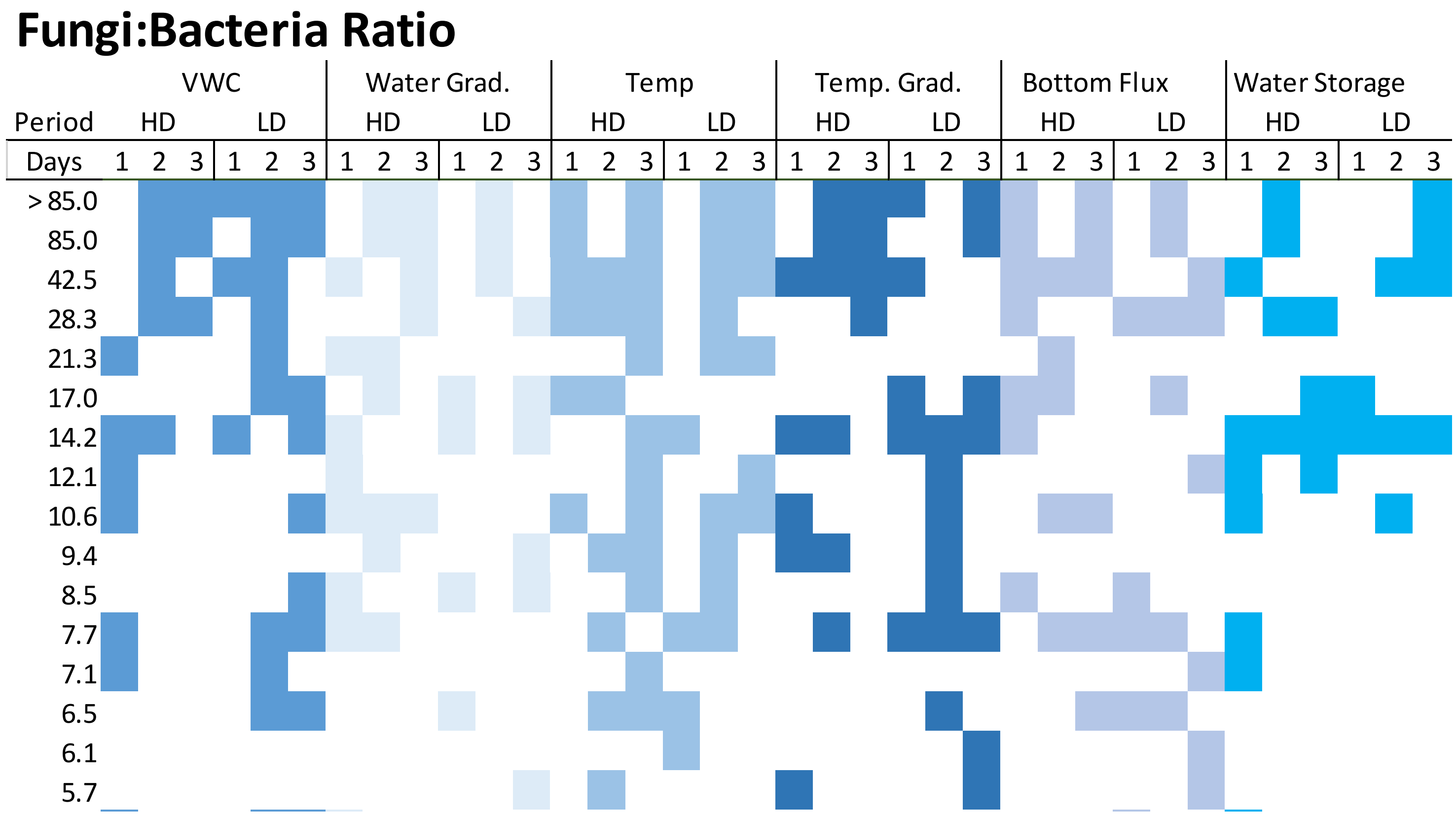

Figure A28: 2018 F:B and physical conditions covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

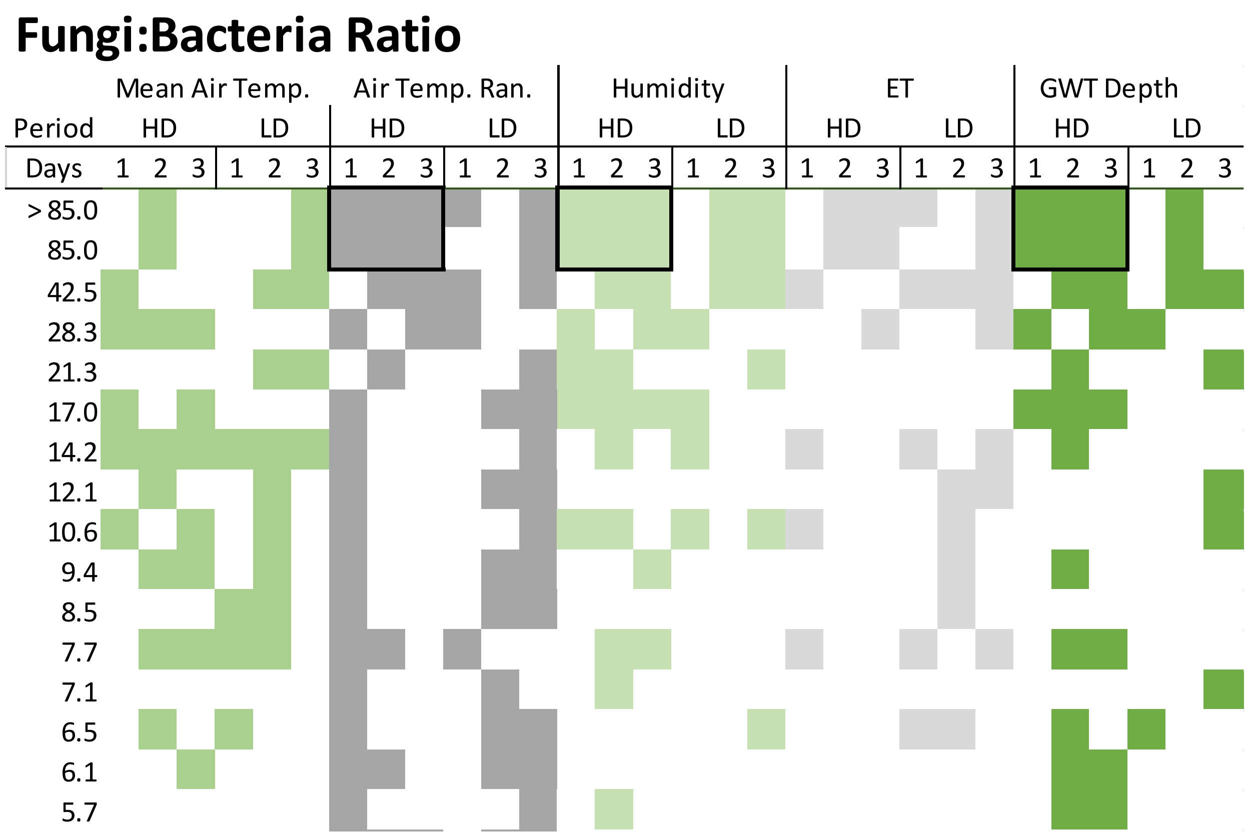

Figure A29: 2018 F:B and weather condition covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

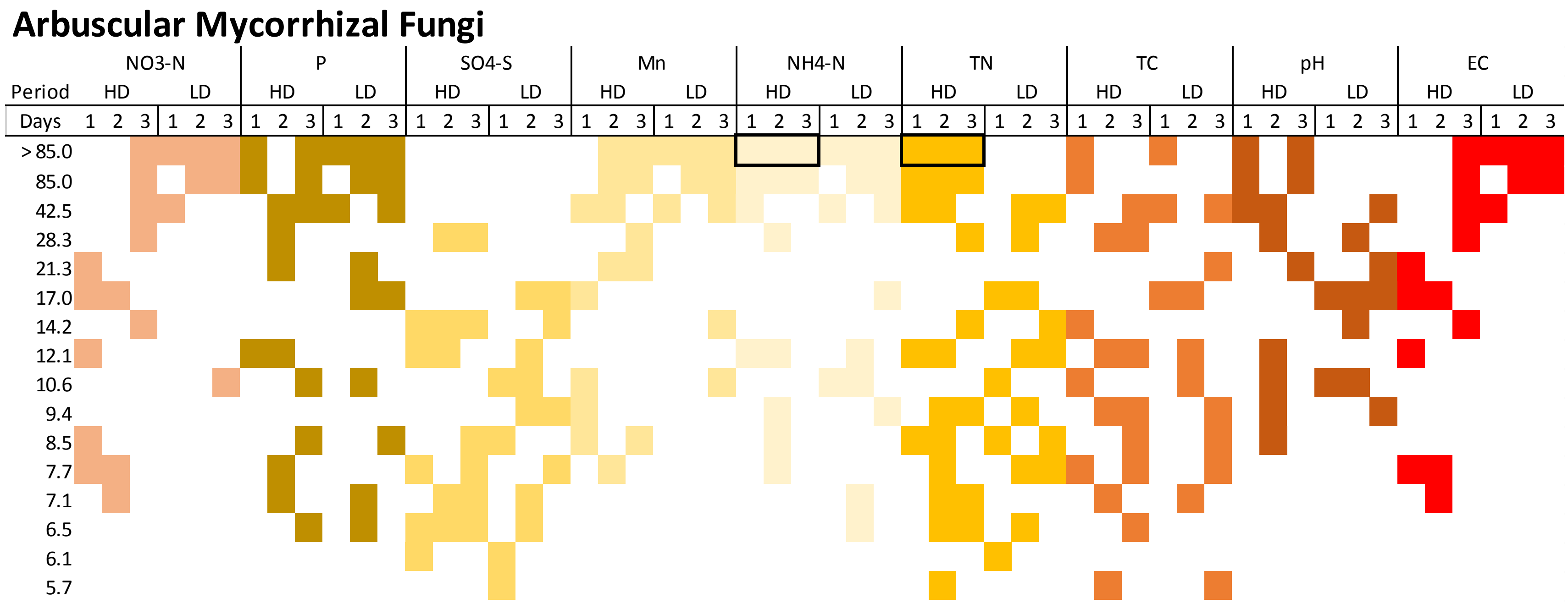

Figure A30: 2018 AMF and chemical covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Arbuscular Mycorrhizal Fungi

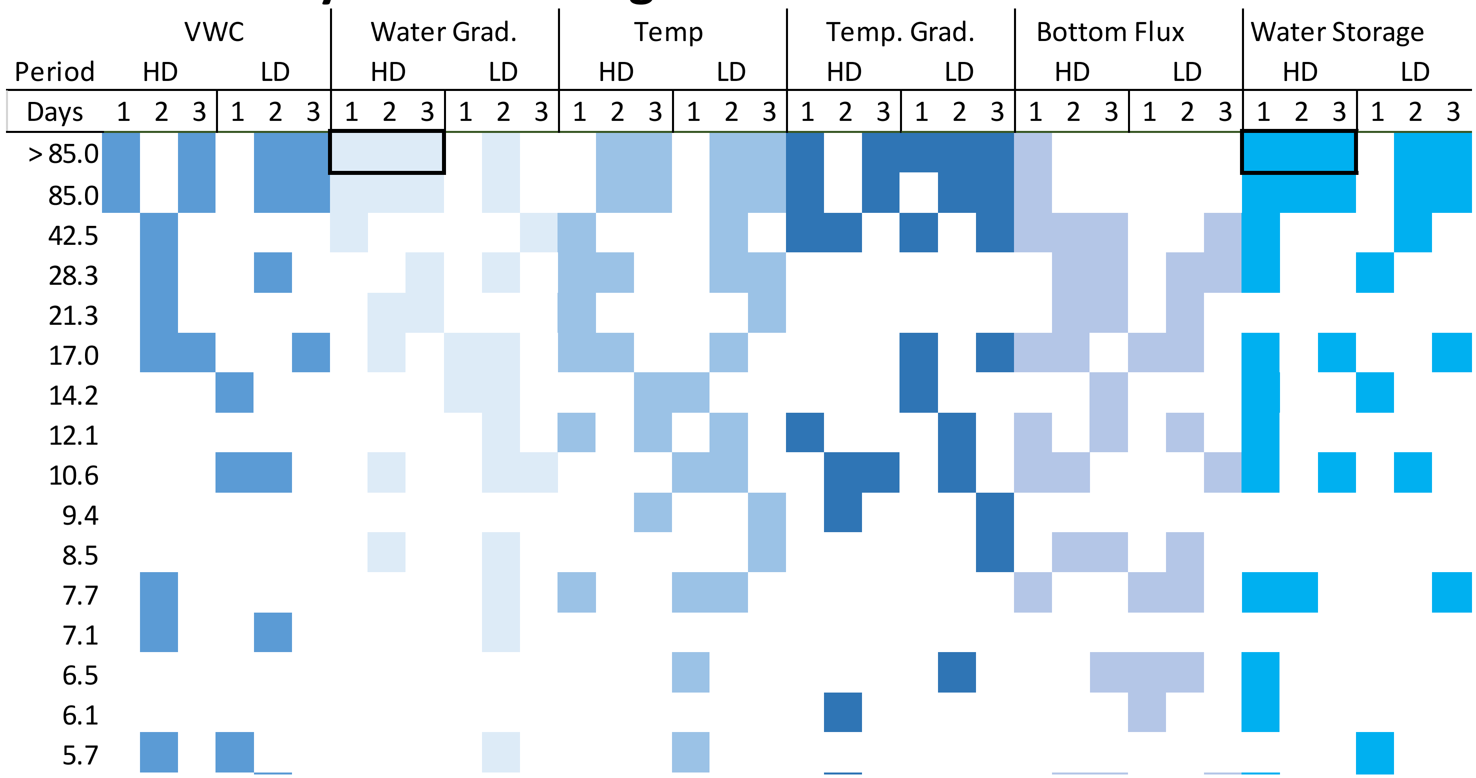

Figure A31: 2018 AMF and physical conditions covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

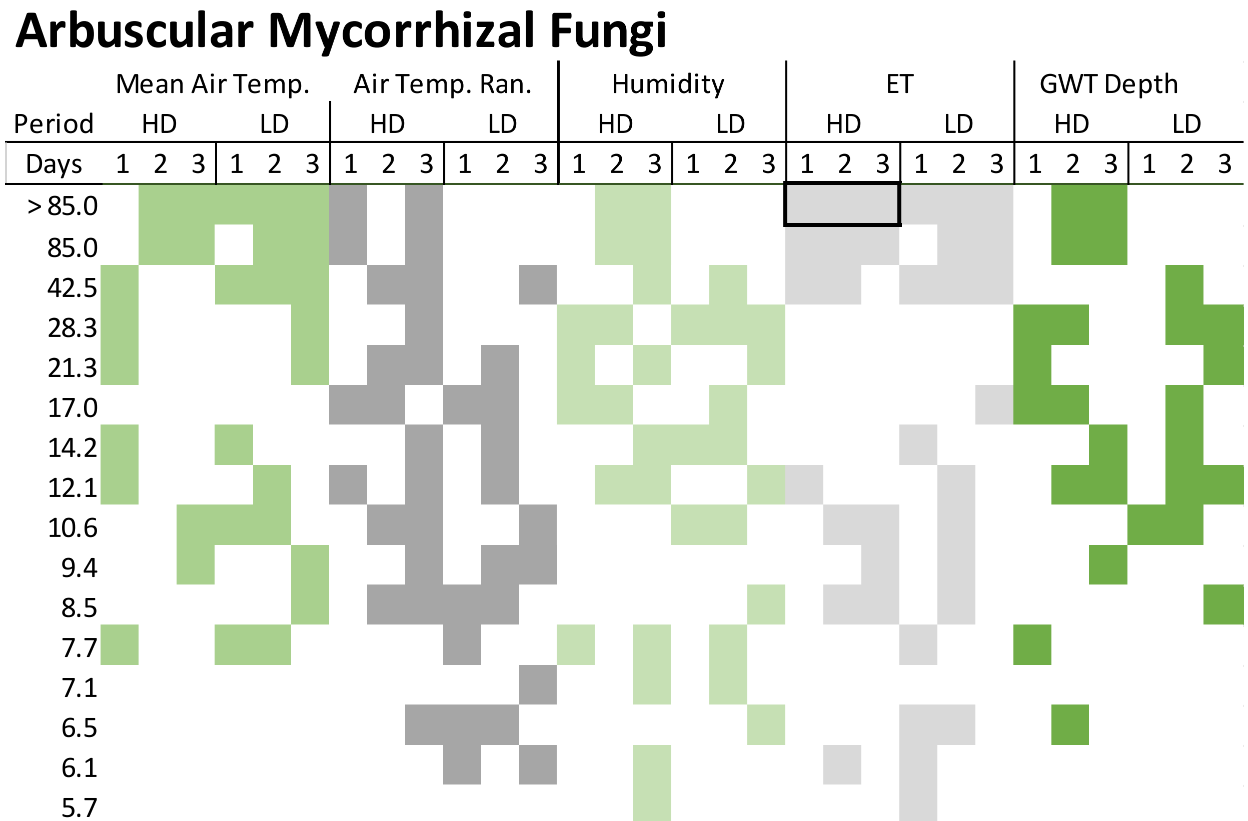

Figure A32: 2018 AMF and weather condition covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

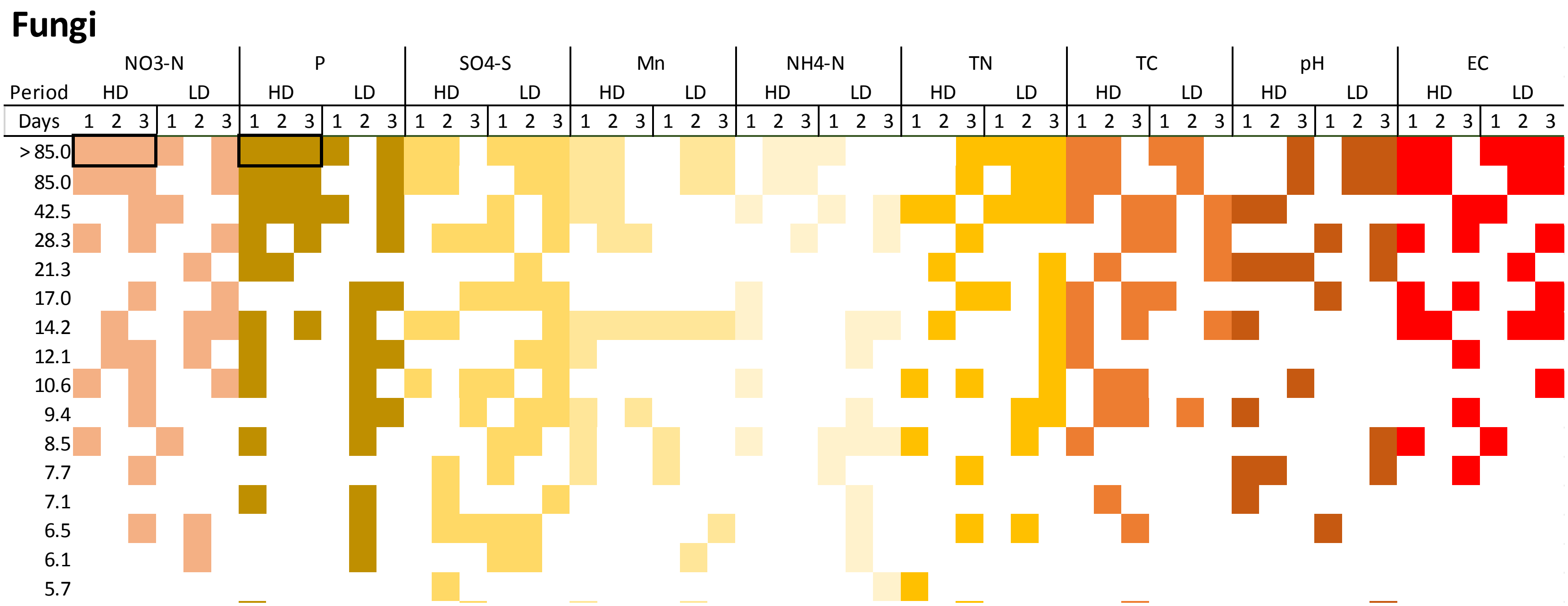

Figure A33: 2018 Fungi and chemical covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

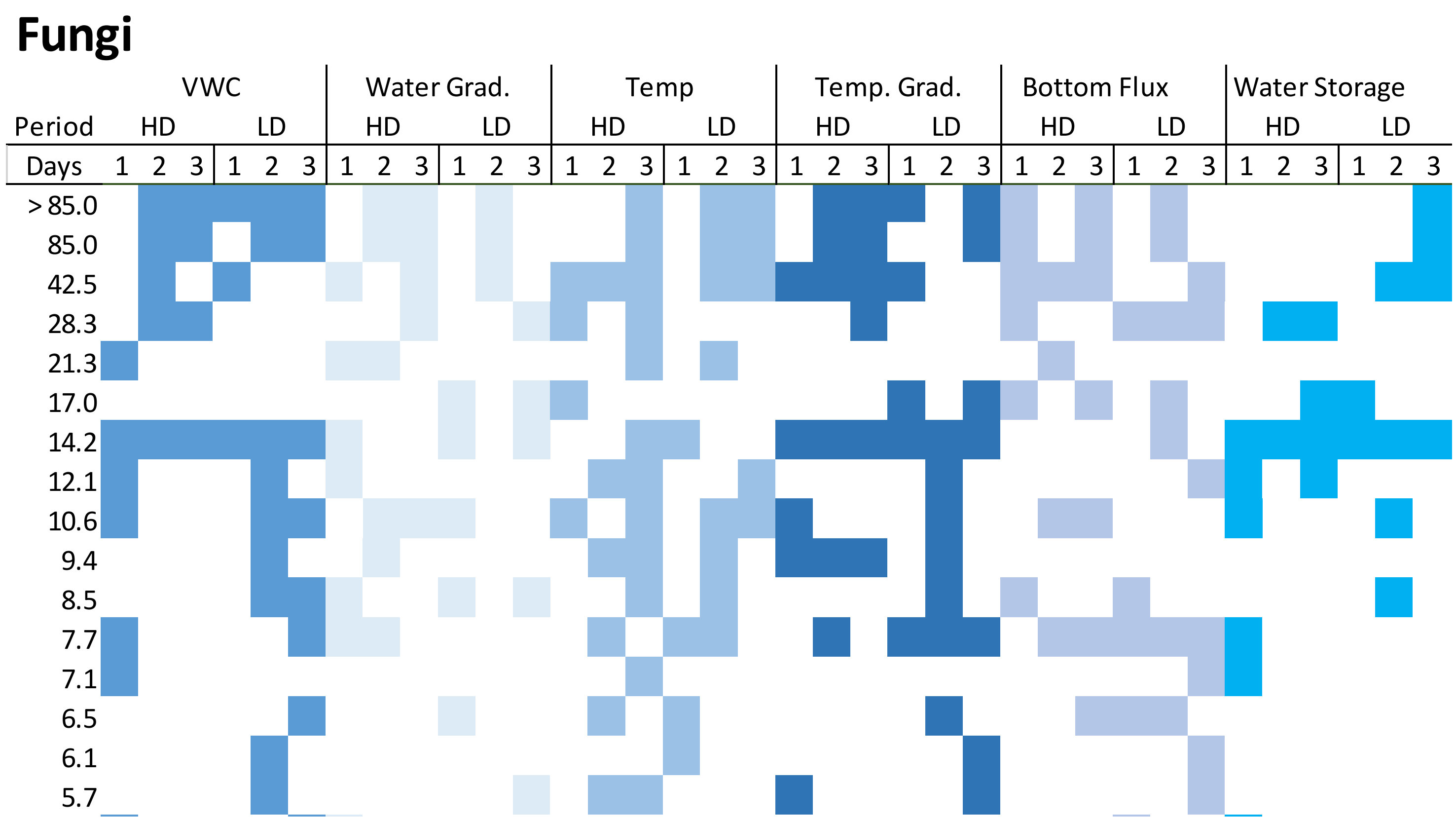

Figure A34: 2018 Fungi and physical conditions covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

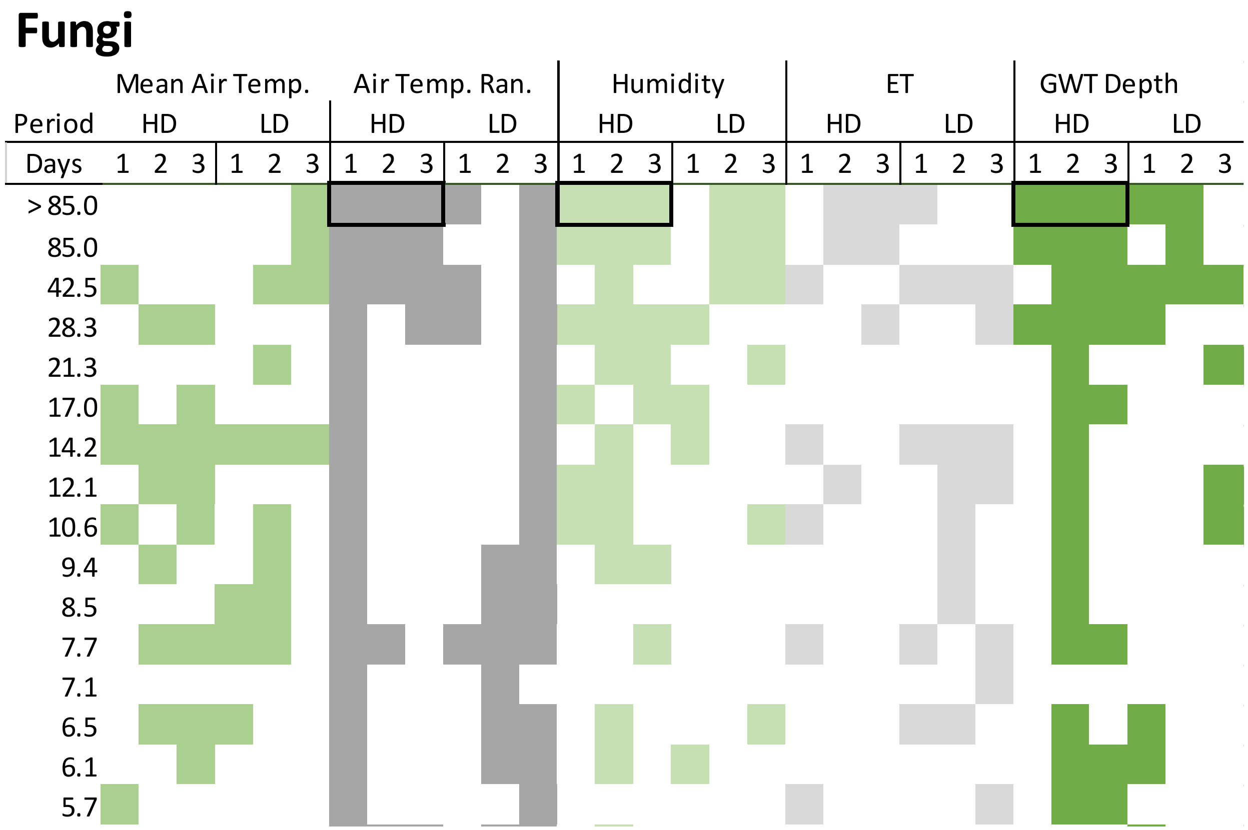

Figure A35: 2018 Fungi and weather condition covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

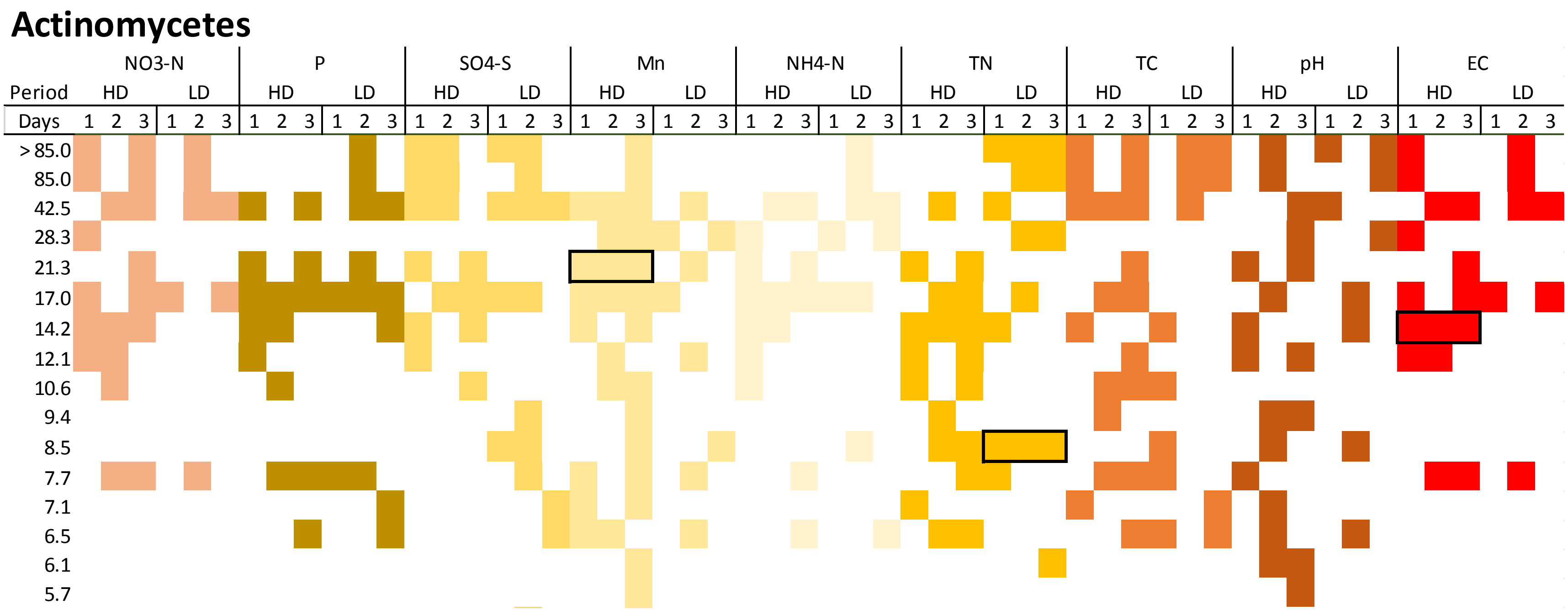

Figure A36: 2018 Actinomycete and chemical covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

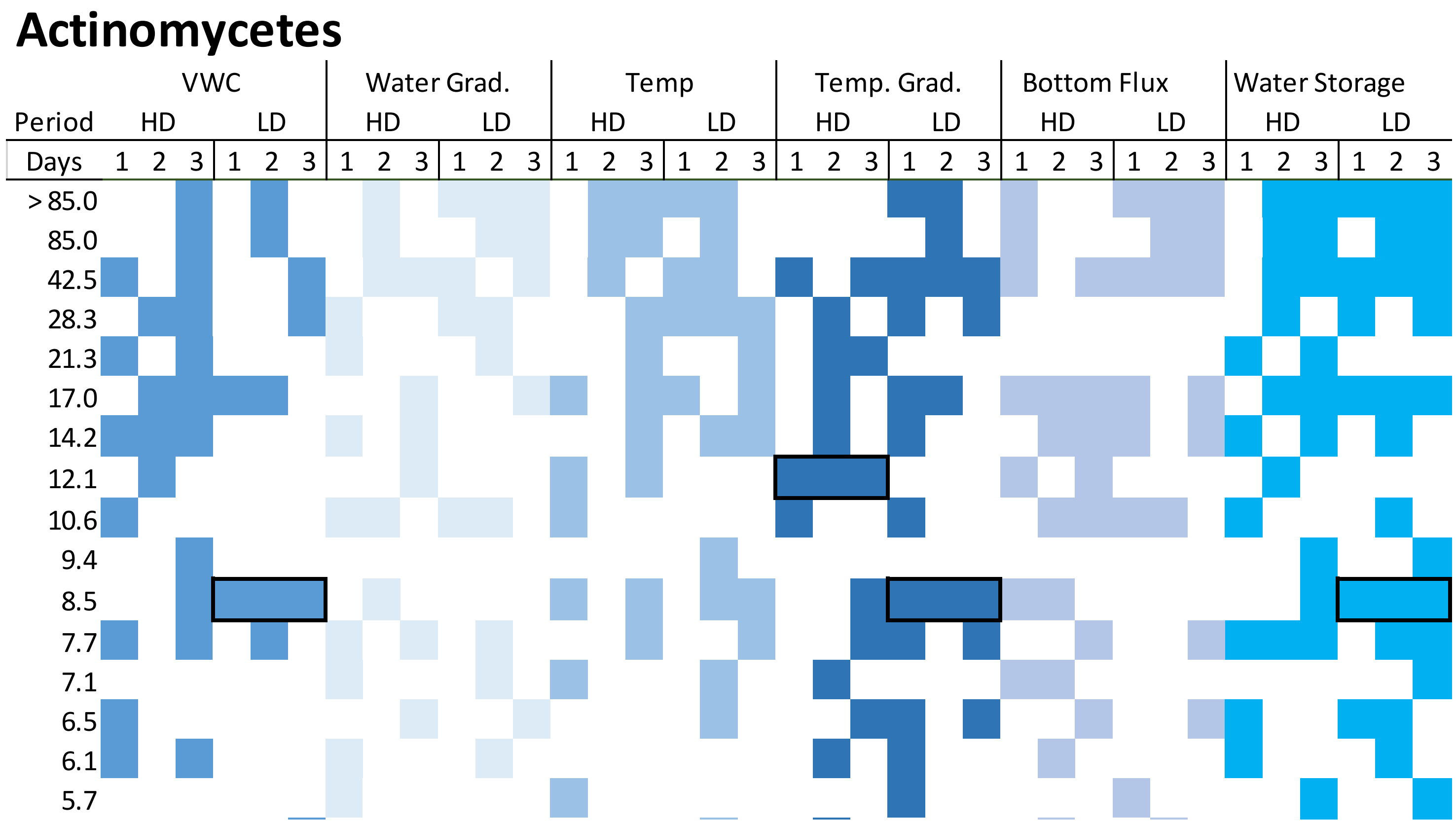

Figure A37: 2018 Actinomycete and physical conditions covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

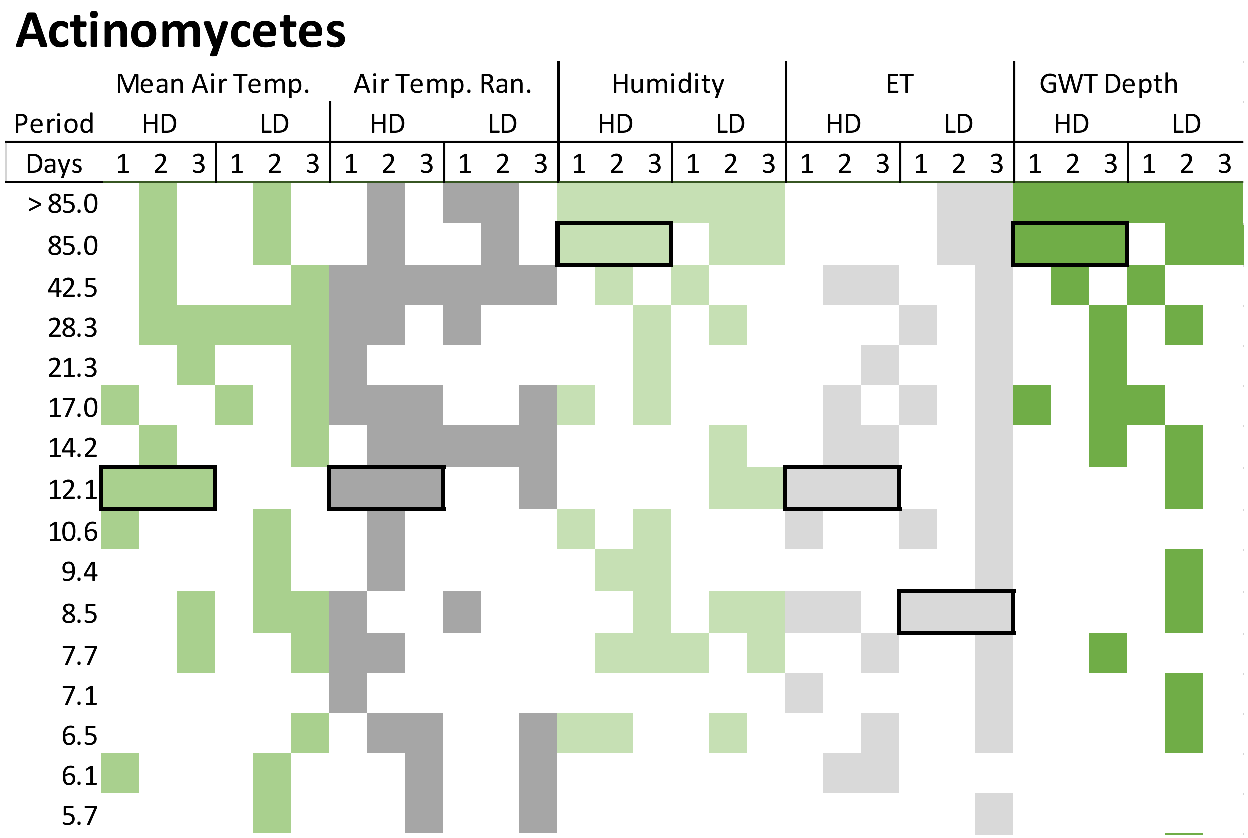

Figure A38: 2018 Actinomycete and weather condition covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

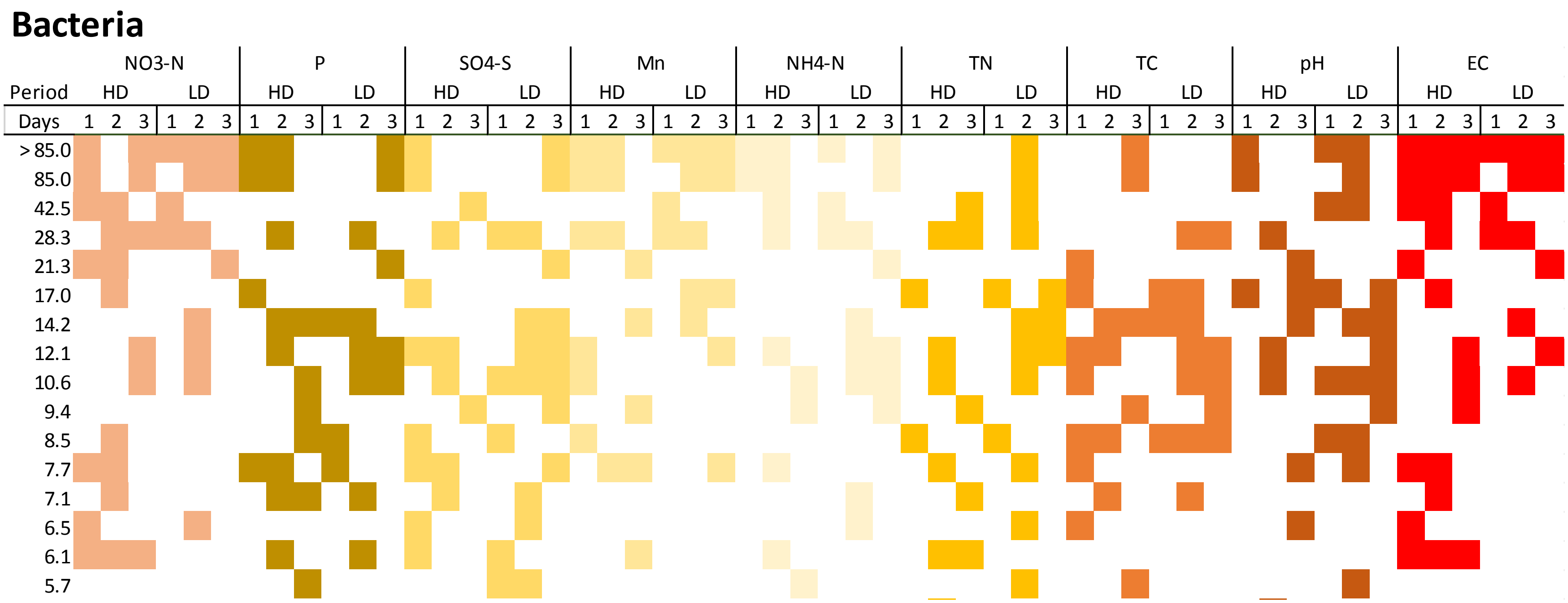

Figure A39: 2018 Bacteria and chemical covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

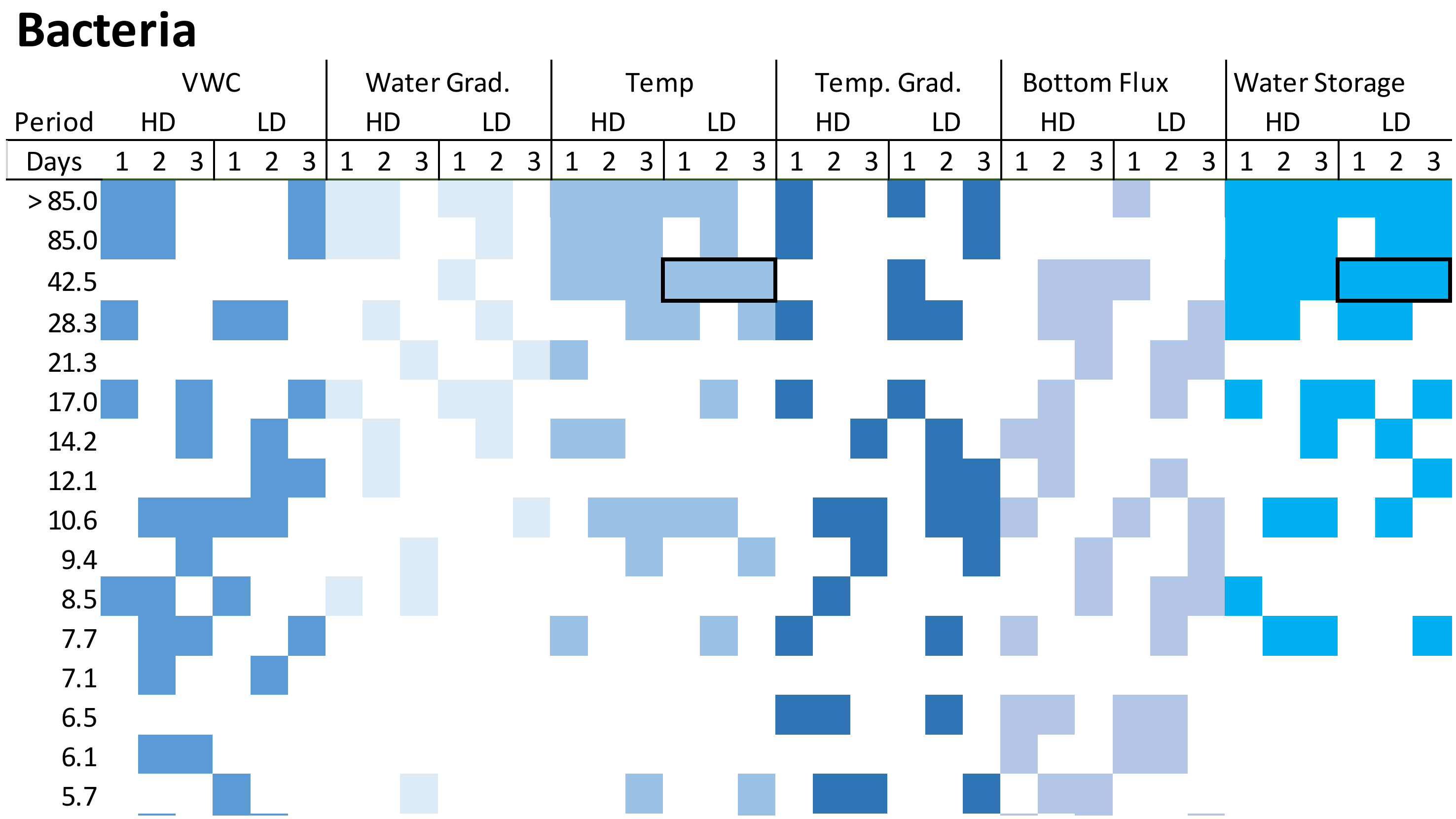

Figure A40: 2018 Bacteria and physical conditions covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

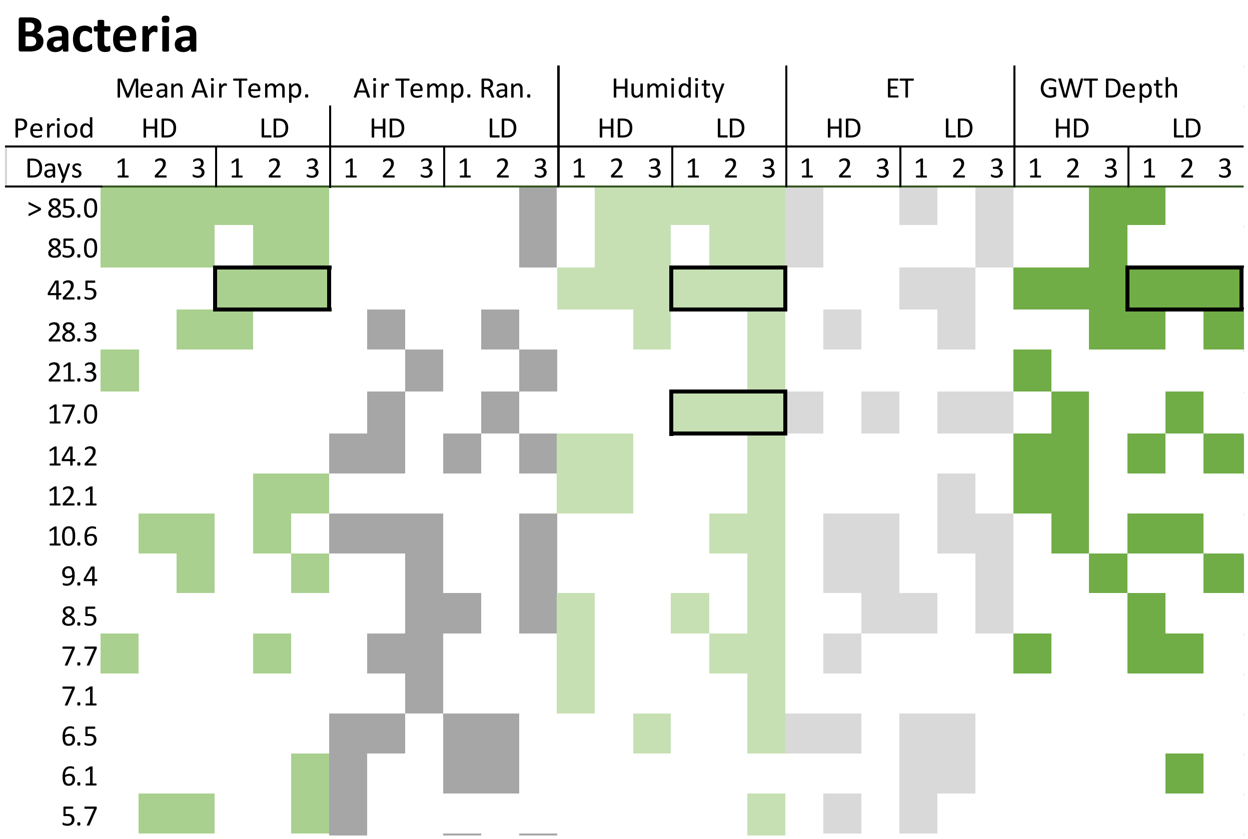

Figure A41: 2018 Bacteria and weather condition covariate cross spectral density analysis, where colored boxes indicate frequencies above the 95% CI. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Table A1: 2017 TMA and chemical covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Microbial Abundance

	NO3-N						P						SO4-S					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	3.1	0.0	3.1	0.0	3.1	0.0	3.1	3.1	3.1	0.0	3.1	3.1	3.1	3.1	0.0	3.1	3.1
106.0	0.3	1.6	0.3	-2.1	0.1	-2.0	0.1	1.7	-1.6	-2.4	-0.5	-2.2	2.7	2.0	3.1	0.9	-2.8	1.7
53.0	-0.7	-1.6	-1.3	-0.5	-1.3	-0.4	2.7	-2.9	1.3	-1.2	1.9	2.4	0.0	-1.2	-0.9	0.7	0.8	2.6
35.3	-2.9	-0.9	2.0	-1.7	1.7	-0.6	1.5	-0.5	3.0	-1.1	2.0	2.0	1.0	0.5	-1.3	-0.7	1.4	2.9
26.5	-3.1	-1.0	0.2	-1.9	-0.4	3.1	-2.5	-2.7	-0.2	0.1	-0.8	0.3	2.2	3.0	1.3	-2.4	-0.8	2.0
21.2	-1.4	2.1	0.2	0.3	-3.0	-0.7	-2.0	2.5	-1.9	-1.6	-3.0	-2.4	-3.0	1.4	0.9	0.4	-2.7	-2.0
17.7	-1.4	1.2	-2.3	2.6	-2.2	-1.2	2.9	-0.3	0.6	-0.5	-2.3	1.0	-2.2	-0.6	1.2	0.7	-2.6	-2.8
15.1	2.5	0.1	-1.3	1.0	-2.3	1.2	2.9	1.3	0.5	2.9	3.1	-1.5	2.9	0.3	0.1	0.7	-0.9	2.6
13.3	-0.1	1.4	1.0	-0.7	1.4	2.9	0.5	1.1	1.2	2.9	1.4	-2.3	3.0	2.7	1.7	0.7	0.5	0.9
11.8	0.9	0.7	-2.6	-2.3	-0.8	2.9	1.6	-2.3	2.8	-0.7	2.3	-2.6	-1.3	-2.5	-2.1	-2.9	0.6	-1.1
10.6	-2.9	-1.8	-0.2	2.2	1.3	0.8	-1.0	-1.5	-0.3	-2.9	1.6	-2.1	-0.4	-0.9	0.2	3.1	1.5	2.6
9.6	-1.3	2.0	0.7	-1.3	-1.0	2.6	0.2	-0.6	1.2	-0.1	3.1	0.8	2.2	0.5	2.4	-2.5	2.8	-1.4
8.8	2.6	2.7	0.4	-1.5	-1.7	-0.5	-3.1	1.4	0.3	-2.8	-0.4	-1.2	1.6	1.6	-1.1	-2.4	0.9	0.8
8.2	1.6	0.4	-2.9	1.3	2.7	2.1	0.3	1.9	0.2	0.0	0.4	0.1	-1.9	-2.9	1.9	2.6	-1.7	-2.7
7.6	2.5	1.1	2.7	3.0	-1.1	-0.4	2.3	1.2	-0.3	0.5	1.8	-1.4	-1.1	-1.3	1.0	-1.4	-0.9	-3.0
7.1	-0.7	-2.8	0.7	2.7	-1.3	0.8	1.5	-0.6	1.5	2.8	2.8	2.1	2.6	0.5	1.0	2.9	-1.1	1.3
6.6	-2.6	-0.5	-1.7	-0.4	-0.5	2.6	0.8	-1.4	0.6	2.6	3.0	2.3	0.7	2.0	-1.3	-2.8	-0.2	-2.1
6.2	-1.2	-0.4	0.9	1.4	1.9	-1.6	-1.8	-1.3	-1.9	2.2	2.7	-3.0	2.2	-2.8	-2.1	0.8	1.7	2.8
5.9	-1.3	2.8	-2.3	-2.0	-2.9	-1.1	2.4	-0.6	0.1	-0.4	-1.5	1.9	-1.9	-0.8	1.6	-2.2	2.0	-1.3
5.6	1.3	-0.1	3.0	3.0	-2.8	-0.2	1.9	-1.3	0.2	0.4	-2.0	-2.0	-2.1	-1.8	-1.2	2.4	1.7	2.1

	Mn						NH4-N						TN					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	3.1	0.0	3.1	0.0	3.1	0.0	3.1	0.0	3.1	0.0	3.1	3.1	0.0	3.1	0.0	0.0	3.1
106.0	-0.5	1.6	-0.2	-2.3	-0.2	-2.0	-0.9	2.0	-0.2	-2.6	0.1	-2.4	-2.0	0.3	-2.4	1.4	-1.0	-3.0
53.0	2.7	2.5	2.5	-2.7	2.4	-2.7	2.7	1.7	2.1	-2.9	2.5	-2.8	-0.6	-1.9	0.4	0.1	-0.2	-3.0
35.3	-1.6	0.5	-2.7	-0.6	1.2	1.1	1.7	2.6	-0.9	2.0	-2.9	2.6	-1.1	-0.6	-0.8	-1.2	1.8	1.5
26.5	2.7	2.1	-0.7	1.4	2.8	1.3	3.0	-0.9	-1.0	-2.8	-0.3	2.5	-0.7	1.1	-2.7	0.8	1.6	0.5
21.2	2.3	2.9	-2.9	2.7	2.5	2.4	0.3	1.8	1.2	-1.0	0.4	-1.0	0.5	1.9	-1.7	-1.8	1.0	2.9
17.7	2.6	-0.8	3.0	0.0	-3.1	-0.6	-2.7	-0.9	-2.7	0.6	-1.8	-2.5	1.0	2.4	2.2	-1.7	1.2	-0.6
15.1	2.7	-1.4	3.1	-0.3	2.9	-1.1	2.3	-1.5	2.3	-0.7	2.6	-0.2	0.4	-2.1	0.1	-3.0	-3.1	1.9
13.3	2.5	2.2	1.6	1.4	-2.7	3.1	-2.5	0.2	-2.1	2.4	1.2	-2.8	-1.9	1.9	1.1	1.3	2.7	0.6
11.8	2.4	-2.0	-0.5	-0.4	2.1	0.3	2.3	-2.6	-0.3	-0.9	0.2	-0.8	2.2	-1.6	1.9	2.6	2.2	-0.7
10.6	3.1	-2.2	2.4	-1.1	-3.0	-2.7	-3.0	-0.6	-3.1	-0.3	-0.3	0.3	3.1	-2.2	-0.7	0.3	2.7	-0.9
9.6	-2.1	-0.3	-1.5	-2.2	3.0	1.7	-1.5	1.8	0.3	-1.0	-1.3	2.6	-2.5	-0.6	0.4	0.4	2.4	0.7
8.8	-2.3	1.4	-1.2	-1.3	-1.0	-1.3	1.3	2.2	0.2	-2.9	-0.2	-0.6	-1.8	0.7	1.8	-1.7	-1.5	0.9
8.2	1.4	-0.6	-1.1	0.6	-0.6	1.5	1.8	0.0	-1.3	-0.4	-0.1	1.2	0.8	-0.8	-1.1	-1.5	-0.3	-2.6
7.6	-2.3	0.6	0.4	-1.4	2.9	-0.5	-1.9	0.7	0.4	-2.4	1.1	-1.4	-0.9	0.3	-0.6	0.7	2.7	-1.1
7.1	2.7	0.1	1.6	-0.3	1.5	-2.2	2.9	-0.4	-2.1	-0.5	-0.5	2.4	3.1	-2.1	-1.5	2.2	2.7	-2.4
6.6	0.8	-1.8	-1.9	-1.2	-3.1	0.8	3.0	-0.9	0.0	-1.0	-1.3	2.1	0.3	-1.3	0.1	1.7	-3.1	1.5
6.2	-2.7	0.7	2.7	0.0	2.4	-1.3	-1.2	0.5	2.5	2.2	0.9	-2.2	0.4	-0.1	0.6	-2.2	2.1	2.3
5.9	-0.3	-1.5	0.3	-0.6	0.5	0.1	-1.5	2.7	-0.1	-0.7	-1.3	0.3	0.3	-1.0	0.9	-0.8	0.8	-1.1
5.6	1.5	-0.7	-0.5	-0.2	-1.7	0.2	0.8	0.6	-0.6	0.4	1.7	2.6	1.7	-2.1	1.3	1.0	-1.6	-1.9

	TC						pH						EC					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	3.1	0.0	3.1	3.1	3.1	3.1	3.1	0.0	3.1	3.1	3.1	3.1	3.1	0.0	3.1	3.1	3.1	0.0
106.0	-2.5	0.0	-2.1	2.3	-1.6	3.1	-2.5	-0.1	-2.4	1.8	-2.1	2.2	2.4	1.1	-3.1	-2.2	3.0	1.5
53.0	-1.2	-2.0	2.3	-3.0	0.1	-3.1	-2.6	-0.2	-1.4	-2.1	3.0	-1.7	-0.2	-0.8	-0.5	0.2	0.3	0.1
35.3	0.8	-0.5	-2.4	-1.2	1.5	2.1	2.5	-2.3	0.5	2.5	-0.7	-1.3	2.4	-1.3	1.0	1.4	0.1	-3.0
26.5	-1.1	-1.6	-0.8	-0.2	1.1	1.2	1.5	-0.9	0.9	3.1	-1.5	-2.1	2.1	-2.2	-1.0	1.1	-1.2	2.1
21.2	0.3	2.2	-1.7	-1.0	1.3	2.7	-1.7	-0.3	0.8	2.2	-2.5	-1.0	-1.8	0.8	-0.2	1.1	-2.1	-1.3
17.7	3.1	1.6	0.4	-1.4	1.4	0.1	0.6	-3.0	0.4	-1.3	-2.4	2.9	-1.1	0.7	0.0	0.3	-2.2	2.3
15.1	1.6	-2.5	-0.4	-3.0	3.1	-1.9	-2.8	0.0	-1.6	1.4	-1.1	1.3	-2.9	0.1	-1.3	1.7	-1.4	2.3
13.3	-2.0	0.7	1.9	-0.4	2.3	-1.5	-2.3	-1.2	-1.7	1.6	-0.4	0.9	2.8	-0.7	-2.1	-1.4	-0.1	1.5
11.8	2.6	-1.7	0.7	0.7	2.2	2.6	-2.1	-1.5	1.2	-1.4	0.2	0.4	-0.1	-2.3	0.1	-2.2	0.5	-0.3
10.6	0.5	2.7	1.5	-1.0	2.6	0.5	1.9	1.8	-1.7	-2.0	-0.2	1.9	2.2	-2.5	-2.9	-1.3	-0.3	-3.1
9.6	2.7	-1.1	0.0	-1.0	2.4	1.0	-0.9	2.3	1.0	-1.9	-0.8	-2.2	-1.7	1.4	0.8	-1.2	-1.0	3.0
8.8	-3.1	2.2	2.0	-0.9	-1.5	-0.2	-2.8	-0.3	-1.2	3.1	2.3	-3.1	2.1	0.3	-1.4	-1.2	2.3	1.4
8.2	1.6	-1.3	-0.2	0.2	-0.6	-3.1	1.1	0.7	-1.0	2.6	2.6	-0.1	-0.7	-1.3	-1.2	2.7	1.8	1.2
7.6	-2.3	-2.6	-0.3	-0.2	1.5	-1.4	-1.4	-2.2	-3.1	-1.7	-1.2	2.3	1.5	-2.2	-2.7	2.1	-1.3	1.2
7.1	2.4	-1.8	-0.8	1.8	2.5	2.1	-0.7	1.4	0.8	-1.3	-1.4	0.9	-0.4	2.7	-2.0	-0.6	-1.5	1.4
6.6	1.2	-1.4	0.1	-1.6	3.1	2.2	3.1	2.1	-3.1	2.9	0.2	-1.2	-2.0	2.2	3.0	1.6	0.7	1.2
6.2	-1.8	0.4	-0.4	0.3	2.8	2.9	0.5	0.4	1.0	-0.6	0.5	-0.9	-1.8	-0.4	0.7	0.1	0.2	-2.1
5.9	1.9	-1.1	-0.5	-0.7	0.7	-1.0	-1.9	1.3	2.5	-2.9	-2.9	2.6	3.1	-0.1	2.2	-2.0	-2.7	-2.5
5.6	-2.7	-1.8	1.6	0.6	-1.6	-1.3	0.8	1.4	-0.1	2.7	1.2	1.9	2.3	2.8	0.6	2.0	1.2	2.9

Table A2: 2017 TMA and physical conditions covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Microbial Abundance

	VWC						Water Grad.						Temp					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	3.1	0.0	0.0	3.1	0.0	3.1	0.0	3.1	0.0	0.0	3.1	0.0	0.0	3.1	0.0	3.1	0.0	0.0
106.0	-2.9	-0.1	-1.0	2.3	-1.1	-2.5	-0.7	-3.1	-1.0	0.6	1.9	0.3	0.0	2.3	0.5	-1.8	0.6	-1.4
53.0	2.0	1.4	2.2	2.6	2.0	2.9	3.0	1.3	-2.3	2.1	1.1	-0.8	-1.4	-1.9	-1.2	-0.5	-1.3	-0.5
35.3	-1.6	0.1	-2.6	-0.8	0.6	0.4	1.7	2.8	-0.3	0.9	-1.9	-2.2	2.7	-1.6	1.7	-2.5	-1.0	-0.9
26.5	-2.6	3.0	1.6	-1.9	-0.6	-0.8	3.0	2.3	-3.0	0.7	-2.5	-1.1	-2.8	-0.5	0.4	-2.3	0.0	-3.0
21.2	0.5	3.1	1.7	1.3	1.4	0.7	-0.9	3.0	-1.1	-0.2	0.1	-1.1	1.7	-2.7	2.4	2.1	2.2	1.4
17.7	2.0	-2.8	2.5	-0.1	-2.4	-1.0	-2.7	-0.1	-3.0	1.2	-0.8	0.3	-1.7	0.5	-1.5	2.3	0.6	0.9
15.1	-0.9	1.5	0.1	1.7	-0.1	2.9	-1.0	1.3	-0.8	1.7	2.2	0.5	3.0	-0.7	-2.7	-0.7	-2.4	1.1
13.3	0.9	2.8	1.0	-0.8	-2.5	-0.7	2.2	-1.9	0.6	-1.6	1.5	2.7	-0.5	1.4	-0.3	-2.2	2.3	-2.2
11.8	2.6	0.0	2.6	-1.1	-2.7	2.2	1.0	0.8	-2.0	2.5	0.7	-1.3	-2.5	1.0	2.9	0.0	-1.5	-3.0
10.6	-0.5	1.1	0.3	1.8	2.2	2.3	-1.0	1.1	0.1	0.8	1.0	0.2	-2.2	-1.0	-1.5	0.1	0.3	0.8
9.6	1.4	-2.2	-2.7	1.6	1.3	-0.7	-0.7	2.3	-2.6	-1.3	-0.9	1.9	2.4	-1.0	-2.4	2.5	2.6	0.5
8.8	1.8	-2.1	2.3	-2.4	1.3	1.3	1.3	-1.5	2.6	-3.1	1.2	-3.1	-0.1	2.2	-0.4	1.6	-0.9	-1.1
8.2	-1.2	-3.1	3.1	2.9	2.8	-2.3	2.6	0.8	2.6	1.0	0.3	2.3	1.9	0.2	-0.3	-0.3	0.0	1.8
7.6	1.5	-1.9	2.9	2.8	-2.3	1.8	2.6	-2.2	2.9	2.6	-3.1	0.4	-1.7	0.6	-0.1	-0.1	0.5	-1.6
7.1	-1.0	2.8	-2.6	1.8	-2.6	-0.2	-2.9	0.5	2.2	-0.4	1.8	-2.2	-2.2	1.6	2.4	0.8	3.0	-0.9
6.6	-1.6	-2.8	-2.7	-0.4	2.8	-0.2	3.1	3.0	-3.1	-1.2	1.2	-1.9	2.5	0.8	1.6	-2.7	-0.2	-2.5
6.2	-0.3	-1.3	2.1	-3.1	1.1	-0.7	-1.9	-1.0	0.5	1.7	0.8	-0.6	0.2	1.2	2.0	-2.7	2.7	-0.6
5.9	-2.8	1.4	-1.9	-1.9	-2.2	-1.6	2.7	2.4	-2.8	2.4	1.9	1.9	-2.7	1.4	-1.8	-1.6	-2.1	-1.8
5.6	-2.0	-1.8	-3.0	3.1	-2.3	-1.4	1.5	1.8	1.9	1.3	1.1	3.1	-1.2	-0.9	-1.7	-1.8	-2.0	-0.6

	Temp. Grad.						Bottom Flux						Water Storage					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	3.1	0.0	3.1	0.0	3.1	0.0	3.1	0.0	3.1	0.0	3.1	0.0	3.1	0.0	0.0	0.0	0.0
106.0	-0.8	1.7	0.0	-2.2	0.1	-2.1	-0.8	1.6	-0.1	-2.6	-0.2	-1.9	-0.1	2.4	0.5	-1.4	0.9	-1.5
53.0	-2.0	-2.4	-1.8	-1.1	-1.9	-1.2	-2.0	-2.4	-1.9	-1.1	-1.9	-1.0	1.5	1.0	1.5	2.3	1.5	2.4
35.3	2.3	-1.8	1.5	-2.8	-1.4	-1.4	0.6	2.5	-0.6	1.4	3.0	-3.1	-2.1	-0.2	2.9	-1.2	0.3	0.4
26.5	3.0	-0.7	-0.1	-2.8	-0.5	2.8	1.0	-2.8	-2.6	1.6	-2.3	0.7	-2.4	-0.1	0.2	-1.8	0.5	-2.8
21.2	1.4	-2.9	2.1	1.7	1.8	1.1	-2.7	-0.7	-2.0	-2.1	-2.1	-2.9	0.6	2.6	1.2	1.2	1.3	0.4
17.7	-2.0	0.1	-1.8	2.0	0.1	0.5	-1.8	0.5	-2.2	2.1	0.3	0.9	2.3	-2.0	2.0	-1.3	-2.5	-1.2
15.1	2.7	-0.8	-3.0	-0.9	-2.8	0.7	-2.9	-0.2	-2.5	-0.3	-2.1	1.6	-1.6	1.0	-1.0	1.2	-0.6	2.7
13.3	-0.7	1.1	-0.5	-2.5	2.0	-2.5	-2.7	-0.7	-2.6	1.8	0.0	2.0	0.2	2.2	0.8	-1.5	3.0	-1.5
11.8	-2.9	0.6	2.5	-0.4	-2.0	2.8	0.0	-2.9	-1.7	2.6	0.9	-0.6	2.5	-0.3	1.3	-1.2	-2.9	2.0
10.6	-3.1	-2.1	-2.3	-0.8	-0.5	0.0	2.5	-2.4	-3.0	-1.5	-1.3	-0.8	-1.0	0.3	-0.2	1.3	1.5	1.9
9.6	1.2	-2.4	2.4	1.0	1.1	-1.1	-0.8	2.4	-0.4	-0.9	-0.7	-2.7	1.9	-1.2	2.4	1.5	1.8	0.1
8.8	-0.5	1.7	-0.7	1.2	-1.3	-1.6	-0.5	1.9	-0.3	1.3	-1.2	-1.4	2.9	-1.1	2.5	-1.9	1.9	1.9
8.2	1.5	-0.2	-0.7	-0.6	-0.4	1.3	2.3	0.9	0.0	0.1	0.3	2.2	1.5	-0.5	-2.2	-1.1	-0.8	1.1
7.6	-2.4	0.1	-0.7	-0.8	-0.2	-2.2	-1.6	0.6	1.1	-0.1	0.6	-1.5	2.6	-1.3	-2.5	-2.3	-1.6	2.8
7.1	-1.6	2.0	3.0	1.8	-2.7	-0.4	2.2	-0.2	0.7	-0.9	1.0	-2.7	-1.4	2.8	-2.8	2.3	-2.1	-0.1
6.6	1.1	2.8	-0.3	2.2	-1.4	2.0	1.1	-0.9	1.1	2.5	-1.1	2.3	-1.3	2.9	-2.1	0.2	2.9	-0.1
6.2	0.0	-3.1	1.8	2.8	2.2	-1.2	-2.7	-1.6	-0.7	0.8	0.1	2.9	1.1	2.1	2.7	-1.5	-2.3	0.4
5.9	3.0	0.6	-2.5	-2.3	-2.8	-2.5	-0.2	-2.2	0.7	0.9	0.3	0.7	-2.3	1.8	-1.6	-1.3	-1.8	-1.5
5.6	-2.0	-1.6	-2.5	-2.6	-2.8	-1.5	0.5	1.0	0.2	-0.1	-0.3	1.2	-1.2	-0.8	-1.9	-1.8	-2.1	-0.6

Table A3: 2017 TMA and weather condition covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Microbial Abundance

	Mean Air Temp.						Air Temp. Ran.						Humidity						ET						GWT Depth					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	0.0	3.1	0.0	3.1	0.0	3.1	3.1	0.0	3.1	0.0	0.0	3.1	0.0	3.1	0.0	3.1	0.0	3.1	3.1	0.0	3.1	0.0
106.0	0.2	2.8	0.7	-1.5	0.9	-1.0	-0.9	1.7	-0.4	-2.6	-0.2	-2.1	1.2	-2.5	1.8	-0.5	2.0	0.0	-0.4	2.1	0.1	-2.2	0.3	-1.7	1.5	-2.3	2.0	-0.3	2.2	0.2
53.0	-1.4	-1.9	-1.3	-0.5	-1.3	-0.5	-1.9	-2.4	-1.8	-1.0	-1.8	-1.0	0.6	0.1	0.7	1.5	0.7	1.5	-1.8	-2.2	-1.6	-0.8	-1.7	-0.8	-1.2	-1.7	-1.1	-0.3	-1.1	-0.3
35.3	2.7	-1.7	1.6	-2.7	-1.2	-1.0	0.9	2.8	-0.2	1.7	-3.0	-2.8	-2.4	-0.4	2.8	-1.5	0.0	0.2	1.6	-2.8	0.5	2.4	-2.3	-2.1	1.9	-2.4	0.8	2.8	-2.0	-1.8
26.5	3.0	-1.0	-0.1	-2.8	-0.5	2.8	-1.1	1.2	2.1	-0.6	1.8	-1.3	2.7	-1.3	-0.4	-3.1	-0.8	2.5	-2.6	-0.3	0.6	-2.1	0.2	-2.8	2.1	-1.9	-1.0	2.6	-1.3	1.9
21.2	1.4	-3.1	2.1	1.9	1.9	1.2	-3.0	-1.2	-2.3	-2.5	-2.4	3.1	-0.3	1.6	0.5	0.2	0.3	-0.5	1.8	-2.6	2.6	2.3	2.4	1.6	-1.3	0.6	-0.5	-0.8	-0.7	-1.5
17.7	-1.9	0.3	-1.7	2.1	0.3	0.7	2.4	-1.7	2.6	0.1	-1.7	-1.3	-1.9	0.3	-1.6	2.1	0.4	0.8	-3.1	-0.9	-2.9	0.9	-0.9	-0.5	0.0	2.2	0.3	-2.3	2.3	2.7
15.1	3.1	-0.7	-2.6	-0.7	-2.5	1.1	-1.0	1.5	-0.4	1.5	-0.3	-3.0	2.0	-1.8	2.6	-1.7	2.7	0.0	-1.7	0.8	-1.1	0.8	-1.0	2.6	-1.6	0.9	-1.0	0.9	-0.9	2.7
13.3	-0.3	1.6	0.0	-2.1	2.4	-2.0	-1.2	0.7	-0.9	-3.0	1.5	-2.9	1.2	3.1	1.5	-0.6	-2.4	-0.5	-1.1	0.8	-0.8	-2.9	1.6	-2.8	-1.6	0.3	-1.3	2.9	1.1	3.0
11.8	-2.9	0.5	2.5	-0.4	-2.0	2.9	-1.5	2.0	-2.3	1.0	-0.6	-2.0	1.9	-0.9	1.1	-1.8	2.9	1.4	-1.7	1.7	-2.6	0.8	-0.8	-2.2	1.9	-0.9	1.1	-1.8	2.9	1.5
10.6	-2.7	-1.5	-2.0	-0.5	-0.3	0.2	2.3	-2.8	3.0	-1.8	-1.6	-1.1	-1.0	0.2	-0.3	1.2	1.4	1.9	2.5	-2.6	-3.0	-1.5	-1.4	-0.8	-3.0	-1.8	-2.2	-0.7	-0.5	0.0
9.6	1.2	-1.9	2.7	1.3	1.5	-0.7	-0.6	2.5	0.9	-0.6	-0.4	-2.5	2.8	-0.3	-2.0	2.9	3.1	1.0	-0.3	2.8	1.2	-0.3	-0.1	-2.2	0.4	-2.8	1.8	0.4	0.6	-1.5
8.8	-0.6	1.6	-0.7	1.1	-1.4	-1.7	-1.0	1.2	-1.2	0.7	-1.8	-2.1	2.5	-1.6	2.3	-2.1	1.7	1.4	0.0	2.2	-0.2	1.7	-0.8	-1.1	0.2	2.4	0.0	1.9	-0.6	-0.9
8.2	1.7	0.2	-0.5	-0.5	-0.2	1.6	2.4	0.8	0.1	0.2	0.4	2.2	-0.5	-2.0	-2.7	-2.7	-2.4	-0.6	1.5	-0.1	-0.7	-0.7	-0.5	1.3	-3.1	1.6	0.9	1.0	1.2	3.0
7.6	-2.4	-0.2	-0.9	-0.9	-0.2	-2.4	-2.8	-0.5	-1.2	-1.2	-0.5	-2.7	0.5	2.8	2.1	2.1	2.7	0.6	-2.6	-0.4	-1.1	-1.1	-0.4	-2.6	-1.0	1.2	0.5	0.5	1.2	-1.0
7.1	0.3	-2.3	-1.4	-2.9	-1.0	1.6	1.1	-1.4	-0.5	-2.1	-0.1	2.4	3.0	0.4	1.4	-0.2	1.7	-2.0	0.4	-2.2	-1.3	-2.9	-0.9	1.7	-3.0	0.7	1.6	0.0	2.0	-1.8
6.6	1.5	-0.4	0.7	2.9	-0.7	2.8	-0.5	-2.5	-1.4	0.9	-2.8	0.8	1.5	-0.5	0.7	2.9	-0.7	2.8	-1.6	2.7	-2.4	-0.2	2.5	-0.2	2.1	0.2	1.3	-2.7	-0.1	-2.8
6.2	-0.7	0.2	1.1	2.7	2.0	-1.4	-2.6	-1.6	-0.7	0.9	0.2	3.1	0.6	1.5	2.4	-2.2	-3.0	-0.1	-2.4	-1.4	-0.5	1.1	0.3	-3.1	-1.6	-0.6	0.3	1.9	1.2	-2.2
5.9	3.1	1.0	-2.2	-2.1	-2.6	-2.2	0.4	-1.7	1.4	1.5	1.0	1.3	2.5	0.3	-2.9	-2.7	3.0	-2.9	-1.8	2.4	-0.8	-0.7	-1.2	-0.9	0.6	-1.5	1.6	1.7	1.2	1.5
5.6	-1.8	-1.4	-2.2	-2.4	-2.6	-1.2	-3.0	-2.6	2.9	2.8	2.5	-2.3	2.1	2.5	1.7	1.5	1.3	2.7	-1.9	-1.5	-2.3	-2.4	-2.6	-1.2	1.4	1.8	1.0	0.9	0.6	2.1

Table A4: 2017 F:B and chemical covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Fungi:Bacteria Ratio

	NO3-N						P						SO4-S					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	3.1	0.0	3.1	3.1	0.0	3.1	3.1	0.0	3.1	3.1	0.0	3.1	0.0	3.1	0.0	0.0	3.1	3.1
106.0	2.4	1.5	-2.8	2.2	1.2	-1.6	2.2	1.6	1.6	1.9	0.6	-1.9	-1.6	1.9	0.0	-1.1	-1.7	2.1
53.0	3.1	-2.5	-0.1	-0.5	-1.1	0.1	0.2	2.5	2.5	-1.2	2.1	3.0	-2.5	-2.1	0.4	0.7	0.9	-3.1
35.3	-3.1	-2.0	1.5	1.5	2.0	0.5	1.4	-1.6	2.6	2.2	2.3	3.1	0.9	-0.6	-1.8	2.5	1.6	-2.3
26.5	2.6	3.0	-1.9	-2.8	-2.0	-1.3	-3.0	1.3	-2.3	-0.8	-2.4	2.2	1.7	0.7	-0.8	3.0	-2.4	-2.4
21.2	0.4	2.7	-2.9	2.5	-2.8	1.0	-0.1	3.1	1.3	0.6	-2.8	-0.7	-1.1	2.0	-2.2	2.7	-2.5	-0.4
17.7	-2.0	-1.0	0.4	0.5	-0.7	2.6	2.4	-2.5	-2.9	-2.7	-0.8	-1.6	-2.7	-2.7	-2.3	-1.4	-1.1	1.0
15.1	-2.9	0.1	-1.4	1.9	-3.1	2.6	-2.5	1.4	0.3	-2.5	2.3	0.0	-2.6	0.4	-0.1	1.5	-1.7	-2.3
13.3	-0.7	0.8	1.0	2.5	1.2	1.5	0.0	0.5	1.3	-0.1	1.3	2.6	2.5	2.1	1.7	-2.4	0.4	-0.5
11.8	2.1	1.0	-2.6	1.7	-1.5	2.4	2.8	-2.0	2.8	-2.9	1.6	-3.0	-0.1	-2.2	-2.1	1.1	-0.1	-1.6
10.6	2.4	-1.8	1.1	-2.3	1.8	1.8	-1.9	-1.5	1.1	-1.0	2.1	-1.0	-1.3	-0.9	1.6	-1.4	2.0	-2.6
9.6	-0.6	2.2	0.1	0.3	-0.9	-2.3	0.9	-0.4	0.5	1.5	-3.1	2.2	2.9	0.6	1.7	-0.8	2.9	0.0
8.8	3.0	2.9	0.6	-0.6	-2.4	-0.9	-2.7	1.7	0.5	-2.0	-1.1	-1.6	2.0	1.9	-0.9	-1.6	0.2	0.3
8.2	-2.8	0.6	-1.7	2.2	2.3	-1.8	2.2	2.1	1.4	0.9	0.0	2.5	0.1	-2.7	3.1	-2.7	-2.2	-0.3
7.6	2.7	1.0	-2.6	-2.8	-3.1	-2.9	2.4	1.1	0.8	0.9	-0.2	2.3	-1.0	-1.4	2.1	-0.9	-2.9	0.7
7.1	0.3	-2.8	2.9	2.9	-2.4	-0.3	2.4	-0.6	-2.6	3.0	1.7	1.0	-2.7	0.5	-3.1	3.1	-2.2	0.2
6.6	-1.7	-0.2	2.3	2.5	1.9	-2.2	1.7	-1.0	-1.7	-0.8	-0.8	-2.5	1.6	2.3	2.8	0.1	2.2	-0.6
6.2	-2.6	0.1	-0.3	1.7	2.2	2.7	3.1	-0.8	-3.1	2.4	3.0	1.2	0.8	-2.3	3.0	1.1	1.9	0.8
5.9	-0.8	-2.4	3.1	-0.8	-1.8	-1.2	2.9	0.4	-0.8	0.8	-0.3	1.8	-1.4	0.2	0.7	-1.0	-3.1	-1.4
5.6	1.3	-2.5	3.1	1.9	-3.0	-2.7	1.8	2.5	0.3	-0.7	-2.2	1.8	-2.1	2.0	-1.1	1.3	1.5	-0.4

	Mn						NH4-N						TN					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	3.1	0.0	3.1	3.1	0.0	3.1	0.0	3.1	3.1	3.1	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1
106.0	1.6	1.5	3.0	2.0	0.8	-1.6	1.2	1.9	3.0	1.7	1.2	-2.0	0.1	0.2	0.8	-0.6	0.0	-2.6
53.0	0.2	1.5	-2.5	-2.7	2.6	-2.1	0.2	0.8	-2.9	-2.9	2.7	-2.3	-3.1	-2.8	1.6	0.1	0.0	-2.5
35.3	-1.8	-0.6	3.1	2.7	1.4	2.2	1.5	1.5	-1.4	-1.0	-2.7	-2.6	-1.3	-1.8	-1.3	2.1	2.0	2.6
26.5	2.2	-0.2	-2.8	0.5	1.2	3.1	2.5	3.0	-3.1	2.6	-1.9	-2.0	-1.2	-1.2	1.5	-0.1	0.0	2.4
21.2	-2.1	-2.8	0.3	-1.3	2.7	-2.2	2.1	2.4	-1.9	1.2	0.6	0.7	2.4	2.5	1.5	0.4	1.3	-1.7
17.7	2.1	-2.9	-0.5	-2.1	-1.6	3.1	3.1	-3.0	0.1	-1.5	-0.3	1.3	0.5	0.3	-1.3	2.4	2.7	-3.1
15.1	-2.8	-1.3	2.9	0.6	2.0	0.4	3.0	-1.5	2.1	0.2	1.7	1.2	1.2	-2.1	0.0	-2.1	2.3	-2.9
13.3	2.0	1.7	1.6	-1.7	-2.9	1.7	-3.1	-0.4	-2.0	-0.7	1.0	2.0	-2.4	1.3	1.1	-1.8	2.6	-0.8
11.8	-2.7	-1.7	-0.5	-2.7	1.4	-0.2	-2.8	-2.3	-0.3	3.1	-0.5	-1.3	-2.9	-1.2	1.8	0.3	1.5	-1.1
10.6	2.2	-2.2	-2.6	0.7	-2.5	-1.7	2.4	-0.6	-1.8	1.5	0.2	1.3	2.2	-2.2	0.7	2.1	-3.1	0.2
9.6	-1.4	-0.1	-2.2	-0.6	3.1	-3.1	-0.8	2.0	-0.4	0.6	-1.2	-2.2	-1.8	-0.5	-0.3	2.0	2.5	2.1
8.8	-1.9	1.6	-1.1	-0.5	-1.8	-1.8	1.7	2.4	0.4	-2.0	-1.0	-1.1	-1.4	1.0	2.0	-0.9	-2.2	0.4
8.2	-2.9	-0.5	0.1	1.5	-1.1	-2.4	-2.5	0.2	-0.1	0.5	-0.5	-2.7	2.8	-0.6	0.1	-0.6	-0.7	-0.3
7.6	-2.1	0.5	1.5	-0.9	0.9	-3.0	-1.8	0.6	1.4	-2.0	-0.9	2.3	-0.7	0.2	0.5	1.1	0.7	2.7
7.1	-2.6	0.1	-2.5	-0.2	0.4	2.9	-2.4	-0.3	0.1	-0.3	-1.6	1.3	-2.2	-2.1	0.7	2.4	1.6	2.8
6.6	1.7	-1.5	2.1	1.7	-0.6	2.3	-2.3	-0.6	-2.3	1.9	1.1	-2.7	1.3	-0.9	-2.2	-1.7	-0.6	3.0
6.2	2.2	1.2	1.6	0.2	2.6	3.0	-2.6	1.0	1.3	2.4	1.1	2.0	-1.0	0.4	-0.6	-1.9	2.4	0.3
5.9	0.3	-0.5	-0.7	0.6	1.7	0.1	-0.9	-2.5	-1.0	0.5	-0.2	0.3	0.8	0.1	0.0	0.4	2.0	-1.1
5.6	1.5	3.1	-0.4	-1.3	-2.0	-2.3	0.8	-1.9	-0.5	-0.7	1.5	0.2	1.7	1.7	1.4	-0.1	-1.8	1.9

	TC						pH						EC					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	3.1	0.0	0.0	3.1	3.1	3.1
106.0	-0.4	-0.1	1.1	0.4	-0.5	-2.8	-0.4	-0.2	0.8	-0.1	-1.1	2.6	-1.8	1.0	0.1	2.1	-2.2	1.8
53.0	2.6	-3.0	-2.8	-3.0	0.2	-2.5	1.2	-1.2	-0.1	-2.1	-3.1	-1.1	-2.7	-1.8	0.7	0.2	0.5	0.6
35.3	0.6	-1.6	-2.9	2.1	1.8	-3.1	2.4	2.8	0.1	-0.5	-0.4	-0.2	2.2	-2.4	0.5	-1.6	0.4	-1.9
26.5	-1.6	2.3	-2.9	-1.1	-0.5	3.1	1.0	3.1	-1.2	2.2	-3.1	-0.3	1.6	1.8	3.1	0.2	-2.8	-2.3
21.2	2.2	2.9	1.5	1.3	1.5	-1.9	0.2	0.3	-2.2	-1.8	-2.2	0.6	0.0	1.4	3.0	-3.0	-1.9	0.4
17.7	2.6	-0.6	-3.1	2.8	2.9	-2.4	0.1	1.1	-3.1	2.9	-0.9	0.4	-1.6	-1.4	2.7	-1.8	-0.7	-0.2
15.1	2.4	-2.5	-0.5	-2.2	2.3	-0.5	-2.0	0.0	-1.8	2.3	-1.9	2.8	-2.1	0.1	-1.5	2.6	-2.3	-2.5
13.3	-2.5	0.2	2.0	2.9	2.2	-2.9	-2.8	-1.8	-1.7	-1.5	-0.5	-0.5	2.3	-1.3	-2.0	1.8	-0.3	0.0
11.8	-2.5	-1.4	0.7	-1.5	1.5	2.2	-0.8	-1.2	1.2	2.6	-0.5	-0.1	1.1	-1.9	0.0	1.8	-0.2	-0.8
10.6	-0.4	2.7	2.9	0.8	3.1	1.6	0.9	1.9	-0.3	-0.2	0.3	2.9	1.3	-2.5	-1.5	0.6	0.2	-2.0
9.6	-2.9	-0.9	-0.6	0.7	2.5	2.5	-0.2	2.5	0.4	-0.2	-0.6	-0.8	-1.0	1.5	0.2	0.5	-0.9	-1.8
8.8	-2.7	2.5	2.2	0.0	-2.2	-0.6	-2.4	-0.1	-1.0	-2.4	1.5	2.8	2.5	0.6	-1.2	-0.4	1.5	1.0
8.2	-2.7	-1.2	0.9	1.1	-1.1	-0.7	3.1	0.9	0.2	-2.7	2.2	2.2	1.3	-1.1	0.0	-2.6	1.4	-2.7
7.6	-2.2	-2.7	0.8	0.3	-0.5	2.4	-1.2	-2.3	-2.0	-1.3	3.1	-0.3	1.6	-2.3	-1.6	2.5	3.0	-1.3
7.1	-2.9	-1.8	1.3	2.0	1.4	1.0	0.3	1.4	3.0	-1.1	-2.5	-0.2	0.5	2.7	0.2	-0.4	-2.6	0.3
6.6	2.1	-1.0	-2.2	1.3	-0.7	-2.6	-2.2	2.4	0.9	-0.5	2.6	0.3	-1.0	2.5	0.8	-1.8	3.1	2.6
6.2	3.1	0.9	-1.6	0.5	3.1	0.9	-0.9	0.9	-0.2	-0.4	0.7	-2.9	3.0	0.1	-0.4	0.3	0.5	2.2
5.9	2.4	0.0	-1.4	0.5	1.8	-1.1	-1.3	2.4	1.6	-1.7	-1.7	2.6	-2.6	0.9	1.3	-0.9	-1.5	-2.5
5.6	-2.7	2.0	1.7	-0.5	-1.9	2.6	0.8	-1.1	0.0	1.6	0.9	-0.6	2.3	0.3	0.7	0.9	1.0	0.4

Table A5: 2017 F:B and physical conditions covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Fungi:Bacteria Ratio

	VWC						Water Grad.						Temp						Temp. Grad.						Bottom Flux						Water Storage					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	0.0	3.1	0.0	0.0	3.1	0.0	3.1	3.1	0.0	3.1	0.0	3.1	3.1	3.1	3.1	3.1	0.0	0.0	3.1	3.1	3.1	0.0	3.1	0.0	0.0	3.1	3.1	0.0	0.0	3.1	3.1	3.1	3.1	3.1	0.0
106.0	-0.8	-0.2	2.2	0.3	0.0	-2.1	1.4	3.1	2.2	-1.4	3.0	0.7	2.0	2.2	-2.6	2.5	1.7	-1.0	1.3	1.6	-3.1	2.1	1.1	-1.7	1.3	1.5	3.1	1.7	0.9	-1.5	1.9	2.3	-2.6	2.9	2.0	-1.1
53.0	-0.5	0.5	-2.9	2.6	2.2	-2.8	0.6	0.3	-1.1	2.1	1.2	-0.2	2.4	-2.9	0.0	-0.5	-1.1	0.0	1.8	2.9	-0.5	-1.1	-1.8	-0.6	1.8	2.9	-0.7	-1.1	-1.7	-0.5	-1.0	0.1	2.7	2.3	1.7	3.0
35.3	-1.8	-1.1	-3.1	2.5	0.9	1.5	1.6	1.6	-0.8	-2.1	-1.6	-1.1	2.6	-2.7	1.2	0.8	-0.7	0.2	2.2	-2.9	1.0	0.4	-1.1	-0.3	0.4	1.4	-1.1	-1.6	-3.0	-2.0	-2.3	-1.3	2.4	2.1	0.6	1.5
26.5	-3.1	0.7	-0.6	-2.8	-2.2	1.0	2.5	0.0	1.2	-0.2	2.2	0.7	3.0	-2.8	-1.8	3.0	-1.6	-1.2	2.5	-3.0	-2.2	2.5	-2.1	-1.6	0.5	1.1	1.5	0.7	2.4	2.5	-3.0	-2.4	-1.9	-2.8	-1.1	-1.0
21.2	2.3	-2.6	-1.4	-2.7	1.6	2.3	1.0	-2.7	2.1	2.0	0.3	0.5	-2.7	-2.1	-0.7	-2.0	2.4	3.0	-3.0	-2.3	-0.9	-2.3	2.0	2.7	-0.8	-0.1	1.2	0.1	-1.8	-1.2	2.5	-3.1	-1.8	-2.9	1.5	2.1
17.7	1.5	1.3	-1.0	-2.2	-0.9	2.8	3.1	-2.2	-0.3	-0.9	0.7	-2.2	-2.2	-1.6	1.3	0.2	2.1	-1.6	-2.5	-2.0	0.9	-0.1	1.6	-2.0	-2.3	-1.7	0.5	0.0	1.8	-1.6	1.8	2.1	-1.5	2.9	-1.0	2.5
15.1	-0.1	1.6	-0.1	2.6	-1.0	-1.9	-0.3	1.4	-0.9	2.6	1.3	1.9	-2.5	-0.7	-2.9	0.2	3.0	2.5	-2.8	-0.8	-3.1	-0.1	2.6	2.1	-2.1	-0.1	-2.7	0.6	-3.0	3.0	-0.8	1.0	-1.2	2.1	-1.5	-2.2
13.3	0.3	2.2	1.0	2.4	-2.6	-2.1	1.7	-2.5	0.6	1.6	1.4	1.3	-1.1	0.8	-0.3	1.0	2.2	2.7	-1.3	0.5	-0.5	0.7	1.8	2.4	3.1	-1.2	-2.6	-1.3	-0.1	0.6	-0.4	1.7	0.9	1.7	2.9	-2.9
11.8	-2.5	0.4	2.6	2.9	2.9	1.7	2.2	1.2	-2.0	0.2	0.0	-1.7	-1.3	1.3	2.9	-2.3	-2.3	2.8	-1.7	1.0	2.5	-2.7	-2.8	2.3	1.2	-2.5	-1.7	0.3	0.2	-1.1	-2.6	0.0	1.3	2.8	2.7	1.5
10.6	-1.4	1.1	1.6	-2.7	2.7	-2.9	-1.9	1.2	1.5	2.7	1.5	1.3	3.1	-1.0	-0.1	1.9	0.8	1.9	2.2	-2.0	-1.0	1.1	0.0	1.0	1.6	-2.4	-1.6	0.4	-0.8	0.3	-1.9	0.4	1.1	-3.1	2.0	3.0
9.6	2.1	-2.1	2.9	-3.0	1.4	0.8	-0.1	2.5	3.0	0.3	-0.8	-2.9	3.1	-0.8	-3.1	-2.2	2.7	1.9	1.8	-2.2	1.7	2.6	1.3	0.4	-0.2	2.5	-1.0	0.8	-0.5	-1.2	2.5	-1.0	1.7	-3.1	1.9	1.6
8.8	2.2	-1.9	2.5	-1.6	0.5	0.9	1.8	-1.3	2.8	-2.3	0.4	2.7	0.3	2.5	-0.2	2.5	-1.6	-1.5	-0.1	2.0	-0.5	2.1	-2.0	-2.0	-0.1	2.1	-0.1	2.1	-1.9	-1.9	-3.0	-0.8	2.7	-1.1	1.2	1.5
8.2	0.8	-3.0	-2.0	-2.5	2.4	0.0	-1.7	0.9	-2.5	1.9	-0.1	-1.6	-2.4	0.4	0.8	0.7	-0.5	-2.1	-2.8	0.0	0.5	0.3	-0.9	-2.6	-2.0	1.0	1.1	1.0	-0.1	-1.7	-2.8	-0.3	-1.0	-0.1	-1.2	-2.8
7.6	1.6	-2.0	-2.3	-3.0	1.9	-0.8	2.8	-2.3	-2.3	3.0	1.2	-2.1	-1.6	0.5	0.9	0.4	-1.5	2.2	-2.2	0.0	0.4	-0.3	-2.2	1.5	-1.5	0.6	2.1	0.3	-1.4	2.3	2.8	-1.4	-1.4	-1.8	2.7	0.3
7.1	-0.1	2.8	-0.4	2.0	2.6	-1.3	-2.0	0.5	-1.9	-0.2	0.8	3.0	-1.3	1.6	-1.7	1.0	1.9	-2.0	-0.6	2.0	-1.0	2.0	2.5	-1.5	-3.1	-0.2	2.8	-0.7	-0.1	2.4	-0.4	2.8	-0.6	2.5	3.1	-1.2
6.6	-0.7	-2.5	1.3	2.5	-1.0	1.3	-2.2	-2.9	0.9	1.7	-2.6	-0.4	-2.9	1.1	-0.6	0.2	2.3	-1.0	2.1	-3.1	-2.6	-1.2	1.1	-2.8	2.1	-0.6	-1.2	-0.9	1.3	-2.5	-0.4	-3.0	2.0	3.1	-0.9	1.4
6.2	-1.7	-0.8	1.0	-2.9	1.4	-2.7	3.0	-0.5	-0.7	1.9	1.1	-2.6	-1.2	1.7	0.9	-2.5	3.0	-2.6	-1.4	-2.6	0.6	3.0	2.4	3.0	2.2	-1.1	-1.8	1.1	0.3	0.9	-0.3	2.6	1.5	-1.3	-2.1	-1.7
5.9	-2.2	2.5	-2.8	-0.7	-1.1	-1.6	-3.1	-2.9	2.5	-2.7	3.0	1.8	-2.2	2.4	-2.8	-0.4	-1.0	-1.8	-2.8	1.7	2.9	-1.1	-1.7	-2.6	0.3	-1.2	-0.3	2.1	1.5	0.7	-1.8	2.9	-2.5	-0.1	-0.7	-1.5
5.6	-2.0	2.0	-2.9	2.0	-2.6	2.5	1.5	-0.7	2.0	0.2	0.8	0.6	-1.2	2.9	-1.6	-2.9	-2.2	-3.1	-2.0	2.2	-2.4	2.6	-3.1	2.4	0.4	-1.5	0.3	-1.3	-0.6	-1.2	-1.3	3.0	-1.8	-2.9	-2.3	-3.0

Table A6: 2017 F:B and weather condition covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Fungi:Bacteria Ratio

	Mean Air Temp.						Air Temp. Ran.						Humidity						ET						GWT Depth					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	3.1	3.1	3.1	3.1	3.1	0.0	0.0	0.0	3.1	3.1	0.0	3.1	3.1	3.1	0.0	3.1	3.1	0.0	3.1	3.1	3.1	3.1	0.0	0.0	3.1	3.1	0.0	3.1	3.1	0.0
106.0	2.3	2.7	-2.3	2.8	2.0	-0.6	1.2	1.6	2.8	1.7	0.9	-1.7	-3.0	-2.6	-1.3	-2.5	3.0	0.4	1.6	2.0	-3.0	2.1	1.3	-1.3	-2.8	-2.4	-1.1	-2.3	-3.1	0.6
53.0	2.4	-2.8	0.0	-0.5	-1.1	0.1	1.9	3.0	-0.5	-1.0	-1.6	-0.4	-1.9	-0.8	2.0	1.5	0.9	2.1	2.1	3.1	-0.4	-0.9	-1.5	-0.3	2.6	-2.6	0.2	-0.3	-0.9	0.3
35.3	2.6	-2.8	1.2	0.5	-0.9	0.1	0.7	1.6	-0.7	-1.3	-2.8	-1.7	-2.5	-1.6	2.4	1.8	0.3	1.4	1.4	2.3	0.0	-0.6	-2.1	-1.0	1.8	2.7	0.4	-0.3	-1.7	-0.6
26.5	2.5	3.0	-2.2	2.5	-2.1	-1.6	-1.6	-1.1	0.0	-1.5	0.1	0.6	2.2	2.7	-2.5	2.2	-2.4	-1.9	-3.1	-2.6	-1.5	-3.0	-1.4	-0.9	1.6	2.1	-3.1	1.7	-2.9	-2.5
21.2	-3.1	-2.4	-1.0	-2.2	2.2	2.8	-1.2	-0.5	0.9	-0.3	-2.2	-1.6	1.6	2.2	-2.6	2.4	0.5	1.1	-2.6	-2.0	-0.5	-1.7	2.6	-3.0	0.6	1.2	2.7	1.4	-0.5	0.1
17.7	-2.4	-1.9	1.1	-0.1	1.8	-1.8	1.8	2.4	-0.9	-2.1	-0.2	2.5	-2.4	-1.8	1.1	0.0	1.9	-1.8	2.7	-3.1	-0.1	-1.2	0.6	-3.0	-0.5	0.1	3.0	1.9	-2.5	0.1
15.1	-2.4	-0.7	-2.8	0.2	2.9	2.5	-0.2	1.5	-0.6	2.4	-1.2	-1.6	2.8	-1.7	2.4	-0.9	1.9	1.5	-0.9	0.8	-1.3	1.7	-1.9	-2.3	-0.8	0.9	-1.2	1.8	-1.7	-2.2
13.3	-0.8	1.0	0.1	1.1	2.3	2.9	-1.8	0.1	-0.9	0.2	1.4	2.0	0.6	2.5	1.5	2.6	-2.5	-1.9	-1.7	0.2	-0.8	0.3	1.4	2.1	-2.1	-0.3	-1.2	-0.2	1.0	1.6
11.8	-1.7	0.9	2.5	-2.7	-2.7	2.4	-0.3	2.3	-2.4	-1.2	-1.3	-2.5	-3.1	-0.6	1.1	2.2	2.1	1.0	-0.5	2.1	-2.6	-1.5	-1.5	-2.7	-3.1	-0.6	1.1	2.2	2.1	1.0
10.6	2.6	-1.5	-0.6	1.4	0.2	1.3	1.3	-2.8	-1.9	0.0	-1.1	0.0	-2.0	0.2	1.1	3.0	1.9	3.0	1.6	-2.6	-1.7	0.3	-0.9	0.2	2.4	-1.8	-0.9	1.1	0.0	1.0
9.6	1.9	-1.8	2.0	2.9	1.6	0.8	0.1	2.7	0.2	1.1	-0.2	-1.0	-2.8	-0.2	-2.6	-1.8	-3.1	2.4	0.4	3.0	0.5	1.4	0.1	-0.7	1.0	-2.6	1.2	2.0	0.7	-0.1
8.8	-0.2	1.9	-0.5	2.0	-2.1	-2.1	-0.6	1.4	-1.0	1.6	-2.5	-2.5	2.9	-1.3	2.5	-1.2	1.0	1.0	0.4	2.4	0.0	2.5	-1.6	-1.5	0.6	2.6	0.2	2.8	-1.3	-1.3
8.2	-2.6	0.3	0.7	0.5	-0.6	-2.3	-2.0	1.0	1.3	1.1	0.0	-1.7	1.5	-1.9	-1.5	-1.7	-2.9	1.8	-2.8	0.1	0.4	0.2	-0.9	-2.6	-1.2	1.8	2.1	1.9	0.8	-0.9
7.6	-2.3	-0.3	0.2	-0.4	-2.2	1.4	-2.6	-0.6	-0.2	-0.8	-2.6	1.0	0.7	2.7	3.1	2.5	0.7	-2.0	-2.5	-0.5	0.0	-0.6	-2.4	1.2	-0.9	1.1	1.6	1.0	-0.8	2.8
7.1	1.3	-2.3	0.8	-2.7	-2.1	0.5	2.1	-1.4	1.7	-1.9	-1.2	1.3	-2.3	0.5	-2.7	0.0	0.7	-3.1	1.4	-2.2	0.9	-2.7	-2.0	0.6	-2.1	0.7	-2.5	0.2	0.9	-2.9
6.6	2.5	-0.1	-1.6	-0.5	1.7	-2.0	0.4	-2.2	2.6	-2.5	-0.3	2.2	2.4	-0.1	-1.6	-0.5	1.7	-2.0	-0.6	3.1	1.6	2.7	-1.3	1.2	3.1	0.5	-1.0	0.1	2.4	-1.4
6.2	-2.2	0.7	-0.1	3.0	2.2	2.8	2.3	-1.1	-1.9	1.1	0.4	1.0	-0.8	2.1	1.2	-2.0	-2.7	-2.1	2.5	-0.9	-1.7	1.3	0.6	1.2	-3.0	-0.1	-0.9	2.2	1.4	2.0
5.9	-2.6	2.0	-3.1	-0.9	-1.5	-2.3	1.0	-0.6	0.5	2.7	2.1	1.3	3.0	1.4	2.5	-1.6	-2.1	-3.0	-1.2	-2.8	-1.7	0.5	-0.1	-0.9	1.1	-0.5	0.7	2.9	2.3	1.5
5.6	-1.9	2.4	-2.2	2.8	-2.8	2.7	-3.0	1.2	3.0	1.7	2.3	1.5	2.0	0.0	1.7	0.4	1.1	0.3	-1.9	2.3	-2.2	2.8	-2.9	2.6	1.4	-0.7	1.1	-0.3	0.4	-0.4

Table A7: 2017 AMF and chemical phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Arbuscular Mycorrhizal Fungi

	NO3-N						P						SO4-S					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	0.0	3.1	3.1	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	3.1	3.1	0.0	0.0	0.0	0.0
106.0	-0.5	1.4	3.0	1.9	1.5	2.3	-0.6	1.5	1.1	1.5	0.9	2.0	1.9	1.9	-0.5	-1.4	-1.3	-0.3
53.0	0.4	-0.5	0.4	-1.0	-1.3	0.1	-2.4	-1.8	3.0	-1.6	1.9	3.0	1.2	-0.1	0.9	0.3	0.7	-3.1
35.3	1.7	3.1	2.0	2.3	2.6	2.9	-0.1	-2.8	3.0	3.0	3.0	-0.9	-0.6	-1.8	-1.3	-2.9	2.3	0.0
26.5	2.2	2.8	-1.9	-2.8	0.2	0.5	2.8	1.1	-2.3	-0.8	-0.2	-2.3	1.2	0.5	-0.8	3.0	-0.2	-0.6
21.2	-2.7	2.3	1.5	1.7	-2.4	0.9	3.0	2.7	-0.5	-0.2	-2.4	-0.8	2.0	1.6	2.2	1.9	-2.1	-0.4
17.7	-2.7	0.3	-2.7	-1.7	0.7	-2.4	1.7	-1.2	0.3	1.5	0.6	-0.2	2.8	-1.4	0.9	2.7	0.3	2.3
15.1	-0.3	-2.4	-0.2	-2.1	2.4	1.3	0.1	-1.2	1.5	-0.1	1.5	-1.4	0.1	-2.2	1.1	-2.4	-2.5	2.7
13.3	1.5	0.5	0.2	1.1	-2.9	3.0	2.1	0.2	0.5	-1.5	-2.8	-2.2	-1.7	1.7	0.9	2.5	2.6	1.0
11.8	0.2	1.4	-1.7	1.5	-2.5	-2.6	0.9	-1.6	-2.6	3.1	0.5	-1.8	-2.0	-1.8	-1.2	0.8	-1.2	-0.4
10.6	3.1	-3.0	-0.9	-3.0	2.4	0.8	-1.2	-2.7	-0.9	-1.8	2.7	-2.0	-0.6	-2.0	-0.4	-2.1	2.6	2.7
9.6	-2.8	1.9	0.5	-1.2	0.2	2.6	-1.2	-0.7	1.0	-0.1	-2.0	0.8	0.8	0.4	2.2	-2.4	-2.3	-1.4
8.8	1.8	2.7	1.6	-2.1	0.7	1.0	2.4	1.5	1.4	2.9	2.0	0.3	0.8	1.6	0.0	-3.0	-3.0	2.2
8.2	2.1	1.1	-1.7	2.7	-2.7	-1.7	0.8	2.7	1.4	1.4	1.2	2.6	-1.3	-2.1	3.1	-2.3	-0.9	-0.3
7.6	-1.8	0.5	3.1	-0.5	-1.9	0.1	-2.0	0.6	0.1	-3.0	1.0	-1.0	0.9	-1.9	1.5	1.4	-1.7	-2.5
7.1	-1.2	-2.5	1.2	0.0	-2.6	-0.2	0.9	-0.3	2.0	0.1	1.6	1.1	2.1	0.8	1.6	0.2	-2.3	0.3
6.6	2.7	0.4	-1.7	-0.6	1.1	1.1	-0.1	-0.5	0.6	2.4	-1.6	0.8	-0.2	2.8	-1.2	-3.0	1.4	2.7
6.2	0.1	1.8	0.4	-0.3	2.8	2.3	-0.5	1.0	-2.4	0.4	-2.7	0.8	-2.9	-0.6	-2.6	-0.9	2.5	0.3
5.9	-2.3	-2.2	1.6	2.3	2.9	2.7	1.4	0.6	-2.3	-2.4	-2.0	-0.5	-2.9	0.5	-0.7	2.0	1.5	2.5
5.6	2.8	3.1	-0.9	2.8	2.6	0.8	-3.0	1.9	2.7	0.2	-2.8	-1.0	-0.7	1.4	1.3	2.2	0.8	3.1

	Mn						NH4-N						TN					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	0.0	3.1	3.1	0.0	3.1	3.1	3.1	3.1	0.0	0.0	3.1	3.1	0.0	0.0	0.0	0.0	0.0
106.0	-1.3	1.4	2.5	1.6	1.2	2.3	-1.7	1.8	2.4	1.3	1.6	1.9	-2.8	0.1	0.3	-0.9	0.4	1.3
53.0	-2.4	-2.7	-2.0	3.1	2.3	-2.1	-2.4	2.8	-2.4	3.0	2.4	-2.3	0.5	-0.8	2.1	-0.4	-0.3	-2.5
35.3	3.0	-1.8	-2.7	-2.8	2.1	-1.8	0.0	0.3	-0.9	-0.2	-2.0	-0.2	-2.8	-2.9	-0.8	2.9	2.7	-1.3
26.5	1.7	-0.4	-2.8	0.5	-2.9	-1.4	2.1	2.9	-3.1	2.6	0.3	-0.2	-1.7	-1.4	1.5	-0.1	2.2	-2.1
21.2	1.0	3.1	-1.6	-2.1	3.1	-2.3	-1.0	2.0	2.5	0.4	1.0	0.6	-0.8	2.1	-0.4	-0.4	1.6	-1.8
17.7	1.4	-1.7	2.7	2.0	-0.2	-1.8	2.4	-1.8	-3.0	2.7	1.1	2.6	-0.2	1.6	1.8	0.3	-2.2	-1.8
15.1	-0.1	2.4	-2.1	2.9	1.3	-1.0	-0.6	2.3	-3.0	2.5	0.9	-0.1	-2.4	1.6	1.2	0.2	1.5	2.0
13.3	-2.2	1.3	0.8	-3.0	-0.7	-3.1	-0.9	-0.8	-2.8	-2.1	-3.1	-2.7	-0.3	0.9	0.3	3.1	-1.5	0.7
11.8	1.7	-1.2	0.4	-3.0	0.3	1.0	1.6	-1.8	0.6	2.9	-1.6	0.0	1.5	-0.8	2.8	0.1	0.4	0.1
10.6	2.9	2.9	1.7	0.0	-1.9	-2.7	3.1	-1.7	2.5	0.8	0.8	0.3	2.8	2.9	-1.3	1.4	-2.5	-0.8
9.6	2.7	-0.3	-1.7	-2.1	-2.1	1.7	-3.0	1.8	0.1	-1.0	-0.1	2.6	2.3	-0.7	0.2	0.5	-2.7	0.7
8.8	-3.1	1.4	-0.1	-1.9	1.4	0.1	0.5	2.2	1.3	2.8	2.2	0.8	-2.6	0.8	2.9	-2.3	0.9	2.3
8.2	2.0	0.1	0.1	1.9	0.2	-2.4	2.4	0.7	0.0	1.0	0.7	-2.6	1.4	0.0	0.1	-0.1	0.5	-0.2
7.6	-0.3	0.0	0.9	1.4	2.1	0.0	0.1	0.1	0.8	0.4	0.3	-0.9	1.1	-0.3	-0.1	-2.8	2.0	-0.6
7.1	2.2	0.4	2.1	-3.0	0.2	3.1	2.3	-0.1	-1.6	3.1	-1.7	1.4	2.6	-1.8	-1.0	-0.5	1.4	2.9
6.6	-0.1	-1.0	-1.9	-1.4	-1.4	-0.7	2.1	-0.1	0.0	-1.2	0.3	0.6	-0.6	-0.4	0.1	1.5	-1.5	0.0
6.2	-1.5	2.9	2.2	-1.8	-3.1	2.6	0.0	2.7	2.0	0.5	1.7	1.6	1.7	2.2	0.1	2.4	3.0	-0.2
5.9	-1.2	-0.3	-2.1	-2.6	0.0	-2.3	-2.4	-2.3	-2.4	-2.7	-1.8	-2.1	-0.7	0.3	-1.5	-2.8	0.3	2.8
5.6	2.9	2.5	1.9	-0.4	-2.6	1.2	2.2	-2.5	1.9	0.2	0.9	-2.7	3.1	1.1	-2.5	0.9	-2.5	-0.9

	TC						pH						EC					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	3.1	3.1	0.0
106.0	3.0	-0.2	0.6	0.0	-0.2	1.1	3.0	-0.2	0.3	-0.5	-0.7	0.2	1.6	0.9	-0.4	1.7	-1.8	-0.5
53.0	-0.1	-1.0	-2.2	2.8	0.0	-2.5	-1.4	0.9	0.4	-2.6	2.9	-1.1	1.0	0.2	1.2	-0.2	0.2	0.7
35.3	-0.9	-2.8	-2.4	2.9	2.4	-0.7	0.8	1.7	0.5	0.3	0.2	2.2	0.7	2.7	1.0	-0.8	1.1	0.5
26.5	-2.1	2.2	-2.9	-1.1	1.7	-1.4	0.5	2.9	-1.2	2.2	-0.9	1.5	1.1	1.6	3.1	0.2	-0.6	-0.5
21.2	-1.0	2.4	-0.4	0.5	1.9	-2.0	-3.0	-0.1	2.1	-2.6	-1.9	0.6	-3.1	1.0	1.1	2.5	-1.5	0.3
17.7	1.9	0.7	0.1	0.6	-2.0	-1.1	-0.6	2.4	0.1	0.7	0.5	1.7	-2.4	-0.2	-0.4	2.3	0.7	1.1
15.1	-1.3	1.3	0.7	0.2	1.5	-1.8	0.7	-2.5	-0.6	-1.7	-2.7	1.4	0.5	-2.4	-0.3	-1.3	-3.0	2.4
13.3	-0.4	-0.2	1.1	1.5	-1.9	-1.4	-0.7	-2.1	-2.5	-2.9	1.7	1.0	-1.9	-1.6	-2.9	0.5	1.9	1.5
11.8	1.8	-0.9	1.6	-1.8	0.5	-2.9	-2.8	-0.8	2.1	2.4	-1.6	1.1	-0.8	-1.5	1.0	1.6	-1.3	0.4
10.6	0.3	1.5	0.9	0.1	-2.6	0.6	1.6	0.7	-2.3	-0.9	0.9	1.9	1.9	2.6	2.8	-0.2	0.8	-3.1
9.6	1.2	-1.2	-0.2	-0.9	-2.7	1.1	-2.4	2.3	0.8	-1.8	0.4	-2.2	3.1	1.3	0.6	-1.1	0.2	3.0
8.8	2.4	2.3	3.1	-1.5	0.9	1.3	2.7	-0.3	-0.1	2.5	-1.6	-1.6	1.3	0.3	-0.3	-1.8	-1.6	2.8
8.2	2.2	-0.6	1.0	1.6	0.2	-0.6	1.7	1.5	0.2	-2.3	-2.9	2.3	-0.1	-0.5	0.0	-2.2	2.6	-2.6
7.6	-0.3	3.1	0.1	2.6	0.7	-0.9	0.6	-2.8	-2.6	1.1	-2.0	2.8	-2.8	-2.8	-2.3	-1.4	-2.0	1.7
7.1	1.9	-1.5	-0.3	-0.8	1.3	1.1	-1.2	1.7	1.3	2.3	-2.7	-0.1	-1.0	3.0	-1.4	3.0	-2.8	0.4
6.6	0.3	-0.5	0.1	-1.8	-1.5	0.8	2.2	2.9	-3.0	2.7	1.8	-2.6	-2.9	3.0	3.1	1.4	2.3	-0.3
6.2	-0.6	2.7	-0.9	-1.5	-2.6	0.5	1.7	2.7	0.5	-2.4	1.3	2.9	-0.6	1.8	0.2	-1.6	1.1	1.7
5.9	0.9	0.2	-2.8	-2.7	0.2	2.8	-2.8	2.6	0.1	1.3	2.9	0.2	2.2	1.2	-0.1	2.2	3.1	1.4
5.6	-1.2	1.3	-2.3	0.4	-2.5	-0.3	2.3	-1.7	2.4	2.6	0.3	2.9	-2.5	-0.3	3.0	1.8	0.3	-2.4

Table A8: 2017 AMF and physical conditions covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Arbuscular Mycorrhizal Fungi

	VWC						Water Grad.						Temp						Temp. Grad.						Bottom Flux						Water Storage					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	3.1	0.0	3.1	0.0	0.0	3.1	0.0	3.1	3.1	3.1	3.1	3.1	0.0	3.1	3.1	3.1	3.1	3.1	0.0	0.0	3.1	3.1	0.0	3.1	0.0	0.0	3.1	0.0	0.0	3.1	0.0	3.1	3.1	3.1	3.1	3.1
106.0	2.6	-0.3	1.7	0.0	0.3	1.8	-1.4	3.0	1.7	-1.7	-2.9	-1.7	-0.8	2.2	-3.1	2.1	2.0	2.9	-1.5	1.5	2.7	1.7	1.5	2.2	-1.6	1.4	2.6	1.4	1.2	2.4	-0.9	2.2	-3.1	2.5	2.3	2.8
53.0	3.1	2.5	-2.3	2.1	1.9	-2.8	-2.1	2.3	-0.6	1.6	1.0	-0.2	-0.2	-0.9	0.5	-0.9	-1.4	0.0	-0.8	-1.3	0.0	-1.5	-2.0	-0.6	-0.9	-1.3	-0.2	-1.6	-2.0	-0.5	2.7	2.1	-3.0	1.8	1.4	3.0
35.3	3.0	-2.2	-2.6	-3.0	1.6	-2.5	0.1	0.5	-0.3	-1.3	-1.0	1.2	1.1	2.4	1.7	1.6	0.0	2.5	0.7	2.2	1.5	1.2	-0.4	2.1	-1.1	0.2	-0.6	-0.8	-2.4	0.3	2.5	-2.5	2.9	2.9	1.3	-2.5
26.5	2.7	0.6	-0.5	-2.8	0.0	2.8	2.1	-0.1	1.2	-0.2	-1.9	2.5	2.5	-3.0	-1.7	3.0	0.7	0.6	2.0	3.1	-2.2	2.5	0.1	0.2	0.1	1.0	1.5	0.7	-1.6	-2.0	2.9	-2.6	-1.9	-2.7	1.1	0.8
21.2	-0.8	-3.0	3.0	2.8	2.0	2.3	-2.2	-3.1	0.2	1.2	0.7	0.5	0.4	-2.5	-2.6	-2.7	2.8	3.0	0.2	-2.7	-2.8	-3.1	2.4	2.7	2.3	-0.5	-0.7	-0.7	-1.4	-1.3	-0.6	2.8	2.6	2.6	1.9	2.0
17.7	0.8	2.6	2.1	2.0	0.5	-2.2	2.4	-1.0	2.9	-3.0	2.1	-0.9	-2.9	-0.4	-1.8	-1.9	-2.8	-0.2	3.1	-0.7	-2.2	-2.3	3.0	-0.7	-3.0	-0.4	-2.6	-2.2	-3.1	-0.3	1.1	-2.9	1.7	0.8	0.4	-2.4
15.1	2.6	-1.0	1.1	-1.4	-1.7	3.0	2.4	-1.2	0.3	-1.4	0.5	0.6	0.1	3.1	-1.7	2.5	2.2	1.1	-0.1	2.9	-1.9	2.3	1.9	0.8	0.6	-2.7	-1.5	2.9	2.5	1.7	1.9	-1.5	0.0	-1.9	-2.3	2.8
13.3	2.4	1.9	0.2	1.0	-0.5	-0.6	-2.5	-2.8	-0.2	0.3	-2.7	2.8	1.1	0.5	-1.1	-0.4	-1.9	-2.1	0.8	0.2	-1.3	-0.7	-2.3	-2.4	-1.1	-1.6	2.9	-2.7	2.1	2.1	1.8	1.3	0.0	0.4	-1.2	-1.4
11.8	1.9	0.8	-2.7	2.7	1.8	3.0	0.2	1.6	-1.1	-0.1	-1.1	-0.5	3.1	1.7	-2.5	-2.5	2.9	-2.3	2.6	1.4	-2.9	-2.9	2.5	-2.7	-0.8	-2.1	-0.8	0.0	-0.9	0.1	1.8	0.5	2.2	2.5	1.6	2.7
10.6	-0.8	-0.1	-0.4	2.9	-3.0	2.3	-1.3	0.0	-0.5	1.9	2.1	0.3	-2.5	-2.2	-2.1	1.2	1.4	0.8	2.9	3.1	-3.0	0.3	0.6	0.0	2.3	2.7	2.7	-0.3	-0.2	-0.7	-1.3	-0.8	-0.9	2.5	2.6	2.0
9.6	-0.1	-2.3	-2.9	1.7	2.5	-0.7	-2.2	2.3	-2.8	-1.2	0.3	1.9	0.9	-1.0	-2.6	2.5	-2.5	0.5	-0.3	-2.5	2.2	1.1	2.3	-1.1	-2.3	2.3	-0.6	-0.8	0.5	-2.7	0.4	-1.2	2.2	1.6	3.0	0.2
8.8	1.0	-2.1	-2.9	-3.0	-2.6	2.8	0.6	-1.5	-2.6	2.6	-2.7	-1.7	-0.9	2.2	0.8	1.1	1.6	0.4	-1.3	1.7	0.4	0.6	1.1	-0.1	-1.3	1.9	0.9	0.7	1.2	0.0	2.1	-1.1	-2.6	-2.5	-1.9	-2.9
8.2	-0.6	-2.4	-2.0	-2.0	-2.7	0.1	-3.1	1.5	-2.5	2.4	1.1	-1.5	2.5	1.0	0.9	1.1	0.8	-2.1	2.1	0.6	0.5	0.8	0.4	-2.5	2.9	1.6	1.2	1.5	1.1	-1.6	2.1	0.2	-1.0	0.3	0.0	-2.8
7.6	-2.8	-2.5	-2.9	-0.7	-3.1	2.3	-1.7	-2.8	-2.9	-0.9	2.4	0.9	0.3	0.0	0.3	2.7	-0.2	-1.1	-0.4	-0.5	-0.2	2.0	-1.0	-1.7	0.4	0.0	1.5	2.7	-0.2	-1.0	-1.6	-1.9	-2.0	0.5	-2.3	-3.0
7.1	-1.6	3.1	-2.0	-0.9	2.4	-1.2	2.8	0.8	2.8	-3.0	0.6	3.1	-2.8	1.9	2.9	-1.8	1.7	-1.8	-2.1	2.3	-2.7	-0.9	2.3	-1.4	1.7	0.1	1.2	2.7	-0.3	2.5	-1.9	3.1	-2.3	-0.3	2.9	-1.1
6.6	-2.5	-2.0	-2.7	-0.6	-1.8	-1.7	2.2	-2.4	-3.1	-1.4	2.8	2.9	1.6	1.6	1.7	-2.9	1.5	2.3	0.2	-2.6	-0.3	2.0	0.3	0.6	0.2	-0.1	1.1	2.3	0.5	0.9	-2.2	-2.5	-2.0	0.0	-1.7	-1.6
6.2	1.0	0.9	1.6	1.5	2.0	3.1	-0.6	1.2	0.0	-0.1	1.7	-3.0	1.4	-2.9	1.5	1.8	-2.7	-3.0	1.3	-0.9	1.3	1.0	3.0	2.6	-1.5	0.7	-1.2	-0.9	0.9	0.5	2.4	-1.9	2.2	3.0	-1.5	-2.1
5.9	2.6	2.7	2.0	2.3	-2.7	2.3	1.7	-2.6	1.1	0.4	1.4	-0.6	2.6	2.7	2.1	2.7	-2.6	2.1	2.0	1.9	1.4	1.9	3.0	1.3	-1.2	-1.0	-1.7	-1.1	-0.2	-1.7	3.0	3.1	2.3	3.0	-2.3	2.4
5.6	-0.5	1.4	-0.5	2.9	3.1	-0.4	2.9	-1.3	-1.9	1.1	0.2	-2.2	0.2	2.3	0.8	-1.9	-2.9	0.4	-0.6	1.5	0.0	-2.8	2.6	-0.5	1.9	-2.1	2.7	-0.3	-1.2	2.2	0.2	2.4	0.5	-2.0	-3.0	0.4

Table A9: 2017 AMF and weather condition covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Arbuscular Mycorrhizal Fungi

	Mean Air Temp.						Air Temp. Ran.						Humidity						ET						GWT Depth					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	3.1	3.1	3.1	3.1	3.1	3.1	0.0	3.1	0.0	0.0	3.1	0.0	3.1	3.1	3.1	3.1	3.1	0.0	3.1	3.1	3.1	3.1	3.1	0.0	3.1	3.1	3.1	3.1	3.1
106.0	-0.6	2.6	-2.8	2.4	2.4	-3.0	-1.7	1.5	2.3	1.3	1.3	2.2	0.5	-2.7	-1.8	-2.9	-2.9	-2.0	-1.2	1.9	2.8	1.8	1.7	2.6	0.7	-2.5	-1.6	-2.6	-2.7	-1.8
53.0	-0.2	-0.8	0.5	-1.0	-1.4	0.1	-0.7	-1.3	0.0	-1.4	-1.8	-0.4	1.8	1.2	2.5	1.0	0.6	2.1	-0.6	-1.2	0.1	-1.3	-1.7	-0.3	0.0	-0.6	0.7	-0.8	-1.2	0.3
35.3	1.0	2.3	1.6	1.3	-0.2	2.5	-0.8	0.5	-0.2	-0.5	-2.1	0.6	2.3	-2.7	2.8	2.6	1.0	-2.6	-0.1	1.2	0.5	0.2	-1.4	1.3	0.3	1.5	0.8	0.6	-1.0	1.7
26.5	2.0	2.8	-2.2	2.6	0.2	0.2	-2.0	-1.3	0.0	-1.5	2.4	2.4	1.7	2.5	-2.5	2.2	-0.2	-0.1	2.7	-2.8	-1.5	-3.0	0.8	0.9	1.2	1.9	-3.1	1.7	-0.7	-0.7
21.2	0.1	-2.8	-2.8	-3.0	2.6	2.8	2.0	-1.0	-1.0	-1.1	-1.8	-1.6	-1.6	1.8	1.8	1.6	0.9	1.1	0.6	-2.4	-2.4	-2.5	3.0	-3.0	-2.6	0.8	0.8	0.6	-0.1	0.1
17.7	3.1	-0.6	-2.0	-2.2	-3.1	-0.5	1.1	-2.6	2.3	2.1	1.2	-2.5	-3.1	-0.6	-2.0	-2.2	-3.0	-0.4	1.9	-1.8	3.1	2.9	2.0	-1.7	-1.2	1.3	-0.1	-0.3	-1.1	1.5
15.1	0.2	3.0	-1.6	2.5	2.1	1.2	2.4	-1.1	0.6	-1.6	-2.0	-2.9	-0.8	2.0	-2.6	1.5	1.1	0.1	1.7	-1.8	-0.1	-2.3	-2.6	2.7	1.8	-1.7	0.0	-2.1	-2.5	2.8
13.3	1.3	0.7	-0.8	-0.3	-1.8	-1.9	0.4	-0.2	-1.7	-1.2	-2.7	-2.8	2.8	2.2	0.7	1.2	-0.3	-0.4	0.5	-0.2	-1.6	-1.1	-2.7	-2.7	0.0	-0.6	-2.1	-1.6	-3.1	3.1
11.8	2.6	1.3	-2.9	-2.9	2.5	-2.7	-2.2	2.7	-1.4	-1.5	-2.4	-1.2	1.2	-0.1	2.0	1.9	1.1	2.2	-2.5	2.5	-1.7	-1.7	-2.6	-1.5	1.2	-0.1	2.0	1.9	1.1	2.2
10.6	-3.0	-2.7	-2.6	0.6	0.8	0.3	2.0	2.3	2.4	-0.7	-0.5	-1.1	-1.3	-1.0	-0.9	2.3	2.5	1.9	2.2	2.5	2.6	-0.4	-0.2	-0.8	3.1	-2.9	-2.8	0.4	0.6	0.0
9.6	-0.3	-2.0	2.5	1.3	2.7	-0.7	-2.1	2.5	0.7	-0.5	0.8	-2.5	1.4	-0.4	-2.2	3.0	-2.0	1.0	-1.8	2.8	1.0	-0.2	1.1	-2.2	-1.1	-2.8	1.6	0.5	1.8	-1.5
8.8	-1.4	1.6	0.4	0.6	1.0	-0.2	-1.8	1.2	0.0	0.1	0.6	-0.6	1.7	-1.6	-2.8	-2.6	-2.2	2.9	-0.8	2.2	0.9	1.1	1.6	0.4	-0.6	2.4	1.2	1.3	1.8	0.6
8.2	2.3	0.9	0.7	0.9	0.6	-2.2	2.9	1.6	1.3	1.6	1.2	-1.6	0.1	-1.3	-1.5	-1.3	-1.6	1.8	2.1	0.7	0.5	0.7	0.3	-2.5	-2.5	2.4	2.2	2.4	2.0	-0.8
7.6	-0.4	-0.8	-0.4	1.9	-1.0	-1.9	-0.8	-1.1	-0.8	1.6	-1.3	-2.2	2.5	2.2	2.5	-1.4	2.0	1.1	-0.6	-1.0	-0.7	1.7	-1.2	-2.1	1.0	0.6	0.9	-3.0	0.4	-0.5
7.1	-0.2	-2.0	-0.8	0.7	-2.2	0.6	0.6	-1.1	0.0	1.5	-1.4	1.4	2.5	0.7	1.9	-2.9	0.5	-3.0	-0.1	-1.9	-0.7	0.8	-2.1	0.7	2.7	1.0	2.1	-2.7	0.7	-2.7
6.6	0.6	0.4	0.7	2.7	0.9	1.4	-1.4	-1.6	-1.3	0.7	-1.1	-0.7	0.6	0.4	0.7	2.7	0.9	1.3	-2.5	-2.7	-2.4	-0.4	-2.1	-1.7	1.2	1.0	1.3	-2.9	1.5	2.0
6.2	0.5	2.5	0.6	1.0	2.8	2.4	-1.3	0.7	-1.2	-0.8	1.0	0.6	1.8	-2.5	1.9	2.3	-2.1	-2.5	-1.1	0.8	-1.0	-0.6	1.2	0.8	-0.3	1.7	-0.2	0.2	2.0	1.6
5.9	2.2	2.3	1.7	2.2	-3.1	1.6	-0.5	-0.4	-1.0	-0.5	0.5	-1.1	1.5	1.6	1.1	1.5	2.5	1.0	-2.7	-2.6	3.1	-2.7	-1.7	3.0	-0.3	-0.2	-0.8	-0.3	0.7	-0.9
5.6	-0.4	1.8	0.2	-2.6	2.8	-0.2	-1.5	0.6	-0.9	2.6	1.7	-1.3	-2.8	-0.6	-2.2	1.3	0.4	-2.6	-0.4	1.7	0.1	-2.6	2.8	-0.2	2.8	-1.3	-2.9	0.7	-0.2	3.1

Table A10: 2017 Fungi and chemical covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Fungi

	NO3-N						P						SO4-S						Mn						NH4-N					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	3.1	0.0	3.1	3.1	0.0	0.0	3.1	0.0	0.0	3.1	0.0	0.0	0.0	3.1	0.0	0.0	3.1	3.1	3.1	0.0	3.1	3.1	0.0	0.0	0.0	3.1	3.1	3.1	0.0	3.1
106.0	2.4	1.5	-2.8	2.3	0.8	-1.3	2.3	1.6	1.5	2.0	0.2	-1.6	-1.5	1.9	0.0	-1.0	-2.1	2.3	1.6	1.5	3.0	2.1	0.4	-1.3	1.2	1.9	2.9	1.8	0.8	-1.7
53.0	-3.1	-2.6	-0.2	-0.6	-1.0	0.1	0.3	2.4	2.4	-1.3	2.2	3.0	-2.3	-2.2	0.3	0.6	1.1	-3.1	0.4	1.5	-2.6	-2.8	2.7	-2.1	0.3	0.7	-3.0	-3.0	2.8	-2.3
35.3	-3.0	-1.8	1.4	1.5	2.1	0.3	1.4	-1.4	2.4	2.2	2.4	2.9	1.0	-0.4	-2.0	2.5	1.8	-2.5	-1.7	-0.4	2.9	2.6	1.6	2.0	1.6	1.7	-1.5	-1.0	-2.5	-2.8
26.5	2.6	2.9	-1.8	-2.9	-2.3	-1.3	-3.1	1.1	-2.2	-0.9	-2.7	2.2	1.6	0.5	-0.6	2.8	-2.7	-2.4	2.1	-0.4	-2.7	0.4	0.9	3.1	2.5	2.9	-2.9	2.5	-2.1	-2.0
21.2	0.5	2.8	3.1	2.7	-3.0	1.1	-0.1	-3.1	1.1	0.8	-3.0	-0.6	-1.1	2.0	-2.4	2.9	-2.7	-0.3	-2.1	-2.7	0.0	-1.1	2.6	-2.1	2.2	2.5	-2.1	1.4	0.5	0.8
17.7	-1.9	-0.9	0.7	0.3	-1.7	2.6	2.5	-2.4	-2.6	-2.8	-1.8	-1.5	-2.7	-2.6	-2.0	-1.6	-2.1	1.1	2.2	-2.8	-0.2	-2.2	-2.6	-3.1	-3.1	-3.0	0.4	-1.6	-1.3	1.3
15.1	-3.0	0.2	-1.9	1.2	1.8	2.8	-2.6	1.4	-0.2	-3.1	0.9	0.2	-2.6	0.4	-0.6	0.9	-3.1	-2.0	-2.8	-1.2	2.5	-0.1	0.7	0.6	3.0	-1.4	1.6	-0.5	0.4	1.4
13.3	-0.8	0.9	1.2	-3.1	1.0	1.3	-0.1	0.5	1.4	0.6	1.1	2.4	2.4	2.1	1.9	-1.7	0.2	-0.7	1.9	1.7	1.8	-0.9	-3.1	1.5	3.1	-0.4	-1.9	0.0	0.8	1.8
11.8	2.3	1.1	-2.6	1.7	-1.1	2.0	2.9	-1.9	2.7	-2.9	2.0	2.8	0.0	-2.1	-2.2	1.1	0.3	-2.0	-2.5	-1.6	-0.6	-2.7	1.8	-0.6	-2.6	-2.2	-0.4	3.1	-0.1	-1.7
10.6	2.4	-1.8	1.4	-1.7	1.0	1.9	-1.9	-1.5	1.4	-0.5	1.4	-0.9	-1.3	-0.9	1.9	-0.8	1.2	-2.5	2.2	-2.2	-2.2	1.3	3.0	-1.6	2.4	-0.6	-1.5	2.0	-0.5	1.4
9.6	-0.5	2.1	0.0	0.2	-1.3	-0.4	1.0	-0.5	0.5	1.4	2.8	-2.2	3.0	0.6	1.6	-0.9	2.6	1.8	-1.4	-0.2	-2.2	-0.7	2.7	-1.3	-0.7	1.9	-0.4	0.5	-1.6	-0.4
8.8	3.1	2.9	0.3	-0.4	-2.5	-0.8	-2.7	1.7	0.2	-1.7	-1.2	-1.5	2.0	1.9	-1.3	-1.3	0.1	0.4	-1.9	1.6	-1.4	-0.2	-1.9	-1.7	1.8	2.4	0.0	-1.8	-1.1	-1.0
8.2	-2.7	0.6	-1.7	2.1	2.2	-1.6	2.3	2.1	1.4	0.8	-0.1	2.6	0.1	-2.7	3.1	-2.9	-2.2	-0.2	-2.9	-0.5	0.1	1.3	-1.1	-2.3	-2.5	0.2	-0.1	0.3	-0.5	-2.6
7.6	2.6	1.0	-2.3	-3.0	3.0	-3.1	2.4	1.1	1.0	0.8	-0.4	2.2	-1.0	-1.4	2.3	-1.1	-3.1	0.6	-2.2	0.5	1.7	-1.1	0.7	-3.1	-1.8	0.6	1.7	-2.1	-1.1	2.2
7.1	0.3	-2.9	3.0	2.9	-2.7	-1.6	2.5	-0.7	-2.5	3.0	1.5	-0.3	-2.7	0.5	-3.0	3.1	-2.4	-1.1	-2.6	0.0	-2.4	-0.1	0.2	1.7	-2.4	-0.4	0.2	-0.3	-1.8	0.0
6.6	-1.7	-0.2	2.0	2.6	2.4	-2.2	1.7	-1.1	-2.0	-0.7	-0.4	-2.5	1.6	2.2	2.4	0.2	2.7	-0.6	1.7	-1.5	1.8	1.8	-0.2	2.3	-2.3	-0.7	-2.6	2.0	1.6	-2.7
6.2	-2.5	-0.1	-0.5	1.9	1.4	2.6	-3.1	-1.0	3.0	2.6	2.2	1.2	0.8	-2.5	2.8	1.2	1.1	0.7	2.2	1.0	1.3	0.4	1.8	3.0	-2.6	0.8	1.1	2.6	0.3	2.0
5.9	-0.7	-2.3	-2.7	-1.0	-1.7	-1.0	3.0	0.5	-0.3	0.6	-0.2	2.0	-1.2	0.3	1.2	-1.2	-3.0	-1.2	0.4	-0.4	-0.2	0.4	1.8	0.3	-0.8	-2.5	-0.5	0.3	0.0	0.5
5.6	1.2	-2.5	2.8	1.9	-2.6	-2.8	1.7	2.6	0.1	-0.6	-1.8	1.6	-2.2	2.1	-1.3	1.3	1.9	-0.5	1.4	-3.1	-0.7	-1.2	-1.5	-2.4	0.6	-1.8	-0.7	-0.7	1.9	0.0

	TN						TC						pH						EC					
Period	HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	3.1	0.0	0.0	3.1	3.1	3.1
106.0	0.1	0.2	0.8	-0.5	-0.4	-2.3	-0.4	-0.1	1.1	0.5	-0.9	-2.5	-0.4	-0.2	0.8	0.0	-1.4	2.9	-1.8	1.0	0.1	2.2	-2.6	2.1
53.0	-3.0	-2.8	1.5	0.0	0.1	-2.5	2.7	-3.0	-2.9	-3.1	0.4	-2.6	1.3	-1.2	-0.2	-2.2	-3.0	-1.1	-2.5	-1.8	0.6	0.1	0.6	0.6
35.3	-1.2	-1.6	-1.4	2.1	2.2	2.4	0.7	-1.4	-3.0	2.1	1.9	3.0	2.4	3.1	-0.1	-0.5	-0.3	-0.4	2.3	-2.2	0.3	-1.7	0.5	-2.1
26.5	-1.2	-1.4	1.6	-0.2	-0.3	2.4	-1.7	2.2	-2.7	-1.3	-0.8	3.1	0.9	2.9	-1.1	2.1	2.9	-0.3	1.5	1.6	-3.0	0.1	-3.0	-2.3
21.2	2.4	2.5	1.2	0.6	1.1	-1.6	2.2	2.9	1.2	1.5	1.4	-1.8	0.2	0.3	-2.5	-1.6	-2.4	0.7	0.1	1.4	2.8	-2.8	-2.0	0.4
17.7	0.6	0.4	-1.0	2.3	1.7	-3.0	2.7	-0.5	-2.8	2.6	1.9	-2.4	0.2	1.2	-2.8	2.7	-1.9	0.4	-1.6	-1.4	3.1	-1.9	-1.7	-0.2
15.1	1.2	-2.0	-0.5	-2.7	0.9	-2.7	2.3	-2.4	-1.0	-2.8	0.9	-0.2	-2.0	0.1	-2.3	1.6	3.0	3.0	-2.2	0.2	-1.9	1.9	2.7	-2.3
13.3	-2.5	1.3	1.3	-1.0	2.4	-1.0	-2.6	0.2	2.1	-2.7	2.0	-3.1	-2.9	-1.8	-1.6	-0.8	-0.7	-0.7	2.2	-1.3	-1.9	2.6	-0.4	-0.2
11.8	-2.7	-1.2	1.8	0.3	1.9	-1.5	-2.4	-1.3	0.6	-1.5	1.9	1.7	-0.7	-1.1	1.1	2.6	-0.1	-0.5	1.2	-1.9	0.0	1.8	0.2	-1.2
10.6	2.2	-2.2	1.0	2.7	2.4	0.3	-0.4	2.7	-3.1	1.4	2.3	1.7	0.9	1.9	0.0	0.4	-0.5	3.0	1.3	-2.5	-1.2	1.1	-0.5	-1.9
9.6	-1.7	-0.5	-0.3	1.9	2.1	-2.3	-2.8	-1.0	-0.7	0.6	2.1	-2.0	-0.1	2.4	0.3	-0.3	-1.0	1.1	-1.0	1.5	0.1	0.4	-1.3	0.0
8.8	-1.3	1.0	1.6	-0.6	-2.3	0.5	-2.6	2.5	1.8	0.2	-2.3	-0.5	-2.3	-0.1	-1.4	-2.1	1.4	2.9	2.6	0.6	-1.6	-0.1	1.4	1.0
8.2	2.8	-0.6	0.1	-0.8	-0.8	-0.1	-2.7	-1.2	0.9	0.9	-1.1	-0.6	3.1	0.9	0.2	-2.9	2.1	2.4	1.3	-1.1	0.0	-2.8	1.3	-2.5
7.6	-0.8	0.2	0.7	1.0	0.6	2.6	-2.2	-2.7	1.0	0.1	-0.7	2.3	-1.3	-2.3	-1.8	-1.4	2.9	-0.4	1.6	-2.2	-1.4	2.4	2.9	-1.4
7.1	-2.2	-2.1	0.8	2.4	1.3	1.5	-2.9	-1.8	1.4	2.0	1.2	-0.2	0.3	1.4	3.0	-1.1	-2.7	-1.5	0.6	2.7	0.3	-0.4	-2.9	-1.0
6.6	1.3	-1.0	-2.5	-1.6	-0.2	3.0	2.2	-1.1	-2.5	1.4	-0.2	-2.6	-2.2	2.4	0.6	-0.4	3.1	0.3	-1.0	2.4	0.4	-1.7	-2.7	2.6
6.2	-1.0	0.3	-0.8	-1.8	1.6	0.2	3.1	0.7	-1.8	0.7	2.3	0.8	-0.9	0.8	-0.4	-0.2	-0.1	-3.0	3.1	-0.1	-0.7	0.5	-0.3	2.1
5.9	1.0	0.2	0.5	0.2	2.1	-0.9	2.6	0.1	-0.9	0.3	2.0	-0.9	-1.2	2.5	2.1	-1.9	-1.6	2.8	-2.5	1.0	1.8	-1.0	-1.4	-2.3
5.6	1.5	1.8	1.2	0.0	-1.4	1.8	-2.8	2.1	1.4	-0.5	-1.4	2.4	0.7	-1.0	-0.2	1.7	1.4	-0.7	2.2	0.4	0.4	0.9	1.4	0.3

Table A11: 2017 Fungi and physical conditions covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Fungi

Period	VWC						Water Grad.						Temp					
	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	0.0	3.1	0.0	0.0	3.1	0.0	3.1	3.1	0.0	3.1	0.0	3.1	3.1	3.1	3.1	0.0	0.0
106.0	-0.8	-0.2	2.1	0.4	-0.4	-1.8	1.5	3.1	2.2	-1.3	2.6	0.9	2.1	2.2	-2.7	2.6	1.3	-0.7
53.0	-0.4	0.4	-3.0	2.4	2.3	-2.8	0.7	0.3	-1.2	1.9	1.4	-0.2	2.5	-2.9	-0.1	-0.6	-1.0	0.0
35.3	-1.7	-0.8	3.1	2.4	1.1	1.3	1.7	1.8	-1.0	-2.1	-1.5	-1.4	2.6	-2.5	1.1	0.7	-0.5	0.0
26.5	3.1	0.6	-0.4	-2.9	-2.5	1.0	2.5	-0.1	1.3	-0.4	2.0	0.7	2.9	-3.0	-1.6	2.9	-1.8	-1.2
21.2	2.4	-2.5	-1.6	-2.5	1.5	2.4	1.0	-2.6	1.9	2.2	0.1	0.6	-2.7	-2.1	-1.0	-1.7	2.2	3.1
17.7	1.6	1.4	-0.7	-2.3	-1.9	2.8	-3.1	-2.1	0.1	-1.0	-0.3	-2.2	-2.1	-1.6	1.6	0.1	1.2	-1.5
15.1	-0.1	1.7	-0.6	1.9	-2.3	-1.7	-0.3	1.4	-1.4	1.9	0.0	2.2	-2.6	-0.6	2.9	-0.5	1.6	2.7
13.3	0.2	2.2	1.2	3.1	-2.8	-2.3	1.6	-2.5	0.8	2.4	1.2	1.0	-1.2	0.8	-0.1	1.7	2.0	2.4
11.8	-2.4	0.4	2.6	2.9	-3.0	1.3	2.3	1.2	-2.1	0.2	0.4	-2.2	-1.2	1.4	2.8	-2.3	-1.9	2.4
10.6	-1.4	1.1	2.0	-2.2	1.9	-2.8	-1.9	1.2	1.8	-3.1	0.7	1.4	3.1	-1.0	0.2	2.5	0.0	2.0
9.6	2.1	-2.1	2.8	-3.1	1.1	2.6	0.0	2.4	3.0	0.2	-1.2	-1.1	-3.1	-0.9	-3.1	-2.3	2.3	-2.5
8.8	2.3	-1.9	2.1	-1.3	0.4	1.0	1.8	-1.3	2.4	-2.0	0.3	2.8	0.4	2.5	-0.5	2.7	-1.7	-1.4
8.2	0.8	-3.0	-2.0	-2.7	2.3	0.2	-1.7	0.9	-2.5	1.8	-0.2	-1.5	-2.4	0.4	0.8	0.5	-0.5	-2.0
7.6	1.6	-2.0	-2.1	3.1	1.8	-0.9	2.7	-2.3	-2.1	2.9	1.0	-2.2	-1.6	0.5	1.2	0.2	-1.6	2.1
7.1	0.0	2.7	-0.3	2.0	2.3	-2.6	-1.9	0.4	-1.8	-0.2	0.5	1.7	-1.2	1.5	-1.6	1.0	1.6	3.1
6.6	-0.6	-2.6	1.0	2.5	-0.5	1.3	-2.2	-3.0	0.6	1.8	-2.2	-0.4	-2.8	1.1	-1.0	0.3	2.7	-1.0
6.2	-1.6	-1.0	0.8	-2.7	0.6	-2.8	3.0	-0.7	-0.9	2.1	0.3	-2.7	-1.2	1.5	0.6	-2.3	2.2	-2.6
5.9	-2.1	2.5	-2.3	-0.9	-0.9	-1.4	-3.0	-2.8	3.0	-2.9	3.1	2.0	-2.0	2.5	-2.3	-0.6	-0.8	-1.6
5.6	-2.1	2.1	-3.1	2.0	-2.1	2.3	1.3	-0.6	1.8	0.3	1.3	0.5	-1.4	3.0	-1.8	-2.8	-1.8	3.1

Period	Temp. Grad.						Bottom Flux						Water Storage					
	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	3.1	3.1	3.1	0.0	0.0	0.0	0.0	3.1	3.1	0.0	0.0	3.1	3.1	3.1	3.1	3.1	0.0
106.0	1.4	1.6	-3.1	2.2	0.8	-1.4	1.3	1.5	3.0	1.8	0.5	-1.2	2.0	2.3	-2.6	3.0	1.6	-0.8
53.0	2.0	2.9	-0.6	-1.2	-1.6	-0.6	1.9	2.9	-0.8	-1.2	-1.6	-0.5	-0.9	0.1	2.6	2.2	1.8	3.0
35.3	2.2	-2.7	0.9	0.4	-0.9	-0.5	0.5	1.6	-1.2	-1.6	-2.9	-2.2	-2.2	-1.1	2.2	2.1	0.8	1.2
26.5	2.5	-3.1	-2.1	2.4	-2.3	-1.7	0.5	1.0	1.6	0.5	2.2	2.5	-3.0	-2.6	-1.8	-2.9	-1.4	-1.0
21.2	-3.0	-2.2	-1.2	-2.1	1.8	2.8	-0.8	0.0	0.9	0.3	-2.0	-1.1	2.5	-3.1	-2.1	-2.6	1.3	2.2
17.7	-2.4	-1.9	1.2	-0.3	0.7	-2.0	-2.3	-1.6	0.9	-0.2	0.8	-1.6	1.9	2.2	-1.2	2.8	-2.0	2.6
15.1	-2.8	-0.7	2.7	-0.7	1.3	2.3	-2.1	0.0	3.1	-0.1	2.0	-3.1	-0.8	1.1	-1.7	1.4	-2.8	-1.9
13.3	-1.4	0.6	-0.3	1.4	1.6	2.2	3.0	-1.2	-2.4	-0.6	-0.3	0.3	-0.5	1.7	1.0	2.5	2.7	3.1
11.8	-1.6	1.0	2.4	-2.7	-2.4	1.9	1.3	-2.5	-1.8	0.3	0.6	-1.5	-2.4	0.1	1.2	2.8	3.1	1.1
10.6	2.2	-2.0	-0.7	1.6	-0.8	1.1	1.6	-2.4	-1.3	0.9	-1.5	0.4	-1.9	0.4	1.4	-2.6	1.2	3.1
9.6	1.9	-2.3	1.7	2.5	0.9	2.2	-0.1	2.5	-1.1	0.7	-0.9	0.6	2.6	-1.1	1.7	3.1	1.5	-2.9
8.8	-0.1	2.0	-0.9	2.3	-2.1	-1.9	0.0	2.1	-0.4	2.4	-2.0	-1.8	-3.0	-0.8	2.4	-0.8	1.1	1.6
8.2	-2.8	0.0	0.5	0.1	-0.9	-2.5	-2.0	1.0	1.1	0.9	-0.1	-1.5	-2.8	-0.3	-1.0	-0.3	-1.3	-2.7
7.6	-2.3	0.0	0.6	-0.5	-2.3	1.4	-1.5	0.6	2.4	0.2	-1.6	2.2	2.8	-1.4	-1.2	-2.0	2.5	0.2
7.1	-0.6	1.9	-1.0	2.0	2.3	-2.8	-3.1	-0.3	2.9	-0.7	-0.3	1.2	-0.4	2.8	-0.6	2.5	2.9	-2.5
6.6	2.1	3.1	-2.9	-1.1	1.6	-2.8	2.1	-0.6	-1.5	-0.8	1.8	-2.5	-0.3	-3.1	1.6	-3.1	-0.5	1.4
6.2	-1.4	-2.8	0.4	-3.1	1.6	3.0	2.2	-1.2	-2.0	1.3	-0.5	0.9	-0.2	2.5	1.3	-1.1	-2.9	-1.7
5.9	-2.7	1.8	-2.9	-1.3	-1.6	-2.4	0.4	-1.1	0.2	1.9	1.6	0.9	-1.7	2.9	-2.0	-0.3	-0.5	-1.3
5.6	-2.2	2.3	-2.6	2.6	-2.6	2.2	0.3	-1.4	0.1	-1.2	-0.1	-1.4	-1.4	3.1	-2.1	-2.9	-1.9	3.1

Table A12: 2017 Fungi and weather condition covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Fungi

	Mean Air Temp.						Air Temp. Ran.						Humidity						ET						GWT Depth					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	3.1	3.1	3.1	3.1	3.1	0.0	0.0	0.0	3.1	3.1	0.0	0.0	3.1	3.1	0.0	3.1	3.1	0.0	3.1	3.1	3.1	3.1	0.0	0.0	3.1	3.1	0.0	3.1	3.1	0.0
106.0	2.3	2.6	-2.4	2.9	1.6	-0.3	1.2	1.5	2.8	1.8	0.5	-1.4	-2.9	-2.6	-1.4	-2.4	2.6	0.7	1.7	2.0	-3.0	2.2	1.0	-1.0	-2.7	-2.4	-1.2	-2.2	2.9	0.9
53.0	2.5	-2.9	-0.1	-0.6	-1.0	0.1	2.0	2.9	-0.6	-1.1	-1.5	-0.4	-1.8	-0.9	1.9	1.4	1.0	2.1	2.2	3.1	-0.5	-1.0	-1.3	-0.3	2.7	-2.7	0.1	-0.4	-0.8	0.3
35.3	2.6	-2.6	1.0	0.5	-0.8	-0.1	0.8	1.9	-0.8	-1.4	-2.6	-1.9	-2.4	-1.4	2.2	1.7	0.5	1.1	1.5	2.6	-0.2	-0.7	-1.9	-1.2	1.8	2.9	0.2	-0.3	-1.5	-0.9
26.5	2.4	2.8	-2.1	2.4	-2.3	-1.6	-1.6	-1.2	0.1	-1.6	-0.1	0.6	2.1	2.5	-2.4	2.1	-2.6	-1.9	3.1	-2.8	-1.4	3.1	-1.6	-0.9	1.6	2.0	-3.0	1.6	3.1	-2.5
21.2	-3.0	-2.4	-1.2	-2.0	2.0	2.9	-1.1	-0.5	0.7	-0.1	-2.4	-1.5	1.6	2.2	-2.9	2.7	0.3	1.2	-2.6	-1.9	-0.7	-1.5	2.5	-2.9	0.6	1.2	2.4	1.7	-0.7	0.2
17.7	-2.4	-1.8	1.4	-0.2	0.9	-1.8	1.9	2.5	-0.6	-2.2	-1.2	2.5	-2.3	-1.7	1.4	-0.1	0.9	-1.7	2.7	-3.0	0.2	-1.4	-0.3	-2.9	-0.4	0.2	-3.0	1.8	2.8	0.2
15.1	-2.5	-0.6	3.0	-0.4	1.6	2.7	-0.3	1.6	-1.1	1.7	-2.5	-1.4	2.7	-1.7	2.0	-1.5	0.5	1.7	-1.0	0.9	-1.8	1.0	3.1	-2.1	-0.9	1.0	-1.7	1.2	-3.1	-1.9
13.3	-0.9	1.0	0.2	1.8	2.1	2.7	-1.8	0.1	-0.7	0.9	1.2	1.8	0.5	2.5	1.7	-3.0	-2.7	-2.1	-1.8	0.2	-0.6	1.0	1.3	1.8	-2.2	-0.3	-1.1	0.5	0.8	1.4
11.8	-1.6	0.9	2.4	-2.7	-2.3	2.0	-0.2	2.4	-2.4	-1.2	-0.9	-2.9	-3.0	-0.5	1.0	2.2	2.5	0.5	-0.4	2.1	-2.7	-1.5	-1.1	-3.1	-3.0	-0.5	1.0	2.2	2.5	0.6
10.6	2.6	-1.5	-0.3	1.9	-0.6	1.4	1.3	-2.8	-1.6	0.6	-1.9	0.1	-2.0	0.2	1.4	-2.7	1.1	3.1	1.6	-2.6	-1.4	0.8	-1.6	0.3	2.4	-1.7	-0.5	1.7	-0.8	1.1
9.6	2.0	-1.9	2.0	2.8	1.2	2.6	0.2	2.6	0.1	1.0	-0.6	0.8	-2.7	-0.2	-2.7	-1.9	2.8	-2.0	0.5	2.9	0.4	1.3	-0.3	1.1	1.1	-2.7	1.1	1.9	0.4	1.8
8.8	-0.1	1.9	-0.9	2.2	-2.2	-2.0	-0.5	1.4	-1.3	1.8	-2.6	-2.4	3.0	-1.3	2.2	-1.0	0.9	1.1	0.4	2.4	-0.3	2.8	-1.7	-1.5	0.7	2.6	-0.1	3.0	-1.4	-1.2
8.2	-2.6	0.3	0.7	0.3	-0.7	-2.2	-1.9	1.0	1.3	0.9	-0.1	-1.5	1.5	-1.9	-1.5	-1.9	-2.9	1.9	-2.8	0.1	0.4	0.0	-0.9	-2.4	-1.1	1.8	2.1	1.7	0.7	-0.7
7.6	-2.3	-0.3	0.4	-0.5	-2.4	1.3	-2.7	-0.6	0.1	-0.9	-2.7	0.9	0.6	2.7	-2.9	2.4	0.6	-2.1	-2.5	-0.5	0.2	-0.8	-2.6	1.1	-0.9	1.1	1.8	0.8	-1.0	2.7
7.1	1.3	-2.3	0.9	-2.7	-2.3	-0.8	2.2	-1.5	1.7	-1.9	-1.5	0.1	-2.2	0.4	-2.7	0.0	0.4	1.9	1.4	-2.2	1.0	-2.7	-2.2	-0.7	-2.0	0.6	-2.5	0.2	0.6	2.2
6.6	2.5	-0.2	-1.9	-0.4	2.2	-2.0	0.4	-2.2	2.3	-2.4	0.2	2.3	2.5	-0.2	-1.9	-0.4	2.2	-2.0	-0.6	3.0	1.3	2.8	-0.9	1.2	3.1	0.4	-1.3	0.2	2.8	-1.4
6.2	-2.1	0.6	-0.3	3.1	1.4	2.8	2.4	-1.2	-2.1	1.3	-0.4	1.0	-0.8	1.9	1.0	-1.8	2.7	-2.2	2.5	-1.1	-1.9	1.5	-0.2	1.2	-2.9	-0.2	-1.1	2.3	0.6	2.0
5.9	-2.5	2.1	-2.6	-1.1	-1.3	-2.1	1.1	-0.6	1.0	2.5	2.2	1.5	3.1	1.5	3.0	-1.7	-2.0	-2.8	-1.1	-2.8	-1.2	0.3	0.0	-0.7	1.3	-0.4	1.2	2.7	2.4	1.7
5.6	-2.0	2.5	-2.4	2.9	-2.4	2.5	-3.1	1.3	2.7	1.7	2.8	1.4	1.9	0.1	1.5	0.5	1.5	0.1	-2.0	2.4	-2.5	2.8	-2.4	2.5	1.3	-0.6	0.8	-0.2	0.8	-0.5

Table A13: 2017 Actinomycete and chemical covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Actinomycetes

	NO3-N						P						SO4-S						Mn						NH4-N					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	3.1	3.1	3.1	3.1	3.1	0.0	3.1	3.1	3.1	3.1	3.1	3.1	0.0	0.0	0.0	0.0	0.0	0.0	3.1	3.1	3.1	3.1	3.1	3.1	0.0	3.1	3.1	3.1	3.1
106.0	-0.6	-1.8	-2.6	-2.5	-2.2	2.5	-0.7	-1.8	1.7	-2.9	-2.8	2.3	1.8	-1.4	0.2	0.5	1.2	-0.1	-1.4	-1.8	-3.1	-2.7	-2.6	2.6	-1.7	-1.4	3.1	-3.0	-2.2	2.1
53.0	-0.3	0.6	-2.8	2.6	2.7	-2.6	-3.1	-0.7	-0.2	2.0	-0.4	0.3	0.5	1.0	-2.3	-2.4	-1.5	0.5	-3.1	-1.6	1.1	0.4	0.1	1.5	-3.1	-2.4	0.7	0.3	0.2	1.3
35.3	0.2	1.0	2.1	2.4	-2.2	2.2	-1.7	1.4	3.1	3.0	-1.9	-1.5	-2.2	2.4	-1.3	-2.9	-2.5	-0.6	1.4	2.4	-2.7	-2.8	-2.7	-2.4	-1.6	-1.8	-0.9	-0.1	-0.5	-0.9
26.5	-0.7	-0.2	-0.2	0.6	-1.5	-1.4	-0.1	-2.0	-0.5	2.6	-1.9	2.1	-1.6	-2.6	1.0	0.1	-1.9	-2.5	-1.1	2.8	-1.1	-2.4	1.7	3.0	-0.8	-0.2	-1.3	-0.3	-1.4	-2.1
21.2	-2.3	-0.3	-1.6	-2.2	0.1	1.3	-2.9	0.1	2.6	2.1	0.1	-0.4	2.4	-1.1	-0.9	-2.1	0.4	-0.1	1.4	0.4	1.6	0.2	-0.7	-1.9	-0.6	-0.6	-0.6	2.8	-2.8	1.0
17.7	1.4	2.6	-1.3	-1.1	2.2	0.3	-0.6	1.1	1.6	2.1	2.1	2.4	0.6	0.9	2.2	-3.0	1.8	-1.3	-0.9	0.7	-2.3	2.6	1.3	0.8	0.1	0.6	-1.7	-3.0	2.6	-1.1
15.1	-0.1	2.2	-3.0	-1.9	2.3	1.2	0.3	-2.9	-1.2	0.0	1.4	-1.4	0.3	2.4	-1.6	-2.2	-2.6	2.7	0.1	0.7	1.4	3.1	1.2	-1.0	-0.3	0.6	0.6	2.7	0.8	-0.2
13.3	2.1	-3.0	0.8	-1.8	0.6	0.0	2.7	2.9	1.0	1.8	0.7	1.0	-1.1	-1.8	1.5	-0.5	-0.2	-2.1	-1.6	-2.2	1.4	0.3	2.8	0.1	-0.3	2.0	-2.3	1.3	0.4	0.4
11.8	-1.8	-3.0	2.6	-1.2	1.5	-1.6	-1.1	0.3	1.7	0.4	-1.8	-0.8	2.3	0.0	3.0	-1.9	2.8	0.6	-0.3	0.6	-1.6	0.6	-1.9	2.0	-0.4	0.0	-1.4	0.2	2.4	1.0
10.6	-0.8	0.8	-2.3	0.1	-2.3	-1.3	1.2	1.1	-2.3	1.4	-1.9	2.1	1.8	1.7	-1.8	1.0	-2.1	0.5	-1.0	0.4	0.3	3.1	-0.3	1.4	-0.8	2.0	1.1	-2.4	2.5	-1.9
9.6	1.6	-1.4	-2.7	-1.5	-2.3	-0.4	3.1	2.2	-2.3	-0.3	1.9	-2.2	-1.2	-3.0	-1.1	-2.6	1.6	1.9	0.7	2.6	1.3	-2.4	1.8	-1.3	1.4	-1.6	3.1	-1.2	-2.5	-0.4
8.8	-0.2	-0.2	2.4	1.6	3.0	2.1	0.4	-1.4	2.2	0.3	-2.0	1.4	-1.2	-1.2	0.8	0.7	-0.7	-2.9	1.2	-1.5	0.7	1.8	-2.6	1.3	-1.5	-0.7	2.1	0.2	-1.8	1.9
8.2	-1.0	-2.5	-2.0	-2.1	-2.8	-2.1	-2.3	-0.9	1.1	2.9	1.2	2.2	1.9	0.5	2.8	-0.8	-1.0	-0.6	-1.1	2.8	-0.2	-2.9	0.1	-2.7	-0.7	-2.9	-0.4	2.4	0.7	-3.0
7.6	-0.5	-2.1	0.8	-0.6	2.9	-2.6	-0.8	-2.0	-2.2	-3.1	-0.6	2.6	2.1	1.8	-0.9	1.3	3.0	1.1	0.9	-2.7	-1.5	1.3	0.6	-2.7	1.3	-2.5	-1.5	0.3	-1.2	2.7
7.1	2.9	0.3	-0.5	-1.8	-0.7	-1.1	-1.2	2.6	0.2	-1.7	-2.8	0.2	-0.1	-2.6	-0.2	-1.6	-0.5	-0.6	0.0	-3.1	0.4	1.4	2.1	2.2	0.2	2.8	2.9	1.3	0.1	0.6
6.6	0.6	3.1	-0.1	2.5	1.4	-1.2	-2.2	2.2	2.2	-0.9	-1.4	-1.5	-2.3	-0.8	0.4	0.0	1.7	0.5	-2.3	1.8	-0.3	1.6	-1.2	-2.9	0.0	2.6	1.6	1.8	0.6	-1.6
6.2	1.3	3.1	-0.5	-2.2	-0.4	1.9	0.7	2.2	3.0	-1.5	0.5	0.4	-1.7	0.7	2.8	-2.8	-0.6	-0.1	-0.3	-2.1	1.3	2.6	0.1	2.2	1.2	-2.3	1.0	-1.5	-1.4	1.2
5.9	1.5	0.0	1.7	-1.8	-2.2	1.9	-1.1	2.9	-2.2	-0.3	-0.8	-1.4	1.0	2.7	-0.7	-2.1	2.7	1.7	2.6	2.0	-2.0	-0.4	1.2	-3.1	1.4	-0.1	-2.3	-0.5	-0.6	-2.9
5.6	-1.7	-0.1	-1.5	1.2	-3.1	0.8	-1.2	-1.3	2.1	-1.3	-2.3	-1.0	1.2	-1.8	0.7	0.6	1.4	-3.1	-1.5	-0.7	1.3	-2.0	-2.0	1.2	-2.3	0.6	1.3	-1.4	1.4	-2.6

	TN						TC						pH						EC					
Period	HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	3.1	3.1	0.0	0.0	3.1	3.1	3.1	3.1	0.0	3.1	3.1	0.0	3.1	3.1	0.0	0.0	3.1	0.0	0.0	3.1	0.0	3.1	0.0	0.0
106.0	-2.9	3.1	1.0	1.0	2.9	1.6	2.9	2.8	1.3	1.9	2.4	1.3	2.9	2.8	1.0	1.4	1.8	0.4	1.5	-2.4	0.3	-2.7	0.7	-0.3
53.0	-0.2	0.3	-1.1	-3.1	-2.5	1.1	-0.8	0.1	0.8	0.1	-2.2	1.1	-2.1	2.0	-2.8	1.0	0.7	2.5	0.3	1.4	-2.0	-2.9	-2.0	-2.0
35.3	1.9	1.2	-0.7	3.0	-2.1	-2.0	-2.4	1.4	-2.4	3.0	-2.4	-1.4	-0.7	-0.4	0.6	0.3	1.7	1.5	-0.9	0.6	1.0	-0.8	2.5	-0.2
26.5	1.8	1.8	-3.0	-3.0	0.5	2.3	1.3	-0.9	-1.1	2.3	0.0	3.0	-2.3	-0.1	0.5	-0.7	-2.6	-0.4	-1.7	-1.5	-1.4	-2.7	-2.3	-2.4
21.2	-0.4	-0.6	2.7	2.0	-2.2	-1.4	-0.6	-0.2	2.7	2.8	-1.9	-1.6	-2.6	-2.8	-1.0	-0.3	0.6	0.9	-2.7	-1.7	-2.0	-1.4	1.0	0.7
17.7	-2.5	-2.4	-3.1	0.9	-0.7	0.9	-0.4	3.0	1.4	1.2	-0.5	1.5	-2.8	-1.6	1.4	1.3	2.0	-1.9	1.7	2.1	1.0	2.9	2.2	-2.6
15.1	-2.2	0.0	-1.6	0.4	1.4	2.0	-1.0	-0.4	-2.0	0.3	1.4	-1.8	0.9	2.1	3.0	-1.5	-2.8	1.4	0.8	2.2	-3.0	-1.2	3.1	2.4
13.3	0.3	-2.6	0.9	0.2	2.0	-2.4	0.2	2.6	1.7	-1.5	1.6	1.8	-0.1	0.6	-2.0	0.5	-1.1	-2.1	-1.3	1.1	-2.3	-2.5	-0.9	-1.5
11.8	-0.5	1.0	0.7	-2.6	-1.9	1.1	-0.1	0.9	-0.4	1.8	-1.8	-1.9	1.5	1.1	0.1	-0.3	2.4	2.1	-2.8	0.3	-1.1	-1.1	2.7	1.4
10.6	-1.0	0.4	-2.7	-1.8	-0.9	-3.0	2.7	-1.0	-0.5	-3.0	-1.0	-1.6	-2.3	-1.8	2.6	2.2	2.5	-0.3	-1.9	0.1	1.4	3.0	2.5	1.1
9.6	0.4	2.2	-3.1	0.2	1.2	-2.3	-0.7	1.7	2.8	-1.1	1.2	-1.9	2.0	-1.1	-2.4	-2.0	-2.0	1.1	1.1	-2.1	-2.7	-1.3	-2.2	0.0
8.8	1.7	-2.1	-2.6	1.4	-3.1	-2.8	0.4	-0.6	-2.4	2.2	-3.1	2.4	0.7	3.1	0.7	-0.1	0.7	-0.5	-0.7	-2.5	0.5	1.9	0.7	-2.3
8.2	-1.7	2.7	-0.2	1.3	0.4	-0.5	-1.0	2.1	0.7	3.0	0.1	-1.0	-1.4	-2.1	-0.1	-0.8	-2.9	2.0	3.0	2.2	-0.3	-0.7	2.6	-2.9
7.6	2.3	-2.9	-2.5	-2.9	0.4	3.0	0.9	0.4	-2.2	2.5	-0.8	2.7	1.9	0.9	1.3	1.0	2.8	0.1	-1.6	0.9	1.7	-1.5	2.7	-1.0
7.1	0.4	1.1	-2.7	-2.3	-3.0	2.0	-0.3	1.4	-2.1	-2.7	3.1	0.3	2.9	-1.7	-0.5	0.5	-0.8	-0.9	-3.1	-0.4	3.1	1.2	-0.9	-0.4
6.6	-2.7	2.3	1.7	-1.7	-1.2	-2.2	-1.8	2.2	1.7	1.2	-1.3	-1.5	0.1	-0.6	-1.5	-0.5	2.1	1.4	1.3	-0.5	-1.6	-1.9	2.6	-2.6
6.2	2.8	-2.9	-0.8	0.4	-0.1	-0.6	0.6	-2.4	-1.8	2.9	0.6	0.1	2.9	-2.4	-0.4	2.0	-1.8	2.5	0.6	3.0	-0.7	2.7	-2.0	1.3
5.9	-3.1	2.5	-1.4	-0.7	1.5	2.0	-1.5	2.4	-2.8	-0.6	1.4	2.0	1.0	-1.4	0.2	-2.8	-2.2	-0.6	-0.3	-2.9	-0.1	-1.9	-2.0	0.5
5.6	-1.3	-2.1	-3.1	-0.7	-1.9	-0.9	0.6	-1.8	-2.9	-1.2	-1.9	-0.2	-2.2	1.4	1.8	1.0	0.9	2.9	-0.7	2.8	2.4	0.2	0.9	-2.3

Table A14: 2017 Actinomycete and physical conditions covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Actinomycetes

	VWC						Water Grad.						Temp						Temp. Grad.						Bottom Flux						Water Storage					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	3.1	3.1	3.1	3.1	3.1	3.1	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	0.0	0.0	3.1	3.1	0.0	3.1
106.0	2.5	2.8	2.3	1.9	2.8	2.0	-1.5	-0.2	2.4	0.2	-0.4	-1.5	-0.9	-1.1	-2.5	-2.2	-1.7	3.1	-1.6	-1.7	-2.9	-2.6	-2.3	2.5	-1.7	-1.8	-3.1	-3.0	-2.5	2.7	-1.0	-1.0	-2.4	-1.8	-1.4	3.0
53.0	2.4	-2.7	0.7	-0.6	-0.3	0.8	-2.8	-2.8	2.5	-1.1	-1.2	-2.9	-0.9	0.2	-2.7	2.7	2.7	-2.6	-1.5	-0.2	3.0	2.1	2.0	3.0	-1.6	-0.2	2.9	2.0	2.1	3.1	2.0	-3.0	0.0	-0.9	-0.8	0.3
35.3	1.5	2.0	-2.5	-2.9	3.1	-3.1	-1.5	-1.6	-0.3	-1.2	0.5	0.6	-0.5	0.3	1.8	1.6	1.5	1.9	-0.9	0.1	1.5	1.3	1.1	1.4	-2.6	-1.9	-0.6	-0.8	-0.9	-0.3	0.9	1.7	2.9	3.0	2.8	-3.1
26.5	-0.1	-2.5	1.2	0.6	-1.7	0.9	-0.8	3.1	2.9	-3.1	2.7	0.6	-0.3	0.2	0.0	0.1	-1.1	-1.3	-0.8	0.1	-0.5	-0.4	-1.6	-1.8	-2.8	-2.1	-3.0	-2.2	2.9	2.4	0.0	0.6	-0.2	0.6	-0.6	-1.1
21.2	-0.4	0.6	-0.1	-1.2	-1.8	2.6	-1.8	0.6	-2.9	-2.7	-3.1	0.8	0.8	1.1	0.6	-0.4	-1.0	-2.9	0.5	0.9	0.3	-0.8	-1.4	3.0	2.7	-3.1	2.4	1.6	1.0	-0.9	-0.3	0.1	-0.6	-1.3	-1.9	2.4
17.7	-1.5	-1.4	-2.8	2.6	2.0	0.4	0.1	1.4	-2.0	-2.4	-2.7	1.7	1.1	2.0	-0.5	-1.3	-1.2	2.4	0.8	1.6	-0.8	-1.7	-1.7	1.9	1.0	1.9	-1.2	-1.6	-1.6	2.3	-1.2	-0.6	3.0	1.4	1.9	0.2
15.1	2.8	-2.6	-1.6	-1.2	-1.8	3.0	2.6	-2.9	-2.4	-1.2	0.4	0.6	0.4	1.4	1.9	2.7	2.1	1.1	0.1	1.3	1.6	2.4	1.8	0.8	0.8	1.9	2.1	3.1	2.4	1.6	2.1	3.1	-2.7	-1.7	-2.4	2.8
13.3	3.0	-1.6	0.8	-1.9	3.0	2.6	-1.9	-0.1	0.4	-2.7	0.8	-0.3	1.7	-3.0	-0.5	2.9	1.5	1.1	1.4	3.0	-0.7	2.7	1.2	0.8	-0.5	1.2	-2.8	0.7	-0.7	-1.0	2.4	-2.2	0.6	-2.6	2.3	1.8
11.8	-0.1	2.6	1.5	0.0	-0.5	-2.3	-1.7	-2.8	3.1	-2.7	2.9	0.5	1.1	-2.7	1.8	1.1	0.7	-1.3	0.7	-3.0	1.4	0.7	0.2	-1.7	-2.7	-0.3	-2.8	-2.7	-3.1	1.1	-0.2	2.3	0.2	-0.2	-0.6	-2.6
10.6	1.7	-2.6	-1.8	-0.3	-1.4	0.2	1.1	-2.5	-1.9	-1.2	-2.6	-1.9	-0.1	1.6	2.8	-1.9	3.0	-1.3	-0.9	0.5	1.9	-2.8	2.2	-2.2	-1.6	0.2	1.3	2.8	1.5	-2.9	1.2	2.9	-2.3	-0.7	-2.1	-0.2
9.6	-2.0	0.6	0.1	1.5	0.1	2.6	2.1	-1.1	0.2	-1.5	-2.1	-1.1	-1.0	1.9	0.4	2.3	1.4	-2.5	-2.2	0.4	-1.1	0.8	-0.1	2.2	2.0	-1.1	2.4	-1.0	-1.9	0.6	-1.6	1.6	-1.1	1.4	0.6	-2.8
8.8	-1.0	1.3	-2.1	0.6	-0.3	-2.4	-1.4	1.9	-1.8	0.0	-0.4	-0.5	-2.9	-0.6	1.6	-1.5	-2.4	1.5	3.0	-1.1	1.2	-2.0	-2.9	1.0	3.0	-1.0	1.7	-1.9	-2.8	1.1	0.1	2.4	-1.8	1.2	0.3	-1.8
8.2	2.5	0.3	-2.3	-0.6	-2.7	-0.3	0.1	-2.1	-2.8	-2.4	1.1	-1.9	-0.6	-2.6	0.6	2.6	0.7	-2.4	-1.0	-3.1	0.2	2.2	0.3	-2.9	-0.2	-2.0	0.8	3.0	1.1	-2.0	-1.0	2.9	-1.3	1.8	0.0	-3.1
7.6	-1.6	1.2	1.0	-0.8	1.6	-0.4	-0.4	0.9	1.0	-1.0	0.8	-1.8	1.5	-2.7	-2.0	2.6	-1.8	2.5	0.9	3.1	-2.6	1.9	-2.5	1.9	1.6	-2.6	-0.8	2.6	-1.7	2.6	-0.4	1.7	1.9	0.4	2.4	0.6
7.1	2.6	-0.3	2.5	-2.7	-2.0	-2.1	0.7	-2.7	1.0	1.4	2.5	2.3	1.4	-1.5	1.2	2.6	-2.7	-2.7	2.0	-1.1	1.8	-2.7	-2.1	-2.2	-0.4	3.0	-0.6	0.9	1.6	1.7	2.2	-0.3	2.2	-2.1	-1.5	-1.9
6.6	1.6	0.7	-1.1	2.4	-1.6	2.3	0.1	0.3	-1.5	1.7	3.1	0.7	-0.5	-1.9	-3.0	0.1	1.7	0.0	-1.9	0.1	1.3	-1.2	0.5	-1.7	-1.9	2.7	2.7	-0.9	0.8	-1.4	2.0	0.2	-0.5	3.1	-1.5	2.4
6.2	2.2	2.2	0.7	-0.5	-1.1	2.7	0.5	2.5	-0.9	-2.0	-1.4	2.8	2.6	-1.6	0.6	-0.1	0.4	2.9	2.4	0.4	0.4	-0.9	-0.1	2.2	-0.3	1.9	-2.1	-2.8	-2.2	0.1	-2.7	-0.7	1.3	1.1	1.7	-2.5
5.9	0.1	-1.3	2.1	-1.8	-1.5	1.5	-0.8	-0.4	1.2	2.5	2.6	-1.4	0.2	-1.4	2.1	-1.4	-1.4	1.3	-0.5	-2.1	1.5	-2.2	-2.1	0.5	2.6	1.3	-1.6	1.0	1.0	-2.5	0.5	-1.0	2.4	-1.1	-1.1	1.6
5.6	1.3	-1.8	-1.1	1.3	-2.6	-0.3	-1.6	1.8	-2.5	-0.4	0.8	-2.1	2.0	-0.9	0.2	2.8	-2.3	0.5	1.2	-1.6	-0.6	1.9	-3.1	-0.4	-2.6	1.0	2.1	-1.9	-0.6	2.3	2.0	-0.8	-0.1	2.7	-2.4	0.5

Table A15: 2017 Actinomycete and weather condition covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Actinomycetes

	Mean Air Temp.						Air Temp. Ran.						Humidity						ET						GWT Depth					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	0.0	3.1	3.1	0.0	3.1	3.1	3.1	3.1	3.1	3.1	3.1	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	3.1	3.1	3.1	3.1	0.0	0.0	0.0	0.0	0.0	0.0
106.0	-0.7	-0.7	-2.2	-2.0	-1.4	-2.8	-1.8	-1.8	3.0	-3.1	-2.5	2.4	0.4	0.3	-1.2	-0.9	-0.4	-1.8	-1.3	-1.3	-2.9	-2.6	-2.1	2.8	0.6	0.5	-1.0	-0.7	-0.2	-1.5
53.0	-0.9	0.3	-2.7	2.6	2.7	-2.6	-1.4	-0.2	3.1	2.2	2.2	-3.1	1.1	2.3	-0.7	-1.7	-1.6	-0.6	-1.3	0.0	-3.1	2.3	2.3	-2.9	-0.7	0.5	-2.5	2.8	2.9	-2.4
35.3	-0.5	0.2	1.7	1.4	1.2	1.8	-2.4	-1.6	-0.2	-0.5	-0.6	0.0	0.7	1.5	2.9	2.6	2.5	3.1	-1.7	-0.9	0.5	0.2	0.1	0.7	-1.3	-0.5	0.9	0.6	0.5	1.1
26.5	-0.8	-0.3	-0.5	-0.4	-1.6	-1.7	1.4	2.0	1.7	1.9	0.7	0.5	-1.1	-0.6	-0.8	-0.7	-1.9	-2.0	-0.1	0.4	0.2	0.3	-0.9	-1.0	-1.7	-1.1	-1.3	-1.2	-2.4	-2.6
21.2	0.4	0.8	0.3	-0.6	-1.3	3.1	2.3	2.7	2.2	1.3	0.6	-1.3	-1.2	-0.9	-1.4	-2.3	-2.9	1.5	0.9	1.3	0.8	-0.2	-0.8	-2.7	-2.2	-1.9	-2.4	3.0	2.4	0.5
17.7	0.9	1.7	-0.7	-1.6	-1.5	2.1	-1.1	-0.3	-2.7	2.7	2.7	0.1	0.9	1.8	-0.6	-1.6	-1.5	2.2	-0.3	0.5	-1.9	-2.8	-2.7	0.9	2.8	-2.6	1.3	0.3	0.4	-2.2
15.1	0.5	1.4	2.0	2.7	2.1	1.2	2.6	-2.7	-2.1	-1.4	-2.0	-2.9	-0.6	0.3	0.9	1.6	1.0	0.1	1.9	2.9	-2.8	-2.1	-2.7	2.6	2.1	3.0	-2.7	-2.0	-2.6	2.8
13.3	1.9	-2.8	-0.2	3.1	1.7	1.3	1.0	2.5	-1.1	2.1	0.8	0.4	-2.9	-1.4	1.3	-1.7	-3.1	2.8	1.1	2.6	-1.0	2.2	0.8	0.5	0.6	2.1	-1.5	1.8	0.4	0.0
11.8	0.7	3.1	1.4	0.7	0.2	-1.7	2.1	-1.7	2.8	2.1	1.6	-0.2	-0.8	1.7	0.0	-0.7	-1.2	-3.1	1.9	-2.0	2.6	1.9	1.4	-0.5	-0.8	1.7	0.0	-0.7	-1.2	-3.1
10.6	-0.5	1.1	2.3	-2.5	2.4	-1.9	-1.9	-0.2	1.0	2.4	1.1	3.1	1.1	2.8	-2.3	-0.9	-2.2	-0.2	-1.6	0.0	1.2	2.7	1.4	-3.0	-0.8	0.8	2.0	-2.8	2.2	-2.1
9.6	-2.2	0.9	-0.8	1.1	0.2	2.6	2.3	-0.9	-2.6	-0.7	-1.6	0.8	-0.6	2.5	0.8	2.7	1.9	-2.0	2.6	-0.6	-2.3	-0.4	-1.3	1.1	-3.1	0.0	-1.7	0.2	-0.6	1.8
8.8	2.9	-1.2	1.2	-2.0	-2.9	0.9	2.5	-1.6	0.8	-2.5	2.9	0.5	-0.3	1.9	-2.0	1.0	0.1	-2.3	-2.8	-0.7	1.7	-1.5	-2.4	1.5	-2.6	-0.4	2.0	-1.3	-2.2	1.7
8.2	-0.8	-2.7	0.4	2.4	0.5	-2.6	-0.2	-2.1	1.0	3.0	1.2	-2.0	-3.0	1.4	-1.8	0.2	-1.7	1.5	-1.1	-2.9	0.1	2.1	0.3	-2.8	0.6	-1.3	1.8	-2.5	2.0	-1.2
7.6	0.8	2.9	-2.8	1.8	-2.5	1.7	0.5	2.6	-3.1	1.5	-2.9	1.4	-2.5	-0.4	0.2	-1.5	0.4	-1.6	0.6	2.7	-3.0	1.6	-2.7	1.5	2.2	-2.0	-1.4	-3.0	-1.1	3.1
7.1	-2.3	0.9	-2.6	-1.1	-0.4	-0.2	-1.5	1.7	-1.8	-0.3	0.5	0.6	0.4	-2.7	0.1	1.6	2.4	2.5	-2.3	1.0	-2.5	-1.1	-0.3	-0.1	0.6	-2.5	0.3	1.8	2.6	2.7
6.6	-1.5	3.1	2.3	-0.5	1.2	-0.9	2.7	1.1	0.2	-2.6	-0.8	-3.0	-1.5	3.1	2.3	-0.5	1.2	-0.9	1.7	0.0	-0.8	2.7	-1.9	2.3	-0.9	-2.6	2.9	0.1	1.8	-0.3
6.2	1.7	-2.6	-0.3	-0.9	-0.3	2.0	-0.1	1.9	-2.1	-2.8	-2.1	0.2	3.0	-1.2	1.0	0.4	1.0	-3.0	0.0	2.1	-1.9	-2.6	-1.9	0.4	0.9	2.9	-1.1	-1.8	-1.1	1.2
5.9	-0.3	-1.8	1.8	-1.9	-1.9	0.8	-3.0	1.8	-0.9	1.6	1.7	-1.9	-1.0	-2.4	1.1	-2.6	-2.6	0.1	1.1	-0.4	-3.1	-0.6	-0.5	2.2	-2.8	2.0	-0.7	1.8	1.9	-1.7
5.6	1.4	-1.4	-0.4	2.1	-2.9	-0.1	0.3	-2.6	-1.5	1.0	2.3	-1.2	-1.0	2.5	-2.8	-0.2	1.0	-2.5	1.4	-1.5	-0.5	2.1	-2.9	-0.2	-1.6	1.8	2.8	-0.9	0.3	3.1

Table A16: 2017 Bacteria and chemical covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Bacteria

	NO3-N						P						SO4-S					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	3.1	3.1	3.1	3.1
106.0	-0.6	0.8	0.4	0.4	0.3	-0.5	-0.7	0.9	-1.6	0.0	-0.3	-0.8	1.8	1.3	-3.1	-2.9	-2.5	3.1
53.0	-0.2	0.7	0.6	-0.7	-0.1	1.3	-3.0	-0.6	-3.1	-1.4	3.0	-2.1	0.6	1.1	1.1	0.5	1.9	-2.0
35.3	-0.1	-2.2	-1.1	-0.9	0.9	-0.9	-1.9	-1.8	-0.1	-0.2	1.2	1.6	-2.4	-0.8	1.8	0.1	0.6	2.5
26.5	-0.2	2.6	2.6	-2.6	1.5	1.6	0.4	0.8	2.3	-0.6	1.1	-1.1	-1.2	0.2	-2.5	-3.1	1.1	0.6
21.2	-3.1	-3.0	1.4	0.7	-0.9	-2.0	2.6	-2.6	-0.6	-1.2	-0.9	2.6	1.6	2.5	2.1	0.9	-0.6	3.0
17.7	1.4	-0.2	1.8	2.0	-1.3	-2.3	-0.6	-1.7	-1.5	-1.1	-1.4	-0.1	0.6	-1.9	-0.9	0.1	-1.7	2.4
15.1	1.0	-1.4	0.4	1.3	-0.5	-1.4	1.3	-0.1	2.1	-3.0	-1.4	2.3	1.3	-1.1	1.8	1.0	0.8	0.0
13.3	2.6	-0.9	-2.4	1.2	-2.0	-3.0	-3.0	-1.3	-2.1	-1.4	-1.9	-1.9	-0.6	0.3	-1.7	2.6	-2.8	1.2
11.8	-0.7	-0.4	0.0	2.1	-1.7	0.9	0.0	2.9	-0.9	-2.5	1.3	1.8	-2.9	2.6	0.5	1.5	-0.4	-3.1
10.6	-0.5	3.0	0.0	2.6	0.7	1.9	1.4	-3.0	0.0	-2.4	1.0	-1.0	2.0	-2.4	0.5	-2.7	0.8	-2.6
9.6	2.7	1.4	0.4	-2.9	1.3	2.4	-2.0	-1.2	0.8	-1.7	-0.9	0.6	0.0	-0.1	2.0	2.2	-1.2	-1.6
8.8	-0.2	2.9	-1.6	-1.9	0.2	-1.0	0.3	1.6	-1.7	3.0	1.6	-1.7	-1.3	1.8	3.1	-2.9	2.8	0.3
8.2	0.5	0.5	1.1	-0.1	0.1	1.1	-0.8	2.0	-2.0	-1.4	-2.2	-0.9	-3.0	-2.8	-0.3	1.2	1.9	2.5
7.6	-0.4	0.6	-2.3	-0.8	-0.1	0.4	-0.6	0.7	1.0	3.0	2.7	-0.6	2.3	-1.8	2.4	1.1	0.0	-2.2
7.1	-2.6	2.5	0.4	0.5	1.9	2.3	-0.4	-1.5	1.1	0.6	-0.2	-2.7	0.7	-0.4	0.7	0.7	2.1	2.8
6.6	2.5	-0.2	-3.1	0.1	-1.6	1.7	-0.4	-1.1	-0.7	3.0	1.9	1.4	-0.5	2.2	-2.6	-2.4	-1.3	-3.0
6.2	0.5	-0.5	2.7	0.6	3.0	-1.0	-0.1	-1.4	-0.1	1.3	-2.5	-2.5	-2.5	-2.9	-0.3	0.0	2.7	-2.9
5.9	2.7	2.4	-0.9	1.3	1.0	-1.2	0.1	-1.1	1.5	2.9	2.5	1.9	2.1	-1.2	3.0	1.1	-0.3	-1.3
5.6	-2.0	2.4	1.5	-1.8	0.1	-2.2	-1.5	1.1	-1.3	1.9	0.9	2.3	0.8	0.6	-2.7	-2.4	-1.7	0.2

	Mn						NH4-N						TN					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	0.0	3.1	3.1	0.0	0.0
106.0	-1.4	0.8	-0.1	0.1	0.0	-0.5	-1.8	1.2	-0.2	-0.2	0.4	-1.0	-2.9	-0.5	-2.3	-2.4	-0.8	-1.5
53.0	-3.0	-1.5	-1.8	-2.9	-2.8	-1.0	-3.0	-2.2	-2.2	-3.1	-2.7	-1.1	-0.1	0.5	2.3	-0.1	0.9	-1.3
35.3	1.2	-0.8	0.4	0.3	0.4	0.8	-1.8	1.3	2.2	2.9	2.6	2.3	1.7	-1.9	2.3	-0.3	1.0	1.2
26.5	-0.7	-0.7	1.7	0.7	-1.6	-0.2	-0.3	2.6	1.5	2.8	1.6	1.0	2.2	-1.7	-0.2	0.1	-2.8	-0.9
21.2	0.6	-2.2	-1.7	3.1	-1.6	1.1	-1.4	3.0	2.4	-0.6	2.6	-2.3	-1.2	3.0	-0.5	-1.4	-3.1	1.6
17.7	-0.9	-2.1	0.9	-0.6	-2.2	-1.7	0.1	-2.2	1.5	0.0	-0.9	2.7	-2.5	1.1	0.0	-2.3	2.0	-1.7
15.1	1.1	-2.8	-1.5	0.0	-1.7	2.7	0.7	-2.9	-2.3	-0.4	-2.0	-2.8	-1.2	2.7	1.8	-2.6	-1.4	-0.6
13.3	-1.1	-0.1	-1.8	-3.0	0.2	-2.8	0.2	-2.2	0.9	-2.0	-2.2	-2.5	0.8	-0.5	-2.3	-3.1	-0.7	1.0
11.8	0.8	-3.1	2.1	-2.3	1.1	-1.7	0.7	2.6	2.3	-2.8	-0.8	-2.8	0.6	-2.7	-1.8	0.7	1.2	-2.6
10.6	-0.8	2.6	2.7	-0.6	2.7	-1.6	-0.6	-2.1	-2.8	0.1	-0.9	1.3	-0.8	2.6	-0.4	0.8	2.1	0.2
9.6	1.9	-0.8	-1.8	2.5	-1.0	1.5	2.5	1.2	-0.1	-2.6	1.0	2.4	1.5	-1.2	0.0	-1.2	-1.6	0.5
8.8	1.1	1.6	3.0	-1.8	0.9	-1.8	-1.5	2.3	-1.9	3.0	1.7	-1.2	1.6	0.9	-0.2	-2.2	0.5	0.3
8.2	0.3	-0.6	2.9	-0.9	3.1	0.4	0.7	0.1	2.8	-1.9	-2.7	0.1	-0.3	-0.7	2.9	-3.0	-2.9	2.6
7.6	1.1	0.0	1.8	1.1	-2.4	0.4	1.5	0.2	1.7	0.1	2.1	-0.6	2.5	-0.3	0.8	-3.1	-2.6	-0.2
7.1	0.8	-0.9	1.2	-2.5	-1.6	-0.7	1.0	-1.3	-2.5	-2.6	2.7	-2.4	1.2	-3.0	-1.8	0.0	-0.4	-0.9
6.6	-0.4	-1.5	3.0	-0.8	2.1	-0.1	1.8	-0.7	-1.3	-0.6	-2.4	1.2	-0.8	-1.0	-1.3	2.1	2.1	0.6
6.2	-1.1	0.6	-1.8	-0.9	-2.9	-0.7	0.4	0.4	-2.0	1.3	1.9	-1.7	2.1	-0.2	2.4	-3.0	-3.1	2.9
5.9	-2.5	-2.0	1.6	2.7	-1.8	0.1	2.6	2.2	1.3	2.6	2.7	0.3	-1.9	-1.4	2.2	2.5	-1.5	-1.1
5.6	-1.8	1.7	-2.1	1.3	1.2	-1.7	-2.6	3.0	-2.1	1.9	-1.7	0.7	-1.7	0.4	-0.2	2.5	1.3	2.4

	TC						pH						EC					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	3.1	0.0	3.1	0.0	0.0	3.1	3.1	0.0	3.1	3.1	3.1	3.1	0.0	0.0	3.1	0.0	3.1	3.1
106.0	2.9	-0.8	-2.0	-1.5	-1.4	-1.8	2.9	-0.8	-2.3	-2.0	-1.9	-2.6	1.5	0.3	-3.0	0.2	-3.0	2.9
53.0	-0.7	0.3	-2.1	3.1	1.2	-1.4	-2.0	2.1	0.6	-2.3	-2.2	0.0	0.4	1.5	1.4	0.0	1.4	1.8
35.3	-2.7	-1.8	0.7	-0.3	0.7	1.8	-0.9	2.7	-2.6	-2.9	-1.5	-1.6	-1.1	-2.6	-2.2	2.3	-0.7	3.0
26.5	1.8	1.9	1.7	-0.9	3.0	-0.2	-1.9	2.6	-3.0	2.4	0.4	2.7	-1.3	1.3	1.4	0.4	0.7	0.7
21.2	-1.4	-2.9	-0.5	-0.6	-2.8	1.4	2.9	0.8	2.1	2.6	-0.3	-2.3	2.8	1.9	1.1	1.5	0.1	-2.6
17.7	-0.4	0.2	-1.7	-2.0	2.3	-1.0	-2.8	1.9	-1.7	-1.9	-1.5	1.8	1.7	-0.6	-2.1	-0.3	-1.3	1.2
15.1	0.0	2.3	1.3	-2.7	-1.5	1.8	1.9	-1.4	0.0	1.7	0.6	-1.2	1.8	-1.3	0.4	2.0	0.3	-0.2
13.3	0.7	-1.6	-1.5	1.6	-1.0	-1.1	0.4	2.7	1.2	-2.8	2.5	1.2	-0.8	-3.1	0.8	0.5	2.8	1.8
11.8	1.0	-2.8	-3.0	-1.1	1.3	0.7	2.6	-2.6	-2.5	3.0	-0.8	-1.6	-1.7	2.9	2.7	2.2	-0.5	-2.3
10.6	2.9	1.2	1.8	-0.5	2.0	1.6	-2.0	0.3	-1.4	-1.5	-0.8	2.9	-1.7	2.3	-2.6	-0.8	-0.9	-2.0
9.6	0.4	-1.7	-0.3	-2.5	-1.6	0.8	3.1	1.8	0.7	2.8	1.5	-2.4	2.3	0.8	0.5	-2.8	1.3	2.8
8.8	0.4	2.4	0.0	-1.3	0.4	-0.7	0.7	-0.1	3.0	2.6	-2.1	2.7	-0.7	0.5	2.8	-1.7	-2.1	0.9
8.2	0.5	-1.3	-2.5	-1.3	3.0	2.1	0.0	0.8	3.0	1.2	0.0	-1.2	-1.8	-1.2	2.8	1.3	-0.8	0.2
7.6	1.1	3.1	1.0	2.3	2.4	-0.6	2.0	-2.7	-1.7	0.8	-0.2	3.1	-1.4	-2.7	-1.4	-1.7	-0.3	2.0
7.1	0.5	-2.7	-1.2	-0.3	-0.6	-2.6	-2.6	0.5	0.4	2.8	1.8	2.4	-2.3	1.8	-2.3	-2.7	1.7	2.9
6.6	0.0	-1.1	-1.2	-1.2	2.0	1.3	1.9	2.3	1.9	-2.9	-0.9	-2.1	3.1	2.4	1.7	2.0	-0.4	0.2
6.2	-0.2	0.3	1.4	-0.6	-2.4	-2.8	2.1	0.4	2.8	-1.5	1.5	-0.3	-0.2	-0.5	2.5	-0.8	1.3	-1.5
5.9	-0.3	-1.5	0.9	2.6	-1.6	-1.1	2.2	0.9	-2.4	0.4	1.1	2.6	0.9	-0.5	-2.7	1.2	1.3	-2.5
5.6	0.3	0.6	0.1	2.0	1.2	3.1	-2.5	-2.5	-1.6	-2.1	-2.2	-0.1	-1.0	-1.1	-0.9	-2.8	-2.2	1.0

Table A17: 2017 Bacteria and physical conditions covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Bacteria

	VWC						Water Grad.						Temp						Temp. Grad.						Bottom Flux						Water Storage					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	3.1	3.1	3.1	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0
106.0	2.5	-0.9	-1.0	-1.6	-0.9	-1.1	-1.5	2.4	-0.9	3.0	2.1	1.7	-0.9	1.6	0.5	0.6	0.8	0.1	-1.6	0.9	0.0	0.2	0.3	-0.6	-1.7	0.8	-0.1	-0.2	0.0	-0.4	-1.0	1.6	0.6	1.0	1.1	0.0
53.0	2.5	-2.5	-2.2	2.4	3.1	-1.6	-2.7	-2.7	-0.4	1.9	2.2	0.9	-0.8	0.4	0.7	-0.7	-0.2	1.2	-1.4	-0.1	0.1	-1.3	-0.8	0.6	-1.5	-0.1	0.0	-1.3	-0.8	0.7	2.1	-2.9	-2.9	2.1	2.6	-2.1
35.3	1.2	-1.2	0.5	0.1	-0.1	0.1	-1.7	1.5	2.8	1.8	-2.7	-2.6	-0.7	-2.9	-1.4	-1.6	-1.7	-1.2	-1.1	-3.1	-1.7	-2.0	-2.1	-1.7	-2.9	1.2	2.5	2.3	2.2	2.8	0.7	-1.5	-0.3	-0.3	-0.4	0.0
26.5	0.3	0.3	-2.3	-2.6	1.3	-2.3	-0.4	-0.4	-0.5	0.0	-0.6	-2.6	0.1	3.0	2.8	-3.1	2.0	1.8	-0.4	2.9	2.4	2.7	1.4	1.3	-2.3	0.7	-0.2	0.9	-0.3	-0.8	0.5	-2.9	2.6	-2.6	2.4	2.0
21.2	-1.2	-2.0	2.9	1.7	-2.7	-0.6	-2.6	-2.1	0.1	0.2	2.2	-2.4	0.0	-1.6	-2.7	2.5	-2.0	0.1	-0.3	-1.7	-2.9	2.2	-2.4	-0.2	1.9	0.5	-0.8	-1.7	0.1	2.1	-1.1	-2.5	2.5	1.6	-2.9	-0.9
17.7	-1.5	2.1	0.3	-0.7	-1.5	-2.1	0.1	-1.4	1.1	0.6	0.1	-0.8	1.1	-0.8	2.7	1.8	1.5	-0.2	0.8	-1.2	2.3	1.4	1.0	-0.6	1.0	-0.9	1.9	1.5	1.2	-0.2	-1.2	2.9	-0.1	-1.8	-1.6	-2.4
15.1	-2.5	0.1	1.8	2.0	1.6	0.4	-2.6	-0.1	0.9	2.0	-2.4	-2.0	1.4	-2.1	-1.0	-0.4	-0.7	-1.5	1.1	-2.3	-1.3	-0.6	-1.1	-1.9	1.8	-1.6	-0.8	0.0	-0.4	-1.0	3.1	-0.5	0.7	1.5	1.1	0.1
13.3	-2.7	0.5	-2.4	1.1	0.4	-0.3	-1.3	2.0	-2.8	0.3	-1.8	3.0	2.2	-0.9	2.6	-0.3	-1.1	-1.9	2.0	-1.2	2.4	-0.6	-1.4	-2.1	0.0	-3.0	0.3	-2.6	3.0	2.3	2.9	-0.1	-2.5	0.4	-0.3	-1.2
11.8	1.0	-1.1	-1.0	-2.9	2.6	0.2	-0.6	-0.3	0.6	0.6	-0.3	3.0	2.2	-0.1	-0.8	-1.9	-2.5	1.3	1.8	-0.5	-1.2	-2.3	-3.0	0.8	-1.6	2.3	0.9	0.7	0.0	-2.6	0.9	-1.4	-2.4	-3.1	2.4	0.0
10.6	1.9	-0.4	0.6	2.2	1.6	-2.9	1.4	-0.4	0.4	1.3	0.4	1.3	0.2	-2.5	-1.2	0.6	-0.3	1.9	-0.7	2.7	-2.0	-0.3	-1.1	1.0	-1.3	2.4	-2.7	-1.0	-1.9	0.3	1.4	-1.2	0.0	1.8	0.9	3.0
9.6	-0.9	-2.8	-3.1	0.0	-2.7	-0.9	-3.0	1.7	-2.9	-2.9	1.4	1.7	0.2	-1.6	-2.8	0.9	-1.4	0.3	-1.1	-3.0	2.0	-0.6	-2.9	-1.3	-3.1	1.8	-0.7	-2.4	1.6	-2.9	-0.4	-1.8	2.0	-0.1	-2.2	-0.1
8.8	-1.0	-1.9	0.3	-2.9	-3.1	0.8	-1.5	-1.3	0.6	2.7	3.1	2.7	-2.9	2.4	-2.4	1.2	1.1	-1.6	2.9	1.9	-2.8	0.8	0.6	-2.1	3.0	2.0	-2.3	0.8	0.7	-2.0	0.0	-0.9	0.5	-2.4	-2.4	1.4
8.2	-2.3	-3.1	0.8	1.4	0.2	2.9	1.5	0.8	0.3	-0.4	-2.3	1.2	0.8	0.3	-2.6	-1.7	-2.6	0.7	0.4	-0.1	-3.0	-2.0	-3.1	0.3	1.2	0.9	-2.3	-1.3	-2.3	1.2	0.4	-0.4	1.8	-2.5	2.9	0.0
7.6	-1.4	-2.4	-2.0	-1.0	-1.4	2.6	-0.3	-2.7	-2.0	-1.2	-2.2	1.2	1.7	0.0	1.2	2.4	1.5	-0.8	1.0	-0.5	0.6	1.7	0.8	-1.4	1.8	0.1	2.4	2.4	1.6	-0.6	-0.3	-1.9	-1.1	0.2	-0.6	-2.7
7.1	-2.9	1.9	-2.9	-0.3	0.6	1.3	1.5	-0.5	1.9	-2.5	-1.2	-0.7	2.2	0.7	2.0	-1.3	-0.1	0.7	2.8	1.0	2.7	-0.4	0.5	1.1	0.3	-1.1	0.3	-3.1	-2.1	-1.2	3.0	1.9	3.1	0.2	1.1	1.4
6.6	-2.8	-2.6	2.2	0.0	1.7	-1.1	1.9	-3.0	1.8	-0.7	0.1	-2.8	1.3	1.0	0.3	-2.3	-1.3	2.9	-0.1	3.1	-1.6	2.6	-2.5	1.1	-0.1	-0.6	-0.2	3.0	-2.2	1.4	-2.5	-3.1	2.9	0.7	1.8	-1.0
6.2	1.4	-1.4	-2.4	2.3	2.2	-0.1	-0.2	-1.1	2.3	0.8	1.9	0.0	1.8	1.1	-2.5	2.7	-2.5	0.0	1.7	3.1	-2.7	1.9	-3.1	-0.6	-1.1	-1.7	1.1	0.0	1.1	-2.8	2.8	2.0	-1.8	-2.4	-1.3	0.9
5.9	1.3	1.0	-0.6	1.4	1.8	-1.6	0.4	1.9	-1.5	-0.6	-0.4	1.8	1.3	0.9	-0.5	1.7	1.9	-1.8	0.7	0.2	-1.1	1.0	1.2	-2.6	-2.5	-2.7	2.0	-2.1	-2.0	0.7	1.7	1.4	-0.3	2.0	2.2	-1.5
5.6	1.0	0.7	1.8	-1.7	0.6	3.0	-1.9	-2.1	0.4	2.8	-2.3	1.2	1.7	1.6	3.1	-0.3	0.9	-2.5	0.9	0.8	2.3	-1.1	0.0	2.9	-2.9	-2.9	-1.3	1.3	2.6	-0.7	1.7	1.6	2.8	-0.4	0.8	-2.5

Table A18: 2017 Bacteria and weather condition covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Bacteria

	Mean Air Temp.						Air Temp. Ran.						Humidity						ET						GWT Depth					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 106.0	0.0	3.1	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	3.1	3.1	3.1	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	3.1	3.1	3.1	3.1
106.0	-0.7	2.0	0.8	0.9	1.2	0.4	-1.8	0.9	-0.3	-0.2	0.1	-0.7	0.3	3.0	1.8	1.9	2.2	1.5	-1.3	1.3	0.1	0.2	0.5	-0.2	0.6	-3.1	2.0	2.1	2.4	1.7
53.0	-0.8	0.4	0.6	-0.7	-0.2	1.3	-1.3	0.0	0.2	-1.2	-0.7	0.8	1.2	2.4	2.6	1.3	1.8	-3.0	-1.2	0.1	0.3	-1.0	-0.5	0.9	-0.6	0.6	0.8	-0.5	0.0	1.5
35.3	-0.7	-2.9	-1.5	-1.9	-2.0	-1.3	-2.6	1.5	2.9	2.6	2.5	-3.1	0.5	-1.7	-0.3	-0.6	-0.8	-0.1	-1.9	2.2	-2.7	-3.0	-3.1	-2.4	-1.5	2.6	-2.3	-2.6	-2.8	-2.1
26.5	-0.4	2.5	2.3	2.7	1.5	1.3	1.8	-1.5	-1.7	-1.3	-2.6	-2.7	-0.7	2.2	2.0	2.4	1.1	1.0	0.3	-3.1	3.0	-2.8	2.1	2.0	-1.2	1.7	1.5	1.9	0.6	0.5
21.2	-0.3	-1.9	-2.9	2.3	-2.2	-0.1	1.6	0.0	-1.0	-2.1	-0.3	1.8	-2.0	2.7	1.7	0.6	2.4	-1.8	0.1	-1.4	-2.5	2.8	-1.7	0.3	-3.0	1.7	0.7	-0.4	1.4	-2.8
17.7	0.9	-1.0	2.5	1.5	1.2	-0.4	-1.1	-3.1	0.5	-0.5	-0.8	-2.4	0.9	-1.0	2.5	1.5	1.3	-0.4	-0.3	-2.2	1.3	0.3	0.0	-1.6	2.8	0.9	-1.9	-2.9	-3.1	1.5
15.1	1.5	-2.2	-0.9	-0.3	-0.8	-1.5	-2.6	0.0	1.3	1.8	1.4	0.7	0.4	3.0	-2.0	-1.4	-1.8	-2.5	2.9	-0.7	0.6	1.1	0.7	0.0	3.1	-0.6	0.7	1.3	0.8	0.1
13.3	2.4	-0.7	2.9	-0.2	-1.0	-1.6	1.5	-1.7	2.0	-1.1	-1.9	-2.6	-2.4	0.7	-1.9	1.3	0.5	-0.2	1.6	-1.6	2.1	-1.0	-1.8	-2.5	1.1	-2.0	1.6	-1.5	-2.3	-2.9
11.8	1.8	-0.6	-1.2	-2.3	-3.0	0.9	-3.1	0.9	0.3	-0.8	-1.6	2.3	0.3	-2.0	-2.6	2.6	1.9	-0.5	3.0	0.6	0.0	-1.1	-1.8	2.1	0.4	-2.0	-2.6	2.6	1.9	-0.5
10.6	-0.3	-3.0	-1.7	0.0	-0.9	1.3	-1.6	1.9	-3.0	-1.3	-2.2	0.0	1.4	-1.3	0.0	1.7	0.8	3.0	-1.4	2.2	-2.7	-1.1	-2.0	0.2	-0.6	3.0	-1.9	-0.2	-1.1	1.1
9.6	-1.1	-2.5	2.3	-0.3	-2.5	-0.9	-2.9	1.9	0.5	-2.2	1.9	-2.7	0.6	-0.9	-2.3	1.3	-0.9	0.8	-2.6	2.2	0.8	-1.9	2.2	-2.4	-1.9	2.9	1.5	-1.2	2.9	-1.7
8.8	2.9	1.8	-2.7	0.7	0.6	-2.2	2.4	1.4	3.1	0.3	0.1	-2.6	-0.3	-1.4	0.3	-2.5	-2.6	0.9	-2.9	2.4	-2.2	1.2	1.1	-1.6	-2.6	2.6	-2.0	1.5	1.3	-1.4
8.2	0.6	0.2	-2.8	-1.9	-2.8	0.5	1.3	0.9	-2.1	-1.3	-2.2	1.2	-1.6	-2.0	1.3	2.2	1.3	-1.7	0.4	0.0	-3.0	-2.1	-3.1	0.3	2.1	1.7	-1.3	-0.5	-1.4	2.0
7.6	1.0	-0.7	0.5	1.6	0.8	-1.6	0.6	-1.0	0.1	1.3	0.4	-1.9	-2.4	2.3	-2.9	-1.7	-2.6	1.4	0.7	-0.9	0.2	1.4	0.5	-1.8	2.3	0.7	1.8	3.0	2.1	-0.2
7.1	-1.6	3.1	-1.7	1.2	2.2	3.1	-0.7	-2.4	-0.9	2.0	3.1	-2.3	1.2	-0.5	1.0	-2.4	-1.3	-0.4	-1.5	-3.1	-1.6	1.3	2.3	-3.1	1.4	-0.3	1.2	-2.2	-1.1	-0.2
6.6	0.3	-0.2	-0.7	-2.9	-1.8	1.9	-1.7	-2.2	-2.7	1.3	2.4	-0.1	0.3	-0.2	-0.7	-2.9	-1.8	1.9	-2.7	3.0	2.5	0.3	1.4	-1.2	1.0	0.4	-0.1	-2.3	-1.2	2.5
6.2	0.9	0.2	2.9	1.9	3.0	-0.8	-0.9	-1.7	1.1	0.0	1.2	-2.6	2.2	1.5	-2.1	-3.1	-1.9	0.5	-0.7	-1.5	1.3	0.2	1.4	-2.5	0.1	-0.7	2.1	1.0	2.2	-1.6
5.9	0.9	0.6	-0.8	1.2	1.4	-2.3	-1.8	-2.1	2.7	-1.5	-1.3	1.3	0.2	-0.1	-1.5	0.5	0.7	-2.9	2.3	1.9	0.5	2.6	2.8	-0.9	-1.6	-1.9	2.9	-1.3	-1.1	1.5
5.6	1.1	1.0	2.5	-0.9	0.3	-3.1	0.0	-0.1	1.4	-2.0	-0.8	2.1	-1.3	-1.4	0.1	3.0	-2.1	0.8	1.1	0.9	2.5	-0.9	0.2	-3.1	-1.9	-2.1	-0.5	2.3	-2.8	0.1

Table A19: 2018 TMA and chemical covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Microbial Abundance

	NO3-N						P						SO4-S					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	0.0	0.0	3.1	3.1	0.0	0.0	3.1	0.0	0.0	0.0	0.0	3.1	0.0	3.1	3.1	0.0	0.0	3.1
85.0	-1.2	0.9	2.0	2.0	0.8	-0.7	2.5	1.0	-0.3	1.4	0.3	-2.1	0.7	-1.9	-2.0	-0.5	-0.8	-2.3
42.5	1.6	-2.5	0.9	-2.0	2.9	1.9	-2.6	2.1	2.2	-0.9	-3.1	-2.9	2.6	-1.8	-0.4	2.7	-2.7	1.8
28.3	0.5	1.5	-0.7	2.7	1.5	0.7	-1.2	-0.6	2.0	1.4	1.7	-0.1	1.4	-0.5	-0.6	2.3	2.1	1.1
21.3	1.8	2.2	-2.9	2.3	0.4	-1.9	-2.1	-1.2	3.1	-1.6	-2.9	-1.8	-1.7	2.4	3.1	1.4	-0.4	-1.7
17.0	-1.8	-0.2	2.7	2.9	-0.6	-2.1	-3.1	2.2	3.1	-0.1	0.3	-1.7	2.4	2.4	2.7	0.8	-0.6	-1.0
14.2	-1.8	-0.1	1.2	-0.9	-0.8	1.1	-1.0	1.2	-0.4	1.0	-0.4	2.6	-0.2	-1.5	0.4	2.0	-1.5	-2.3
12.1	-2.0	2.0	2.9	0.5	-0.9	-2.4	-1.8	-0.2	2.9	-2.8	-1.3	-2.2	-2.1	-1.0	2.2	-0.7	-1.0	-2.3
10.6	0.4	2.9	-1.9	3.1	-1.4	0.4	0.4	2.2	2.5	1.7	-1.2	-2.9	-2.0	0.7	0.9	0.4	-1.5	-2.4
9.4	-1.4	0.1	0.6	1.1	0.9	1.7	-2.4	-1.7	1.9	-0.5	-1.9	2.3	2.2	1.9	1.4	-2.0	-1.4	-3.1
8.5	-1.1	-0.1	-2.0	-1.9	1.2	-2.8	-0.6	0.2	-0.7	1.4	-0.7	1.4	0.8	-0.9	-0.9	-0.4	0.6	-2.5
7.7	3.1	-2.5	-0.7	0.4	3.1	-1.4	2.1	-1.3	1.5	-2.6	3.1	1.9	-2.7	-0.2	1.9	2.7	2.7	-1.8
7.1	3.1	-1.4	2.3	1.0	0.3	2.9	0.0	-1.4	1.5	-2.4	0.2	2.6	2.2	-2.8	0.4	0.9	0.0	3.0
6.5	0.4	-1.3	0.8	0.4	-0.8	1.7	1.9	-1.1	-0.2	-2.3	-0.4	-2.7	1.2	1.1	0.0	-3.1	0.1	2.3
6.1	1.1	1.5	1.3	-0.5	0.3	1.3	2.0	0.1	2.3	2.2	1.2	2.8	-1.1	0.9	3.0	2.0	0.8	2.7
5.7	0.6	-2.9	-2.6	-0.2	-1.3	-1.2	-0.4	-0.2	-0.2	3.1	-2.7	-2.7	-3.0	-3.1	0.0	1.8	-2.2	1.5

	Mn						NH4-N						TN					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	0.0	3.1	0.0	3.1	0.0	0.0	3.1	0.0	0.0	3.1	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1
85.0	-1.5	1.6	1.2	3.0	1.5	-0.1	2.8	1.1	0.3	2.3	0.3	-1.7	1.6	-0.5	-0.2	0.2	-1.0	-2.5
42.5	-2.1	2.4	-2.5	3.1	-2.7	-2.3	-1.2	-2.9	2.2	2.6	-2.7	-2.8	-1.2	2.5	-2.1	0.3	-0.7	-1.9
28.3	2.4	1.6	1.1	1.9	1.9	2.3	1.1	-0.3	1.6	2.4	1.5	1.7	1.8	1.0	-0.6	0.1	-2.5	2.4
21.3	-2.0	1.2	-0.1	-0.3	-2.2	-1.4	-1.8	-2.0	-2.5	-0.6	-1.0	-1.8	-2.4	-2.3	-2.4	2.5	-0.1	-1.4
17.0	-2.3	-2.9	2.9	-1.2	2.3	2.2	-1.8	1.6	2.1	1.1	0.3	0.4	2.2	2.7	2.6	0.1	-0.1	1.4
14.2	-0.6	-0.3	-1.0	-0.3	-0.7	-0.2	-0.6	0.9	-0.1	-0.8	-0.1	1.2	-1.6	0.1	0.7	1.7	-1.7	-1.8
12.1	1.9	1.5	-2.5	0.1	-2.8	3.0	-2.0	-1.6	1.7	1.3	-0.9	-2.3	-2.4	0.5	0.2	2.9	0.1	2.9
10.6	1.6	2.7	-0.6	2.3	1.4	0.8	-1.3	1.7	2.4	-2.1	-1.5	2.9	-1.5	0.9	-0.3	-1.8	-1.6	-1.1
9.4	0.8	-1.7	0.6	-1.5	2.7	2.1	-1.2	-1.8	1.9	0.6	-1.9	-2.9	2.9	-2.3	2.7	-1.2	-1.3	0.5
8.5	0.3	-2.6	-1.7	-0.6	-1.8	0.1	-0.2	1.2	1.4	-1.1	0.6	-1.1	0.0	1.4	-2.2	1.1	0.6	1.5
7.7	0.1	-1.2	-2.7	0.3	-2.3	-0.9	1.3	-1.4	-0.6	0.5	2.9	-1.3	1.3	-1.2	0.8	2.2	1.9	-2.0
7.1	3.1	1.0	1.4	0.6	2.0	-2.0	-2.7	0.5	0.7	1.0	0.4	-2.7	-3.0	-3.1	0.4	-2.4	1.4	2.8
6.5	-1.0	2.6	-1.8	0.1	-2.6	0.9	0.4	-2.9	0.7	-0.4	-0.1	2.4	-0.4	2.4	0.0	-2.1	-0.2	2.0
6.1	2.0	-0.3	1.5	-0.1	-0.2	1.4	1.7	-0.3	0.1	-1.1	0.7	1.9	1.2	-0.8	2.4	2.8	1.0	3.1
5.7	0.6	0.0	1.2	-0.1	0.6	-1.0	0.4	0.7	-1.3	-0.4	-2.5	0.2	1.2	2.7	2.4	3.1	-2.5	-2.4

	TC						pH						EC					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	0.0	0.0	3.1	0.0	0.0	3.1	3.1	3.1	0.0	3.1	3.1	3.1	0.0	0.0	3.1	3.1	0.0	0.0
85.0	1.4	0.7	-3.1	0.8	-1.4	-2.9	2.1	-1.8	-0.3	-1.6	-1.9	2.8	-1.5	1.0	1.6	2.0	0.8	-0.9
42.5	-2.6	-3.0	1.6	-0.2	1.7	-1.9	-1.5	1.8	-2.8	0.9	-2.0	-2.2	1.6	-2.7	0.9	-2.5	-3.0	2.4
28.3	2.0	-1.3	0.5	-0.5	0.1	0.9	2.7	-0.6	2.3	-1.1	-1.1	2.1	0.8	1.3	-0.3	2.8	1.6	1.2
21.3	2.3	-1.8	-2.3	-2.8	-2.3	1.2	-1.6	-1.4	0.6	2.8	0.1	1.1	1.7	-3.0	-3.0	-0.3	0.9	-2.0
17.0	0.9	2.4	2.2	-1.0	-1.7	2.8	1.7	2.4	-0.7	0.8	-0.6	1.0	-1.5	-0.2	2.4	3.0	0.7	-2.0
14.2	-0.3	2.3	-0.2	1.5	-1.6	1.0	-0.8	-2.3	-2.6	2.3	2.4	-2.6	-1.1	0.2	0.9	-0.7	-0.7	1.0
12.1	1.6	-0.5	0.3	-1.9	-0.2	-2.2	-2.9	-1.4	-0.5	2.7	2.6	-1.7	-2.2	2.1	-3.1	0.4	-0.7	-2.2
10.6	2.0	-3.1	-0.1	1.4	-0.9	-2.4	-2.5	0.0	1.5	-1.3	-0.2	-2.6	-0.8	2.2	-1.9	3.1	-1.3	-0.1
9.4	2.4	-1.8	1.9	-1.3	-2.1	2.9	1.0	-2.1	-0.1	-1.9	-2.3	-3.1	0.5	1.1	1.1	-1.0	1.2	1.6
8.5	-0.1	-1.0	-1.1	1.3	-2.6	2.5	0.2	2.7	1.7	0.0	0.5	0.6	-1.4	0.0	-1.8	-1.2	2.6	-1.9
7.7	2.4	2.6	1.4	-0.6	-0.7	-2.0	-0.1	0.8	2.7	-2.7	-0.2	0.8	-2.8	-2.0	-0.6	0.3	-2.9	-1.1
7.1	3.0	-1.7	1.5	-1.7	-0.4	2.8	0.2	1.6	-0.7	-1.4	2.5	-2.3	2.2	-1.4	2.0	0.5	0.5	-3.1
6.5	1.0	-0.8	-0.3	-0.8	1.1	-2.9	-1.9	2.5	-2.3	-2.3	1.5	-1.9	0.7	-2.4	0.7	0.1	-1.2	1.4
6.1	1.1	2.2	2.0	1.4	1.6	2.5	-1.8	-1.6	-1.7	3.0	0.2	2.3	0.4	1.2	1.5	-0.4	-0.3	0.8
5.7	0.8	-2.7	-1.0	2.7	2.9	2.4	-2.6	1.9	1.6	3.0	-2.6	1.1	-2.5	-2.7	-2.6	-0.2	-0.3	-0.3

Table A20: 2018 TMA and physical conditions covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Microbial Abundance

	VWC						Water Grad.						Temp						Temp. Grad.						Bottom Flux						Water Storage					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	3.1	0.0	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	0.0	3.1	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	0.0	3.1	3.1	3.1	3.1	3.1	3.1	0.0
85.0	2.6	0.9	0.1	0.3	0.3	-1.4	2.6	2.4	0.9	-2.1	-3.0	-2.9	-1.7	-3.1	1.9	-2.3	2.7	0.7	2.2	0.9	0.3	2.3	0.6	-1.5	1.3	-0.2	-1.3	-2.5	-0.7	-2.8	-2.0	2.8	1.8	-2.7	2.4	0.2
42.5	-2.4	1.2	-2.4	-3.1	1.2	1.8	-1.3	2.8	2.1	1.9	-0.4	-2.7	-0.3	-2.4	-1.7	2.8	-0.8	-0.6	-2.1	2.0	2.9	2.3	-2.8	-2.7	-2.3	1.8	2.6	0.0	-3.0	-2.7	0.5	-1.7	-0.9	-3.1	-0.2	0.0
28.3	2.7	2.3	1.3	1.3	2.1	2.4	1.8	0.1	0.2	-1.1	0.9	1.3	-1.3	-2.0	-2.6	2.3	-2.1	-1.5	3.0	2.2	1.5	0.0	2.2	2.7	-0.2	-1.0	-1.4	-2.5	-1.0	-0.6	2.5	1.7	1.3	1.0	1.7	2.2
21.3	-0.5	1.2	1.7	-0.7	-1.6	-1.3	-0.7	-1.1	-0.5	-0.9	-2.2	-2.2	1.5	2.7	3.0	0.6	0.0	0.9	1.6	1.8	3.1	-0.4	-0.6	0.5	-2.2	-0.8	-0.8	2.6	2.8	-2.4	-0.6	0.5	1.7	-0.6	-1.0	-1.5
17.0	2.3	2.7	-0.1	1.3	1.8	0.2	1.8	-0.1	3.0	-1.8	3.0	-2.3	-1.4	-1.2	2.5	1.3	-2.2	2.9	1.3	1.6	-1.7	1.3	0.8	-0.9	-1.2	-1.0	2.7	-3.0	-1.9	3.0	2.4	2.6	0.0	-0.5	1.7	0.3
14.2	-0.6	-0.1	-0.7	1.6	-0.7	0.7	-0.5	2.5	0.8	-0.4	-0.9	0.9	1.5	1.6	0.8	2.2	1.4	2.4	0.1	0.3	-0.5	-0.6	-0.1	0.9	1.6	1.7	0.8	-1.8	1.1	2.3	-0.5	-0.2	-0.8	1.3	-0.5	0.5
12.1	2.5	1.8	-2.2	-0.6	-1.8	-2.8	1.9	-1.3	-0.8	-1.0	-2.5	2.0	-1.6	-2.6	-0.3	2.1	0.3	-0.7	-2.8	2.4	-1.6	0.9	-1.0	-2.0	-1.2	-2.3	-0.1	1.8	0.6	-0.4	2.3	1.2	-2.8	-0.5	-2.2	3.1
10.6	-0.7	1.1	-1.8	1.2	0.4	-1.6	-2.1	-1.7	1.8	-2.0	-2.2	2.3	-1.0	0.7	-2.0	-1.5	0.0	-1.6	-1.9	-0.3	-2.9	-2.6	-1.0	-2.6	2.1	-2.6	0.9	-2.6	2.9	1.3	-1.4	0.1	-2.6	1.4	-0.6	-2.4
9.4	2.1	0.2	2.9	2.5	-0.9	3.1	2.0	-1.5	0.8	-2.5	-0.4	2.2	2.9	0.3	2.4	0.4	-1.2	-1.9	1.9	-0.6	1.4	-1.1	-2.2	-3.1	2.1	-0.5	1.5	-1.2	-2.3	-2.8	-1.1	2.6	-2.0	2.8	0.6	0.4
8.5	0.9	-1.5	-3.1	0.0	-1.0	0.6	0.2	2.0	0.4	-1.0	-1.6	-1.0	2.4	-0.5	-2.1	-0.8	0.1	1.9	1.6	-1.3	-3.1	-1.2	-0.7	0.9	-2.2	1.2	-0.3	2.4	1.8	-2.7	0.9	-1.9	2.9	-0.2	-1.3	0.4
7.7	-0.5	-1.2	-2.5	-0.5	-2.1	-1.1	-0.8	1.9	0.4	-1.7	-2.4	-1.7	2.6	1.6	0.3	3.1	0.8	2.2	1.8	0.8	-0.5	1.9	0.0	1.4	2.1	1.1	-0.3	2.7	0.2	1.6	-0.6	-1.6	-2.9	-0.4	-2.4	-1.0
7.1	0.0	-2.0	-0.8	0.9	-0.6	1.3	-1.8	1.1	-2.8	0.8	-2.3	1.5	-1.8	2.5	-2.0	-0.3	-2.3	0.2	-2.0	2.5	-1.7	0.0	-2.5	0.4	-2.1	2.2	-2.1	-3.0	-2.3	-0.2	0.8	-1.3	0.4	0.4	0.2	2.5
6.5	-0.1	-2.5	-1.3	1.5	-1.8	1.5	0.3	-0.6	0.3	-0.1	-0.2	-2.6	-3.1	0.8	1.6	2.9	1.7	-1.2	2.1	-0.3	0.4	1.6	0.4	-2.4	1.8	-0.7	0.0	-1.8	0.1	-2.7	-0.7	-3.0	-2.4	1.1	-2.4	1.3
6.1	2.8	0.2	0.9	0.1	0.1	1.4	2.6	-1.8	0.0	-1.0	-0.7	0.5	2.2	-0.9	0.1	-1.3	-1.7	0.0	1.8	-1.2	-0.3	-1.2	-1.9	0.0	1.0	-2.2	-1.1	-2.5	-3.0	-1.2	-2.9	0.3	1.7	0.2	-0.1	1.2
5.7	-2.1	-2.6	1.6	-3.1	-1.4	3.1	-2.3	0.5	-2.0	0.1	-0.1	-0.7	2.7	1.7	-0.6	1.7	3.1	1.4	1.8	0.7	-1.5	0.2	2.1	0.4	0.7	-0.3	-2.6	-0.4	1.0	-0.6	-1.5	-2.4	1.5	-0.8	-1.3	-2.7

Table A21: 2018 TMA and weather condition covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Microbial Abundance

	Mean Air Temp.						Air Temp. Ran.						Humidity						ET						GWT Depth					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	3.1	3.1	3.1	3.1	0.0	3.1	0.0	0.0	0.0	0.0	3.1	0.0	3.1	3.1	3.1	3.1	0.0	3.1	0.0	0.0	3.1	0.0	3.1	0.0	3.1	3.1	0.0	3.1	3.1
85.0	-2.0	2.8	1.7	-2.8	2.3	0.3	1.6	0.1	-0.9	0.1	-0.3	-2.3	-1.2	-2.6	2.6	-1.8	-3.1	1.2	2.3	0.8	-0.2	2.1	0.4	-1.6	-0.6	-2.0	-3.1	-1.0	-2.5	1.8
42.5	-1.1	3.0	-2.4	-3.1	-1.7	-1.5	-2.5	1.6	2.5	1.1	-3.1	-2.9	0.6	-1.6	-0.7	-0.7	0.0	0.2	-1.4	2.7	-2.7	1.8	-2.0	-1.8	0.6	-1.6	-0.7	0.0	0.0	0.2
28.3	-1.8	-2.5	-3.0	1.9	-2.6	-2.0	1.4	0.7	0.2	-2.1	0.6	1.2	-0.8	-1.5	-2.0	0.4	-1.6	-1.0	1.8	1.1	0.6	1.2	1.0	1.6	-0.7	-1.4	-1.9	-2.8	-1.5	-0.9
21.3	1.4	2.7	2.8	0.0	0.0	0.9	-1.9	-0.6	-0.4	3.0	3.1	-2.3	0.3	1.6	1.8	-0.8	-1.0	-0.1	2.0	-3.0	-2.8	-0.2	0.7	1.5	1.1	2.4	2.6	3.1	-0.2	0.6
17.0	-1.3	-1.2	2.5	0.6	-2.1	2.9	-1.4	-1.2	2.5	-2.7	-2.1	2.9	-1.2	-1.0	2.7	0.0	-1.9	3.1	2.8	3.0	0.3	-2.9	2.0	0.7	-1.4	-1.2	2.5	1.0	-2.1	2.9
14.2	0.5	0.8	0.1	0.5	0.4	1.4	2.7	3.0	2.3	-2.5	2.6	-2.7	2.4	2.7	2.0	1.0	2.3	-3.0	0.7	0.9	0.2	-2.4	0.5	1.5	3.0	-3.0	2.5	2.4	2.9	-2.4
12.1	-2.3	2.9	-1.1	1.5	-0.5	-1.4	-1.2	-2.3	0.0	1.0	0.6	-0.4	0.7	-0.4	1.9	-2.4	2.5	1.5	-2.2	2.9	-1.0	0.9	-0.4	-1.4	-0.1	-1.2	1.1	-3.1	1.7	0.7
10.6	-1.4	0.2	-2.5	-2.1	-0.5	-2.1	-2.7	-1.0	2.5	3.1	-1.8	2.9	-0.1	1.6	-1.2	0.4	0.8	-0.8	-2.1	-0.4	3.1	-2.8	-1.2	-2.8	-0.7	0.9	-1.8	-0.5	0.2	-1.4
9.4	2.5	-0.1	2.1	-0.4	-1.6	-2.3	2.9	0.3	2.5	-1.5	-1.2	-1.9	0.4	-2.2	-0.1	1.3	2.6	1.8	-3.1	0.6	2.8	-1.4	-0.9	-1.6	3.1	0.5	2.7	0.8	-1.0	-1.7
8.5	1.9	-1.0	-2.5	-1.2	-0.4	1.5	-2.6	0.8	-0.8	-2.4	1.3	-3.1	1.2	-1.7	3.0	1.9	-1.2	0.7	-2.7	0.7	-0.8	-1.3	1.2	3.1	2.6	-0.3	-1.8	2.5	0.3	2.2
7.7	2.4	1.5	0.2	2.0	0.6	2.1	1.1	0.1	-1.2	0.9	-0.7	0.7	-2.6	2.8	1.4	-1.9	1.9	-3.0	1.1	0.1	-1.2	1.3	-0.7	0.7	2.6	1.7	0.4	-2.8	0.8	2.3
7.1	-1.2	2.9	-1.6	-1.4	-1.9	0.5	3.0	0.9	2.6	2.2	2.3	-1.5	-0.3	-2.4	-0.7	-1.4	-1.0	1.4	-2.9	1.3	3.0	2.1	2.7	-1.1	-2.0	2.1	-2.4	-2.6	-2.7	-0.3
6.5	2.8	0.4	1.2	1.5	1.3	-1.6	1.5	-0.9	-0.2	-2.2	-0.1	-3.0	-1.4	2.5	-3.0	-0.3	-2.9	0.5	1.7	-0.7	0.1	2.9	0.1	-2.7	-2.7	1.2	1.9	-2.8	2.0	-0.9
6.1	1.9	-1.1	-0.1	-2.1	-1.9	0.0	-0.6	2.7	-2.6	0.8	1.8	-2.5	-2.7	0.6	1.6	-2.4	-0.3	1.7	0.7	-2.3	-1.2	3.1	-3.1	-1.1	-0.5	2.8	-2.5	2.9	2.0	-2.4
5.7	1.7	0.8	-1.5	0.8	2.0	0.4	-1.2	-2.1	1.9	0.2	-0.8	-2.5	2.6	1.6	-0.6	-1.5	2.9	1.2	0.7	-0.3	-2.5	0.0	1.0	-0.6	-2.8	2.5	0.3	3.1	-2.5	2.1

Table A22: 2018 F:B and chemical covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Fungi:Bacteria Ratio

	NO3-N						P						SO4-S						Mn					
Period	HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	0.0	0.0	3.1	0.0	3.1	0.0	3.1	0.0	0.0	0.0	3.1	3.1	0.0	3.1	3.1	3.1	0.0	3.1	0.0	0.0	0.0	0.0	3.1	0.0
85.0	-1.1	-0.5	2.0	0.5	3.0	-0.6	2.7	-0.4	-0.4	0.0	2.5	-1.9	0.9	3.0	-2.1	-2.0	1.4	-2.2	-1.4	0.2	1.1	1.5	-2.6	0.0
42.5	2.6	2.6	-1.3	-1.9	-2.7	2.4	-1.7	0.9	0.0	-0.9	-2.5	-2.3	-2.7	-3.0	-2.7	2.7	-2.1	2.4	-1.1	1.3	1.5	-3.1	-2.0	-1.7
28.3	1.0	-1.6	-1.4	-3.1	2.8	0.2	-0.7	2.6	1.3	1.8	2.9	-0.6	2.0	2.7	-1.2	2.7	-3.0	0.7	2.9	-1.4	0.5	2.4	-3.1	1.9
21.3	2.2	3.0	3.1	2.4	-0.4	-2.2	-1.7	-0.4	2.9	-1.4	2.6	-2.0	-1.3	-3.1	2.8	1.5	-1.3	-1.9	-1.6	2.0	-0.4	-0.2	-3.0	-1.7
17.0	-1.3	0.2	1.5	-2.6	0.1	-0.8	-2.6	2.6	1.8	0.8	1.0	-0.4	3.0	2.8	1.5	1.6	0.1	0.3	-1.8	-2.5	1.7	-0.4	3.1	-2.9
14.2	-2.5	0.5	2.6	-0.4	-1.2	0.6	-1.7	1.8	1.0	1.5	-0.8	2.0	-0.9	-1.0	1.8	2.5	-2.0	-2.8	-1.4	0.2	0.5	0.1	-1.2	-0.7
12.1	2.3	-0.6	-0.6	-0.4	-0.2	-2.4	2.5	-2.9	-0.7	2.5	-0.7	-2.3	2.3	2.6	-1.4	-1.7	-0.3	-2.3	0.0	-1.2	0.3	-0.8	-2.2	3.0
10.6	1.1	-1.3	-2.7	-1.7	-1.4	0.9	1.1	-2.1	1.8	3.1	-1.2	-2.4	-1.2	2.7	0.1	1.9	-1.5	-1.9	2.3	-1.6	-1.4	-2.5	1.4	1.3
9.4	-2.3	0.7	-0.1	0.8	2.2	0.7	3.1	-1.1	1.3	-0.8	-0.7	1.3	1.3	2.5	0.8	-2.3	-0.1	2.2	-0.1	-1.1	0.0	-1.8	-2.3	1.2
8.5	-0.1	-3.0	-2.8	-2.9	1.0	-2.4	0.4	-2.6	-1.6	0.5	-0.8	1.7	1.9	2.5	-1.7	-1.4	0.5	-2.1	1.3	0.8	-2.5	-1.6	-1.9	0.5
7.7	-3.1	2.6	-1.4	-2.8	2.3	-1.5	2.2	-2.5	0.8	0.5	2.3	1.8	-2.6	-1.4	1.1	-0.5	2.0	-1.9	0.3	-2.4	2.9	-3.0	-3.0	-1.0
7.1	2.9	0.8	1.5	2.4	-0.9	-3.1	-0.3	0.7	0.6	-1.0	-0.9	3.0	2.0	-0.6	-0.5	2.2	-1.1	-3.0	2.9	-3.1	0.5	2.0	0.8	-1.6
6.5	2.3	-1.7	1.1	1.1	-0.9	1.4	-2.5	-1.5	0.1	-1.5	-0.5	-3.0	3.1	0.7	0.3	-2.3	0.0	2.0	0.9	2.2	-1.6	0.8	-2.7	0.6
6.1	-2.0	-1.7	2.8	0.9	-0.2	1.3	-1.0	-3.1	-2.6	-2.6	0.7	2.8	2.2	-2.3	-1.9	-2.8	0.3	2.7	-1.0	2.8	3.0	1.3	-0.7	1.4
5.7	-1.0	0.7	2.4	0.1	0.5	-0.9	-2.0	-2.9	-1.5	-2.8	-0.9	-2.4	1.7	0.5	-1.3	2.1	-0.3	1.9	-1.0	-2.7	-0.2	0.2	2.4	-0.7

	NH4-N						TN						TC						pH						EC					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	0.0	0.0	0.0	3.1	3.1	3.1	3.1	0.0	0.0	0.0	3.1	0.0	0.0	3.1	0.0	0.0	3.1	3.1	3.1	0.0	3.1	0.0	3.1	0.0	0.0	0.0	0.0	3.1	0.0
85.0	2.9	-0.3	0.2	0.9	2.5	-1.6	1.7	-1.9	-0.3	-1.3	1.2	-2.4	1.5	-0.7	3.1	-0.6	0.8	-2.8	2.3	3.1	-0.4	-3.1	0.2	2.9	-1.3	-0.4	1.5	0.5	3.0	-0.8
42.5	-0.3	2.3	0.0	2.6	-2.0	-2.2	-0.3	1.3	1.9	0.3	0.0	-1.3	-1.6	2.2	-0.7	-0.2	2.4	-1.3	-0.6	0.6	1.3	0.9	-1.4	-1.6	2.6	2.5	-1.4	-2.4	-2.3	2.9
28.3	1.6	3.0	0.9	2.9	2.8	1.3	2.3	-2.0	-1.2	0.6	-1.2	1.9	2.6	2.0	-0.2	0.0	1.3	0.5	-3.0	2.6	1.6	-0.6	0.2	1.6	1.4	-1.7	-1.0	-3.0	2.8	0.7
21.3	-1.4	-1.2	-2.7	-0.4	-1.8	-2.1	-2.0	-1.4	-2.6	2.6	-0.9	-1.6	2.7	-1.0	-2.5	-2.6	-3.1	1.0	-1.2	-0.6	0.3	2.9	-0.7	0.8	2.1	-2.1	3.0	-0.1	0.1	-2.2
17.0	-1.2	2.0	0.9	1.9	1.1	1.6	2.7	3.0	1.4	0.9	0.7	2.6	1.4	2.8	1.0	-0.1	-0.9	-2.2	2.2	2.8	-2.0	1.6	0.1	2.3	-1.0	0.2	1.2	-2.4	1.5	-0.8
14.2	-1.3	1.5	1.3	-0.3	-0.6	0.7	-2.3	0.6	2.1	2.2	-2.2	-2.3	-1.0	2.9	1.2	2.0	-2.1	0.5	-1.5	-1.7	-1.1	2.8	1.9	-3.1	-1.8	0.8	2.4	-0.2	-1.2	0.4
12.1	2.3	2.0	-1.8	0.4	-0.3	-2.4	2.0	-2.2	3.0	2.0	0.7	2.8	-0.4	3.1	3.0	-2.9	0.4	-2.3	1.5	2.2	2.2	1.8	-3.0	-1.8	2.1	-0.6	-0.4	-0.6	-0.1	-2.3
10.6	-0.6	-2.5	1.7	-0.7	-1.5	-2.9	-0.8	2.9	-1.1	-0.3	-1.6	-0.6	2.8	-1.1	-0.9	2.9	-0.9	-2.0	-1.8	2.0	0.8	0.1	-0.1	-2.1	0.0	-2.0	-2.7	-1.7	-1.2	0.4
9.4	-2.1	-1.2	1.3	0.3	-0.7	2.4	2.1	-1.7	2.0	-1.5	0.0	-0.5	1.5	-1.2	1.3	-1.6	-0.8	1.9	0.1	-1.5	-0.7	-2.2	-1.0	2.3	-0.4	1.7	0.5	-1.3	2.5	0.7
8.5	0.8	-1.7	0.5	-2.0	0.4	-0.8	1.1	-1.5	-3.0	0.2	0.5	1.8	0.9	2.4	-2.0	0.3	-2.7	2.9	1.2	-0.1	0.8	-0.9	0.4	1.0	-0.4	-2.9	-2.7	-2.2	2.5	-1.5
7.7	1.4	-2.6	-1.3	-2.8	2.2	-1.4	1.4	-2.4	0.1	-1.0	1.1	-2.1	2.5	1.4	0.7	2.5	-1.4	-2.1	0.0	-0.4	1.9	0.3	-1.0	0.7	-2.7	3.1	-1.3	-2.9	2.6	-1.2
7.1	-2.9	2.7	-0.1	2.3	-0.7	-2.4	3.0	-0.9	-0.5	-1.0	0.3	3.1	2.8	0.5	0.7	-0.4	-1.5	3.1	0.0	-2.6	-1.5	0.0	1.4	-2.0	2.0	0.8	1.2	1.9	-0.6	-2.7
6.5	2.3	3.0	0.9	0.4	-0.2	2.1	1.5	1.9	0.3	-1.3	-0.3	1.7	2.9	-1.2	-0.1	0.0	1.0	3.1	0.0	2.1	-2.1	-1.5	1.4	-2.2	2.6	-2.8	1.0	0.8	-1.3	1.1
6.1	-1.4	2.8	1.5	0.4	0.2	1.9	-1.9	2.3	-2.4	-2.0	0.5	3.1	-1.9	-1.0	-2.8	2.9	1.1	2.5	1.4	1.5	-0.3	-1.8	-0.3	2.3	-2.7	-2.0	2.9	1.1	-0.8	0.8
5.7	-1.2	-2.0	-2.6	-0.1	-0.7	0.5	-0.4	0.0	1.0	-2.9	-0.6	-2.0	-0.8	0.9	-2.3	3.1	-1.5	2.8	2.1	-0.8	0.3	-2.9	-0.8	1.4	2.2	0.9	2.4	0.2	1.6	0.0

Table A23: 2018 F:B and physical conditions covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Fungi:Bacteria Ratio

	VWC						Water Grad.						Temp					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	0.0	0.0	0.0	3.1	0.0	3.1	0.0	0.0	3.1	0.0	3.1	0.0	3.1	3.1	3.1	0.0	0.0
85.0	2.7	-0.4	0.1	-1.1	2.5	-1.3	2.8	1.0	0.8	2.7	-0.8	-2.8	-1.5	1.8	1.8	2.5	-1.4	0.8
42.5	-1.5	0.1	1.7	-3.0	1.8	2.3	-0.3	1.6	-0.2	2.0	0.2	-2.1	0.7	2.7	2.3	2.9	-0.2	-0.1
28.3	-3.1	-0.7	0.7	1.8	-2.9	1.9	2.4	-3.0	-0.5	-0.6	2.2	0.8	-0.8	1.3	3.1	2.8	-0.9	-2.0
21.3	-0.1	2.0	1.5	-0.5	-2.4	-1.6	-0.3	-0.3	-0.7	-0.7	-3.0	-2.4	1.9	-2.8	2.7	0.8	-0.8	0.7
17.0	2.8	3.1	-1.3	2.1	2.6	1.4	2.3	0.3	1.8	-1.0	-2.5	-1.1	-0.9	-0.8	1.3	2.1	-1.5	-2.1
14.2	-1.3	0.5	0.8	2.1	-1.2	0.2	-1.2	3.1	2.2	0.1	-1.4	0.4	0.8	2.1	2.2	2.7	0.9	1.9
12.1	0.5	-0.8	0.6	-1.6	-1.2	-2.8	-0.1	2.3	1.9	-1.9	-1.9	1.9	2.7	1.0	2.5	1.2	0.9	-0.7
10.6	0.1	-3.1	-2.5	2.7	0.5	-1.1	-1.4	0.4	1.0	-0.5	-2.2	2.8	-0.2	2.7	-2.7	0.0	0.0	-1.1
9.4	1.2	0.8	2.3	2.2	0.4	2.2	1.1	-0.9	0.2	-2.8	0.9	1.2	2.0	0.9	1.8	0.1	0.1	-2.9
8.5	2.0	1.9	2.4	-0.9	-1.1	1.0	1.2	-0.9	-0.4	-1.9	-1.7	-0.7	-2.8	2.9	-3.0	-1.7	0.0	2.3
7.7	-0.4	-2.4	3.0	2.5	-2.9	-1.2	-0.7	0.7	-0.3	1.4	3.1	-1.8	2.7	0.4	-0.4	-0.2	0.1	2.1
7.1	-0.3	0.1	-1.6	2.3	-1.7	1.6	-2.0	-3.0	2.6	2.1	2.9	1.8	-2.0	-1.6	-2.8	1.1	2.8	0.5
6.5	1.8	-3.0	-1.1	2.2	-1.9	1.1	2.2	-1.0	0.6	0.6	-0.3	-2.9	-1.2	0.4	1.9	-2.7	1.6	-1.5
6.1	-0.3	-3.0	2.3	1.6	-0.4	1.4	-0.4	1.3	1.5	0.4	-1.2	0.5	-0.8	2.2	1.6	0.1	-2.3	0.0
5.7	2.6	1.0	0.2	-2.8	0.5	-2.8	2.4	-2.2	3.0	0.4	1.7	-0.3	1.1	-1.0	-1.9	2.0	-1.3	1.7

	Temp. Grad.						Bottom Flux						Water Storage					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	0.0	0.0	0.0	3.1	0.0	0.0	3.1	0.0	3.1	0.0	3.1	3.1	0.0	3.1	3.1	3.1	0.0
85.0	2.4	-0.5	0.2	0.8	2.7	-1.4	1.4	-1.6	-1.4	2.3	1.4	-2.7	-1.9	1.4	1.7	2.2	-1.7	0.3
42.5	-1.2	0.9	0.7	2.4	-2.1	-2.1	-1.3	0.7	0.4	0.0	-2.3	-2.1	1.5	-2.9	3.1	-3.1	0.4	0.5
28.3	-2.7	-0.8	0.9	0.4	-2.9	2.2	0.3	2.2	-2.0	-2.1	0.2	-1.1	3.0	-1.3	0.6	1.5	2.9	1.7
21.3	2.0	2.6	2.8	-0.2	-1.4	0.2	-1.8	0.0	-1.0	2.7	2.0	-2.7	-0.2	1.4	1.5	-0.4	-1.8	-1.7
17.0	1.8	1.9	-2.9	2.1	1.5	0.4	-0.7	-0.6	1.5	-2.2	-1.1	-2.0	2.9	2.9	-1.2	0.4	2.5	1.5
14.2	-0.7	0.9	0.9	-0.1	-0.5	0.4	0.9	2.3	2.2	-1.3	0.7	1.8	-1.2	0.4	0.6	1.8	-1.0	0.0
12.1	1.6	-0.3	1.2	-0.1	-0.4	-2.1	3.1	1.3	2.7	0.8	1.2	-0.5	0.3	-1.5	-0.1	-1.5	-1.6	3.1
10.6	-1.2	1.7	2.7	-1.2	-0.9	-2.1	2.8	-0.6	0.1	-1.1	2.9	1.8	-0.7	2.1	2.9	2.9	-0.5	-1.9
9.4	1.1	0.0	0.8	-1.4	-0.9	2.3	1.2	0.1	0.8	-1.5	-1.0	2.5	-2.0	-3.1	-2.6	2.5	1.8	-0.6
8.5	2.6	2.1	2.4	-2.1	-0.8	1.3	-1.2	-1.7	-1.2	1.4	1.7	-2.3	2.0	1.5	2.1	-1.1	-1.4	0.8
7.7	1.9	-0.4	-1.3	-1.4	-0.8	1.3	2.3	-0.1	-1.0	-0.5	-0.6	1.5	-0.5	-2.8	2.7	2.7	3.1	-1.1
7.1	-2.2	-1.6	-2.6	1.3	2.7	0.8	-2.3	-1.9	-3.0	-1.7	2.9	0.1	0.5	0.8	-0.4	1.7	-0.9	2.9
6.5	-2.2	-0.7	0.7	2.3	0.3	-2.8	-2.6	-1.1	0.2	-1.1	-0.1	-3.1	1.2	2.8	-2.1	1.8	-2.5	1.0
6.1	-1.3	1.9	1.2	0.3	-2.4	0.0	-2.1	0.9	0.3	-1.1	2.7	-1.3	0.4	-2.9	-3.1	1.7	-0.6	1.2
5.7	0.2	-2.0	-2.8	0.6	-2.3	0.7	-0.9	-3.0	2.4	-0.1	2.9	-0.3	-3.1	1.2	0.2	-0.5	0.5	-2.3

Table A24: 2018 F:B and weather condition covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Fungi:Bacteria Ratio

	Mean Air Temp.						Air Temp. Ran.						Humidity						ET						GWT Depth					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	0.0	3.1	3.1	3.1	0.0	3.1	0.0	0.0	0.0	3.1	3.1	0.0	3.1	3.1	3.1	0.0	0.0	3.1	0.0	0.0	0.0	3.1	0.0	0.0	3.1	3.1	3.1	0.0	3.1
85.0	-1.9	1.4	1.7	2.0	-1.8	0.4	1.8	-1.2	-1.0	-1.4	1.9	-2.2	-1.0	2.3	2.5	3.0	-0.9	1.3	2.5	-0.5	-0.3	0.7	2.6	-1.5	-0.4	2.8	3.1	-2.4	-0.3	1.9
42.5	-0.1	1.9	1.6	-3.1	-1.1	-0.9	-1.6	0.4	0.2	1.2	-2.5	-2.4	1.5	-2.8	-3.0	-0.7	0.6	0.7	-0.4	1.6	1.3	1.9	-1.4	-1.2	1.5	-2.8	-3.0	0.0	0.6	0.7
28.3	-1.3	0.7	2.6	2.4	-1.4	-2.5	2.0	-2.4	-0.4	-1.6	1.9	0.7	-0.3	1.7	-2.7	0.9	-0.4	-1.5	2.4	-1.9	0.0	1.7	2.3	1.1	-0.1	1.8	-2.6	-2.3	-0.2	-1.4
21.3	1.8	-2.8	2.6	0.1	-0.8	0.6	-1.5	0.3	-0.6	-3.1	2.3	-2.6	0.8	2.5	1.6	-0.7	-1.8	-0.4	2.4	-2.1	-3.1	-0.1	-0.1	1.3	1.5	-3.0	2.3	-3.1	-1.0	0.4
17.0	-0.8	-0.8	1.3	1.4	-1.3	-2.1	-0.9	-0.8	1.2	-1.9	-1.4	-2.2	-0.7	-0.6	1.4	0.9	-1.2	-2.0	-3.0	-2.9	-0.9	-2.1	2.8	2.0	-0.9	-0.8	1.2	1.9	-1.4	-2.2
14.2	-0.2	1.4	1.5	1.0	-0.1	0.9	2.0	-2.7	-2.5	-2.0	2.2	3.1	1.7	-3.0	-2.9	1.5	1.8	2.8	0.0	1.5	1.7	-2.0	0.1	1.0	2.3	-2.5	-2.3	2.9	2.4	-2.9
12.1	2.1	0.2	1.7	0.5	0.2	-1.5	3.1	1.3	2.7	0.0	1.2	-0.5	-1.3	-3.1	-1.7	3.0	3.1	1.4	2.1	0.3	1.7	0.0	0.2	-1.5	-2.1	2.4	-2.4	2.2	2.3	0.7
10.6	-0.7	2.3	3.0	-0.6	-0.5	-1.6	-2.0	1.0	1.7	-1.7	-1.7	-2.9	0.6	-2.7	-1.9	1.9	0.8	-0.3	-1.3	1.6	2.4	-1.3	-1.1	-2.3	0.0	2.9	-2.6	1.0	0.2	-0.9
9.4	1.7	0.5	1.5	-0.7	-0.3	3.0	2.0	0.9	1.9	-1.8	0.1	-2.8	-0.5	-1.6	-0.7	1.0	-2.5	0.9	2.4	1.2	2.2	-1.7	0.4	-2.5	2.2	1.1	2.0	0.6	0.3	-2.7
8.5	2.9	2.5	2.9	-2.2	-0.6	1.8	-1.6	-2.1	-1.6	3.0	1.2	-2.7	2.2	1.7	2.2	1.0	-1.3	1.1	-1.7	-2.2	-1.7	-2.3	1.1	-2.8	-2.6	-3.1	-2.7	1.5	0.1	2.5
7.7	2.6	0.3	-0.6	-1.2	-0.1	2.0	1.2	-1.1	-1.9	-2.3	-1.5	0.6	-2.5	1.6	0.7	1.1	1.1	-3.0	1.2	-1.1	-1.9	-2.0	-1.5	0.6	2.7	0.5	-0.4	0.2	0.1	2.2
7.1	-1.5	-1.2	-2.5	-0.1	-3.0	0.8	2.8	3.1	1.7	-2.7	1.2	-1.2	-0.5	-0.2	-1.6	0.0	-2.1	1.8	-3.1	-2.8	2.2	-2.8	1.6	-0.8	-2.3	-2.0	3.0	-1.2	2.4	0.0
6.5	-1.5	0.0	1.5	2.2	1.2	-1.9	-2.9	-1.3	0.1	-1.5	-0.2	3.0	0.6	2.1	-2.7	0.4	-3.0	0.2	-2.7	-1.1	0.4	-2.7	0.0	-3.0	-0.8	0.7	2.2	-2.1	1.9	-1.2
6.1	-1.2	2.0	1.4	-0.6	-2.5	0.0	2.6	-0.5	-1.1	2.3	1.3	-2.5	0.5	-2.6	3.0	-1.0	-0.8	1.7	-2.3	0.8	0.2	-1.7	2.7	-1.1	2.7	-0.4	-1.0	-2.0	1.4	-2.4
5.7	0.1	-1.9	-2.8	1.2	-2.4	0.7	-2.8	1.5	0.6	0.5	1.0	-2.1	1.0	-1.1	-1.9	-1.2	-1.5	1.6	-0.9	-2.9	2.5	0.4	2.9	-0.3	1.9	-0.2	-1.0	-2.8	-0.6	2.5

Table A25: 2018 AMF and chemical phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Arbuscular Mycorrhizal Fungi

	NO3-N						P						SO4-S					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	3.1	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	3.1	3.1	3.1	3.1	3.1	3.1
85.0	2.6	-1.8	1.5	-0.1	-0.8	0.0	0.0	-1.7	-0.9	-0.7	-1.3	-1.4	-1.8	1.7	-2.6	-2.7	-2.4	-1.6
42.5	2.7	2.4	-1.2	0.0	-2.7	-2.1	-1.6	0.7	0.1	1.0	-2.5	-0.6	-2.6	3.1	-2.5	-1.7	-2.1	-2.2
28.3	2.1	2.8	-0.4	-2.5	2.6	1.9	0.5	0.7	2.3	2.4	2.8	1.1	3.1	0.9	-0.2	-3.0	-3.1	2.3
21.3	1.1	2.0	-2.3	3.0	-2.4	-2.8	-2.8	-1.4	-2.5	-0.8	0.6	-2.6	-2.4	2.3	-2.6	2.1	3.0	-2.5
17.0	-0.9	0.3	2.7	1.6	0.5	-1.8	-2.2	2.7	3.1	-1.3	1.4	-1.4	-2.9	2.9	2.7	-0.5	0.5	-0.7
14.2	-2.5	1.6	-0.4	2.7	2.5	2.0	-1.7	3.0	-2.0	-1.7	2.9	-2.8	-0.9	0.2	-1.2	-0.7	1.7	-1.4
12.1	0.3	2.4	2.5	-1.0	-1.3	2.3	0.4	0.1	2.4	2.0	-1.7	2.4	0.2	-0.7	1.7	-2.3	-1.4	2.4
10.6	-2.2	-1.9	1.7	-0.9	-1.2	-1.1	-2.1	-2.7	-0.1	-2.3	-1.1	1.9	1.8	2.1	-1.8	2.7	-1.4	2.4
9.4	-1.0	1.2	-2.7	2.9	1.1	-1.6	-2.0	-0.6	-1.4	1.3	-1.7	-1.0	2.5	3.0	-1.9	-0.2	-1.2	-0.1
8.5	-0.8	-1.8	-1.3	-1.2	-1.0	1.9	-0.3	-1.5	-0.1	2.2	-2.9	-0.2	1.1	-2.6	-0.2	0.3	-1.6	2.2
7.7	0.3	-0.9	-2.6	0.3	1.7	0.2	-0.7	0.3	-0.5	-2.7	1.7	-2.7	0.8	1.4	-0.1	2.6	1.4	-0.1
7.1	-2.9	0.7	2.0	1.4	0.4	-2.4	0.3	0.6	1.2	-2.0	0.4	-2.6	2.5	-0.7	0.1	1.3	0.2	-2.3
6.5	-1.1	-2.9	1.2	0.6	-0.5	2.0	0.3	-2.7	0.2	-2.1	-0.1	-2.4	-0.3	-0.6	0.4	-2.8	0.4	2.6
6.1	1.2	3.1	-0.4	1.4	0.7	2.8	2.1	1.7	0.5	-2.2	1.6	-2.0	-1.0	2.5	1.2	-2.3	1.2	-2.0
5.7	2.2	0.9	-1.7	0.2	2.0	2.5	1.3	-2.7	0.6	-2.7	0.6	1.0	-1.4	0.7	0.9	2.2	1.2	-1.1

	Mn						NH4-N						TN					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	3.1	3.1	3.1
85.0	2.3	-1.1	0.7	0.9	-0.1	0.6	0.3	-1.6	-0.3	0.2	-1.3	-1.0	-0.9	3.1	-0.8	-2.0	-2.5	-1.8
42.5	-1.0	1.1	1.7	-1.2	-2.0	0.0	-0.2	2.0	0.1	-1.8	-2.1	-0.5	-0.2	1.1	2.1	2.2	-0.1	0.4
28.3	-2.2	3.0	1.5	3.0	3.0	-2.8	2.8	1.1	1.9	-2.8	2.6	2.9	-2.8	2.4	-0.2	1.2	-1.4	-2.8
21.3	-2.7	1.0	0.5	0.4	1.3	-2.3	-2.5	-2.2	-1.9	0.1	2.5	-2.7	-3.0	-2.4	-1.8	-3.1	-2.9	-2.2
17.0	-1.4	-2.5	2.9	-2.5	-2.8	2.4	-0.8	2.0	2.1	-0.2	1.5	0.6	3.1	3.1	2.6	-1.2	1.0	1.6
14.2	-1.3	1.4	-2.6	-3.1	2.6	0.7	-1.3	2.6	-1.7	2.7	3.1	2.1	-2.2	1.8	-0.9	-1.0	1.5	-0.9
12.1	-2.1	1.9	-2.9	-1.4	3.1	1.4	0.3	-1.3	1.3	-0.2	-1.4	2.3	-0.1	0.8	-0.2	1.4	-0.3	1.2
10.6	-0.9	-2.2	3.0	-1.6	1.6	-0.7	2.5	3.1	-0.2	0.2	-1.4	1.4	2.3	2.3	-3.0	0.5	-1.4	-2.6
9.4	1.1	-0.6	-2.7	0.3	2.9	-1.2	-0.9	-0.7	-1.3	2.4	-1.8	0.1	-3.0	-1.2	-0.6	0.6	-1.1	-2.8
8.5	0.5	1.9	-1.0	0.1	2.3	-1.5	0.1	-0.6	2.0	-0.3	-1.6	-2.7	0.3	-0.4	-1.5	1.8	-1.6	-0.1
7.7	-2.6	0.4	1.6	0.1	2.7	0.7	-1.5	0.2	-2.6	0.3	1.6	0.3	-1.5	0.4	-1.1	2.1	0.5	-0.4
7.1	-2.9	3.1	1.1	1.0	2.1	-0.9	-2.4	2.6	0.4	1.4	0.6	-1.7	-2.7	-1.0	0.1	-2.0	1.6	-2.5
6.5	-2.5	1.0	-1.5	0.3	-2.2	1.2	-1.1	1.8	1.0	-0.1	0.3	2.7	-2.0	0.7	0.4	-1.9	0.1	2.3
6.1	2.1	1.3	-0.2	1.8	0.3	3.0	1.8	1.3	-1.7	0.8	1.2	-2.8	1.3	0.8	0.6	-1.5	1.4	-1.6
5.7	2.2	-2.5	2.0	0.3	-2.4	2.6	2.0	-1.8	-0.4	0.1	0.8	-2.4	2.9	0.2	-3.1	-2.8	0.9	1.3

	TC						pH						EC					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	0.0	3.1	3.1	0.0	3.1	3.1	0.0	3.1	0.0	3.1	3.1	3.1	3.1	3.1	0.0	0.0	0.0	0.0
85.0	-1.1	-2.0	2.6	-1.3	-3.0	-2.2	-0.3	1.8	-0.9	2.5	2.8	-2.8	2.3	-1.7	1.0	-0.1	-0.7	-0.2
42.5	-1.5	1.9	-0.5	1.7	2.3	0.4	-0.5	0.4	1.4	2.8	-1.4	0.1	2.7	2.2	-1.2	-0.5	-2.4	-1.6
28.3	-2.6	0.1	0.8	0.6	1.1	2.1	-1.9	0.7	2.6	-0.1	0.0	-3.0	2.5	2.7	0.0	-2.4	2.7	2.4
21.3	1.6	-2.0	-1.6	-2.1	1.2	0.4	-2.3	-1.6	1.2	-2.8	-2.7	0.2	1.0	-3.1	-2.4	0.5	-1.9	-2.8
17.0	1.8	2.8	2.2	-2.2	-0.5	3.1	2.6	2.9	-0.8	-0.5	0.5	1.3	-0.6	0.3	2.4	1.8	1.9	-1.8
14.2	-1.0	-2.2	-1.8	-1.2	1.6	1.9	-1.5	-0.6	2.1	-0.4	-0.6	-1.6	-1.8	2.0	-0.7	2.8	2.5	1.9
12.1	-2.4	-0.2	-0.2	2.8	-0.6	2.4	-0.6	-1.1	-1.0	1.2	2.2	2.9	0.1	2.4	2.7	-1.1	-1.1	2.4
10.6	-0.5	-1.7	-2.8	-2.6	-0.7	2.4	1.3	1.4	-1.1	1.0	0.0	2.2	3.0	-2.6	1.7	-0.9	-1.1	-1.6
9.4	2.7	-0.7	-1.3	0.4	-1.9	-0.4	1.3	-1.0	3.0	-0.1	-2.1	-0.1	0.8	2.2	-2.2	0.8	1.4	-1.6
8.5	0.1	-2.7	-0.5	2.0	1.5	0.9	0.4	1.0	2.3	0.7	-1.7	-1.0	-1.1	-1.8	-1.2	-0.5	0.4	2.8
7.7	-0.3	-2.0	-0.5	-0.7	-2.0	-0.4	-2.9	2.4	0.7	-2.9	-1.5	2.4	0.7	-0.4	-2.5	0.2	2.0	0.5
7.1	-3.0	0.4	1.2	-1.3	-0.3	-2.5	0.5	-2.7	-1.0	-1.0	2.7	-1.3	2.5	0.7	1.7	0.9	0.6	-2.1
6.5	-0.5	-2.4	0.0	-0.5	1.4	-2.6	2.8	0.8	-2.0	-2.1	1.9	-1.6	-0.8	2.2	1.0	0.3	-0.9	1.7
6.1	1.2	-2.5	0.3	-3.0	2.1	-2.2	-1.7	0.0	2.8	-1.3	0.7	-2.4	0.5	2.8	-0.3	1.5	0.1	2.4
5.7	2.5	1.1	-0.2	-3.1	0.0	-0.2	-1.0	-0.5	2.4	-2.8	0.7	-1.5	-0.8	1.1	-1.7	0.3	3.1	-2.9

Table A26: 2018 AMF and physical conditions covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Arbuscular Mycorrhizal Fungi

	VWC						Water Grad.						Temp						Temp. Grad.						Bottom Flux						Water Storage					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	0.0	3.1	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	3.1	3.1	3.1	0.0	0.0	3.1	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	3.1	3.1	3.1	3.1	3.1	0.0	0.0	0.0	0.0	0.0
85.0	0.1	-1.7	-0.4	-1.8	-1.2	-0.7	0.1	-0.3	0.3	2.0	1.7	-2.2	2.1	0.5	1.4	1.8	1.2	1.4	-0.3	-1.8	-0.3	0.1	-1.0	-0.8	-1.2	-2.9	-1.9	1.6	-2.3	-2.1	1.8	0.1	1.2	1.5	0.8	0.9
42.5	-1.4	-0.2	1.8	-1.1	1.8	-2.2	-0.2	1.4	0.0	-2.4	0.2	-0.4	0.8	2.5	2.5	-1.5	-0.2	1.7	-1.0	0.6	0.8	-2.0	-2.2	-0.4	-1.2	0.5	0.5	1.9	-2.3	-0.4	1.6	-3.1	-3.0	-1.2	0.4	2.3
28.3	-1.9	-2.6	1.7	2.3	-3.1	-2.7	-2.8	1.4	0.5	-0.1	2.0	2.4	0.4	-0.6	-2.2	-3.0	-1.0	-0.4	-1.6	-2.7	1.9	1.0	-3.0	-2.5	1.5	0.4	-1.1	-1.5	0.1	0.6	-2.1	3.1	1.6	2.0	2.8	-2.9
21.3	-1.2	1.1	2.4	0.1	1.9	-2.2	-1.4	-1.3	0.1	-0.2	1.2	-3.0	0.8	2.5	-2.7	1.4	-2.8	0.1	0.9	1.6	-2.6	0.4	2.8	-0.3	-2.9	-0.9	-0.1	-3.0	-0.1	3.0	-1.3	0.4	2.4	0.1	2.5	-2.3
17.0	-3.1	3.1	-0.1	0.0	3.0	0.5	2.7	0.4	3.0	-3.0	-2.1	-2.0	-0.5	-0.7	2.5	0.0	-1.1	-3.1	2.2	2.0	-1.7	0.1	1.9	-0.6	-0.3	-0.6	2.7	2.0	-0.7	-3.0	-3.0	3.0	0.0	-1.7	2.9	0.6
14.2	-1.3	1.7	-2.3	-1.1	2.6	1.7	-1.2	-2.0	-0.8	-3.1	2.3	1.8	0.8	-2.9	-0.8	-0.5	-1.6	-2.9	-0.6	2.1	-2.1	3.0	-3.1	1.8	0.9	-2.8	-0.8	1.8	-1.9	-3.1	-1.1	1.6	-2.4	-1.4	2.7	1.4
12.1	-1.5	2.2	-2.6	-2.2	-2.2	1.9	-2.1	-1.0	-1.3	-2.5	-2.9	0.3	0.7	-2.3	-0.7	0.6	-0.1	-2.3	-0.5	2.7	-2.0	-0.7	-1.4	2.6	1.0	-2.0	-0.5	0.2	0.2	-2.0	-1.7	1.5	3.0	-2.1	-2.6	1.5
10.6	3.1	2.5	1.8	-2.8	0.6	-3.0	1.7	-0.2	-0.9	0.3	-2.1	0.8	2.8	2.1	1.6	0.8	0.2	-3.0	1.8	1.1	0.8	-0.3	-0.8	2.2	-0.4	-1.2	-1.8	-0.3	3.0	-0.2	2.3	1.5	1.0	-2.6	-0.4	2.4
9.4	2.4	1.3	-0.4	-2.0	-0.7	-0.1	2.3	-0.4	-2.4	-0.7	-0.2	-1.1	-3.0	1.4	-0.8	2.2	-1.0	1.1	2.3	0.5	-1.8	0.7	-2.0	0.0	2.4	0.6	-1.8	0.6	-2.1	0.2	-0.8	-2.6	1.0	-1.7	0.7	-2.9
8.5	1.2	3.0	-2.4	0.8	3.1	-1.0	0.5	0.2	1.1	-0.3	2.5	-2.6	2.7	-2.2	-1.4	0.0	-2.1	0.3	1.8	-3.0	-2.4	-0.4	-2.9	-0.6	-1.9	-0.6	0.4	3.1	-0.4	2.0	1.2	2.6	-2.7	0.6	2.8	-1.2
7.7	3.0	0.4	1.8	-0.6	2.8	0.6	2.7	-2.8	-1.6	-1.8	2.5	0.0	-0.2	-3.1	-1.7	2.9	-0.5	-2.4	-1.0	2.4	-2.5	1.7	-1.3	3.0	-0.6	2.7	-2.3	2.6	-1.1	-3.0	2.9	0.0	1.5	-0.5	2.5	0.6
7.1	0.3	0.0	-1.1	1.3	-0.5	2.3	-1.5	-3.1	-3.1	1.2	-2.1	2.5	-1.5	-1.8	-2.3	0.1	-2.2	1.2	-1.7	-1.7	-2.0	0.4	-2.3	1.5	-1.8	-2.0	-2.4	-2.6	-2.1	0.8	1.1	0.7	0.1	0.8	0.3	-2.7
6.5	-1.7	2.1	-1.0	1.7	-1.5	1.7	-1.3	-2.3	0.7	0.1	0.1	-2.3	1.7	-0.8	2.0	3.1	2.0	-0.9	0.6	-2.0	0.8	1.8	0.7	-2.1	0.3	-2.3	0.3	-1.6	0.4	-2.4	-2.2	1.6	-2.1	1.3	-2.0	1.6
6.1	2.9	1.8	-0.9	2.0	0.5	3.0	2.7	-0.2	-1.8	0.9	-0.3	2.1	2.3	0.8	-1.6	0.6	-1.3	1.5	1.9	0.4	-2.1	0.8	-1.5	1.5	1.1	-0.6	-2.9	-0.6	-2.6	0.3	-2.8	1.9	0.0	2.1	0.3	2.8
5.7	-0.5	1.2	2.4	-2.7	2.0	0.5	-0.7	-2.0	-1.1	0.6	-3.0	3.0	-2.0	-0.8	0.3	2.2	0.2	-1.2	-2.9	-1.8	-0.7	0.7	-0.8	-2.2	2.3	-2.8	-1.7	0.0	-1.9	3.1	0.1	1.4	2.3	-0.4	2.0	1.0

Table A27: 2018 AMF and weather condition covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Arbuscular Mycorrhizal Fungi

	Mean Air Temp.						Air Temp. Ran.						Humidity						ET						GWT Depth					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	3.1	3.1	3.1	3.1	0.0	3.1	3.1	3.1	3.1	0.0	3.1	0.0	0.0	0.0	0.0	3.1	0.0	3.1	3.1	3.1	3.1
85.0	1.8	0.1	1.2	1.3	0.8	1.0	-0.9	-2.6	-1.5	-2.0	-1.9	-1.6	2.6	1.0	2.0	2.3	1.6	1.9	-0.2	-1.8	-0.8	0.0	-1.2	-0.9	-3.1	1.5	2.6	-3.1	2.2	2.5
42.5	0.0	1.6	1.8	-1.2	-1.1	0.8	-1.5	0.2	0.4	3.1	-2.5	-0.6	1.6	-3.0	-2.8	1.2	0.6	2.5	-0.3	1.3	1.5	-2.5	-1.4	0.5	1.6	-3.0	-2.8	1.9	0.6	2.5
28.3	-0.1	-1.2	-2.7	2.9	-1.5	-0.9	3.1	2.0	0.5	-1.1	1.7	2.4	0.9	-0.2	-1.7	1.4	-0.5	0.2	-2.8	2.5	1.0	2.3	2.1	2.8	1.0	-0.1	-1.6	-1.8	-0.4	0.3
21.3	0.7	2.5	-2.8	0.7	-2.8	0.1	-2.5	-0.7	0.3	-2.6	0.3	3.1	-0.3	1.5	2.5	-0.1	2.5	-1.0	1.3	-3.1	-2.2	0.5	-2.1	0.7	0.4	2.3	-3.1	-2.5	-3.1	-0.2
17.0	-0.4	-0.7	2.5	-0.7	-0.9	-3.1	-0.5	-0.7	2.5	2.3	-1.0	3.1	-0.3	-0.5	2.7	-1.2	-0.8	-2.9	-2.6	-2.8	0.3	2.1	-3.1	1.0	-0.5	-0.7	2.4	-0.2	-1.0	3.1
14.2	-0.1	2.6	-1.5	-2.2	-2.6	2.3	2.1	-1.5	0.7	1.1	-0.4	-1.7	1.7	-1.9	0.4	-1.7	-0.8	-2.1	0.0	2.7	-1.4	1.1	-2.5	2.5	2.3	-1.3	1.0	-0.3	-0.2	-1.5
12.1	0.0	-3.0	-1.5	-0.1	-0.9	-3.1	1.0	-2.0	-0.5	-0.5	0.2	-2.1	3.0	-0.1	1.4	2.4	2.1	-0.1	0.0	-3.0	-1.5	-0.6	-0.8	-3.0	2.2	-0.9	0.7	1.7	1.3	-0.9
10.6	2.3	1.7	1.1	0.2	-0.4	2.7	1.1	0.4	-0.2	-0.9	-1.6	1.4	-2.6	3.0	2.4	2.7	1.0	-2.3	1.7	1.0	0.5	-0.5	-1.0	2.0	3.0	2.3	1.8	1.8	0.3	-2.9
9.4	2.9	1.0	-1.2	1.4	-1.4	0.7	-3.0	1.4	-0.8	0.3	-1.0	1.1	0.7	-1.1	2.9	3.1	2.7	-1.4	-2.7	1.7	-0.5	0.4	-0.7	1.4	-2.8	1.6	-0.6	2.6	-0.8	1.3
8.5	2.2	-2.7	-1.8	-0.5	-2.7	-0.1	-2.4	-1.0	-0.1	-1.6	-0.9	1.6	1.4	2.8	-2.6	2.7	2.9	-0.9	-2.4	-1.0	-0.2	-0.6	-1.0	1.5	2.9	-2.0	-1.1	-3.1	-1.9	0.6
7.7	-0.3	3.1	-1.8	1.9	-0.7	-2.6	-1.7	1.7	3.1	0.8	-2.1	2.3	0.9	-1.9	-0.5	-2.0	0.6	-1.3	-1.7	1.7	3.1	1.1	-2.1	2.3	-0.1	-3.0	-1.6	-3.0	-0.5	-2.4
7.1	-0.9	-1.3	-1.9	-1.0	-1.8	1.5	-3.0	3.0	2.3	2.6	2.5	-0.5	0.0	-0.3	-1.0	-1.0	-0.8	2.4	-2.6	-2.9	2.7	2.5	2.9	-0.1	-1.7	-2.1	-2.7	-2.2	-2.6	0.7
6.5	1.3	-1.2	1.6	1.7	1.6	-1.3	0.0	-2.6	0.2	-2.0	0.2	-2.7	-2.9	0.9	-2.6	-0.1	-2.6	0.8	0.2	-2.3	0.4	3.1	0.5	-2.4	2.0	-0.5	2.3	-2.6	2.3	-0.6
6.1	2.0	0.5	-1.9	-0.2	-1.5	1.6	-0.5	-2.0	1.9	2.8	2.3	-0.9	-2.6	2.2	-0.2	-0.5	0.2	-3.0	0.8	-0.7	-3.0	-1.2	-2.7	0.4	-0.4	-1.9	2.0	-1.5	2.4	-0.8
5.7	-3.0	-1.7	-0.6	1.3	-0.9	-2.2	0.4	1.7	2.8	0.6	2.5	1.2	-2.1	-0.9	0.2	-1.0	0.0	-1.4	2.3	-2.7	-1.6	0.5	-1.9	3.1	-1.2	0.0	1.1	-2.7	0.8	-0.5

Table A28: 2018 Fungi and chemical covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Fungi

	NO3-N						P						SO4-S						Mn						NH4-N						TN						TC						pH						EC					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	0.0	0.0	3.1	0.0	3.1	0.0	3.1	0.0	0.0	0.0	3.1	3.1	0.0	3.1	3.1	3.1	0.0	3.1	0.0	0.0	0.0	0.0	3.1	0.0	3.1	0.0	0.0	0.0	3.1	3.1	3.1	3.1	0.0	0.0	0.0	3.1	0.0	0.0	3.1	0.0	0.0	3.1	3.1	3.1	0.0	3.1	0.0	3.1	0.0	0.0	3.1	0.0	3.1	0.0
85.0	-1.2	-0.3	2.1	0.5	3.0	-0.6	2.6	-0.2	-0.3	-0.1	2.5	-2.0	0.8	3.1	-2.0	-2.0	1.4	-2.2	-1.5	0.4	1.2	1.5	-2.6	-0.1	2.8	-0.1	0.3	0.8	2.5	-1.7	1.6	-1.8	-0.2	-1.3	1.2	-2.4	1.4	-0.5	-3.1	-0.7	0.8	-2.8	2.2	-3.1	-0.3	-3.1	0.3	2.8	-1.4	-0.2	1.6	0.5	3.0	-0.8
42.5	2.8	2.6	-1.3	-2.2	-2.7	2.4	-1.5	0.9	0.0	-1.1	-2.4	-2.4	-2.5	-3.0	-2.6	2.5	-2.1	2.3	-0.9	1.3	1.6	2.9	-2.0	-1.8	-0.1	2.3	0.0	2.4	-2.0	-2.3	-0.1	1.3	1.9	0.1	0.0	-1.4	-1.5	2.2	-0.6	-0.4	2.4	-1.4	-0.4	0.6	1.3	0.7	-1.4	-1.7	2.8	2.5	-1.3	-2.7	-2.3	2.9
28.3	0.8	-1.3	-1.5	3.0	2.8	0.0	-0.9	2.8	1.2	1.6	3.0	-0.9	1.7	3.0	-1.4	2.5	-3.0	0.4	2.7	-1.2	0.4	2.2	-3.1	1.6	1.4	-3.1	0.8	2.7	2.8	1.0	2.1	-1.8	-1.4	0.4	-1.2	1.6	2.3	2.2	-0.3	-0.2	1.3	0.2	3.0	2.9	1.5	-0.8	0.2	1.3	1.2	-1.5	-1.1	3.1	2.8	0.4
21.3	2.4	-3.1	2.5	2.4	-0.3	-2.1	-1.4	-0.2	2.3	-1.4	2.7	-1.9	-1.1	-2.9	2.2	1.5	-1.2	-1.8	-1.4	2.1	-1.0	-0.2	-2.9	-1.6	-1.2	-1.1	3.0	-0.4	-1.8	-2.0	-1.7	-1.3	3.1	2.6	-0.8	-1.5	2.9	-0.8	-3.1	-2.6	-3.0	1.1	-1.0	-0.4	-0.2	2.9	-0.6	0.9	2.3	-2.0	2.5	-0.1	0.1	-2.1
17.0	-1.4	-0.3	1.3	-2.2	-0.2	-0.7	-2.7	2.2	1.7	1.2	0.8	-0.3	2.8	2.3	1.3	2.0	-0.1	0.4	-1.9	-3.0	1.5	0.0	2.8	-2.7	-1.4	1.5	0.7	2.3	0.8	1.8	2.6	2.6	1.2	1.3	0.4	2.8	1.3	2.3	0.8	0.3	-1.2	-2.0	2.1	2.3	-2.1	2.0	-0.2	2.4	-1.1	-0.3	1.0	-2.0	1.2	-0.6
14.2	-1.9	0.4	2.6	-0.3	-1.0	0.5	-1.1	1.7	1.0	1.5	-0.6	2.0	-0.3	-1.0	1.8	2.6	-1.8	-2.9	-0.8	0.2	0.5	0.2	-1.0	-0.8	-0.7	1.4	1.3	-0.3	-0.4	0.6	-1.7	0.6	2.1	2.2	-2.0	-2.4	-0.4	2.8	1.2	2.1	-1.9	0.4	-0.9	-1.8	-1.1	2.9	2.1	3.1	-1.2	0.7	2.4	-0.2	-1.0	0.4
12.1	2.5	-0.6	-1.0	-0.4	0.3	-2.4	2.7	-2.9	-1.1	2.6	-0.1	-2.2	2.5	2.6	-1.8	-1.7	0.2	-2.3	0.2	-1.1	-0.1	-0.8	-1.6	3.0	2.5	2.0	-2.2	0.4	0.2	-2.4	2.2	-2.2	2.5	2.0	1.3	2.9	-0.2	3.1	2.6	-2.9	1.0	-2.2	1.7	2.2	1.8	1.8	-2.5	-1.7	2.3	-0.6	-0.8	-0.5	0.5	-2.2
10.6	1.1	-1.2	-2.6	-1.8	-1.4	1.0	1.1	-1.9	1.9	3.1	-1.2	-2.4	-1.3	2.8	0.2	1.8	-1.5	-1.9	2.3	-1.4	-1.3	-2.5	1.4	1.3	-0.6	-2.4	1.8	-0.7	-1.5	-2.9	-0.8	3.1	-1.0	-0.3	-1.6	-0.5	2.7	-0.9	-0.8	2.8	-0.9	-1.9	-1.8	2.1	0.9	0.1	-0.2	-2.1	0.0	-1.9	-2.6	-1.7	-1.2	0.5
9.4	-2.5	0.7	0.0	0.6	2.3	0.7	2.8	-1.1	1.4	-1.0	-0.5	1.3	1.1	2.5	0.9	-2.5	0.0	2.2	-0.3	-1.1	0.1	-2.0	-2.1	1.2	-2.3	-1.2	1.4	0.2	-0.5	2.5	1.9	-1.7	2.1	-1.6	0.1	-0.5	1.3	-1.2	1.4	-1.8	-0.7	1.9	-0.1	-1.5	-0.6	-2.3	-0.9	2.3	-0.6	1.7	0.6	-1.5	2.6	0.7
8.5	-0.2	2.9	2.9	3.0	1.2	-2.3	0.3	-3.0	-2.1	0.0	-0.7	1.8	1.8	2.1	-2.3	-1.8	0.7	-2.1	1.2	0.4	-3.1	-2.0	-1.7	0.5	0.7	-2.1	0.0	-2.4	0.6	-0.7	1.0	-1.9	2.7	-0.3	0.6	1.9	0.8	2.1	-2.5	-0.1	-2.6	2.9	1.1	-0.5	0.3	-1.4	0.6	1.0	-0.5	3.0	3.0	-2.6	2.6	-1.4
7.7	-3.1	2.6	-1.1	-2.9	2.3	-1.6	2.2	-2.6	1.1	0.4	2.3	1.8	-2.6	-1.4	1.5	-0.5	2.0	-1.9	0.2	-2.4	-3.1	-3.0	-3.0	-1.0	1.4	-2.7	-1.0	-2.8	2.2	-1.4	1.4	-2.5	0.4	-1.0	1.1	-2.2	2.5	1.4	1.0	2.5	-1.4	-2.1	-0.1	-0.4	2.3	0.3	-0.9	0.7	-2.7	3.0	-1.0	-3.0	2.6	-1.3
7.1	2.8	0.8	0.9	2.6	-0.9	-3.1	-0.3	0.7	0.0	-0.8	-1.0	2.9	1.9	-0.6	-1.1	2.4	-1.2	-3.0	2.8	-3.1	0.0	2.2	0.7	-1.7	-3.0	2.7	-0.7	2.6	-0.8	-2.5	3.0	-0.9	-1.1	-0.8	0.2	3.1	2.7	0.5	0.1	-0.1	-1.6	3.1	-0.1	-2.6	-2.1	0.2	1.3	-2.0	1.9	0.8	0.6	2.1	-0.7	-2.8
6.5	2.1	-1.6	1.0	1.5	-1.0	1.4	-2.7	-1.4	0.0	-1.1	-0.5	-3.1	2.9	0.8	0.2	-1.9	-0.1	1.9	0.7	2.3	-1.6	1.2	-2.7	0.5	2.1	3.1	0.9	0.8	-0.2	2.0	1.2	2.1	0.2	-0.9	-0.4	1.7	2.7	-1.1	-0.1	0.4	1.0	3.0	-0.3	2.2	-2.1	-1.1	1.4	-2.2	2.3	-2.7	0.9	1.2	-1.3	1.1
6.1	-1.7	-1.6	2.7	0.9	-0.3	1.2	-0.7	-3.0	-2.6	-2.7	0.6	2.7	2.5	-2.3	-2.0	-2.8	0.2	2.6	-0.7	2.8	2.9	1.3	-0.8	1.4	-1.1	2.9	1.4	0.3	0.1	1.9	-1.6	2.4	-2.5	-2.1	0.4	3.0	-1.6	-0.9	-2.9	2.8	1.0	2.4	1.7	1.5	-0.3	-1.9	-0.4	2.2	-2.4	-1.9	2.8	1.0	-0.9	0.8
5.7	-0.7	0.7	2.2	0.1	0.3	-0.8	-1.7	-2.9	-1.7	-2.8	-1.1	-2.3	1.9	0.5	-1.5	2.1	-0.5	1.9	-0.8	-2.8	-0.3	0.2	2.2	-0.7	-1.0	-2.1	-2.8	-0.1	-0.9	0.5	-0.1	0.0	0.9	-2.9	-0.8	-2.0	-0.5	0.9	-2.5	3.1	-1.7	2.8	2.3	-0.8	0.1	-2.9	-1.0	1.4	2.5	0.8	2.2	0.2	1.4	0.0

Table A29: 2018 Fungi and physical conditions covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Fungi

	VWC						Water Grad.						Temp					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	0.0	0.0	0.0	3.1	0.0	3.1	0.0	0.0	3.1	0.0	3.1	3.1	3.1	3.1	3.1	0.0	0.0
85.0	2.6	-0.3	0.2	-1.2	2.5	-1.4	2.7	1.2	0.9	2.7	-0.8	-2.9	-1.6	1.9	1.9	2.5	-1.4	0.8
42.5	-1.3	0.1	1.7	3.0	1.8	2.3	-0.1	1.6	-0.1	1.7	0.3	-2.2	0.8	2.7	2.4	2.6	-0.2	-0.1
28.3	3.0	-0.5	0.5	1.5	-2.9	1.6	2.1	-2.7	-0.6	-0.8	2.2	0.5	-1.0	1.5	2.9	2.5	-0.8	-2.3
21.3	0.1	2.2	0.9	-0.5	-2.3	-1.5	-0.1	-0.1	-1.3	-0.8	-3.0	-2.4	2.1	-2.6	2.2	0.8	-0.8	0.8
17.0	2.7	2.6	-1.4	2.5	2.3	1.6	2.2	-0.2	1.6	-0.5	-2.7	-0.9	-1.0	-1.3	1.2	2.5	-1.7	-1.9
14.2	-0.7	0.4	0.8	2.1	-1.0	0.2	-0.6	3.0	2.2	0.2	-1.2	0.3	1.4	2.1	2.2	2.7	1.1	1.9
12.1	0.7	-0.8	0.1	-1.6	-0.6	-2.8	0.1	2.3	1.5	-1.9	-1.3	2.0	3.0	1.0	2.0	1.2	1.5	-0.7
10.6	0.0	-3.0	-2.4	2.6	0.5	-1.0	-1.4	0.5	1.1	-0.5	-2.2	2.8	-0.3	2.9	-2.6	-0.1	0.0	-1.0
9.4	1.0	0.8	2.4	2.0	0.5	2.2	0.9	-0.9	0.3	-3.0	1.0	1.3	1.8	0.9	1.9	-0.1	0.2	-2.8
8.5	1.9	1.5	1.8	-1.4	-1.0	1.0	1.1	-1.3	-1.0	-2.4	-1.5	-0.6	-2.9	2.5	2.8	-2.2	0.1	2.3
7.7	-0.4	-2.5	-2.9	2.5	-2.9	-1.2	-0.7	0.6	0.0	1.3	3.1	-1.8	2.7	0.4	-0.1	-0.2	0.1	2.1
7.1	-0.3	0.1	-2.2	2.5	-1.8	1.6	-2.1	-3.0	2.0	2.4	2.8	1.8	-2.1	-1.7	2.8	1.3	2.7	0.5
6.5	1.5	-2.9	-1.1	2.6	-2.0	1.1	1.9	-0.9	0.5	1.0	-0.4	-2.9	-1.4	0.5	1.8	-2.3	1.5	-1.6
6.1	0.0	-2.9	2.2	1.5	-0.5	1.4	-0.1	1.4	1.4	0.4	-1.3	0.5	-0.5	2.3	1.5	0.1	-2.3	-0.1
5.7	2.9	0.9	0.1	-2.8	0.3	-2.8	2.7	-2.3	2.8	0.4	1.6	-0.3	1.3	-1.1	-2.1	2.0	-1.5	1.7

	Temp. Grad.						Bottom Flux						Water Storage					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	3.1	0.0	3.1	3.1	0.0	3.1	3.1	3.1	0.0
85.0	2.3	-0.3	0.3	0.8	2.7	-1.4	1.4	-1.5	-1.3	2.3	1.4	-2.7	-1.9	1.5	1.8	2.1	-1.7	0.3
42.5	-1.0	0.9	0.7	2.1	-2.1	-2.2	-1.1	0.7	0.4	-0.2	-2.3	-2.2	1.7	-2.9	-3.1	3.0	0.4	0.5
28.3	-3.0	-0.6	0.7	0.2	-2.9	1.9	0.1	2.5	-2.2	-2.3	0.2	-1.4	2.8	-1.1	0.5	1.3	3.0	1.4
21.3	2.2	2.8	2.2	-0.2	-1.4	0.3	-1.5	0.2	-1.6	2.7	2.0	-2.6	0.0	1.5	0.9	-0.4	-1.7	-1.6
17.0	1.7	1.5	-3.0	2.5	1.3	0.5	-0.8	-1.1	1.3	-1.8	-1.4	-1.9	2.8	2.5	-1.3	0.8	2.2	1.7
14.2	-0.1	0.8	0.9	-0.1	-0.3	0.3	1.5	2.2	2.2	-1.3	0.9	1.7	-0.6	0.3	0.6	1.8	-0.8	-0.1
12.1	1.8	-0.3	0.8	-0.1	0.2	-2.0	-3.0	1.3	2.3	0.8	1.8	-0.4	0.5	-1.5	-0.5	-1.5	-1.0	3.1
10.6	-1.2	1.9	2.8	-1.2	-0.9	-2.1	2.8	-0.4	0.2	-1.1	2.9	1.8	-0.7	2.3	3.0	2.9	-0.6	-1.9
9.4	0.9	0.0	0.9	-1.6	-0.8	2.3	1.0	0.1	0.9	-1.6	-0.9	2.5	-2.2	-3.1	-2.5	2.4	2.0	-0.6
8.5	2.5	1.7	1.8	-2.6	-0.7	1.4	-1.3	-2.1	-1.7	1.0	1.8	-2.3	1.9	1.1	1.5	-1.6	-1.3	0.8
7.7	1.9	-0.4	-1.0	-1.4	-0.7	1.3	2.2	-0.1	-0.7	-0.5	-0.5	1.5	-0.5	-2.8	3.0	2.7	-3.1	-1.1
7.1	-2.3	-1.6	3.1	1.5	2.6	0.7	-2.4	-1.9	2.7	-1.5	2.8	0.1	0.5	0.8	-1.0	1.9	-1.0	2.8
6.5	-2.5	-0.6	0.6	2.7	0.3	-2.8	-2.8	-1.0	0.2	-0.7	-0.1	-3.1	1.0	2.9	-2.2	2.2	-2.5	0.9
6.1	-1.0	1.9	1.1	0.2	-2.5	-0.1	-1.8	1.0	0.2	-1.1	2.6	-1.3	0.7	-2.9	3.1	1.6	-0.7	1.2
5.7	0.4	-2.0	-3.0	0.6	-2.5	0.8	-0.6	-3.0	2.2	-0.1	2.7	-0.2	-2.8	1.2	0.0	-0.5	0.3	-2.3

Table A30: 2018 Fungi and weather condition covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Fungi

	Mean Air Temp.						Air Temp. Ran.						Humidity						ET						GWT Depth					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	0.0	3.1	3.1	3.1	0.0	3.1	0.0	0.0	0.0	3.1	3.1	0.0	3.1	3.1	3.1	0.0	0.0	3.1	0.0	0.0	0.0	3.1	0.0	0.0	3.1	3.1	3.1	0.0	3.1
85.0	-2.0	1.5	1.7	2.0	-1.8	0.4	1.7	-1.1	-0.9	-1.4	1.9	-2.3	-1.1	2.4	2.6	3.0	-0.9	1.3	2.4	-0.4	-0.2	0.6	2.6	-1.6	-0.5	3.0	-3.1	-2.5	-0.3	1.8
42.5	0.0	1.9	1.7	3.0	-1.0	-1.0	-1.4	0.4	0.2	0.9	-2.5	-2.4	1.7	-2.8	-3.0	-0.9	0.6	0.7	-0.3	1.6	1.4	1.6	-1.3	-1.3	1.7	-2.8	-3.0	-0.2	0.6	0.7
28.3	-1.5	0.9	2.5	2.2	-1.4	-2.8	1.7	-2.1	-0.6	-1.8	1.9	0.4	-0.5	2.0	-2.8	0.7	-0.3	-1.8	2.1	-1.7	-0.2	1.5	2.3	0.9	-0.4	2.1	-2.7	-2.5	-0.2	-1.7
21.3	2.0	-2.6	2.0	0.1	-0.7	0.7	-1.2	0.4	-1.2	3.1	2.3	-2.5	1.0	2.6	1.0	-0.7	-1.7	-0.3	2.6	-2.0	2.7	-0.1	-0.1	1.4	1.7	-2.9	1.8	-3.1	-1.0	0.5
17.0	-0.9	-1.2	1.1	1.8	-1.6	-2.0	-1.0	-1.3	1.1	-1.5	-1.6	-2.0	-0.8	-1.1	1.3	1.3	-1.4	-1.8	-3.1	2.9	-1.0	-1.7	2.5	2.2	-1.0	-1.3	1.1	2.3	-1.7	-2.0
14.2	0.4	1.3	1.5	1.0	0.1	0.8	2.6	-2.8	-2.5	-2.0	2.4	3.0	2.3	-3.1	-2.9	1.5	2.0	2.7	0.6	1.4	1.7	-1.9	0.3	1.0	2.9	-2.5	-2.3	3.0	2.6	-3.0
12.1	2.3	0.2	1.3	0.5	0.7	-1.4	-3.0	1.3	2.3	0.1	1.8	-0.4	-1.1	-3.1	-2.1	3.0	-2.6	1.5	2.3	0.3	1.3	0.0	0.8	-1.4	-1.8	2.4	-2.8	2.3	2.9	0.7
10.6	-0.7	2.4	3.1	-0.6	-0.5	-1.6	-2.0	1.2	1.8	-1.7	-1.8	-2.8	0.6	-2.5	-1.8	1.8	0.8	-0.2	-1.4	1.8	2.5	-1.3	-1.1	-2.2	0.0	3.1	-2.5	1.0	0.2	-0.9
9.4	1.4	0.5	1.6	-0.8	-0.2	3.1	1.8	0.9	2.0	-1.9	0.2	-2.8	-0.7	-1.6	-0.6	0.8	-2.3	0.9	2.1	1.2	2.3	-1.9	0.5	-2.5	2.0	1.1	2.1	0.4	0.4	-2.6
8.5	2.8	2.1	2.4	-2.6	-0.4	1.9	-1.7	-2.5	-2.2	2.5	1.3	-2.6	2.1	1.3	1.6	0.5	-1.2	1.2	-1.8	-2.5	-2.2	-2.7	1.2	-2.7	-2.7	2.8	3.1	1.1	0.3	2.6
7.7	2.5	0.2	-0.2	-1.2	-0.1	1.9	1.1	-1.1	-1.6	-2.3	-1.5	0.5	-2.5	1.5	1.0	1.1	1.2	-3.1	1.2	-1.1	-1.6	-2.0	-1.5	0.6	2.7	0.4	0.0	0.2	0.1	2.1
7.1	-1.5	-1.2	-3.1	0.1	-3.1	0.8	2.7	3.1	1.2	-2.5	1.1	-1.3	-0.6	-0.2	-2.1	0.2	-2.2	1.7	3.1	-2.8	1.6	-2.6	1.5	-0.8	-2.3	-2.0	2.4	-1.0	2.3	0.0
6.5	-1.8	0.1	1.4	2.6	1.1	-2.0	-3.1	-1.2	0.0	-1.1	-0.3	3.0	0.3	2.2	-2.8	0.8	-3.1	0.1	-2.9	-1.0	0.3	-2.3	0.0	-3.1	-1.1	0.8	2.1	-1.7	1.8	-1.2
6.1	-0.9	2.0	1.3	-0.7	-2.6	0.0	2.9	-0.4	-1.2	2.3	1.2	-2.5	0.8	-2.6	3.0	-1.0	-0.9	1.6	-2.0	0.9	0.1	-1.8	2.6	-1.2	3.0	-0.3	-1.1	-2.0	1.3	-2.4
5.7	0.4	-2.0	-3.0	1.2	-2.6	0.8	-2.5	1.4	0.4	0.5	0.8	-2.1	1.2	-1.1	-2.1	-1.2	-1.7	1.6	-0.6	-3.0	2.3	0.4	2.7	-0.3	2.1	-0.2	-1.2	-2.9	-0.8	2.5

Table A31: 2018 Actinomycete and chemical covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Actinomycetes

	NO3-N						P						SO4-S					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	0.0	3.1	0.0	3.1	0.0	3.1	3.1	3.1	3.1	3.1	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1
85.0	-1.2	-2.7	-1.1	-3.0	1.0	-3.1	2.6	-2.6	2.8	2.7	0.5	1.9	0.8	0.7	1.1	0.7	-0.6	1.6
42.5	-1.3	0.0	-1.2	2.3	0.4	-0.6	0.7	-1.7	0.2	-2.9	0.7	1.0	-0.3	0.7	-2.5	0.7	1.1	-0.6
28.3	-0.5	-1.3	1.9	0.2	-2.2	-2.5	-2.2	2.9	-1.7	-1.1	-2.0	2.9	0.5	3.0	2.1	-0.2	-1.6	-2.1
21.3	2.9	1.5	0.6	-0.6	-3.1	-2.1	-1.0	-1.9	0.3	1.9	-0.1	-1.9	-0.6	1.7	0.3	-1.5	2.3	-1.8
17.0	0.1	-2.6	-0.8	-1.4	-1.1	0.6	-1.2	-0.2	-0.4	2.0	-0.2	1.0	-1.9	0.0	-0.7	2.8	-1.1	1.7
14.2	-0.3	-1.1	-0.5	2.8	3.0	-1.5	0.5	0.3	-2.0	-1.6	-2.9	-0.1	1.3	-2.5	-1.2	-0.6	2.2	1.4
12.1	0.2	-0.1	-2.6	2.8	-3.0	3.0	0.4	-2.4	-2.7	-0.5	2.8	3.1	0.2	-3.1	2.9	1.6	-3.1	3.1
10.6	1.3	-0.5	-1.7	1.4	1.8	0.9	1.4	-1.2	2.8	0.0	2.0	-2.5	-1.0	-2.8	1.1	-1.3	1.7	-2.0
9.4	0.2	-3.1	1.8	-1.3	2.0	1.0	-0.7	1.4	-3.1	-2.9	-0.9	1.6	-2.5	-1.3	2.7	1.9	-0.3	2.5
8.5	1.8	-2.1	0.9	1.6	1.0	2.7	2.3	-1.7	2.1	-1.3	-0.8	0.5	-2.6	-2.9	1.9	3.1	0.5	2.9
7.7	-2.8	0.2	-1.0	-2.9	-1.0	2.2	2.4	1.3	1.2	0.4	-1.0	-0.7	-2.3	2.5	1.6	-0.6	-1.3	1.9
7.1	-0.4	2.8	-2.0	-1.6	-2.8	0.7	2.8	2.8	-2.8	1.3	-2.8	0.4	-1.3	1.4	2.4	-1.7	-3.0	0.8
6.5	1.7	1.9	1.0	-2.5	2.6	-1.6	-3.1	2.1	-0.1	1.1	3.0	0.3	2.6	-2.0	0.1	0.3	-2.8	-1.0
6.1	-2.0	-2.6	-2.9	-2.5	1.5	-2.2	-1.1	2.3	-1.9	0.2	2.4	-0.7	2.1	3.1	-1.2	0.0	2.0	-0.7
5.7	-2.9	-0.4	1.6	-3.1	-2.5	1.2	2.4	2.3	-2.3	0.3	2.4	-0.2	-0.2	-0.6	-2.0	-1.1	3.0	-2.3

	Mn						NH4-N						TN					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	0.0	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	0.0	3.1	3.1	3.1	3.1	0.0	0.0	0.0
85.0	-1.5	-2.0	-2.0	-2.0	1.7	-2.5	2.9	-2.5	-2.9	-2.7	0.5	2.2	1.6	2.2	2.9	1.4	-0.7	1.4
42.5	1.2	-1.3	1.7	1.1	1.1	1.5	2.1	-0.3	0.1	0.6	1.1	1.0	2.1	-1.3	2.1	-1.7	3.1	2.0
28.3	1.4	-1.1	-2.5	-0.6	-1.8	-0.9	0.1	-3.0	-2.1	-0.1	-2.1	-1.5	0.8	-1.8	2.1	-2.4	0.1	-0.9
21.3	-0.9	0.5	-2.9	3.1	0.6	-1.6	-0.7	-2.8	1.0	2.8	1.7	-2.0	-1.2	-3.0	1.1	-0.4	2.6	-1.5
17.0	-0.4	0.9	-0.5	0.8	1.8	-1.5	0.2	-0.8	-1.3	3.1	-0.2	3.0	-2.2	0.2	-0.9	2.2	-0.6	-2.3
14.2	0.8	-1.3	-2.6	-3.0	3.1	-2.9	0.8	-0.1	-1.7	2.8	-2.7	-1.5	-0.1	-0.9	-0.9	-1.0	2.0	1.8
12.1	-2.1	-0.6	-1.7	2.4	1.3	2.1	0.3	2.5	2.5	-2.7	-3.1	3.0	-0.1	-1.7	0.9	-1.1	-2.0	1.9
10.6	2.6	-0.7	-0.4	0.7	-1.6	1.2	-0.3	-1.7	2.7	2.5	1.7	-3.0	-0.5	-2.5	-0.1	2.8	1.7	-0.6
9.4	2.4	1.4	1.9	2.4	-2.5	1.4	0.4	1.3	-3.0	-1.8	-0.9	2.7	-1.7	0.8	-2.3	2.7	-0.2	-0.2
8.5	3.1	1.6	1.1	2.9	-1.9	-0.7	2.7	-0.8	-2.1	2.5	0.4	-2.0	2.9	-0.6	0.7	-1.7	0.5	0.6
7.7	0.5	1.5	-3.0	-3.0	0.0	2.8	1.7	1.2	-0.9	-2.8	-1.1	2.4	1.6	1.4	0.5	-1.1	-2.2	1.6
7.1	-0.4	-1.1	-2.9	-2.0	-1.1	2.1	0.1	-1.5	2.7	-1.6	-2.6	1.3	-0.2	1.1	2.4	1.3	-1.6	0.6
6.5	0.3	-0.5	-1.7	-2.8	0.9	-2.4	1.7	0.3	0.8	3.0	-2.9	-0.9	0.9	-0.8	0.2	1.3	-3.1	-1.3
6.1	-1.1	1.9	-2.7	-2.1	1.0	-2.0	-1.4	1.9	2.1	-3.1	1.9	-1.5	-1.9	1.4	-1.8	0.8	2.2	-0.3
5.7	-2.9	2.5	-0.9	-3.0	-0.6	1.4	-3.1	-3.1	2.9	3.0	2.6	2.6	-2.3	-1.1	0.3	0.2	2.7	0.1

	TC						pH						EC					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	0.0	3.1	0.0	3.1	0.0	0.0	3.1	0.0	3.1	0.0	3.1	0.0	0.0	3.1	3.1	3.1	0.0	3.1
85.0	1.4	-2.9	0.0	2.1	-1.1	1.1	2.2	0.8	2.8	-0.4	-1.7	0.4	-1.4	-2.6	-1.6	-3.0	1.1	3.0
42.5	0.7	-0.4	-0.5	-2.2	-0.8	2.0	1.8	-2.0	1.4	-1.1	1.8	1.7	-1.3	-0.1	-1.2	1.8	0.8	-0.1
28.3	1.1	2.2	3.1	-3.0	2.7	-2.3	1.8	2.9	-1.3	2.7	1.5	-1.1	-0.1	-1.4	2.3	0.3	-2.1	-2.1
21.3	-2.9	-2.5	1.2	0.6	0.5	1.1	-0.5	-2.1	-2.2	-0.1	2.9	0.9	2.8	2.6	0.5	-3.1	-2.7	-2.1
17.0	2.9	0.0	-1.3	1.1	-2.2	-0.8	-2.6	0.0	2.1	2.9	-1.1	-2.6	0.4	-2.6	-1.1	-1.2	0.2	0.6
14.2	1.2	1.4	-1.8	-1.1	2.2	-1.7	0.7	3.0	2.1	-0.3	-0.1	1.1	0.4	-0.8	-0.7	2.9	3.1	-1.7
12.1	-2.5	-2.6	1.0	0.4	-2.4	3.1	-0.6	2.8	0.2	-1.3	0.5	-2.6	0.0	0.0	-2.4	2.7	-2.9	3.1
10.6	3.0	-0.2	0.1	-0.3	2.4	-2.0	-1.6	2.8	1.8	-3.0	3.1	-2.2	0.2	-1.2	-1.7	1.5	2.0	0.4
9.4	-2.3	1.3	-3.1	2.5	-1.1	2.2	2.6	1.0	1.2	2.0	-1.2	2.5	2.1	-2.1	2.4	2.9	2.3	0.9
8.5	2.7	-2.9	1.7	-1.5	-2.8	1.7	3.0	0.8	-1.8	-2.8	0.4	-0.3	1.5	-2.0	1.0	2.3	2.5	-2.7
7.7	2.8	-1.0	1.1	2.4	1.6	1.6	0.2	-2.8	2.4	0.3	2.1	-1.8	-2.5	0.6	-0.9	-3.0	-0.6	2.5
7.1	-0.5	2.5	-2.8	1.9	2.8	0.6	3.0	-0.5	1.3	2.3	-0.5	1.8	-1.3	2.9	-2.3	-2.1	-2.6	1.0
6.5	2.3	2.4	-0.2	2.6	-1.7	0.1	-0.6	-0.6	-2.2	1.1	-1.3	1.1	2.0	0.7	0.8	-2.8	2.2	-1.9
6.1	-2.0	-1.9	-2.2	-0.6	2.8	-0.9	1.3	0.6	0.4	1.0	1.4	-1.1	-2.8	-2.8	-2.7	-2.4	0.9	-2.6
5.7	-2.7	-0.2	-3.1	-0.1	1.8	-1.4	0.2	-1.9	-0.5	0.2	2.5	-2.8	0.3	-0.2	1.6	-3.1	-1.4	2.1

Table A32: 2018 Actinomycete and physical conditions covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Actinomycetes

	VWC						Water Grad.						Temp						Temp. Grad.						Bottom Flux						Water Storage					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	3.1	3.1	0.0	0.0	3.1	3.1	0.0	3.1	0.0	3.1	0.0	3.1	0.0	0.0	0.0	3.1	3.1	3.1	3.1	3.1	3.1	0.0	3.1	0.0	3.1	3.1	0.0	0.0	0.0	3.1	0.0	0.0	0.0	3.1	3.1
85.0	2.6	-2.7	-3.1	1.6	0.6	2.5	2.7	-1.2	-2.3	-0.9	-2.8	1.0	-1.6	-0.4	-1.3	-1.1	3.0	-1.6	2.3	-2.7	-2.9	-2.8	0.8	2.5	1.4	2.4	1.8	-1.3	-0.5	1.1	-1.9	-0.8	-1.4	-1.4	2.6	-2.1
42.5	0.9	-2.5	1.8	1.2	-1.3	-0.6	2.0	-1.0	0.0	-0.1	-2.9	1.2	3.0	0.1	2.5	0.8	3.0	-3.1	1.2	-1.7	0.9	0.3	1.0	1.2	1.0	-1.9	0.6	-2.0	0.9	1.2	-2.4	0.8	-3.0	1.2	-2.7	-2.5
28.3	1.7	-0.5	-2.3	-1.2	-1.6	-0.9	0.8	-2.7	2.8	2.7	-2.8	-2.0	-2.3	1.6	0.1	-0.2	0.5	1.5	2.0	-0.5	-2.1	-2.5	-1.5	-0.6	-1.2	2.5	1.3	1.2	1.6	2.4	1.5	-1.0	-2.4	-1.5	-2.0	-1.1
21.3	0.6	0.5	-1.0	2.8	1.1	-1.5	0.4	-1.8	3.0	2.5	0.5	-2.3	2.6	2.0	0.2	-2.2	2.7	0.8	2.7	1.1	0.3	3.1	2.1	0.4	-1.1	-1.5	2.7	-0.3	-0.8	-2.5	0.5	-0.2	-1.1	2.8	1.8	-1.6
17.0	-2.1	0.3	2.8	-3.0	1.3	2.9	-2.5	-2.5	-0.5	0.3	2.5	0.3	0.6	2.7	-0.9	-2.9	-2.7	-0.7	-3.1	-0.9	1.2	-2.9	0.3	1.8	0.7	2.8	-0.8	-1.0	-2.4	-0.6	-2.0	0.1	2.9	1.6	1.2	3.0
14.2	0.9	-1.0	-2.3	-1.0	3.1	-1.9	1.0	1.6	-0.8	-3.0	2.8	-1.7	3.0	0.6	-0.8	-0.4	-1.1	-0.2	1.5	-0.6	-2.1	3.1	-2.6	-1.8	3.1	0.8	-0.8	1.8	-1.4	-0.4	1.0	-1.1	-2.4	-1.3	-3.0	-2.2
12.1	-1.6	-0.3	-1.5	1.7	2.3	2.6	-2.2	2.8	-0.1	1.3	1.6	1.0	0.7	1.6	0.4	-1.9	-1.8	-1.6	-0.5	0.3	-0.8	-3.1	3.1	-3.0	1.0	1.8	0.7	-2.2	-1.6	-1.3	-1.8	-1.0	-2.1	1.8	1.9	2.2
10.6	0.3	-2.3	-1.6	-0.5	-2.6	-1.1	-1.2	1.2	2.0	2.7	1.0	2.8	0.0	-2.7	-1.8	3.1	-3.0	-1.1	-1.0	2.6	-2.6	2.0	2.3	-2.2	3.0	0.3	1.1	2.1	-0.2	1.7	-0.5	3.0	-2.4	-0.2	2.7	-2.0
9.4	-2.6	-3.0	-2.1	0.1	0.2	2.4	-2.7	1.6	2.1	1.3	0.7	1.5	-1.8	-2.9	-2.6	-2.0	-0.1	-2.6	-2.7	2.5	2.7	2.7	-1.1	2.5	-2.6	2.6	2.8	2.7	-1.3	2.8	0.5	-0.6	-0.7	0.4	1.6	-0.3
8.5	-2.5	2.8	-0.3	-2.7	-1.1	-0.2	3.1	0.0	-3.1	2.5	-1.7	-1.9	-1.0	-2.5	0.7	2.8	-0.1	1.1	-1.9	3.0	-0.3	2.4	-0.8	0.1	0.7	-0.8	2.5	-0.4	1.7	2.8	-2.5	2.3	-0.6	-2.9	-1.4	-0.4
7.7	-0.1	1.4	-2.8	2.5	0.1	2.6	-0.5	-1.8	0.1	1.3	-0.2	2.0	2.9	-2.0	0.0	-0.2	3.1	-0.4	2.1	-2.8	-0.9	-1.4	2.3	-1.2	2.5	-2.5	-0.6	-0.6	2.5	-1.0	-0.3	1.1	3.1	2.6	-0.1	2.6
7.1	2.7	2.2	1.2	-1.7	2.6	-0.9	1.0	-1.0	-0.8	-1.8	1.0	-0.7	1.0	0.4	0.0	-2.9	0.9	-2.0	0.8	0.4	0.3	-2.6	0.8	-1.8	0.7	0.1	-0.1	0.6	1.0	-2.4	-2.7	2.9	2.4	-2.3	-2.8	0.3
6.5	1.2	0.6	-1.2	-1.4	1.6	-1.9	1.6	2.5	0.4	-3.0	-3.1	0.4	-1.7	-2.3	1.7	0.0	-1.2	1.8	-2.8	2.8	0.6	-1.3	-2.5	0.5	3.1	2.5	0.1	1.6	-2.8	0.2	0.7	0.1	-2.3	-1.8	1.1	-2.0
6.1	-0.3	2.4	3.0	-1.9	1.3	-2.0	-0.5	0.4	2.1	-3.0	0.5	-2.9	-0.9	1.4	2.2	3.0	-0.5	2.8	-1.4	1.0	1.8	3.1	-0.7	2.8	-2.2	0.0	0.9	1.8	-1.8	1.6	0.3	2.5	-2.5	-1.8	1.1	-2.2
5.7	0.7	-0.1	-0.5	0.3	-2.5	-0.7	0.5	3.0	2.2	-2.8	-1.3	1.8	-0.8	-2.1	-2.6	-1.2	2.0	-2.5	-1.7	-3.1	2.7	-2.6	0.9	2.9	-2.8	2.2	1.6	3.0	-0.2	1.9	1.3	0.1	-0.6	2.6	-2.5	-0.2

Table A33: 2018 Actinomycete and weather condition covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Actinomycetes

	Mean Air Temp.						Air Temp. Ran.						Humidity						ET						GWT Depth					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	0.0	0.0	3.1	3.1	3.1	3.1	3.1	3.1	0.0	0.0	3.1	0.0	0.0	0.0	0.0	3.1	0.0	3.1	3.1	3.1	3.1	0.0	3.1	0.0	0.0	0.0	0.0	3.1	0.0
85.0	-2.0	-0.8	-1.5	-1.6	2.6	-2.0	1.7	2.8	2.2	1.3	-0.1	1.6	-1.1	0.0	-0.6	-0.6	-2.8	-1.2	2.4	-2.8	2.9	-2.9	0.6	2.3	-0.5	0.6	0.0	0.3	-2.3	-0.6
42.5	2.2	-0.7	1.8	1.2	2.1	2.4	0.8	-2.2	0.4	-0.9	0.7	0.9	-2.4	0.9	-2.8	-2.7	-2.5	-2.3	1.9	-1.0	1.5	-0.2	1.8	2.1	-2.4	0.9	-2.8	-2.0	-2.5	-2.3
28.3	-2.8	1.0	-0.4	-0.6	0.0	1.0	0.5	-2.1	2.9	1.7	-3.1	-2.1	-1.8	2.0	0.6	-2.1	1.0	2.0	0.9	-1.6	-3.0	-1.3	-2.7	-1.6	-1.7	2.1	0.7	1.0	1.1	2.1
21.3	2.5	2.0	0.0	-2.9	2.7	0.8	-0.8	-1.3	3.1	0.1	-0.5	-2.5	1.5	0.9	-1.0	2.6	1.7	-0.3	3.1	2.6	0.7	-3.1	-2.9	1.4	2.2	1.7	-0.2	0.2	2.5	0.5
17.0	0.6	2.7	-0.9	2.7	-2.6	-0.7	0.6	2.7	-1.0	-0.7	-2.6	-0.8	0.8	2.9	-0.8	2.1	-2.4	-0.6	-1.6	0.6	-3.1	-0.9	1.5	-2.9	0.5	2.7	-1.0	3.1	-2.6	-0.8
14.2	2.0	-0.2	-1.5	-2.2	-2.1	-1.2	-2.1	2.0	0.7	1.1	0.1	1.0	-2.4	1.7	0.4	-1.7	-0.2	0.6	2.1	0.0	-1.4	1.2	-2.0	-1.1	-1.8	2.3	0.9	-0.2	0.3	1.2
12.1	0.0	0.8	-0.3	-2.5	-2.6	-2.4	1.0	1.8	0.7	-3.0	-1.6	-1.4	2.9	-2.6	2.6	-0.1	0.3	0.6	0.0	0.8	-0.3	-3.1	-2.6	-2.4	2.1	2.9	1.8	-0.8	-0.4	-0.2
10.6	-0.5	3.1	-2.3	2.6	2.7	-1.7	-1.7	1.8	2.7	1.5	1.5	-2.9	0.9	-1.9	-1.0	-1.3	-2.2	-0.3	-1.1	2.5	-2.9	1.8	2.1	-2.3	0.2	-2.5	-1.6	-2.1	-2.9	-1.0
9.4	-2.2	3.0	-2.9	-2.8	-0.5	-3.0	-1.8	-2.8	-2.5	2.4	-0.1	-2.6	2.0	0.9	1.2	-1.2	-2.7	1.1	-1.5	-2.5	-2.2	2.4	0.2	-2.3	-1.6	-2.7	-2.3	-1.6	0.1	-2.4
8.5	-1.5	-2.9	0.3	2.3	-0.6	0.6	0.2	-1.2	2.1	1.1	1.2	2.4	-2.3	2.6	-0.4	-0.8	-1.3	-0.1	0.2	-1.3	2.0	2.2	1.1	2.3	-0.8	-2.2	1.0	-0.3	0.1	1.3
7.7	2.8	-2.1	-0.1	-1.3	2.9	-0.6	1.4	2.8	-1.5	-2.4	1.5	-2.0	-2.2	-0.9	1.1	1.1	-2.1	0.7	1.4	2.8	-1.5	-2.0	1.5	-2.0	3.0	-1.9	0.1	0.2	3.1	-0.4
7.1	1.6	0.9	0.4	2.2	1.3	-1.7	-0.5	-1.2	-1.7	-0.4	-0.7	2.5	2.5	1.8	1.3	2.3	2.3	-0.8	-0.1	-0.8	-1.3	-0.5	-0.3	2.9	0.8	0.1	-0.4	1.1	0.5	-2.5
6.5	-2.1	-2.7	1.3	-1.4	-1.6	1.4	2.8	2.2	0.0	1.2	-3.0	0.0	0.0	-0.6	-2.8	3.1	0.5	-2.8	3.1	2.5	0.2	0.0	-2.7	0.3	-1.4	-2.0	2.1	0.6	-0.9	2.1
6.1	-1.2	1.1	2.0	2.2	-0.7	2.9	2.5	-1.4	-0.5	-1.1	3.0	0.4	0.4	2.8	-2.6	1.9	0.9	-1.7	-2.4	-0.1	0.8	1.1	-1.9	1.7	2.7	-1.3	-0.4	0.9	-3.1	0.5
5.7	-1.8	-3.0	2.7	-2.0	0.9	2.8	1.6	0.4	-0.1	-2.7	-2.0	0.0	-0.9	-2.2	-2.7	1.9	1.7	-2.6	-2.8	2.2	1.7	-2.8	-0.1	1.8	0.0	-1.3	-1.8	0.2	2.6	-1.7

Table A34: 2018 Bacteria and chemical covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Bacteria

	NO3-N						P						SO4-S					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	3.1	3.1	0.0	3.1	3.1	0.0	3.1	3.1	0.0
85.0	1.8	-1.5	-0.7	-1.3	-1.3	0.3	-0.8	-1.5	-3.0	-1.8	-1.8	-1.1	-2.6	1.9	1.5	2.5	-2.9	-1.3
42.5	1.2	-1.2	1.7	0.9	-2.8	2.2	-3.0	-2.9	3.1	1.9	-2.5	-2.5	2.2	-0.5	0.4	-0.8	-2.2	2.2
28.3	-2.8	1.2	1.4	-3.1	0.8	1.2	1.8	-1.0	-2.2	1.8	1.0	0.3	-1.9	-0.8	1.5	2.7	1.3	1.6
21.3	-0.4	-0.6	-2.3	-1.7	-1.2	0.9	2.0	2.3	-2.6	0.7	1.8	1.0	2.4	-0.4	-2.6	-2.7	-2.1	1.1
17.0	2.5	1.3	2.7	1.1	2.3	2.9	1.2	-2.6	3.1	-1.9	-3.1	-2.9	0.5	-2.4	2.7	-1.0	2.3	-2.2
14.2	2.5	-2.7	2.8	3.0	0.2	-2.9	-3.0	-1.4	1.2	-1.4	0.6	-1.5	-2.2	2.2	2.0	-0.3	-0.6	-0.1
12.1	-2.6	2.9	1.1	-2.2	-0.1	0.5	-2.4	0.7	1.1	0.8	-0.6	0.6	-2.6	-0.1	0.4	2.9	-0.2	0.6
10.6	-2.2	2.9	1.0	-0.6	-1.2	-2.2	-2.1	2.2	-0.8	-2.0	-1.0	0.8	1.8	0.6	-2.5	3.0	-1.3	1.3
9.4	-1.1	-1.6	-1.4	3.1	-1.2	-2.2	-2.1	2.9	-0.1	1.5	2.2	-1.5	2.4	0.2	-0.6	0.0	2.8	-0.6
8.5	-1.6	0.9	-1.9	-1.2	-2.2	-0.1	-1.1	1.3	-0.7	2.2	2.3	-2.3	0.3	0.1	-0.8	0.3	-2.7	0.1
7.7	0.1	-1.1	2.0	0.6	2.0	-0.7	-0.9	0.0	-2.1	-2.4	2.0	2.7	0.7	1.2	-1.7	2.9	1.6	-1.0
7.1	2.8	0.2	0.6	1.3	0.9	-1.4	-0.3	0.1	-0.3	-2.1	0.8	-1.7	2.0	-1.2	-1.4	1.2	0.6	-1.3
6.5	-1.4	0.0	-2.2	1.1	-0.1	1.7	0.0	0.2	3.1	-1.6	0.3	-2.7	-0.6	2.4	-3.0	-2.4	0.8	2.3
6.1	1.1	1.0	-0.2	0.5	-2.2	0.6	2.1	-0.4	0.7	-3.1	-1.3	2.1	-1.0	0.4	1.4	3.1	-1.7	2.1
5.7	1.2	-3.0	-1.4	3.1	1.2	-1.9	0.2	-0.3	1.0	0.2	-0.2	2.8	-2.4	3.1	1.2	-1.2	0.3	0.8

	Mn						NH4-N						TN					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	3.1	0.0	3.1	3.1	3.1	3.1	3.1	0.0
85.0	1.4	-0.9	-1.5	-0.3	-0.7	0.8	-0.5	-1.3	-2.5	-0.9	-1.8	-0.8	-1.7	-3.0	-3.0	-3.1	-3.1	-1.5
42.5	-2.5	-2.5	-1.7	-0.4	-2.1	-2.0	-1.6	-1.5	3.0	-0.9	-2.1	-2.5	-1.6	-2.4	-1.3	3.1	-0.1	-1.5
28.3	-0.9	1.3	-3.0	2.4	1.2	2.8	-2.2	-0.6	-2.6	2.8	0.8	2.2	-1.5	0.7	1.5	0.6	3.1	2.8
21.3	2.1	-1.6	0.4	2.0	2.5	1.4	2.3	1.5	-1.9	1.7	-2.6	1.0	1.8	1.3	-1.8	-1.5	-1.7	1.4
17.0	2.0	-1.5	2.9	-3.0	-1.1	0.9	2.6	3.0	2.1	-0.7	-3.0	-0.9	0.2	-2.2	2.6	-1.7	2.8	0.1
14.2	-2.7	-2.9	0.6	-2.7	0.3	2.0	-2.7	-1.7	1.5	3.1	0.8	-2.9	2.7	-2.5	2.3	-0.7	-0.8	0.4
12.1	1.3	2.4	2.0	-2.6	-2.1	-0.4	-2.6	-0.7	-0.1	-1.4	-0.2	0.5	-2.9	1.3	-1.6	0.2	0.9	-0.5
10.6	-0.9	2.7	2.3	-1.3	1.7	-1.8	2.5	1.7	-0.9	0.5	-1.3	0.3	2.3	0.9	2.6	0.8	-1.4	2.6
9.4	1.1	2.9	-1.4	0.5	0.6	-1.7	-1.0	2.8	0.0	2.7	2.2	-0.4	-3.1	2.2	0.7	0.9	2.9	2.9
8.5	-0.2	-1.6	-1.6	0.1	1.2	2.7	-0.7	2.2	1.4	-0.3	-2.8	1.5	-0.5	2.4	-2.1	1.8	-2.7	-2.2
7.7	-2.8	0.2	0.0	0.4	2.9	-0.1	-1.6	-0.1	2.1	0.6	1.8	-0.5	-1.7	0.1	-2.7	2.4	0.8	-1.3
7.1	2.8	2.6	-0.3	0.9	2.6	0.0	-3.0	2.1	-1.0	1.3	1.0	-0.7	3.0	-1.5	-1.3	-2.0	2.0	-1.5
6.5	-2.9	-2.4	1.4	0.8	-1.9	0.9	-1.5	-1.6	-2.4	0.3	0.6	2.4	-2.3	-2.6	-3.0	-1.4	0.5	2.1
6.1	2.1	-0.8	0.0	0.9	-2.6	0.8	1.7	-0.7	-1.5	-0.1	-1.7	1.3	1.2	-1.2	0.9	-2.4	-1.5	2.5
5.7	1.2	-0.1	2.3	-3.1	3.1	-1.8	1.0	0.6	-0.1	2.9	0.0	-0.6	1.8	2.6	-2.8	0.1	0.1	-3.1

	TC						pH						EC					
Period	HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	3.1	3.1	0.0	3.1	3.1	3.1	0.0	3.1	3.1	0.0	3.1	3.1	0.0	0.0	0.0	0.0	0.0	0.0
85.0	-1.9	-1.8	0.4	-2.4	2.8	-1.9	-1.2	2.0	-3.1	1.4	2.2	-2.5	1.5	-1.5	-1.1	-1.3	-1.3	0.1
42.5	-3.0	-1.6	2.4	2.6	2.3	-1.5	-1.9	-3.1	-1.9	-2.6	-1.5	-1.9	1.2	-1.3	1.7	0.3	-2.4	2.7
28.3	-1.3	-1.6	2.6	0.0	-0.7	1.4	-0.6	-1.0	-1.9	-0.7	-1.8	2.6	-2.4	1.0	1.8	-3.0	0.8	1.6
21.3	0.1	1.7	-1.7	-0.5	2.4	-2.2	2.5	2.1	1.2	-1.3	-1.5	-2.4	-0.5	0.5	-2.4	2.0	-0.7	0.8
17.0	-1.0	-2.4	2.2	-2.8	1.2	1.6	-0.2	-2.4	-0.7	-1.0	2.3	-0.2	2.8	1.3	2.4	1.2	-2.6	3.0
14.2	-2.3	-0.3	1.4	-0.8	-0.7	-3.1	-2.8	1.4	-0.9	0.0	-2.9	-0.4	-3.1	-2.4	2.5	-3.1	0.2	-3.1
12.1	1.0	0.4	-1.5	1.7	0.5	0.6	2.8	-0.5	-2.3	0.1	-2.9	1.2	-2.8	3.0	1.4	-2.3	0.0	0.6
10.6	-0.5	-3.1	2.8	-2.2	-0.6	1.3	1.2	-0.1	-1.8	1.3	0.1	1.1	3.0	2.2	1.0	-0.5	-1.0	-2.7
9.4	2.7	2.8	-0.1	0.7	2.1	-1.0	1.2	2.5	-2.1	0.2	1.9	-0.6	0.8	-0.6	-0.9	1.0	-0.9	-2.2
8.5	-0.6	0.1	-1.1	2.0	0.4	-1.2	-0.3	-2.5	1.7	0.7	-2.8	-3.1	-1.9	1.0	-1.8	-0.5	-0.7	0.8
7.7	-0.5	-2.3	-2.1	-0.4	-1.7	-1.2	-3.1	2.2	-0.9	-2.6	-1.3	1.6	0.5	-0.7	2.2	0.5	2.3	-0.4
7.1	2.8	-0.1	-0.2	-1.4	0.2	-1.5	0.0	3.1	-2.4	-1.1	-3.1	-0.3	2.0	0.2	0.3	0.9	1.1	-1.1
6.5	-0.8	0.5	2.9	-0.1	1.8	-2.8	2.5	-2.5	0.9	-1.6	2.2	-1.9	-1.2	-1.2	-2.3	0.8	-0.5	1.5
6.1	1.2	1.7	0.5	2.4	-0.8	1.9	-1.8	-2.1	3.1	-2.2	-2.2	1.7	0.4	0.7	0.0	0.6	-2.8	0.2
5.7	1.4	-2.8	0.2	-0.2	-0.9	1.7	-2.0	1.8	2.7	0.1	-0.1	0.3	-1.9	-2.8	-1.4	3.1	2.2	-1.0

Table A35: 2018 Bacteria and physical conditions covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Bacteria

	VWC						Water Grad.						Temp						Temp. Grad.						Bottom Flux						Water Storage					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	0.0	0.0	3.1	3.1	3.1	0.0	0.0	0.0	3.1	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	3.1	0.0	0.0	0.0	3.1	3.1	3.1	0.0	3.1	3.1	0.0	0.0	0.0	0.0	0.0	0.0
85.0	-0.7	-1.5	-2.6	-3.0	-1.8	-0.5	-0.7	-0.1	-1.8	0.9	1.1	-1.9	1.3	0.7	-0.8	0.7	0.6	1.7	-1.1	-1.5	-2.5	-1.0	-1.6	-0.5	-2.0	-2.7	2.2	0.5	-2.9	-1.8	1.0	0.3	-0.9	0.4	0.3	1.2
42.5	-2.8	2.6	-1.5	-0.2	1.8	2.1	-1.7	-2.1	2.9	-1.5	0.2	-2.3	-0.7	-1.1	-0.9	-0.6	-0.2	-0.3	-2.5	-2.9	-2.5	-1.2	-2.2	-2.3	-2.7	-3.1	-2.8	2.8	-2.4	-2.3	0.1	-0.3	-0.1	-0.3	0.4	0.3
28.3	-0.6	2.0	-2.9	1.7	1.4	2.8	-1.5	-0.3	2.3	-0.7	0.2	1.7	1.7	-2.3	-0.5	2.7	-2.8	-1.1	-0.3	1.9	-2.7	0.4	1.4	3.1	2.8	-1.3	0.7	-2.1	-1.8	-0.2	-0.8	1.4	-2.9	1.4	1.0	2.6
21.3	-2.7	-1.6	2.3	1.6	3.1	1.5	-2.9	2.4	0.1	1.4	2.4	0.6	-0.7	-0.1	-2.7	2.9	-1.6	-2.6	-0.6	-1.0	-2.6	1.9	-2.2	-3.0	1.9	2.7	-0.2	-1.5	1.1	0.4	-2.8	-2.2	2.3	1.7	-2.6	1.3
17.0	0.3	-2.1	0.0	-0.5	-1.6	-1.0	-0.1	1.4	3.0	2.7	-0.3	2.7	3.0	0.3	2.5	-0.5	0.7	1.7	-0.7	3.0	-1.6	-0.5	-2.6	-2.1	-3.1	0.4	2.7	1.4	1.1	1.8	0.4	-2.3	0.1	-2.3	-1.6	-0.9
14.2	-2.6	-2.7	0.9	-0.7	0.3	3.0	-2.5	-0.1	2.4	-2.7	0.0	3.1	-0.5	-1.0	2.4	-0.2	2.4	-1.6	-2.0	-2.3	1.1	-2.9	0.9	3.1	-0.4	-0.9	2.4	2.1	2.1	-1.8	-2.5	-2.8	0.8	-1.1	0.4	2.7
12.1	1.9	2.7	2.3	3.0	-1.1	0.1	1.3	-0.5	-2.6	2.6	-1.7	-1.5	-2.2	-1.7	-2.1	-0.5	1.1	2.2	2.9	-3.0	2.9	-1.8	-0.3	0.8	-1.8	-1.5	-1.9	-0.9	1.3	2.5	1.7	2.1	1.6	3.1	-1.5	-0.3
10.6	3.1	1.1	1.2	-2.4	0.7	2.1	1.6	-1.7	-1.5	0.7	-2.0	-0.3	2.8	0.7	1.0	1.1	0.2	2.1	1.8	-0.3	0.1	0.0	-0.7	1.1	-0.4	-2.6	-2.5	0.1	3.1	-1.3	2.3	0.1	0.4	-2.2	-0.3	1.3
9.4	2.3	-1.5	0.9	-1.8	-3.0	-0.7	2.3	3.1	-1.2	-0.5	-2.5	-1.6	-3.1	-1.4	0.5	2.4	3.0	0.6	2.2	-2.3	-0.5	0.9	2.0	-0.6	2.4	-2.2	-0.5	0.9	1.9	-0.3	-0.9	0.9	2.3	-1.4	-1.5	2.8
8.5	0.4	-0.5	-3.0	0.8	2.0	-3.1	-0.3	3.0	0.5	-0.3	1.4	1.6	1.9	0.5	-2.0	0.0	3.0	-1.7	1.0	-0.2	-3.0	-0.4	2.3	-2.7	-2.7	2.2	-0.2	3.1	-1.5	-0.1	0.4	-0.9	3.0	0.6	1.7	3.0
7.7	2.9	0.1	0.2	-0.3	3.1	-0.3	2.5	-3.1	3.1	-1.5	2.8	-0.9	-0.4	3.0	3.0	-3.0	-0.3	3.0	-1.2	2.2	2.2	2.0	-1.1	2.2	-0.8	2.5	2.4	2.9	-0.9	2.4	2.7	-0.2	-0.1	-0.2	2.8	-0.2
7.1	-0.3	-0.5	-2.5	1.3	0.0	-3.0	-2.1	2.7	1.7	1.1	-1.7	-2.8	-2.0	-2.3	2.6	0.0	-1.7	2.2	-2.3	-2.2	2.9	0.3	-1.9	2.4	-2.4	-2.5	2.5	-2.7	-1.6	1.8	0.5	0.2	-1.3	0.7	0.8	-1.7
6.5	-2.0	-1.3	1.9	2.2	-1.1	1.5	-1.6	0.6	-2.7	0.6	0.5	-2.5	1.4	2.1	-1.4	-2.7	2.4	-1.2	0.3	1.0	-2.6	2.2	1.1	-2.4	0.0	0.6	-3.1	-1.1	0.7	-2.7	-2.5	-1.8	0.8	1.8	-1.7	1.3
6.1	2.8	-0.2	-0.6	1.1	-2.4	0.8	2.7	-2.3	-1.5	0.0	3.1	-0.1	2.3	-1.3	-1.4	-0.3	2.1	-0.6	1.8	-1.7	-1.8	-0.1	1.9	-0.6	1.0	-2.7	-2.7	-1.5	0.8	-1.9	-2.8	-0.2	0.2	1.2	-2.6	0.6
5.7	-1.5	-2.7	2.7	0.2	1.1	2.4	-1.7	0.4	-0.8	-2.9	2.4	-1.4	-3.0	1.5	0.6	-1.3	-0.7	0.6	2.4	0.6	-0.3	-2.8	-1.7	-0.3	1.3	-0.4	-1.4	2.9	-2.8	-1.3	-0.9	-2.5	2.7	2.5	1.2	2.9

Table A36: 2018 Bacteria and weather condition covariate phase lag analysis where values indicate positive or negative lags in units of pi, and negative values infer covariate is cycling before the PLFA parameter. High Disturbance (HD), Low Disturbance (LD) Note: Boxed areas represent replication consistency for refinement of scattered cyclical frequencies.

Bacteria

	Mean Air Temp.						Air Temp. Ran.						Humidity						ET						GWT Depth					
Period	HD			LD			HD			LD			HD			LD			HD			LD			HD			LD		
Days	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
> 85.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	3.1	3.1	3.1	3.1	0.0	3.1	0.0	0.0	0.0	0.0	3.1	0.0	3.1	3.1	0.0	3.1	0.0	3.1	3.1	0.0	3.1	3.1	3.1
85.0	1.0	0.3	-1.0	0.2	0.2	1.3	-1.7	-2.3	2.6	3.1	-2.4	-1.3	1.8	1.2	-0.2	1.2	1.1	2.2	-1.0	-1.6	-3.0	-1.1	-1.7	-0.6	2.4	1.8	0.4	2.0	1.7	2.8
42.5	-1.5	-1.9	-1.6	-0.3	-1.1	-1.2	-2.9	3.0	-3.0	-2.4	-2.5	-2.6	0.2	-0.2	0.1	2.1	0.6	0.5	-1.8	-2.2	-1.9	-1.6	-1.4	-1.5	0.2	-0.2	0.1	2.8	0.6	0.5
28.3	1.2	-2.9	-0.9	2.3	2.9	-1.6	-1.9	0.4	2.3	-1.7	-0.1	1.6	2.2	-1.9	0.1	0.8	-2.3	-0.6	-1.4	0.8	2.7	1.7	0.3	2.1	2.3	-1.7	0.2	-2.4	-2.2	-0.5
21.3	-0.8	-0.1	-2.9	2.3	-1.6	-2.6	2.3	3.0	0.2	-1.0	1.5	0.5	-1.8	-1.1	2.4	1.4	-2.6	2.7	-0.2	0.5	-2.2	2.0	-0.9	-1.9	-1.1	-0.4	-3.1	-1.0	-1.9	-2.8
17.0	3.0	0.3	2.5	-1.2	0.8	1.7	3.0	0.3	2.5	1.7	0.8	1.6	-3.1	0.5	2.7	-1.8	1.0	1.8	0.9	-1.8	0.4	1.5	-1.3	-0.5	3.0	0.3	2.5	-0.8	0.8	1.6
14.2	-1.5	-1.8	1.7	-1.9	1.3	-2.7	0.7	0.4	-2.4	1.4	-2.7	-0.4	0.4	0.1	-2.7	-1.4	-3.1	-0.8	-1.4	-1.7	1.8	1.5	1.5	-2.5	1.0	0.7	-2.1	0.1	-2.5	-0.2
12.1	-2.9	-2.5	-2.9	-1.2	0.3	1.4	-1.8	-1.5	-1.8	-1.7	1.3	2.4	0.1	0.5	0.1	1.2	-3.1	-1.9	-2.8	-2.5	-2.8	-1.8	0.3	1.4	-0.7	-0.3	-0.7	0.5	2.5	-2.7
10.6	2.3	0.2	0.4	0.6	-0.3	1.6	1.1	-1.0	-0.8	-0.5	-1.5	0.3	-2.6	1.5	1.8	3.0	1.0	2.9	1.7	-0.4	-0.2	-0.2	-0.9	1.0	3.0	0.9	1.1	2.1	0.4	2.3
9.4	2.8	-1.8	0.1	1.7	2.6	0.2	-3.1	-1.4	0.5	0.6	3.0	0.6	0.6	2.4	-2.1	-3.0	0.4	-2.0	-2.8	-1.1	0.8	0.6	-3.0	0.9	-2.9	-1.2	0.7	2.9	-3.1	0.8
8.5	1.4	0.1	-2.4	-0.5	2.5	-2.2	-3.1	1.8	-0.7	-1.6	-2.0	-0.4	0.7	-0.7	3.1	2.7	1.8	-2.9	3.1	1.8	-0.8	-0.6	-2.1	-0.5	2.1	0.8	-1.7	-3.1	-3.1	-1.5
7.7	-0.5	2.8	2.9	2.2	-0.4	2.8	-1.9	1.4	1.5	1.1	-1.8	1.4	0.8	-2.2	-2.1	-1.7	0.8	-2.2	-1.9	1.5	1.5	1.4	-1.8	1.5	-0.3	3.0	3.1	-2.7	-0.3	3.0
7.1	-1.5	-1.8	2.9	-1.1	-1.3	2.5	2.7	2.4	0.9	2.5	2.9	0.5	-0.6	-0.9	-2.4	-1.1	-0.4	-2.8	-3.1	2.9	1.3	2.4	-2.9	0.9	-2.3	-2.6	2.1	-2.3	-2.1	1.7
6.5	1.0	1.7	-1.8	2.2	2.0	-1.6	-0.4	0.3	3.1	-1.5	0.6	-2.9	3.1	-2.5	0.3	0.4	-2.2	0.5	-0.1	0.6	-2.9	-2.7	0.8	-2.7	1.7	2.4	-1.1	-2.1	2.7	-0.9
6.1	1.9	-1.6	-1.6	-1.0	1.9	-0.6	-0.6	2.2	2.2	1.9	-0.6	-3.1	-2.7	0.1	0.1	-1.4	-2.7	1.1	0.8	-2.7	-2.8	-2.1	0.7	-1.8	-0.5	2.3	2.3	-2.4	-0.5	-3.0
5.7	2.3	0.6	-0.3	-2.1	-1.8	-0.3	-0.6	-2.2	3.1	-2.8	1.7	3.1	-3.1	1.5	0.6	1.8	-0.9	0.5	1.3	-0.4	-1.3	-2.9	-2.8	-1.3	-2.2	2.4	1.4	0.1	0.0	1.4

APPENDIX B. CHAPTER 2

Table B1: 2017 enzyme activity results, and respective biotic and abiotic explanatory variables by DOY and treatment replication.

		NR	AO	BG	NO_3^-N	P	SO_4^{2-}	Mn^{2+}	NH_4^+	TN	TC	DailyMax	DailyTemp	WeeklyTemp	DailyMoist	WeeklyMoist
Trt	DOY	µg NO2 - N g-1 24 h-1	µg NO2 - N g-1 5h-1	µg P-Nitrophenol - g-1 1 h-1	lbs/acre	ppm	lbs/acre	ppm	ppm	%	%	°C	°C	°C	cm³/cm³	cm³/cm³
HD-1	191	0.66	1.41	445.53	8.00	7.00	4.00	35.50	9.40	0.27	2.66	28.47	25.67	25.07	0.20	0.21
HD-2	191	0.68	1.76	462.38	13.00	8.00	4.00	34.00	8.50	0.29	2.64	31.60	27.13	26.41	0.19	0.21
HD-3	191	0.21	1.37	438.03	5.00	8.00	4.00	34.00	10.20	0.26	2.62	28.86	25.86	25.19	0.24	0.25
HD-1	205	1.37	2.50	612.66	12.00	6.00	5.00	30.50	10.60	0.28	2.61	22.86	21.50	23.49	0.22	0.21
HD-2	205	2.09	2.02	508.24	15.00	7.00	6.00	28.00	11.10	0.26	2.66	23.43	21.69	24.09	0.21	0.18
HD-3	205	2.25	2.37	464.90	10.00	10.00	4.00	32.50	15.80	0.28	2.65	23.63	21.97	23.97	0.24	0.23
HD-1	212	2.27	2.19	598.54	13.00	7.00	8.00	31.00	9.20	0.27	2.56	26.16	24.12	23.19	0.19	0.20
HD-2	212	1.38	2.21	459.51	12.00	7.00	7.00	30.50	13.70	0.27	2.57	26.33	23.81	23.20	0.17	0.19
HD-3	212	3.41	2.04	594.89	4.00	8.00	4.00	37.50	16.50	0.27	2.55	26.73	24.35	23.67	0.21	0.23
HD-1	222	1.61	2.16	539.27	10.00	7.00	4.00	31.50	13.10	0.27	2.61	21.53	20.07	20.24	0.21	0.21
HD-2	222	1.18	1.55	489.22	9.00	6.00	4.00	23.50	12.90	0.24	2.44	21.76	19.97	19.98	0.22	0.20
HD-3	222	0.6	1.77	440.17	10.00	7.00	4.00	30.50	9.20	0.26	2.58	21.96	20.31	20.49	0.23	0.23
HD-1	226	1.19	2.57	534.15	7.00	7.00	4.00	28.50	8.80	0.26	2.60	20.76	19.40	19.97	0.25	0.21
HD-2	226	0.76	2.15	492.43	6.00	7.00	4.00	30.00	10.80	0.27	2.64	20.90	19.41	19.67	0.28	0.21
HD-3	226	0.6	2.03	534.46	3.00	7.00	4.00	31.00	10.80	0.25	2.57	21.16	19.63	20.19	0.24	0.23
HD-1	265	0.05	2.50	466.87	8.00	6.00	8.00	21.00	7.50	0.28	2.65	21.23	19.22	17.37	0.25	0.20
HD-2	265	0.41	2.34	424.04	15.00	7.00	3.00	21.50	8.50	0.28	2.72	21.56	19.39	17.27	0.23	0.18
HD-3	265	4.17	2.10	547.04	9.00	12.00	7.00	21.00	7.50	0.27	2.62	21.86	19.58	16.86	0.21	0.18
HD-1	268	0.15	2.07	334.30	7.00	5.00	6.00	21.50	6.00	0.28	2.68	15.20	14.92	17.62	0.28	0.25
HD-2	268	0.96	1.83	438.91	8.00	5.00	5.00	18.50	5.50	0.27	2.71	15.63	15.08	17.30	0.29	0.23
HD-3	268	0.42	2.04	258.54	8.00	7.00	6.00	25.50	6.00	0.27	2.60	15.33	14.92	17.37	0.33	0.22
HD-1	279	0.21	2.18	378.76	5.00	6.00	6.00	34.50	9.10	0.27	2.73	14.06	12.29	13.55	0.25	0.26
HD-2	279	2.3	1.53	296.27	4.00	7.00	7.00	33.50	10.10	0.27	2.54	14.50	12.43	13.69	0.27	0.28
HD-3	279	0.63	2.09	479.11	3.00	9.00	4.00	35.50	7.90	0.29	2.81	14.43	13.57	12.24	0.28	0.28
LD-1	191	0.31	1.37	444.73	17.00	7.00	4.00	33.50	8.20	0.28	2.75	27.03	24.67	23.92	0.18	0.19
LD-2	191	0.22	1.51	475.55	10.00	7.00	4.00	32.00	9.60	0.29	2.73	27.13	24.67	23.97	0.19	0.20
LD-3	191	0.73	1.85	507.00	10.00	6.00	4.00	35.00	9.40	0.27	2.78	28.80	25.61	25.11	0.24	0.25
LD-1	205	0.96	1.98	490.86	17.00	9.00	7.00	33.00	8.80	0.29	2.65	22.67	21.59	23.33	0.21	0.19
LD-2	205	0.68	2.24	477.09	8.00	6.00	4.00	32.00	8.20	0.29	2.76	22.17	21.15	22.94	0.22	0.19
LD-3	205	0.89	2.13	467.60	10.00	9.00	4.00	33.50	9.50	0.26	2.66	22.56	21.22	23.22	0.25	0.24
LD-1	212	0.81	1.78	409.04	5.00	8.00	4.00	28.00	9.90	0.28	2.62	24.86	23.24	22.69	0.17	0.19
LD-2	212	1.22	2.01	469.54	20.00	11.00	7.00	34.50	16.10	0.28	2.75	24.73	23.02	22.35	0.17	0.20
LD-3	212	1.02	2.10	499.36	11.00	8.00	4.00	34.50	14.60	0.26	2.61	25.46	23.37	22.68	0.18	0.22
LD-1	222	0.65	2.01	547.09	10.00	8.00	4.00	33.00	14.50	0.28	2.70	21.33	19.87	19.87	0.19	0.19
LD-2	222	0.29	1.53	417.36	2.00	5.00	4.00	23.00	15.60	0.24	2.36	20.86	19.55	19.55	0.20	0.20
LD-3	222	1.97	2.01	536.32	9.00	9.00	4.00	32.00	10.70	0.26	2.63	21.30	19.63	19.62	0.23	0.21
LD-1	226	0.73	1.99	509.71	10.00	6.00	4.00	28.50	7.60	0.28	2.68	20.60	19.38	19.60	0.22	0.19
LD-2	226	2.8	2.16	518.10	5.00	6.00	4.00	28.50	9.10	0.28	2.80	19.90	18.92	19.30	0.24	0.20
LD-3	226	0.25	1.61	467.87	2.00	9.00	4.00	26.50	8.50	0.25	2.51	20.36	19.04	19.33	0.25	0.22
LD-1	265	0.84	2.27	439.20	8.00	8.00	5.00	21.00	7.00	0.27	2.76	20.76	18.98	16.78	0.20	0.17
LD-2	265	2.38	2.30	505.87	9.00	6.00	5.00	21.00	7.40	0.28	2.84	20.13	18.52	16.35	0.22	0.17
LD-3	265	0.44	2.06	399.47	11.00	7.00	6.00	22.50	8.90	0.26	2.67	20.93	18.94	16.57	0.23	0.18
LD-1	268	0.19	2.08	314.86	10.00	5.00	7.00	21.50	6.10	0.28	2.77	15.66	15.45	17.27	0.25	0.21
LD-2	268	0.32	2.25	350.46	7.00	6.00	6.00	24.00	5.90	0.28	2.80	15.30	15.22	16.89	0.25	0.22
LD-3	268	0.10	1.72	327.00	7.00	5.00	5.00	22.00	7.00	0.26	2.56	15.23	14.99	17.02	0.26	0.22
LD-1	279	0.17	1.28	359.98	3.00	8.00	4.00	36.00	11.30	0.28	2.80	14.23	12.79	13.97	0.22	0.24
LD-2	279	0.2	2.34	383.07	6.00	9.00	6.00	35.50	8.70	0.29	2.87	13.90	12.86	13.93	0.23	0.24
LD-3	279	0.06	1.97	400.88	3.00	13.00	5.00	38.00	11.90	0.28	2.77	13.83	12.36	13.56	0.25	0.26

Table B2: 2018 enzyme activity results, and respective biotic and abiotic explanatory variables by DOY and treatment replication.

		NR	AO	BG	NO_3^-N	P	SO_4^{2-}	Mn^{2+}	NH_4^+	TN	TC	DailyMax	DailyTemp	WeeklyTemp	DailyMoist	WeeklyMoist
Trt	DOY	µg NO2 - N g-1 24 h-1	µg NO2 - N g-1 5h-1	µg P-Nitrophenol - g-1 1 h-1	lbs/acre	ppm	lbs/acre	ppm	ppm	%	%	°C	°C	°C	cm³/cm³	cm³/cm³
HD-1	141	3.83	2.40	389.48	13.00	13.00	3.00	52.00	59.40	0.28	2.86	18.33	16.21	17.35	0.24	0.25
HD-2	141	3.07	2.46	454.33	15.00	9.00	3.00	50.50	17.50	0.27	2.88	18.19	16.16	17.29	0.25	0.26
HD-3	141	2.38	1.71	297.83	20.00	11.00	3.00	51.50	53.90	0.25	2.62	18.23	16.23	17.13	0.30	0.31
HD-1	158	2.19	1.96	309.00	58.00	17.00	10.00	39.00	152.70	0.29	2.70	22.26	20.04	21.15	0.24	0.23
HD-2	158	1.84	1.78	264.91	35.00	8.00	5.00	39.00	35.20	0.26	2.69	22.58	19.99	21.07	0.25	0.24
HD-3	158	1.59	1.98	314.57	43.00	7.00	3.00	47.40	55.30	0.27	2.63	23.00	20.19	21.14	0.31	0.29
HD-1	169	2.02	2.65	475.51	61.00	9.00	5.00	41.00	46.80	0.27	2.70	23.20	21.10	21.24	0.26	0.24
HD-2	169	2.60	1.57	404.11	23.00	8.00	4.00	45.50	18.20	0.27	2.77	22.46	20.61	21.34	0.27	0.25
HD-3	169	0.99	2.26	415.36	75.00	6.00	3.00	50.00	34.80	0.25	2.66	22.87	20.70	21.30	0.32	0.31
HD-1	183	2.31	2.50	477.84	88.00	13.00	9.00	41.00	37.20	0.28	2.83	23.06	21.53	21.94	0.19	0.19
HD-2	183	1.64	1.82	407.50	4.00	8.00	4.00	38.00	12.90	0.25	2.73	23.20	21.51	22.08	0.21	0.22
HD-3	183	1.05	1.65	404.94	28.00	8.00	3.00	40.00	19.40	0.26	2.73	22.93	21.25	21.86	0.24	0.25
HD-1	204	1.46	2.21	444.78	55.00	10.00	8.00	35.00	10.90	0.27	2.86	24.23	22.67	21.54	0.22	0.21
HD-2	204	2.41	2.57	409.70	21.00	9.00	5.00	30.00	10.00	0.27	2.84	24.93	23.06	21.54	0.25	0.23
HD-3	204	1.48	2.04	305.63	39.00	12.00	7.00	39.50	11.40	0.27	2.76	22.80	21.74	20.91	0.28	0.26
HD-1	215	1.07	1.87	372.12	54.00	10.00	8.00	25.00	9.50	0.27	2.86	22.16	19.86	21.18	0.16	0.17
HD-2	215	4.39	2.41	462.89	29.00	7.00	8.00	19.50	5.80	0.28	2.90	22.56	20.11	21.39	0.20	0.22
HD-3	215	1.34	2.04	276.76	35.00	11.00	6.00	24.50	7.40	0.26	2.69	21.46	19.11	20.13	0.22	0.24
LD-1	141	0.83	2.38	447.52	33.00	13.00	3.00	41.50	54.40	0.29	2.91	16.60	15.31	16.26	0.26	0.25
LD-2	141	0.40	2.19	273.41	20.00	8.00	3.00	48.50	26.30	0.27	2.87	17.33	15.19	15.91	0.23	0.24
LD-3	141	0.24	2.13	269.74	22.00	13.00	4.00	58.50	53.00	0.28	2.77	17.45	15.27	15.84	0.24	0.26
LD-1	158	0.75	2.22	324.75	48.00	9.00	3.00	34.00	34.00	0.28	2.87	20.85	19.50	20.05	0.24	0.22
LD-2	158	1.35	1.78	293.22	48.00	10.00	4.00	40.50	25.40	0.27	2.88	21.60	19.32	20.16	0.23	0.21
LD-3	158	1.33	2.38	361.78	54.00	11.00	6.00	43.00	41.80	0.27	2.77	21.90	19.71	20.26	0.24	0.24
LD-1	169	0.77	2.34	439.28	23.00	10.00	7.00	36.00	17.40	0.28	2.80	22.80	20.84	20.72	0.26	0.24
LD-2	169	1.22	1.92	361.56	43.00	10.00	5.00	48.50	20.90	0.27	2.83	23.53	20.87	20.79	0.26	0.23
LD-3	169	1.56	2.67	450.86	46.00	9.00	8.00	54.00	22.70	0.27	2.72	23.45	21.20	21.23	0.27	0.25
LD-1	183	0.64	2.60	499.38	22.00	9.00	3.00	31.00	15.40	0.27	2.84	22.20	20.88	21.25	0.20	0.21
LD-2	183	0.83	2.63	453.52	7.00	12.00	6.00	35.00	16.30	0.28	2.86	22.53	20.84	21.35	0.18	0.20
LD-3	183	1.41	1.75	371.48	34.00	11.00	8.00	47.50	30.30	0.26	2.74	23.25	21.63	22.17	0.21	0.22
LD-1	204	1.49	2.22	404.00	2.00	9.00	5.00	26.00	9.60	0.28	2.82	23.26	22.02	20.94	0.26	0.24
LD-2	204	0.43	2.03	336.06	7.00	6.00	4.00	29.00	9.10	0.29	2.85	24.40	22.48	20.92	0.24	0.22
LD-3	204	2.09	2.79	502.60	4.00	8.00	4.00	29.00	7.00	0.27	2.80	24.15	22.58	21.35	0.23	0.23
LD-1	215	0.27	1.88	300.05	10.00	8.00	4.00	17.00	6.30	0.27	2.84	20.96	19.03	20.26	0.22	0.23
LD-2	215	0.38	1.93	298.88	9.00	8.00	5.00	19.50	6.50	0.28	2.88	22.03	19.27	20.64	0.18	0.20
LD-3	215	0.95	2.14	301.67	13.00	7.00	5.00	21.00	7.40	0.27	2.73	21.65	19.43	20.73	0.19	0.21

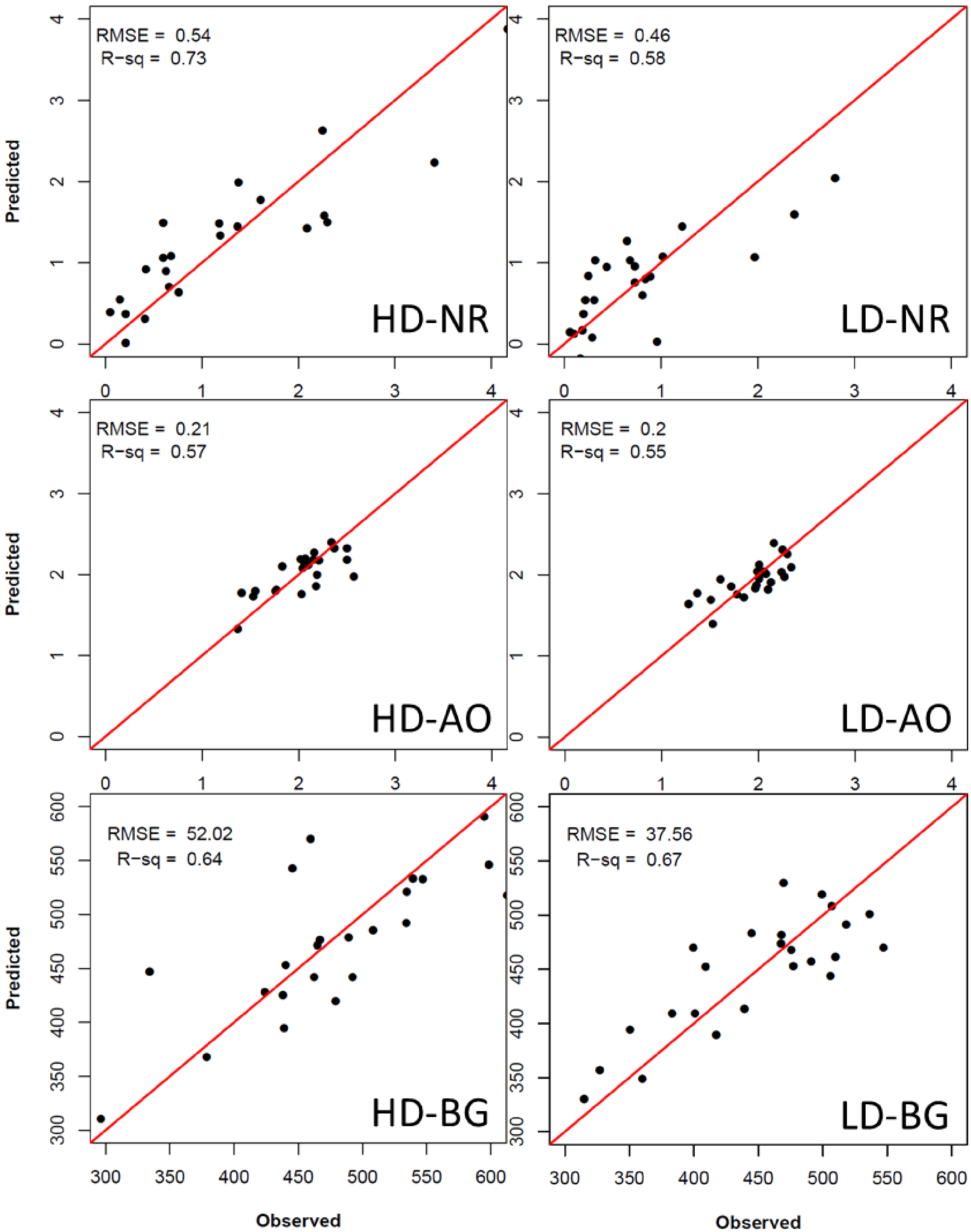

Figure B1: 2017 leave-one-out cross-validation scatter plots. High Disturbance (HD), Low Disturbance (LD), Nitrate Reductase (NR) (µg NO_2 - N g-1 24 h-1), Ammonium Oxidation (AO) (µg NO_2 - N g^{-1} $5h^{-1}$), β-glucosidase (BG) (µg P-Nitrophenol - g^{-1} h^{-1}). Note: Different scales on x and y axis.

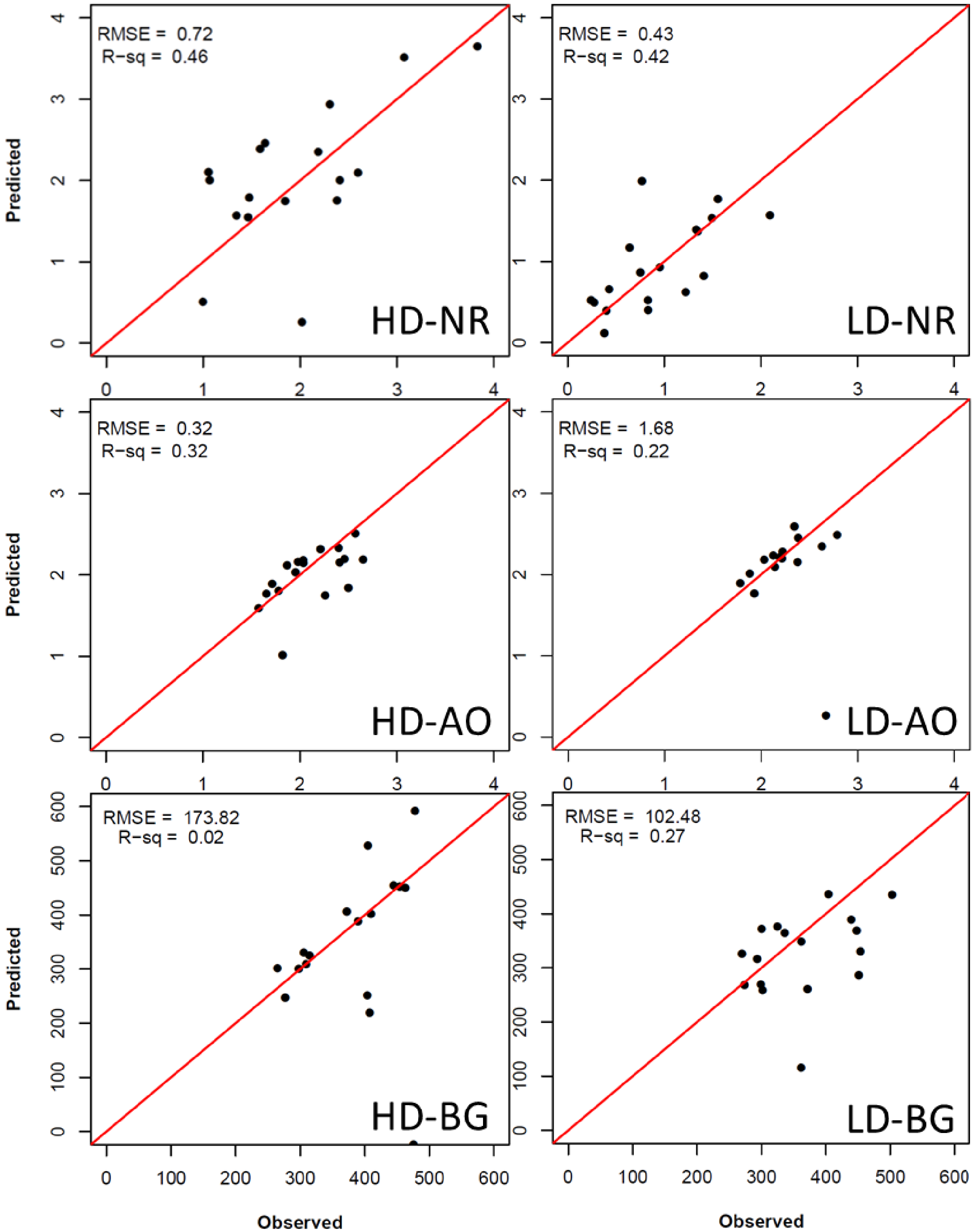

Figure B2: 2018 leave-one-out cross-validation scatter plots. High Disturbance (HD), Low Disturbance (LD), Nitrate Reductase (NR) (µg NO_2 - N g-1 24 h-1), Ammonium Oxidation (AO) (µg NO_2 - N g^{-1} $5h^{-1}$), β-glucosidase (BG) (µg P-Nitrophenol - g^{-1} h^{-1}). Note: Different scales on x and y axis.

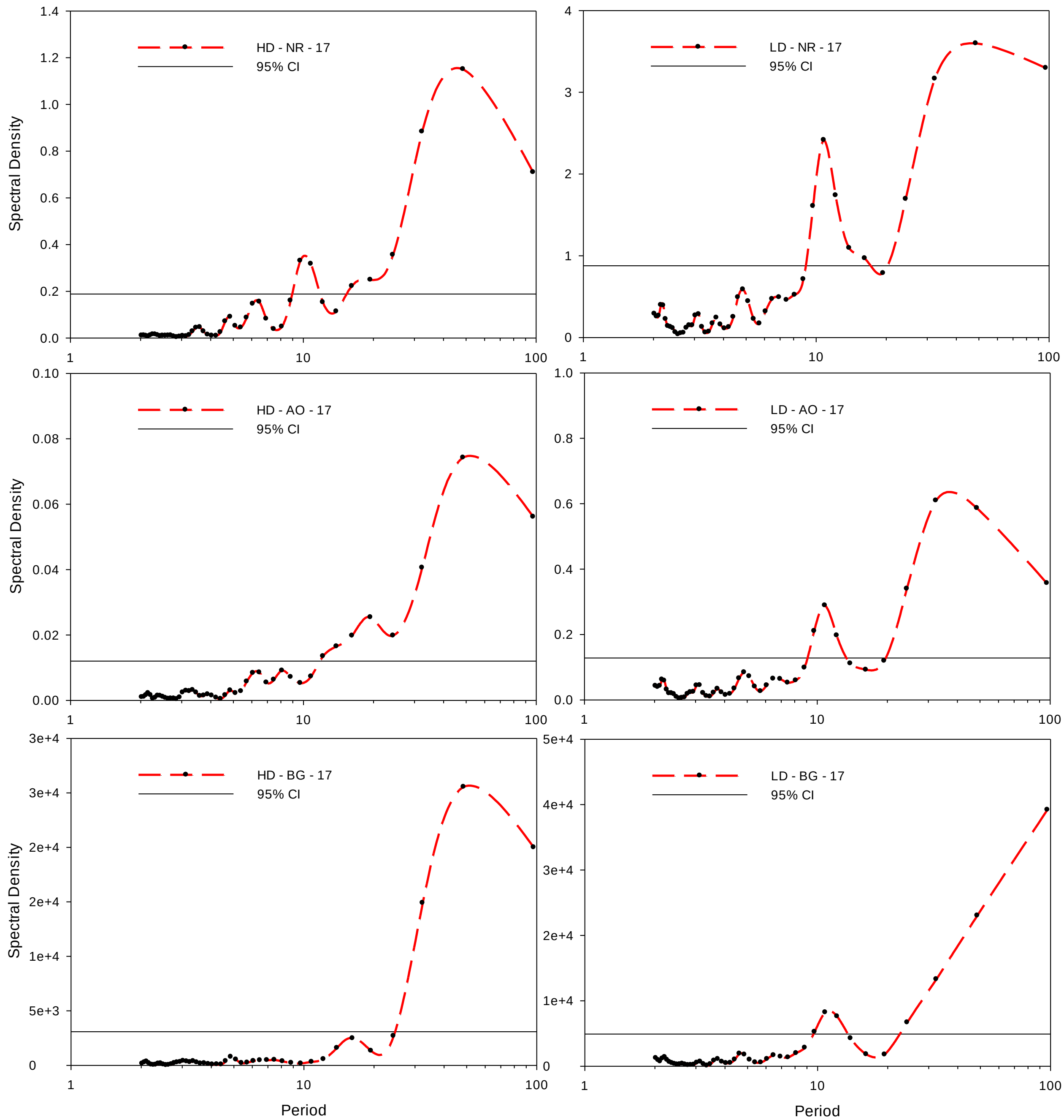

Figure B3: Spectral density periodograms of 2017 empirical enzyme activity models across both treatments and years. High Disturbance (HD) Low Disturbance (LD), Nitrate Reductase (NR), Ammonium Oxidation (AO), Beta-glucosidase (BG), and 2017 (17).

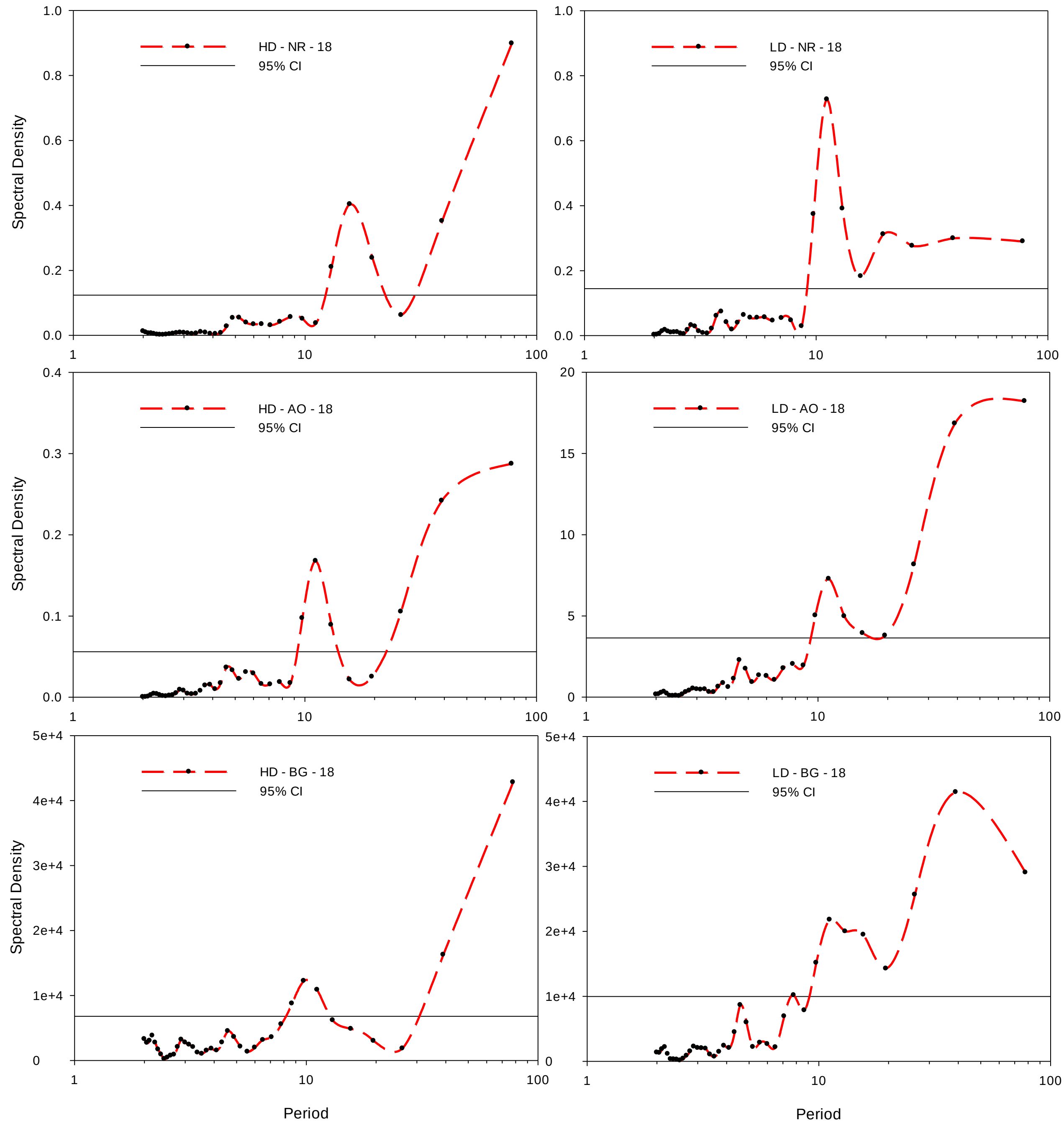

Figure B4: Spectral density periodograms of 2018 empirical enzyme activity models across both treatments. High Disturbance (HD), Low Disturbance (LD), Nitrate Reductase (NR), Ammonium Oxidation (AO), Beta-glucosidase (BG), and 2018 (18).