Spatial Variation of Nutrient Uptake in a Restored West Tennessee Agricultural Wetland

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An Abstract of a Thesis

Spatial Variation of Nutrient Uptake in a Restored West Tennessee Agricultural Wetland

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Master of Science in Biology

The USDA Wetlands Reserve Program (WRP) was originally established to restore wildlife habitat in converted and degraded riparian wetlands, but an increased emphasis has also been put on restoring their ability to reduce nutrient runoff. We analyzed nutrient flux rates and their variability across WRP restoration practices to evaluate nutrient retention rates in four main restoration habitat types: shallow water areas remnant forests, tree planting areas, and natural regeneration areas in a west Tennessee wetland. We collected thirty soil/sediment cores from each habitat, and measured nitrate and phosphate uptake and denitrification potential in continuous-flow incubations for 72 hours, simulating a flood. Analyses show that mean nitrate removal was at least 160% higher in the SWA than other habitats during 6-h sampling round (for all $p<0.001$), and mean phosphate removal was at least 147% higher in RF than all other habitats during 6-h sampling round (for all $p<0.001$). After 72 hours mean denitrification was at least 171% lower in RF than SWA ($p=0.003$), TP ($p=0.02$), and NR ($p<0.001$) habitats. Significant spatial variability in flux rates was found across all habitats. Modeling results show that habitat and soil moisture are consistently important variables across all nutrient flux rates and denitrification. Results suggest that no, one habitat provides optimum nitrogen, phosphorus removal, or denitrification. For management practices, data indicates a multihabitat approach

with a focus on construction of lower elevated areas where water can pool may provide the best overall nutrient retention capacity.

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AGRICULTURAL WETLAND

by

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Dedication

I would like to dedicate this thesis to my parents. Thank you for the support through all my endeavors and through all the adventures to come.

ACKNOWLEDGEMENTS

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SPATIAL VARIATION OF NUTRIENT UPTAKE IN A RESTORED WEST TENNESSEE AGRICULTURAL WETLAND

Introduction

Anthropogenic activities, including agricultural land use, have altered aquatic and terrestrial ecosystems around the globe (Blann, 2009; Matson,1997; McLauchlan, 2006;). These activities have many negative effects on the landscape and, in particular, aquatic ecosystems that receive agricultural pollutants such as nutrients [mainly nitrogen (N) and phosphorus (P)], sediment, and pesticides in runoff. The largest contributor to nutrient pollution in streams is unassimilated fertilizers applied to croplands, and are often mobilized as nitrate (NO_3^-) and phosphate (PO_4^{3-}) forms (Potter, 2004; Scott, 2008). Nutrient loading into the Mississippi River has become a major issue leading to negative ecological impacts both within the river and in the Gulf of Mexico (Gokaraju, 2011; Paerl, 1997). In 2007, the Environmental Protection Agency indicated agricultural practices contribute about 82% of the nitrate NO_3^- runoff and 58% of phosphate PO_4^{3-} runoff in the Gulf of Mexico (Dale, 2007). Nutrient loading into the Mississippi River has remained relatively constant during the last two decades (Lee, 2019), and nutrient transport models indicate that more than 70% of nutrient runoff in the Mississippi River basin is from agricultural land use (Alexander, 2008).

Nutrient pollution in the Mississippi River has a drastic impact on downstream aquatic ecosystems (Galloway, 2008; Howarth, 2002; Prakasa Rao, 2000), specifically resulting in eutrophication of the Gulf of Mexico. Excess nutrients entering the gulf can cause harmful algal blooms, coastal hypoxia, and loss of biodiversity through large areas of the near shore waters (Carpenter, 1998; Carpenter, 2011; Glibert, 2014). Low/absent oxygen conditions make it difficult for fish and aquatic invertebrates to survive (Rabalais, 2002); therefore, populations experience reduced growth rate, increased mortality rate, and lower population abundance (Eby, 2005). Additionally, some species of algae can produce toxins (Gokaraju, 2011; Paerl, 1997), which can kill marine life and also increase human illness and mortality (Gokaraju, 2011). Control on the transport of NO_3^- into streams and rivers is a key solution to the hypoxia/anoxia dead zone in the Gulf of Mexico (Mullholland, 2008).

Nutrient pollution mitigation is difficult due to the complex nature of N and P transport pathways, as they differ among nutrient forms and among landscape characteristics. Nutrient runoff in the Mississippi River Basin is heavily regulated by rainfall, which moves both dissolved and particulate nutrients into streams (Bernal, 2013; McDiffitt, 1989; Outram, 2016; Robinson, 2005). PO_4^{3-} binds to the sediments, tightly linking its movement in streams with sediment erosion (Kleinman, 2003; Uusitalo, 2001). Thus, PO_4^{3-} movement downstream is often regulated by sediment particle size and the flow velocity required to move the particle downstream; however, N retention and movement is more complicated. For example, NO_3^- does not bind easily to soils due to its negative charge and is more mobile across the landscape and in flowing water (Salazar, 2014). Other forms of N are less mobile. Ammonium (NH_4^+) is positively charged and can bind more readily to soil. Additionally, it can quickly undergo nitrification to NO_3^-, be taken up by biota, or in basic soils, be converted to ammonia gas and diffuse into the atmosphere. However, NH_4^+ can be more mobile in sediments with high clay content with positive charged particles.

One solution to reducing nutrient transport into streams is to restore riparian wetlands (Fink, 2006; Mitsch, 2005; Seitzinger, 1994). Historically, riparian wetlands were common in the Lower Mississippi River Basin (LMRB), but large areas of wetlands began to be drained in the 19th century for use as farmland (Dahl, 1996). From 1780-1980, the states that make up the LMRB including Tennessee, Kentucky, Missouri, Arkansas, Louisiana, and Mississippi have lost an estimated 59%, 81%, 87%, 72%, 46%, and 59% of wetland area, respectively (Dahl 1990). Wetland area has begun to increase in some areas in the LMRB because management agencies such as the U.S. Department of Agriculture's Natural Resource Conservation Service (NRCS) have implemented riparian wetland habitat restoration, such as through the 1990 Wetlands Reserve Program (WRP), and since 2014, through the Wetlands Reserve Enhancement Program (WREP) (NRCS, 2014; Stephens, 1984; Yavitt, 2008). Riparian wetlands contain aquatic and terrestrial vegetation that stabilizes the sediment and incorporates nutrients, acting as a natural buffer to reduce nutrient runoff into streams (Mitsch, 2001; Mitsch, 2005). Many studies have shown that wetlands are efficient nutrient sinks through biological uptake of nutrients, microbial N transformations, and denitrification (Bowden, 1987; Gersberg, 1984; Hemond, 1983; Tilton, 1979).

There are several mechanisms in riparian wetlands that retain excess NO_3^- and PO_4^{3-}, with plant uptake being a primary pathway. Nutrient uptake by plants and microorganisms typically increases with both biomass (Zhu, 2011) and nutrient availability, with higher concentrations associated with higher uptake rates (Mullholland, 2008). For example, a common temperate wetland plant, rice cutgrass *(Leersia oryzoides),* had higher nutrient uptake rates with corresponding increases in nutrient additions (Kröger, 2006). However, several factors can alter plant mediated removal rates. Seasonal cycles of vegetation growth and nutrient delivery can reduce the nutrient removal efficiency of wetland vegetation. Uptake is greatest during the growing season (spring, summer) when plants are growing. The issue is some annual plants naturally die in winter, thus, potentially releasing retained nutrients back into the wetland.

Another factor that can influence vegetation nutrient retention is the hydrology. Standing water can influence wetland plant species richness (Jiang, 2020) as well as improve removal of nutrients and vegetation metabolic rates (Nifong, 2021). Also, a factor that can alter plant mediated removal rates of nutrients is the species of plants in a specific wetland habitat. Different species of wetland plants can retain NO_3^- and PO_4^{3-} at different rates. Kao, 2003 found that in five different wetland plant species, different percentages of NO_3^- and PO_4^{3-} were retained by these five wetland vegetation species (Kao,2003). Although, with climate change increasing the temperature of temperate regions, the growing season of annual plants may become longer (Chen, 2011; Matsumoto, 2003) or the plants may even begin to survive through the winter (Kreyling, 2010).

A second important pathway for NO_3^- removal is denitrification. During this anoxic process, NO_3^- is converted to nitric oxide (NO), and then to nitrous oxide (N_2O), and further to dinitrogen (N_2). N_2 gas can then be released into the atmosphere and permanently removed from the wetland. Denitrification is accomplished mainly in anaerobic conditions by microbes located in the soil and sediment. Denitrification rates are most often regulated by NO_3^- concentrations in the overlying water column and underlying sediment (Dodds, 2002; Inwood, 2007; Mulholland, 2008), available organic carbon (Duff, 2007; Fork, 2014), oxygen concentrations (Kemp, 2002; Seitzinger, 1988), and temperature (Hanson, 1994; Speir, 2017). Denitrification has also been correlated to physical properties such as wetland topography (Zak, 1991; Xiong, 2015), hydraulic residence time (Alexander, 2000; Ranalli, 2010; Royer, 2004), and wetland geomorphology (Johnston, 2001).

Wetland sediment plays a key role in PO_4^{3-} removal and storage, as up to 95% of wetland PO_4^{3-} can be stored in the sediment and soil (Hammer, 1989). In addition to biological uptake,

PO_4^{3-} removal from the water column in wetlands occurs through the binding with particles and sedimentation (Richardson, 1993; White, 1999). There is often a strong correlation between water sediment transport and PO_4^{3-} concentrations. For example, PO_4^{3-} availability in a wetland decreased with lowered soil erosion in agricultural runoff (Sharpley, 1992) and with longer wetland hydraulic retention time (Lu, 2009).

Land in western Tennessee has been primarily used for agriculture for the last 250 years (Winters, 1994). Given changes in the profitability of agriculture and demand for wildlife habitat and ecosystem-based solutions, some land that was drained for row crop agriculture near rivers is being restored to wetlands (Mitsch, 2005; Mitsch, 2006). Many of the wetland restoration projects in the LMRB are a part of the USDA National Resources Conservation Service's WRP and WREP. The NRCS manages more than 250 wetlands in west Tennessee and thousands nationwide (NRCS, 2014). When a wetland easement is purchased, NRCS conducts one or several restoration practices to restore the land back towards a more natural wetland state. These restoration practices often involve restoring natural wetland hydrology and/or wetland vegetation, through the implementation of different habitat types. The different habitat types include constructed shallow water areas, natural regeneration habitat, tree planting habitat, and remnant forest habitat. The shallow water area habitat is a constructed area in which water can pool and saturate the soil. The natural regeneration habitat are grassland areas where diverse volunteer vegetation species will grow post agricultural land use. The tree planting habitat consists of sapling trees planted by NRCS managers. The remnant forest is the remaining forest from hundreds of years ago. The goal the NRCS has set in place for the restored wetlands includes returning the land back to bottomland hardwood forest ecosystem prior to agricultural influence.

As part of monitoring, the mitigation strategy of different habitat types in the restored wetlands, the NRCS needs the strategies evaluated for habitat conservation purposes and ecosystem function purposes. For the ecosystem assessment, spatial variability of nutrient retention of the habitat types is essential for continuity of future mitigation projects on other restored wetland sites. As a result of the expectation with habitat differences in structure and functional aspects of mitigation strategies, the spatial variability of structure and functional performance of the different habitats is crucial for monitoring ecosystem function of the restored wetlands.

The primary goal of this project is to examine the spatial variation of nutrient uptake on a restored wetland and determine what factors regulate this variation. The objectives of this project are to: *(i)* measure the spatial variability in nutrient uptake in a restored wetland, *(ii)* measure the spatial variation of the sediment structure in a restored wetland, and *(iii)* determine which environmental factors regulate nutrient removal. I predict that cores closer together will be more similar in both sediment structure and function, but this relationship will not continue across habitat boundaries. For example, habitat (i.e. forest or shallow water area) characteristics will be more important for predicting retention than the physical distance between sample locations. Specifically, I hypothesize that standing water on the habitats will improve nutrient removal. Also, I hypothesize that nutrient (N & P) removal will be regulated by soil moisture and organic matter (AFDM and Total organic carbon); therefore, these soil parameters are the primary drivers of nutrient removal in the habitats.

Methods

Study Area

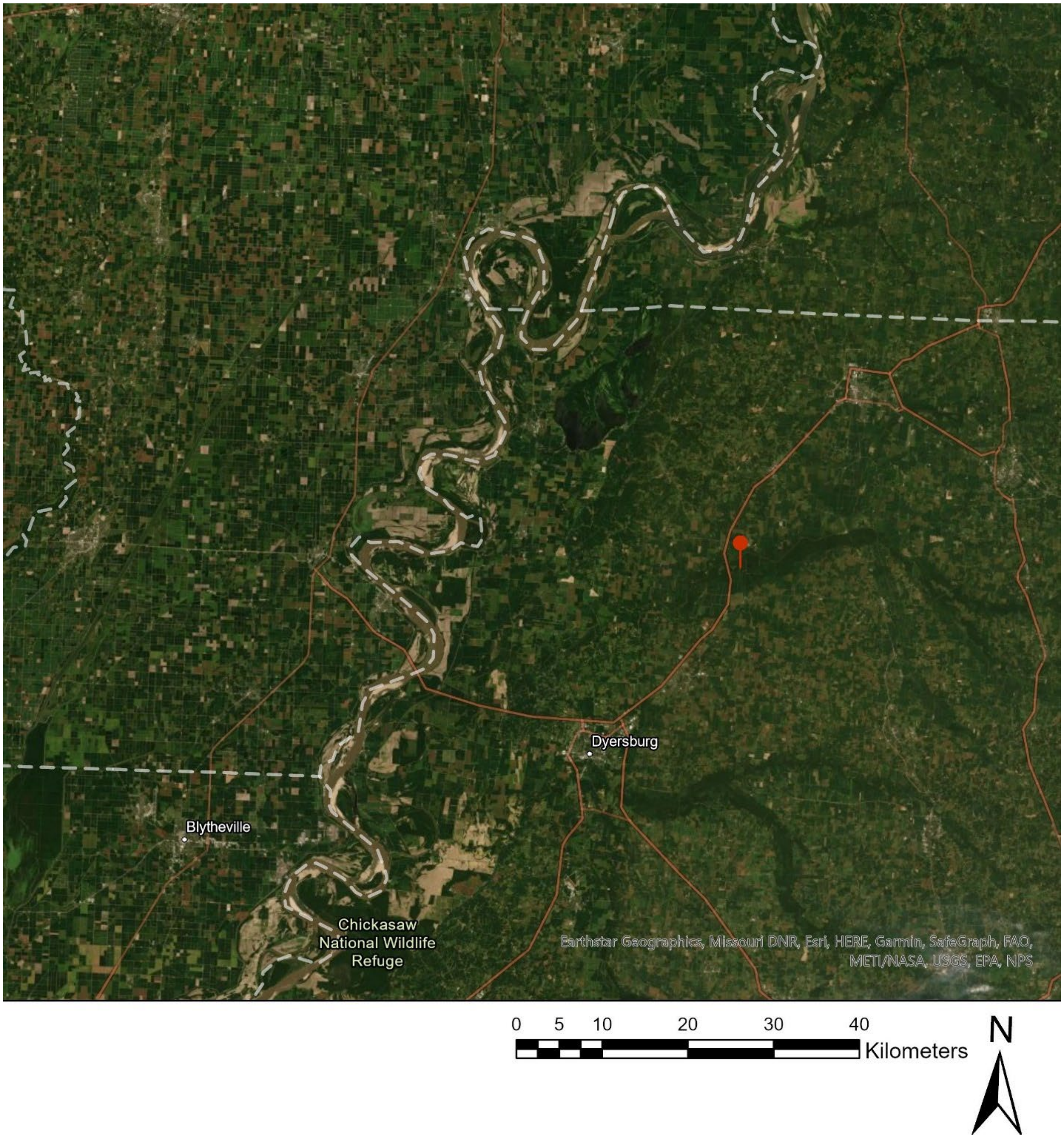
This project primarily focuses on one easement (-89.198330°N, 36.233292°W), in the floodplain habitat of the Lower Mississippi River Basin. The primary objective was the recent process of reverting farmland into a bottomland hardwood forest wetland. The easement is approximately 437.4 acres and is located in western Tennessee in Obion County, immediately east of Highway 51 along the riparian floodplain of the Obion River (Figure 1). Specifically, the easement is a freshwater forested/shrub wetland type that is subject to frequent river flooding with constructed areas where water and permanently flood. Restoration practices were set forth in the year 2008 and include vegetation restoration through planting trees, and installation of ditch plugs, removal of levees, and the creation of dikes to help with flood control and hydrology of the wetland ecosystem. In 2019 and 2020, annual temperatures the easement ranged from 0-35°C with an approximate average range of 7.8-22.7°C.

Field Sample Collection

Sediment/soil cores were collected from four wetland habitat types: Remnant Forest (RF) and Shallow Water Area (SWA) in Fall 2019, and Tree Planting habitat (TP) and Natural Regeneration (NR) in Fall 2020. Soil/sediment cores were collected in 30 cm tall, 7.62 cm diameter acrylic tubes (Figure 2). Thirty cores were collected along transects in each habitat as shown in Figure 3. Within each transect, individual cores were collected at an increasing distance from the previous cores to create a spatial gradient in proximity. This pattern created a distance that varied from 1 to several hundred meters apart in each habitat type. The easement has 1 large RF site with samples collected from six linear transects with five cores along each transect. Cores were taken at approximately 0 m, 1 m, 10 m, 50 m, 100 m and 200 m apart. This easement also has two constructed SWA habitats (Figures 4 and 5), and 15 cores were collected along three transects within each SWA (Figure 4). Maximum transect distance was determined by the length and width of the saturated area. Cores in the first SWA were taken at 0 m, 1 m, 10 m, 100 m, and 170 m (Figure 4), with transects along each edge and in the middle of the inundated area. Cores in the second SWA were taken at 0 m, 1 m, 10 m, 100 m, and 160 m (Figure 5), similar to the previous SWA. Cores were taken at approximately 0 m, 1 m, 10 m, 50 m, 100 m and 200 m. The TP (Figures 7 and 8) and NR (Figures 9 and 10) habitats consisted of two separate field sampling areas. Cores in the TP and NR habitats were taken along transects at approximately 0 m, 10 m, 50 m, 100 m, and 200 m apart along the transect. Transects were approximately 100 m apart. GPS coordinates and collection times were recorded at the point of sample acquisition. Ambient percent soil moisture of the top 15 cm was collected in the field with a Campbell Scientific Hydrosense soil moisture meter. Filtered and unfiltered water samples were taken from the SWA habitats and brought back to the lab for further analysis. A handheld multi-parameter water quality probe (YSI 550MP) was used to record water quality (temperature, dissolved oxygen, water pH) at the starting ends of each transect of each of the both SWA habitats. The filtered and unfiltered water samples and the cores were stored in coolers with ice packs for transport back to Tennessee Tech University. They were later analyzed for ambient water nutrients (NO_3^- , NO_2^- , NH_3^+, and PO_4^{3-}) using colometric analysis. Once back at the laboratory, the water samples were stored in a freezer until analysis, and the sediment cores were stored in an incubation chamber for about 12 hours at ambient average field air temperature to slowly warm them to incubation temperature (20°C).

Figure 1.

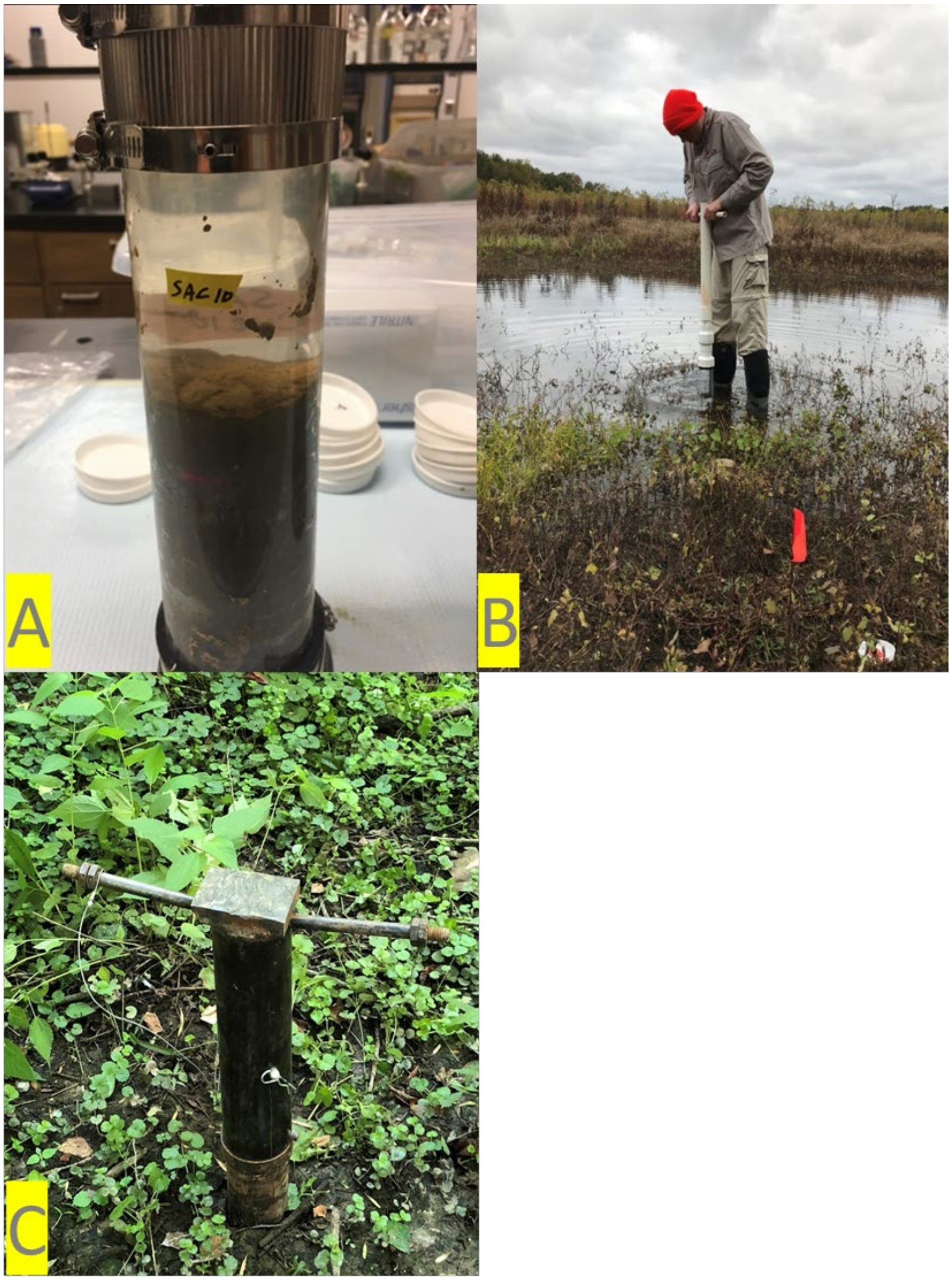
Wetland Location



Note. Red pin shows the point of the easement in western Tennessee.

Figure 2.

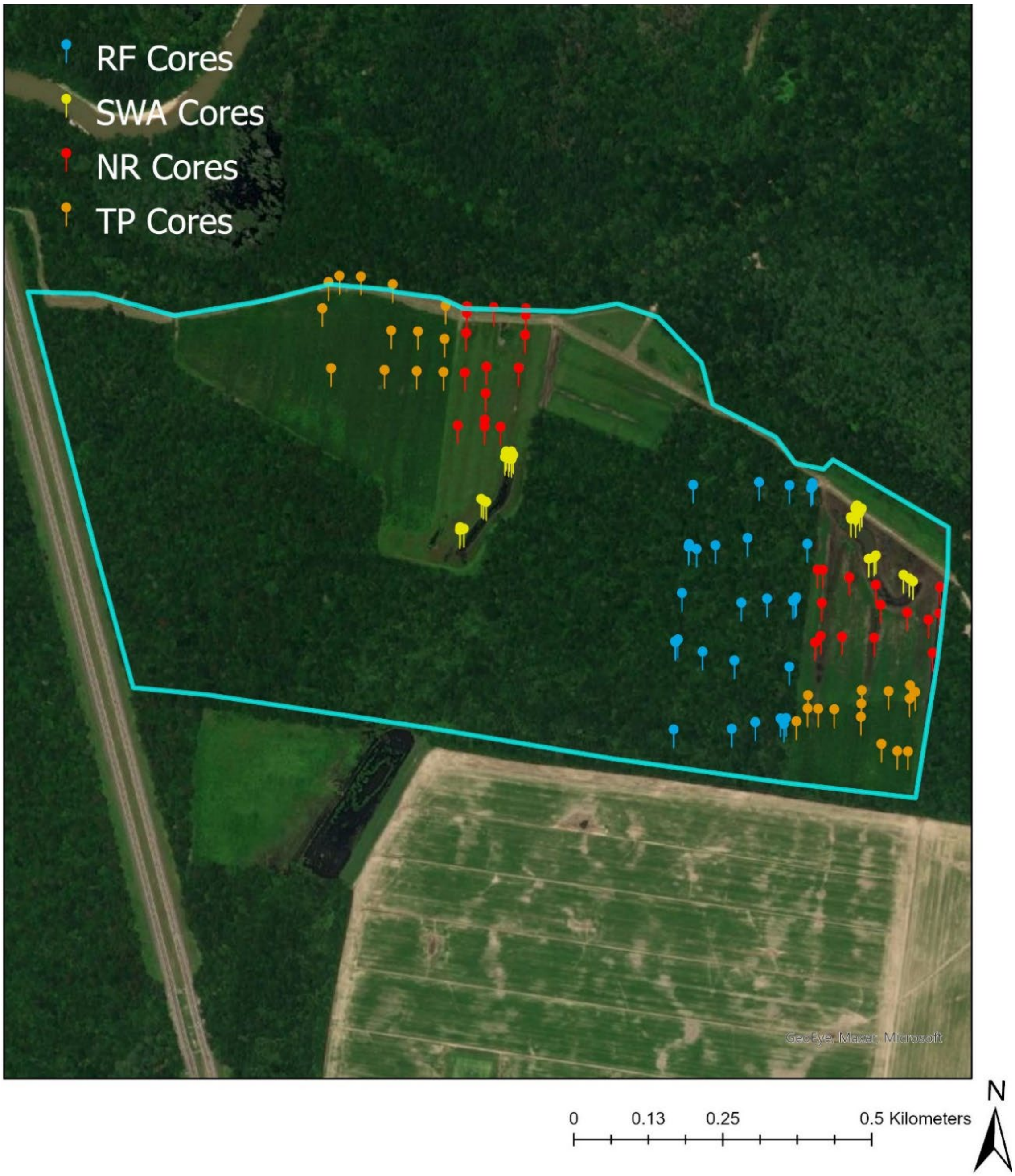
Intact Sediment Core and Field Collection



Note. Intact sediment core collected from the wetland easement (A). Core tube is acrylic, transparent material that is 30 cm in height and 7.62 cm in diameter. Two core collection apparatuses, PVC apparatus for wet cores (B) and metal apparatus for dry cores (C).

Figure 3.

Locations of all Cores



Note. Map of wetland easement boundary and core locations. The easement is delineated by the blue line and cores are represented by pins. Habitat type is represented by the color code. Abbreviations for habitat type are as follows: Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Figure 4.

SWA Cores 1

Note. This is the eastern constructed SWA habitat on the wetland easement. Pins denote core sampling locations.

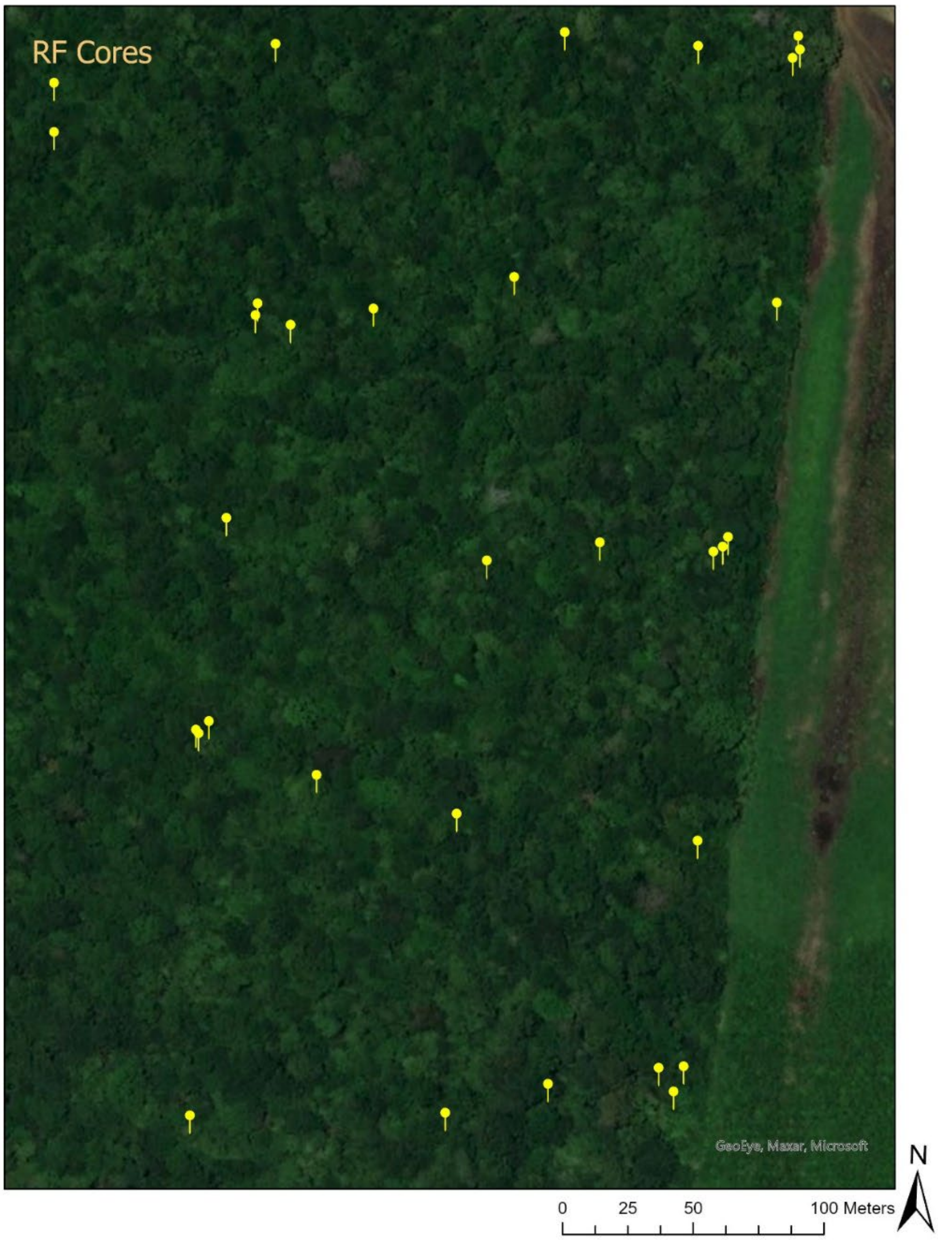
Figure 5.

SWA Cores 2

Note. This is the western constructed SWA habitat on the wetland easement. Pins denote core sampling locations.

Figure 6.

Remnant Forest Cores



Note. This is the RF habitat. Pins denote core sampling locations.

Figure 7.

Tree Planting Cores 1

Note. This is the western TP habitat on the wetland easement. Pins denote core sampling locations.

Figure 8.

Tree Planting Cores 2

Note. This is the eastern TP habitat on the wetland easement. Pins denote core sampling locations.

Figure 9.

Natural Regeneration Cores 1

Note. This is the western NR habitat on the wetland easement. Pins denote core sampling locations.

Figure 10.

Natural Regeneration Cores 2

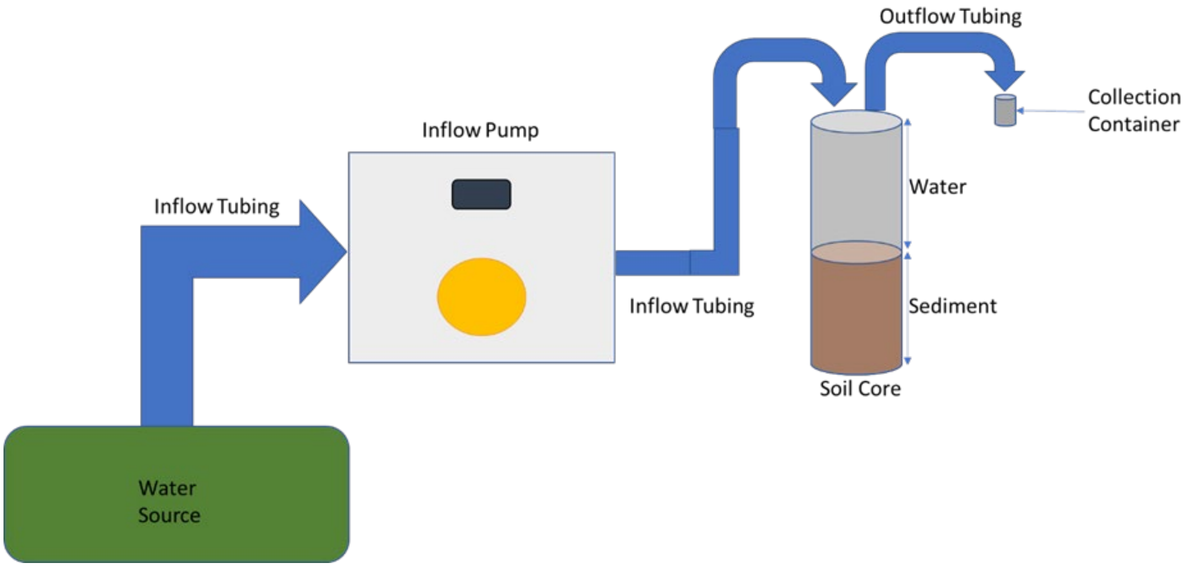
Note. This is the eastern NR habitat on the wetland easement. Pins denote core sampling locations.

Sediment Core Incubations

Sediment core nutrient uptake and denitrification rates were measured in laboratory incubations within an environmental chamber to provide consistent conditions for all cores and across incubations. The flow-through incubation setup is detailed in Figures 11 and 12, and simulated a two-day flood in this riparian wetland. Nutrient retention rates were measured by collecting inflow and outflow water nutrient and dissolved gas samples as described below. The cores were incubated at the average monthly temperature for October in west Tennessee (20°C). Incubation began at 8:00 am on the day after collection. Water nutrient and gas samples were collected from three sampling periods. The first nutrient samples were collected when water began to discharge from the cores, simulating the initial rewetting during a flood event. This first sampling period occurred roughly six hours after the incubation start time. The second nutrient samples were collected at 24-h, and third sampling at 48-h. Gas samples were collected at 24-h, 48-h, and 72-h. Six-hour gas samples were not collected as gas bubbles escaping from voids in the soil as they were rewetted interfered with denitrification measurements.

Figure 11.

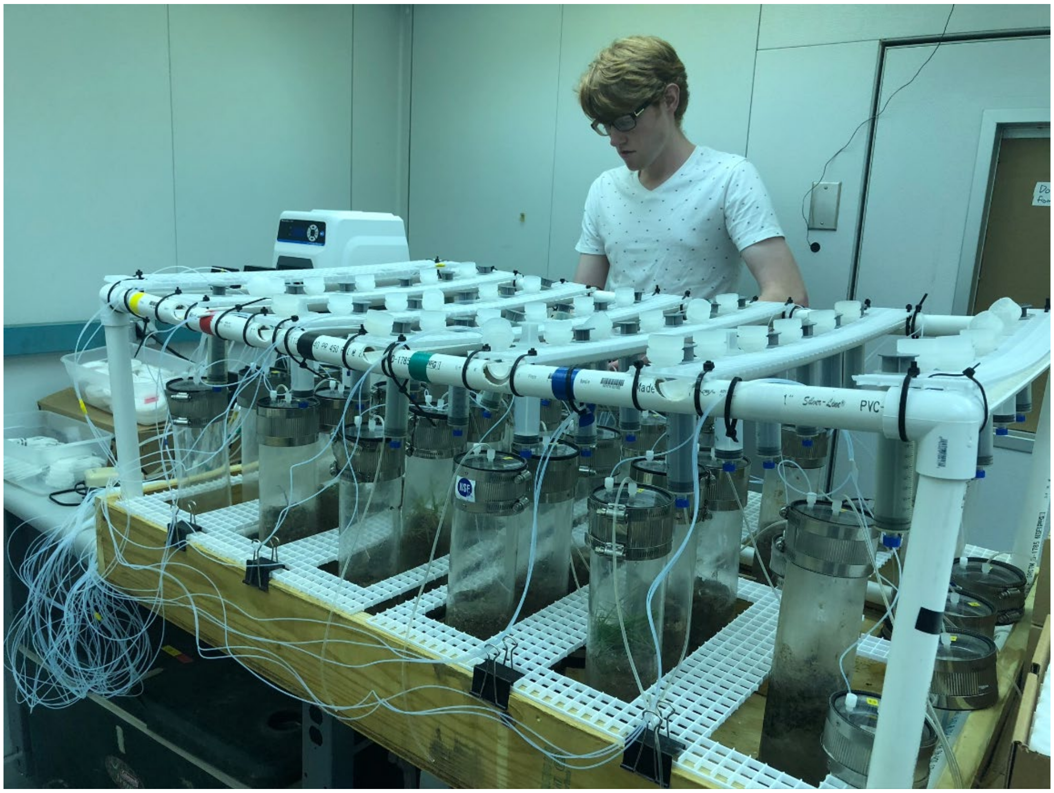
Incubation Flow-Through Diagram



Note. Diagram of the core flow through setup. The inflow pump forces water from the water source, through the inflow tubing, and into the core. When the core fills completely water is then pushed out the outflow tubing and collected for nutrient and dissolved gas analysis.

Figure 12.

Core Incubation Setup



Note. Incubation chamber with sediment/soil cores. Cores are set up in a wooden box for easy positioning of sampling. Capped syringes are used for sample collection.

Nutrient Samples

At each of the three sampling periods, water was collected with a 60 mL syringe, using a separate one for each core. Then samples were filtered through a 0.7 µm pore Merck Millipore glass fiber filter and placed in a 20 mL plastic scintillation vial. Vials were stored on ice until the sampling period is complete, and then stored in a freezer until sample analysis. Water samples were analyzed for nitrate NO_3^-, nitrite (NO_2^-), ammonia (NH_3^+), and PO_4^{3-} concentrations, and nutrients further analyzed using colorimetric methods on a discrete analyzer

(Seal Analytical AQ400 Autoanalyzer), using NO_3^- + NO_2^- EPA method 353.2 Rev. 2.0 (1993), NO_2^- EPA method 353.2 Rev. 2.0 (1993), NH_3^+ EPA method 350.1 Rev. 2.0 (1993), and PO_4^{3-} EPA method 350.1 Rev. 2.0 (1993). Nutrient areal flux calculations were used to measure the net nutrient uptake rates of each core (mg/m2/hr) were calculated using the equation:

$$Areal\ flux = \frac{([Core]out-[Core]in)Qcore-([Ctrl]out-[Ctrl]in)Qctrl}{A}$$

where the $[Core]_{out}$ and $[Core]_{in}$ are the incubated core outflow and inflow nutrient concentrations, respectively; $[Ctrl]_{out}$ and $[Ctrl]_{in}$ are the control core nutrient outflow and inflow concentrations, respectively; Q_{core} and Q_{ctrl} are the water discharge rates through the incubation and control cores; and A is the soil surface area (cm^2) (Speir et al., 2017). The result was either a positive or negative flux value. Negative values indicate net removal of nutrient from the water and positive value indicates net release (leaching) into the water. Control cores (i.e., cores with only water and no soil) were used to account for any changes occurring due to the incubation process.

Denitrification

Denitrification was measured by assessing changes in dinitrogen gas (N_2) in the inflowing and outflowing water. The first denitrification samples were collected 24, 48, and 72 hours after the incubation start time. After the nutrient samples are collected the outflow tubing were then placed into a prelabeled 12 mL exetainer. The exetainer fills from the bottom and was allowed to overflow a minimum to three container volumes to reduce the water contact from the atmosphere. The outflow tube was slowly lifted out of the exetainer tube to minimize air contact with the sample. Immediately after the outflow tube is removed, 157 µL of zinc chloride ($ZnCl_2$) was added to the sample via pipette to stop microbial activity in the sample (Grantz, 2012). Prior to incubation, a concentration of 100g of $ZnCl_2$ is mixed with a concentration of 100mL of ultrapure water (weight: volume 1:1). The exetainer tube was then capped, using the cap to knock off the meniscus before fully capping the exetainer. This prevents any gas contamination from the air into the sample. Triplicate samples were obtained from each core at each time point and stored in submerged water, and placed in a cooler at 4°C in the dark until analysis.

N_2, Argon (Ar), and Dioxygen (O_2) concentrations were used to estimate denitrification and oxygen consumption rates are analyzed with Membrane Inlet Mass Spectrometry (MIMS, Bay Instruments, Easton, MD, USA). Prior to MIMS analysis, the samples were stored on ice to maintain a cold temperature, and the standard water in the MIMS instrument is set to equal the incubation temperature of 20°C. Instrument setup is described in further detail by Kana et al., 1994. Denitrification was measured by direct measurements of N_2 production within cores as the water flows through it. Because gas concentrations can also change due to temperature and pressure, so N_2 and O_2 concentrations are calculated based on the ratio of N_2 to Ar. Ar concentrations only change with adjustments in the temperature, pressure, or salinity; therefore, biological changes do not influence the Ar signal. Biological consumption or production only influences the N_2 and O_2 concentrations. Using the N_2:Ar ratio, the N_2 concentration (μM) will be calculated using the following equation:

$$[N_2]sample = (N_2{:}Ar_{sample} \times Ar_{sol})(\frac{N_2{:}Ar_{sol}}{N_2{:}Ar_{std}})$$

where $N_2{:}Ar_{sample}$ is the measured sample signal, and $N_2{:}Ar_{std}$ is the average of the measured sample signals of the standard water. The terms Ar_{sol} and $N_2{:}Ar_{sol}$ are calculated solubilities for Ar and the N_2:Ar ratio. Next, the denitrification rate (N_2-N μg/cm^2/hr) of N_2 was calculated using the same areal net flux equation that calculated net uptake rates in the nutrients (explained above). The calculated rate was converted to mg N_2-N/m^2/hr to make it comparable to other studies. The same calculations were used to solve O_2 rates. A positive value indicates N_2 production (denitrification) while a negative value indicates N_2 consumption (N_2 fixation).

Soil Analysis

Sediment and soil carbon, N, and P will be measured in each core. After incubation, the sediment cores were taken back to the lab and stored at 4°C until processed. Water was siphoned out of the core, then the space between the overlying sediment layer to the top of the acrylic is measured and recorded. Before the sediment was removed, any detritus and live vegetation were removed from the surface of the sediment and put into aluminum tins to be measured. The top 5 cm of the sediment was removed and homogenized. For homogenization, the sediment is brought up to 600 mL volume with ultrapure water, and mixed in a blender. Approximately 25 mL of slurry was placed in tins for ash-free dry mass (AFDM) measurement. Approximately 45mL of the liquid soil were put in tins for measurement of soil nutrients (C, N, P) and dried at 60°C for 24 h for nutrient analysis.

After it is dried, soil was homogenized with a soil grinder. The samples were then placed in 15 mL falcon tubes or Ziploc bags and stored in a dark, dry space. Soil total organic carbon was measured on a Shimadzu TOC-L total organic carbon analyzer. Soil was digested in an acid persulfate digestion procedure and run on a Perkin Elmer ICP-OES for total phosphorus.

Course Particulate Organic Matter (CPOM) & Vegetation

The detritus and vegetation on the soil core surface were put into separate tins, analyzed for biomass, and dried for 48 hours at 60°C. The samples were weighed to measure dry mass. Then samples were ashed by heating to 500°C in a muffle furnace for three hours. Samples were then stored in a desiccator overnight. Samples were weighed to estimate AFDM. Organic matter of both vegetation and detritus in each core were calculated from the difference ashed mass and dry mass.

Data Analysis

Nutrient Uptake Rates

Data were analyzed to compare structural and functional results of spatial variability of nutrient retention within and among implemented habitat mitigation strategies in this restored west Tennessee wetland easement. Significant differences in nutrient flux rates, denitrification rates, and soil parameters among and between different habitat types were compared using one-way analysis of variance (ANOVA) for each sample time point. Tukey Honest Significant Difference post-hoc tests were used to determine which habitats were different when the overall ANOVA test was significant. Analyses were performed using R Programming Language, R. version 4.0.3.

Data were analyzed further for the determination of which environmental factors will be most important in regulating nutrient removal spatially among and between different habitat mitigation strategies. Generalized linear modeling was used to relate nutrient flux and denitrification rates to soil composition parameters: soil moisture, habitat type, soil nutrient concentration, organic matter, and vegetation biomass. Analyses were performed using R Programming Language, R. version 4.0.3 (R Core Team, 2020) R package “lme4” (Bates, 2012). Model ranking was performed utilizing the R package “MuMIn” (Barton´, 2013) for comparison of Akaike Information Criteria (AICc) for small sample sizes to visualize the importance of each soil parameter were calculated for each response variable.

Spatial Nutrient Uptake Modeling

Spatial variation in nutrient uptake and denitrification rates within and across habitat types were investigated using geostatistical spatial analyses. Semivariograms were made to observe the relationship between semivariance and distance of predicted nutrient flux/denitrification rates. Semivariograms relating response variable to core location were produced using ArcGIS Pro software, followed by spatial interpolation across sampling sites using ordinary kriging. Major range distance was also recorded from each semivariogram in order to predict the minimum distance at which cores are spatially variable from one another. Ordinary kriging assessed the spatial dependence of each response variable, i.e., does sediment core nutrient uptake and denitrification depend on distance from one another, and whether there are spatial patterns across the habitats, such as edge vs. interior changes in rates (Mueller et al 2004, Shit et al. 2016). ArcGIS Pro function cross validated the predicted values with the measured values of rates and R^2 were calculated for each site and sampling round, based on the cross validated predicted values.

Results

Overall spatial variability of nutrient removal can best be explained by habitat type than physical distance between cores. Examining the mean nutrient flux rates, the SWA habitat had the highest removal rate of NO_3^- and PO_4^{3-} earlier on in the inundation experiment. The TP and NR habitats had higher removal of nutrients at 48 hours of core inundation. The RF had average NO_3^- release rates over the whole inundation experiment, but was consistently removing PO_4^{3-}. These results show the importance of spatial variability through habitat type and more specifically answers the hypothesis about standing water being important for nutrient removal. Semivariogram models show that spatial variability for NO_3^- and PO_4^{3-} removal over a period of

48 hours of sediment inundation, physical distance between cores may play a role at 6 hours of inundation, but at 48 hours variability of nutrient removal is less. The soil parameters that primarily regulated NO_3^- removal over the inundation experiment include: habitat, soil moisture, AFDM, and vegetation. The soil parameters that primarily regulated PO_4^{3-} removal over the inundation experiment include: habitat, soil moisture, AFDM, total organic carbon, total phosphorus, vegetation, and detrital organic matter. The soil parameters that primarily regulated denitrification over the inundation experiment include: habitat, sediment oxygen demand, AFDM, soil moisture, total phosphorus, and vegetation. The results of the soil parameters partially answers the soil parameters hypothesis, but the results go further to show that the primary drivers are more than just two or three parameters.

Functional Results

Nitrogen

Nitrate.

Overall, the SWA habitat removed more NO_3^- than all other habitats, and this trend was driven by very high uptake during the first 6 hours of inundation (Figure 13). The NR and TP habitat NO_3^- uptake rates increased over time, switched from a net release of NO_3^- to a net removal between 6-h and 24-h. The RF habitat removed the least NO_3^- of the four habitats with a consistent mean release of NO_3^- during the 48-h incubation.

Habitat differences in NO_3^- flux rates were observed through the inundation experiment. At 6-h the SWA (-173.1mg/m²/h) removed a substantial highest amount of NO_3^- that was 195 mg/m²/h higher than the TP (21.9mg/m²/h) habitat, and significantly different to all habitats (all $p<0.01$, Table 1, Table 2). All other habitats were similar in the 6-h sampling round, and released NO_3^- on average. For the 24-h sampling round, the RF (12.7mg/m²/h) habitat had a 38.7

mg/m²/h higher mean release rate than SWA (-26.0mg/m²/h) habitat (all $p<0.01$). At 48-h, the TP (-24.3mg/m²/h) and SWA (-22.5mg/m²/h) habitats were similar, and removed NO_3^- on average. The RF (3.6mg/m²/h) and NR (-4.0mg/m²/h) habitats average flux rates were close to zero with no substantial NO_3^- release or uptake. The RF habitat was significantly different from the TP ($p<0.01$) and SWA ($p<0.01$) habitats. The NR habitat also differed from SWA ($p<0.01$) and TP ($p<0.01$) habitats.

Temporal patterns in NO_3^- flux rates were observed in all habitats. SWA had the highest NO_3^- removal at 6-h, with 147.1 mg/m²/h, and 150.6 mg/m²/h lower removal at 24-h and 48-h, respectively. The RF had a mean release of NO_3^- during all time points, but released the least NO_3^- during the initial 6-h (3.1mg/m²/h) sampling. The TP habitat had increasing NO_3^- removal over time, with the highest removal at 48-h and release rate at 6-h, and middle removal rate at 24-h (-20.2mg/m²/h). The NR habitat initially released NO_3^- (12.9 mg/m²/h), had the highest removal rates after 24 hours (-23.4 mg/m²/h), and then had a mean rate close to zero at 48-h.

Table 1.

Nitrate, Nitrite, Ammonia, and Dissolved Inorganic Nitrogen Flux Rates (mg/m²/h)

		Nutrient											
Habitat		NO_3^- 6-h	NO_3^- 24-h	NO_3^- 48-h	NO_2^- 6-h	NO_2^- 24-h	NO_2^- 48-h	NH_3^+ 6-h	NH_3^+ 24-h	NH_3^+ 48-h	DIN 6-h	DIN 24-h	DIN 48-h
RF	**Min**	-39.14	-57.09	-75.07	0.03	0.07	0.07	-13.27	-18.20	-44.85	-42.55	-64.42	-72.48
RF	**Max**	36.87	89.49	83.05	0.90	0.59	0.85	1.36	3.37	13.20	28.18	86.38	73.25
RF	**Mean**	3.08	12.67	3.59	0.35	0.28	0.28	-8.14	-8.95	-12.07	-4.71	4.00	-8.21
RF	**SD**	16.77	33.18	28.78	0.23	0.14	0.20	3.47	5.13	13.67	15.56	33.88	26.78
SWA	**Min**	-252.45	-107.63	-96.67	0.00	-0.20	0.02	-12.42	-4.22	-21.45	-258.16	-109.62	-117.86
SWA	**Max**	-28.21	34.15	68.23	0.16	0.40	0.96	3.69	2.16	0.99	-38.80	35.66	48.74
SWA	**Mean**	-173.10	-25.96	-22.48	0.06	0.02	0.31	-7.81	-0.94	-15.82	-180.85	-26.89	-37.98
SWA	**SD**	66.14	34.52	35.06	0.04	0.16	0.24	3.56	1.55	5.36	65.37	34.67	34.39
TP	**Min**	-36.42	-74.60	-49.92	0.00	-0.36	-1.06	-211.37	-14.89	-18.47	-247.68	-62.79	-88.28
TP	**Max**	35.14	-4.87	-4.15	0.74	11.50	8.81	119.13	9.37	19.14	152.93	3.22	-20.94
TP	**Mean**	21.93	-20.16	-24.34	0.15	0.77	0.59	1.63	-4.61	-3.23	23.71	-16.18	-47.65
TP	**SD**	15.09	13.05	11.46	0.15	2.29	2.50	96.86	5.50	10.62	103.27	12.56	14.94
NR	**Min**	-52.18	-44.73	-39.19	-0.07	-0.35	-0.94	96.86	-9.63	-6.00	-177.54	-41.32	-50.51
NR	**Max**	29.62	-6.63	15.36	0.88	11.59	9.87	96.86	13.59	51.15	33.23	-3.54	32.11
NR	**Mean**	12.91	-23.10	-3.97	0.11	1.25	0.87	96.86	-4.44	15.56	-36.14	-19.05	-7.57
NR	**SD**	18.32	8.95	11.88	0.18	2.41	2.24	96.86	4.81	12.43	44.72	9.12	19.12

Note. Flux rate ranges (min and max), means, and standard deviations that were collected at each sampling round for NO_3^-, NO_2^-, NH_3^+, and dissolved inorganic nitrogen (DIN). Values are expressed as mg/m²/h. Sampling rounds are expressed as 6-h, 24-h, and 48-h. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 2.

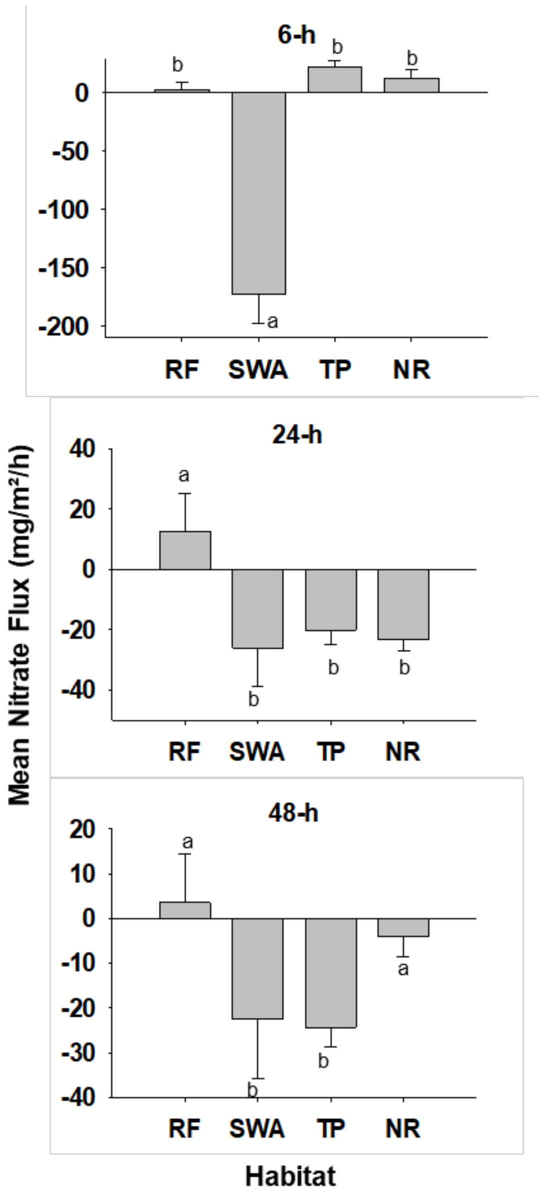
Tukey HSD Post-hoc P-values for Nitrate, Nitrite, Ammonia, and Dissolved Inorganic Nitrogen

Habitat	p-value	Habitat	p-value	Habitat	p-value	Habitat	p-value
NO_3^- 6-h		**NO_2^- 6-h**		**NH_3^+ 6-h**		**DIN 6-h**	
RF-NR	0.74	RF-NR	<0.001*	RF-NR	0.02*	RF-NR	0.27
SWA-NR	<0.001*	SWA-NR	0.66	SWA-NR	0.01*	SWA-NR	<0.001*
TP-NR	0.79	TP-NR	0.87	TP-NR	0.002*	TP-NR	<0.01*
SWA-RF	<0.001*	SWA-RF	<0.001*	SWA-RF	0.99	SWA-RF	<0.001*
TP-RF	0.23	TP-RF	<0.001*	TP-RF	0.9	TP-RF	0.37
TP-SWA	<0.001*	TP-SWA	0.22	TP-SWA	0.9	TP-SWA	<0.001*
NO_3^- 24-h		**NO_2^- 24-h**		**NH_3^+ 24-h**		**DIN 24-h**	
RF-NR	<0.001*	RF-NR	0.13	RF-NR	0.001	RF-NR	<0.01*
SWA-NR	0.98	SWA-NR	0.03*	SWA-NR	0.02	SWA-NR	0.65
TP-NR	0.96	TP-NR	0.7	TP-NR	0.99	TP-NR	0.97
SWA-RF	<0.001*	SWA-RF	0.93	SWA-RF	<0.001*	SWA-RF	<0.001*
TP-RF	<0.001*	TP-RF	0.65	TP-RF	0.002*	TP-RF	0.02*
TP-SWA	0.81	TP-SWA	0.29	TP-SWA	0.011*	TP-SWA	0.37
NO_3^- 48-h		**NO_2^- 48-h**		**NH_3^+ 48-h**		**DIN 48-h**	
RF-NR	0.63	RF-NR	0.53	RF-NR	<0.001*	RF-NR	0.99
SWA-NR	0.02*	SWA-NR	0.6	SWA-NR	<0.001*	SWA-NR	<0.001*
TP-NR	0.009*	TP-NR	0.92	TP-NR	<0.001*	TP-NR	<0.001*
SWA-RF	<0.001*	SWA-RF	0.99	SWA-RF	0.56	SWA-RF	<0.001*
TP-RF	<0.001*	TP-RF	0.89	TP-RF	0.01*	TP-RF	<0.001*
TP-SWA	0.99	TP-SWA	0.92	TP-SWA	<0.001*	TP-SWA	0.46

Note. Tukey HSD post-hoc test results among habitats for 6-h, 24-h, and 48-h. Habitats are Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR). * indicates significant statistical difference.

Figure 13.

Mean Nitrate Flux



***Note*.** Bars represent mean nitrate flux (mg/m²/h) rates across all habitats for each sampled time point. Error bars represent 95% confidence interval. Different letters indicate significant difference among habitat. RF represents Remnant Forest, SWA is Shallow Water Area, TP is Tree Planting, and NR is Natural Regeneration. Negative values indicate nitrate removal from the ecosystem and positive values indicate nitrate release into the ecosystem.

Nitrite.

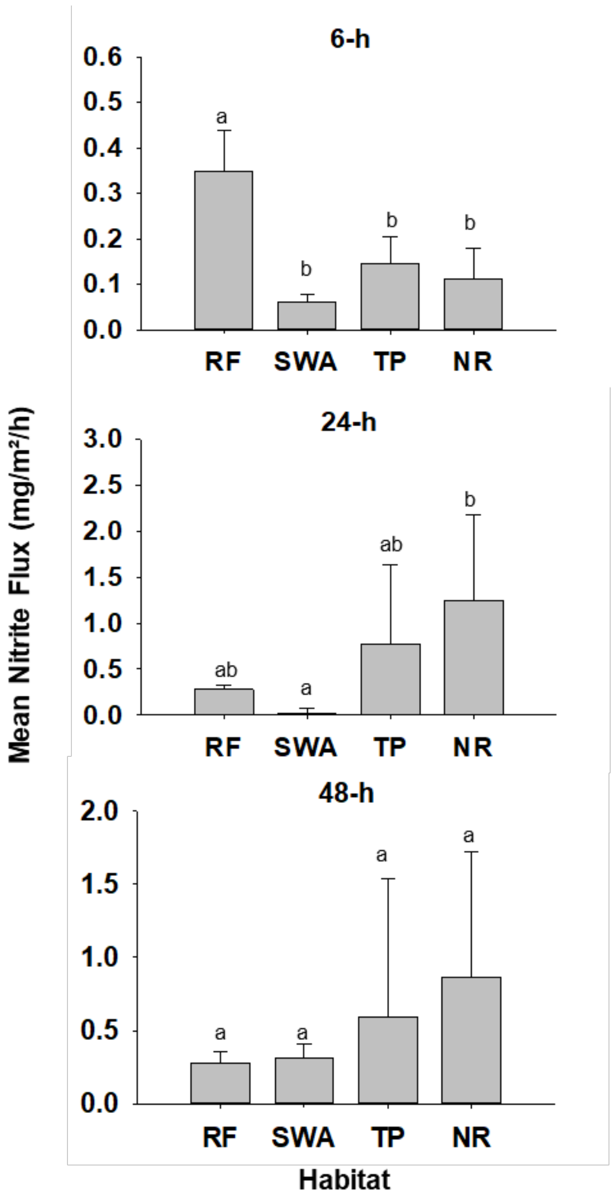
With NO_2^- the habitats over all sampling rounds are releasing NO_2^- (Figure 14). At 6 hours of inundation the RF habitat released the most NO_2^-. The NR habitat was the habitat to release the most NO_2^- over 48 hours, and the TP habitat released NO_2^- at similar rates as the NR habitat.

Differences in habitat mean flux rates of NO_2^- were observed throughout the inundation experiment. Through differences among habitats, all habitats are releasing for NO_2^- over all sampling rounds. At 6-h of core inundation, the RF (0.35 mg/m²/h) habitat had the highest mean flux rate (Table 1) and was on average 0.40 mg/m²/h higher than the SWA (0.10mg/m²/h) habitat (all $p<0.01$, Table 2). All the other habitats tested similar at 6-h. At 24-h of core inundation the SWA (0.01mg/m²/h) habitat consisted of a lower mean NO_2^- flux rate close to zero and the NR (1.2mg/m²/h) habitat consisted of the highest mean flux rate. The NR habitat removed 1.19 mg/m²/h more NO_2^- than the SWA habitat ($p=0.03$). All other habitats were similar at 24-h. All habitats had similar rates in the 48-h of core inundation.

Temporally, all sampling rounds for all habitats show mean release rates of NO_2^-. The RF habitat initially has a higher release rate of NO_2^- at 6-h at and lower mean release rates at the 24-h (0.28 mg/m²/h) and 48-h (0.28 mg/m²/h). Initially, at the 6-h and 24-h, the SWA habitat released less NO_2^- but at 48-h of inundation had the highest mean release rate of 0.3mg/m²/h. The TP habitat starts initially with lowest release of 0.1mg/m²/h, has the highest mean release rate at 24-h of 0.8mg/m²/h, and a release rate of 0.6mg/m²/h. The NR habitat mimics the trend observed in the TP habitat with lowest NO_2^- mean release rate at 6-h (0.1mg/m²/h), the highest mean release at 24-h, and middle release rate at 48-h (0.9mg/m²/h).

Figure 14.

Mean Nitrite Flux



Note. Bars represent mean nitrite flux (mg/m²/h) rates across all habitats for each sampled time point. Error bars represent 95% confidence interval. Different letters indicate significant difference among habitat. RF represents Remnant Forest, SWA is Shallow Water Area, TP is Tree Planting, and NR is Natural Regeneration. Negative values indicate nitrite removal from the ecosystem and positive values indicate nitrite release into the ecosystem.

Ammonia.

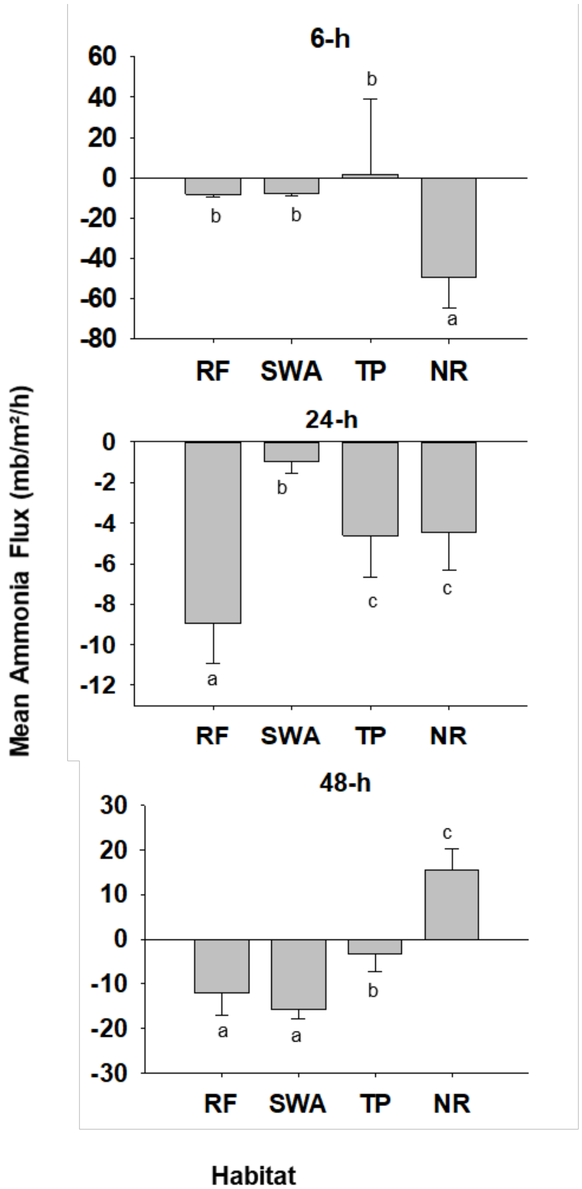
Overall, the RF and SWA habitats had mean removal rates of NH_3^+ over 48 hours of core inundation (Figure 15). The NR habitat had very high removal of NH_3^+ at 6-h and high release of NH_3^+ at 48-h. The NR habitat mean flux rate increases substantially over 48 hours of core inundation.

Differences in mean NH_3^+ flux rates within and among habitats were observed. The NR (-49.16mg/m²/h) habitat has a higher removal rate than the other habitats at 6-h of core inundation and was removing 50.79 mg/m²/h more NH_3^+ than the TP (1.63mg/m²/h) habitat, which was the only habitat releasing NH_3^+ (Table 1). The NR habitat tested significantly different from SWA ($p<0.1$), RF ($p<0.01$), and TP ($p<0.01$) habitats at 6-h (Table 2). All the other habitats were similar at 6-h. At 24-h the SWA (-0.94mg/m²/h) had the lowest and not substantial removal of NH_3^+, that was close to zero, and was 7.16 mg/m²/h lower than the RF (-8.10 mg/m²/h) habitat that had the highest removal of NH_3^+. The SWA habitat was significantly different from TP ($p<0.01$), RF ($p<0.01$), and NR ($p<0.01$) habitats. The RF habitat was also significantly different from the TP ($p<0.01$) and NR ($p=0.001$) habitats. The NR and TP habitats had similar mean rates of NH_3^+ removal. At 48-h the NR (15.56mg/m²/h) habitat was the only mean rate of NH_3^+ release and all other habitats removed NH_3^+ ($p<0.01$). With the NR habitat being the only habitat to release NH_3^+ and the SWA (-15.82mg/m²/h) removing the most NH_3^+, the NR and SWA had a 31.38 mg/m²/h difference. The TP habitat was also significantly different from the RF ($p<0.01$) and SWA ($p<0.01$) habitats. SWA and RF habitats had similar removal rates.

The NH_3^+ flux rates were observed for temporal trends. The data reveal the RF habitat with a gradual decrease in removal of NH_3^+ over time, with the 6-h (-8.14mg/m²/h) being most removal, 24-h being the middle rate, and 48-h (-7.81mg/m²/h) at the lowest rate of removal of NH_3^+. The SWA had the highest rate of NH_3^+ removal at 48-h, lowest at 24-h and middle rate at 6-h (-7.81mg/m²/h). The TP removed most NH_3^+ at 24-h (-4.61mg/m²/h) and removed the least NH_3^+ at 48-h. At 6-h the TP habitat released a non-substantial amount of NH_3^+. The NR habitat mean flux rates increased over time. NR had its highest removal rate at 6-h, lowest removal rate at 24-h (-4.44mg/m²/h), and release of NH_3^+ at 48-h.

Figure 15.

Mean Ammonia Flux



Note. Bars represent mean ammonia flux (mg/m²/h) rates across all habitats for each sampled time point. Error bars represent 95% confidence interval. Different letters indicate significant difference among habitat. RF represents Remnant Forest, SWA is Shallow Water Area, TP is Tree Planting, and NR is Natural Regeneration. Negative values indicate ammonia removal from the ecosystem and positive values indicate ammonia release into the ecosystem.

Dissolved Inorganic Nitrogen.

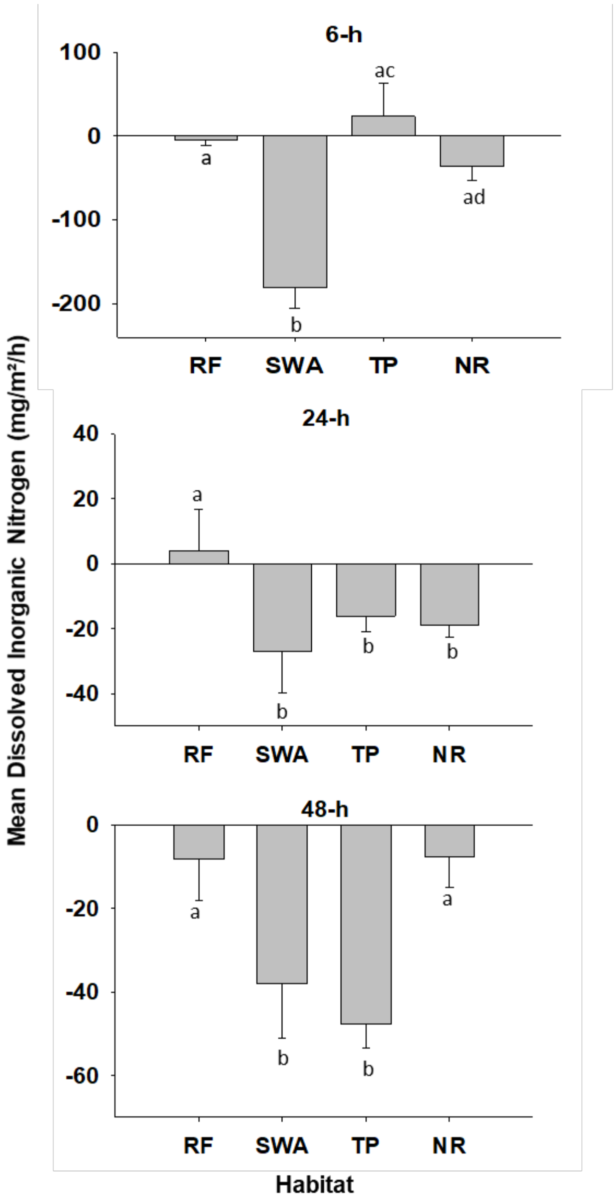
Overall, the SWA habitat initially at 6-h removed a substantially high amount of DIN and removed DIN every sampling time over 48 hours of inundation (Figure 16). The TP habitat flux decreased over the 48 hours of inundation with an increase in removal of DIN since 24-h. The RF habitat had no substantial removal or release of DIN over the 48 hours of core inundation experiment.

Differences in habitats in DIN rates were observed over the course of the core inundation experiment. At 6-h the SWA (-180.8mg/m^2/h) habitat the highest mean removal rate of all habitats and the TP (23.7mg/m^2/h) habitat had the highest and only release rate of all habitats (Table 1). The SWA had 204.5 mg/m^2/h different flux rate than the TP habitat and the SWA habitat was significantly different from the all other habitats ($p<0.001$, Table 2). TP habitat had a release rate that also tested significantly different from the SWA ($p<0.001$) habitat and NR ($p<0.01$) habitat. At 24- h the RF (4.0mg/m^2/h) habitat had a mean release rate for DIN, whereas all the other habitats express mean removal rates, and was 30.9 mg/m^2/h different from the SWA (-26.9mg/m^2/h) habitat (highest removal rate). RF tested significantly different from SWA ($p<0.001$), TP ($p=0.02$), and NR ($p<0.01$) habitats. All other habitats had similar removal rates. At 48-h, all habitats have a mean flux rate that is releasing DIN. The NR (-7.6mg/m^2/h) habitat expresses a mean removal rate that removed 40.0 mg/m^2/h less DIN than TP (-47.6mg/m^2/h) habitat. The NR habitat was significantly different from SWA habitat and TP habitat (all $p<0.001$). The RF (-8.2mg/m^2/h) also removed less DIN than the TP habitat. The RF habitat was also significantly different than SWA and TP habitats (all $p<0.001$). SWA and TP habitats had similar removal rates. RF and NR habitats had similar removal rates.

Temporal trends for DIN were also observed over the course of the inundation experiment. The SWA had the highest removal rate at 6-h and the lowest removal rate at 24-h. At 48-h (-38.0mg/m^2/h) SWA had a middle removal rate. The 6-h removed 153.9 mg/m^2/h more DIN than the 24-h and 142.9 mg/m^2/h more than the 48-h. The highest removal of DIN in the RF habitat occurred at 48-h, at 24-h was a release, and the 6-h (-4.7mg/m^2/h) had the lowest removal of DIN. The TP habitat DIN flux rates decreased over the 48 hours of inundation. At 6-h the TP released a substantial amount of DIN and 24-h (-16.2mg/m^2/h) and 48-h had both removal rates of DIN, with the highest removal observed at 48-h. The NR habitat had mean removal rates of DIN that decreased over 48 hours of the inundation. The highest removal rate was observed at 6-h (-36.1mg/m^2/h), the lowest rate occurred at 48-h, and 24-h (19.0mg/m^2/h) had a rate in the middle.

Figure 16.

Mean Dissolved Inorganic Nitrogen Flux



Note. Bars represent mean dissolved inorganic nitrogen flux (mg/m²/h) rates across all habitats for each sampled time point. Error bars represent 95% confidence interval. Different letters indicate significant difference among habitat. RF represents Remnant Forest, SWA is Shallow Water Area, TP is Tree Planting, and NR is Natural Regeneration. Negative values indicate DIN removal from the ecosystem and positive values indicate DIN release into the ecosystem.

Phosphate

Overall, one of the primary trends with PO_4^{3-} flux rates was the SWA having really low flux, so a substantial removal of PO_4^{3-} at 6-h of core inundation (Figure 17). Another main trend was that the RF habitat was consistent in mean rate at removal of PO_4^{3-} over 48 hours of inundation. The last main trend is that the TP and NR habitats are more effective had removal of PO_4^{3-} at 48 hours are inundation.

Differences in habitats for PO_4^{3-} flux rates were observed over the 48 hours of core inundation. At 6-h the SWA habitat was 32.94 mg/m²/h different than the NR (16.42mg/m²/h) habitat, as the SWA (-16.52mg/m²/h) habitat, substantially, removed the most PO_4^{3-} and the NR habitat released most PO_4^{3-} (Table 3). The RF (-1.88mg/m²/h) removed a non-substantial amount of PO_4^{3-} and the TP (10.56mg/m²/h) habitat also had a mean release of PO_4^{3-} at 6-h. All habitats tested significantly different for one another at 6-h (all $p<0.001$, except NR & TP $p=0.008$, Table 4). At 24-h, the SWA (-5.89mg/m²/h) has highest mean removal rate of PO_4^{3-}, that removed 6.33 mg/m²/h more than the NR (0.44mg/m²/h) habitat, which is releasing a non-substantial amount of PO_4^{3-}. The SWA tested significantly different from the TP (0.23mg/m²/h, $p<0.01$) and NR ($p<0.01$) habitats, and the SWA and RF had similar removal rates of PO_4^{3-}. The RF (-4.01mg/m²/h) habitat also removed more PO_4^{3-} at a difference of 4.45 mg/m²/h than the NR and 4.24 mg/m²/h than TP habitat ($p<0.01$). TP and NR had similar mean rates releasing a non-substantial amount of PO_4^{3-} close to zero. At 48-h the RF (-3.76mg/m²/h) habitat consisted of the highest removal rate, removing 4.18 mg/m²/h more than the NR (0.42mg/m²/h) habitat, released a non-substantial amount of PO_4^{3-} close to zero ($p<0.01$). SWA and TP habitats had similar mean removal rates.

Temporal trends were also observed for PO_4^{3-} flux rates. The SWA decreased in removal rate over time with the most removal of PO_4^{3-} substantially occurring at 6-h (10.63 mg/m²/h more than 24-h and 14.63 mg/m²/h more than 48-h) and the least occurring at 48-h (-1.89mg/m²/h). The RF had consistent mean removal rates across 48 hours of the inundation experiment, with the highest removal being at 24-h, the lowest removal rate at 6-h, and 48-h removal rate in the middle. The TP habitat increased with removal of PO_4^{3-} over the 48 hour inundation experiment. The TP had the highest removal of PO_4^{3-} at 48-h (-1.32mg/m²/h) and at 6-h and 24-h, TP habitat was releasing PO_4^{3-} . The NR habitat consisted of all release rates of PO_4^{3-}, but increased in uptake over time. The highest release rate was in at 6-h and the 24-h and 48-h consisted of similar non-substantial release rates close to zero.

Table 3.

Phosphate Flux Rates

		Nutrient		
		PO_3^{3-}	PO_3^{3-}	PO_3^{3-}
Habitat		**6-h**	**24-h**	**48-h**
RF	**Min**	-5.42	-9.82	-9.15
RF	**Max**	1.61	24.34	14.47
RF	**Mean**	-1.88	-3.76	-3.76
RF	**SD**	1.64	6.05	4.24
SWA	**Min**	-24.27	-9.48	-7.94
SWA	**Max**	-3.16	6.21	30.23
SWA	**Mean**	-16.52	-5.89	-1.89
SWA	**SD**	5.66	2.73	6.42
TP	**Min**	-1.91	-4.30	-4.29
TP	**Max**	32.90	4.02	1.37
TP	**Mean**	10.57	0.24	-1.32
TP	**SD**	7.59	2.21	1.61
NR	**Min**	-8.14	-4.25	-1.48
NR	**Max**	32.97	3.18	2.51
NR	**Mean**	16.42	0.44	0.42
NR	**SD**	9.27	1.69	0.86

Note. Flux rate ranges (min and max), means, and standard deviations that were collected at each sampling round for PO_4^{3-}. Values are expressed as mg/m²/h. Sampling times are expressed as 6-h, 24-h, and 48-h. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 4.

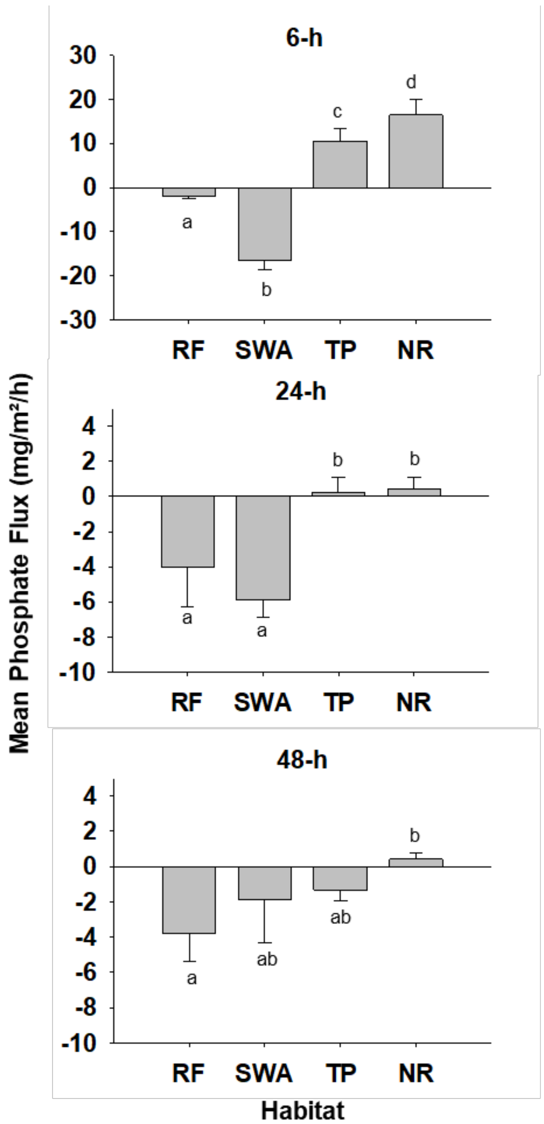
Tukey HSD Post-hoc P-values for Phosphate

Habitat	p-value	Habitat	p-value	Habitat	p-value
PO_4^{3-} 6-h		**PO_4^{3-} 24-h**		**PO_4^{3-} 48-h**	
RF-NR	<0.001*	**RF-NR**	<0.001*	**RF-NR**	<0.001*
SWA-NR	<0.001*	**SWA-NR**	<0.001*	**SWA-NR**	0.11
TP-NR	0.008*	**TP-NR**	0.99	**TP-NR**	0.32
SWA-RF	<0.001*	**SWA-RF**	0.19	**SWA-RF**	0.26
TP-RF	<0.001*	**TP-RF**	<0.001*	**TP-RF**	0.08
TP-SWA	<0.001*	**TP-SWA**	<0.001*	**TP-SWA**	0.94

Note. Tukey HSD post-hoc test results among habitats for 6-h, 24-h, and 48-h. Habitats are Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR). * indicates significant statistical difference.

Figure 17.

Mean Phosphate Flux



***Note*.** Bars represent mean phosphate flux (mg/m²/h) rates across all habitats for each sampled time point. Error bars represent 95% confidence interval. Different letters indicate significant difference among habitat. RF represents Remnant Forest, SWA is Shallow Water Area, TP is Tree Planting, and NR is Natural Regeneration. Negative values indicate phosphate removal from the ecosystem and positive values indicate phosphate release into the ecosystem.

Denitrification

Overall there are a few primary trends with denitrification. The first primary trend was that the NR habitat had the highest denitrification rates over any other habitat (Figure 18). The second trend is the SWA has a gradual increase in denitrification rate over 48 hours of core inundation. Lastly the RF habitat was the least effective habitat for denitrification than other habitats, at 72-h had a non-substantial denitrification rate.

The habitat differences for denitrification rates were observed. At 24-h the NR (7.56 mgN_2-N/m^2/h) habitat consisted of highest mean denitrification rate and was 4.71 mgN_2-N/m^2/h different than the SWA (2.85 mgN_2-N/m^2/h) habitat (Table 5). NR tested significantly different from RF ($p<0.001$) and SWA ($p<0.001$) habitats (Table 6). The TP habitat had a similar denitrification rate to the NR habitat. The TP (5.46 mgN_2-N/m^2/h) habitat had the second highest denitrification rate that was 2.61 mgN_2-N/m^2/h higher than the SWA habitat ($p<0.01$). SWA and RF had similar denitrification rates. At 48-h the NR (6.52 mgN_2-N/m^2/h) habitat consisted of highest mean denitrification rate that was 3.34 mgN_2-N/m^2/h higher than the RF (3.18 mgN_2-N/m^2/h) habitat; thus, resulting with the only significant differences being the NR habitat with RF ($p<0.01$) and TP ($p<0.01$). SWA habitat had similar denitrification rate to all other habitats, and RF and TP also had similar denitrification rates to each other. Lastly, at 72-h the RF (0.28 mgN_2-N/m^2/h) habitat had a non-substantial dentification rate that was close to zero. The NR (5.24 mgN_2-N/m^2/h) habitat had the highest dentification rate that was 4.96 mgN_2-N/m^2/h higher than the RF habitat. The RF was significantly different from all other habitats ($p<0.01$). The other habitats had similar dentification rates.

Temporal comparisons over the course of the 48 hours of core inundation were also observed. The SWA habitat had a gradual increase in denitrification rates with time. The lowest rate was at 24-h, the highest rate was at 72-h (4.33 mgN_2-N/m^2/h), and the middle rate was at 48-h (3.93 mgN_2-N/m^2/h). Over time the RF habitat decreased in dentification rates with the highest at 24-h (3.33 mgN_2-N/m^2/h), lowest at 72-h, and 48-h in the middle. The TP habitat had the highest denitrification rate at 24-h, the lowest at 48-h (3.23 mgN_2-N/m^2/h), and middle at 72-h (3.63 mgN_2-N/m^2/h). The NR habitat gradually decreased with denitrification rates with the highest rate at 24-h, lowest at 72-h, and middle rate recorded at 48-h.

Table 5.

Denitrification and Sediment Oxygen Demand Flux Rates

		Nutrient					
Habitat		**DNF 24-h**	**DNF 48-h**	**DNF 72-h**	**SOD 24-h**	**SOD 48-h**	**SOD 72-h**
RF	**Min**	-5.77	-8.82	-12.13	-71.60	-59.87	-74.43
RF	**Max**	8.34	7.25	3.38	-19.84	-18.60	-19.04
RF	**Mean**	3.33	3.18	0.28	-41.08	-35.46	-43.18
RF	**SD**	2.40	2.99	5.85	14.17	12.51	15.77
SWA	**Min**	-14.31	-17.41	-13.46	-119.81	-111.94	-119.01
SWA	**Max**	11.10	17.76	12.89	-13.87	-22.31	-12.75
SWA	**Mean**	2.85	3.93	4.33	-49.73	-56.78	-68.28
SWA	**SD**	4.48	7.03	5.90	24.38	23.65	22.33
TP	**Min**	1.28	-0.57	-0.30	-74.88	-63.88	-64.24
TP	**Max**	17.48	8.87	15.49	-2.52	0.23	12.36
TP	**Mean**	5.46	3.23	3.63	-39.31	-34.34	-22.23
TP	**SD**	2.86	2.62	3.28	19.30	16.27	21.14
NR	**Min**	3.06	2.12	-0.03	-76.47	-61.88	-55.40
NR	**Max**	13.37	12.45	22.72	-12.68	-16.52	-0.65
NR	**Mean**	7.56	6.52	5.24	-37.87	-41.24	-23.33
NR	**SD**	2.34	2.46	4.70	13.45	10.57	15.06

Note. Flux rate ranges (min and max), means, and standard deviations that were collected at each sampling round for denitrification (DNF) and sediment oxygen demand (SOD). Values are expressed as mgN_2-$N/m^2/h$ or mgO_2-$O/m^2/h$. Sampling times are expressed as 24-h, 48-h, and 72-h. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 6.

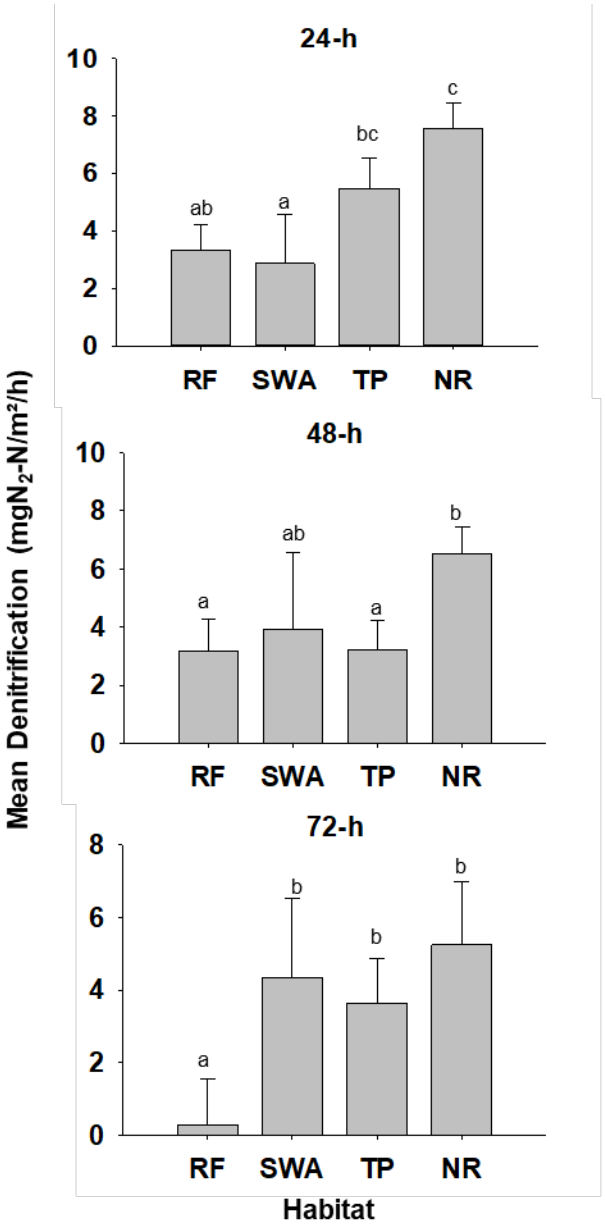
Tukey HSD Post-hoc Test P-values for Denitrification and Sediment Oxygen Demand

Habitat	p-value	Habitat	p-value
DNF 24-h		**SOD 24-h**	
RF-NR	<0.001*	**RF-NR**	0.91
SWA-NR	<0.001*	**SWA-NR**	0.07
TP-NR	0.19	**TP-NR**	0.99
SWA-RF	0.54	**SWA-RF**	0.27
TP-RF	0.17	**TP-RF**	0.98
TP-SWA	0.005*	**TP-SWA**	0.13
DNF 48-h		**SOD 48-h**	
RF-NR	0.02*	**RF-NR**	0.54
SWA-NR	0.09	**SWA-NR**	0.003*
TP-NR	0.09	**TP-NR**	0.38
SWA-RF	0.09	**SWA-RF**	<0.001*
TP-RF	0.09	**TP-RF**	0.99
TP-SWA	0.09	**TP-SWA**	<0.001*
DNF 72-h		**SOD 72-h**	
RF-NR	<0.001*	**RF-NR**	<0.001*
RF-NR	0.86	**SWA-NR**	<0.001*
RF-NR	0.5	**TP-NR**	0.99
RF-NR	0.003*	**SWA-RF**	<0.001*
RF-NR	0.02*	**TP-RF**	<0.001*
RF-NR	0.93	**TP-SWA**	<0.001*

Note. Tukey HSD post-hoc test results among habitats for 24-h, 48-h, and 72-h. Habitats are Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR). * indicates significant statistical difference.

Figure 18.

Mean Denitrification Rates



Note. Bars represent mean denitrification (mgN_2-$N/m^2/h$) rates across all habitats for each sampled time point. Error bars represent 95% confidence interval. Different letters indicate significant difference among habitat. RF represents Remnant Forest, SWA is Shallow Water Area, TP is Tree Planting, and NR is Natural Regeneration.

Sediment Oxygen Demand

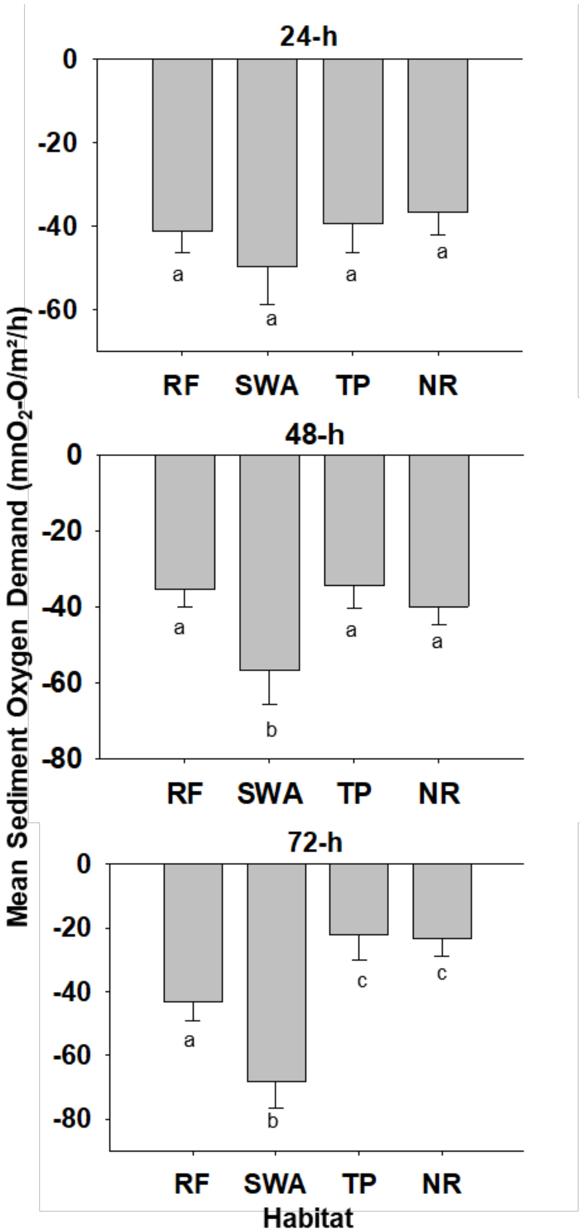
There are a couple primary trends observed with sediment oxygen demand. The first trend is that the SWA habitat always had the highest sediment oxygen demand of all habitats over the course of the 48 hour inundation experiment (Figure 19). The next trend is that the TP habitat decreases over time. The other trend is that all values are negative, so all oxygen is used up at all sampling times.

Habitat differences in sediment oxygen demand are observed over the source of the inundation experiment. At 24-h the SWA (-49.7mgO_2-O/m^2/h) has the highest sediment oxygen demand and the NR (-37.9 mgO_2-O/m^2/h) habitat has the lowest sediment oxygen demand; however, no significant difference among habitats occurred in sediment oxygen demand at 24-h. At 48-h the SWA (-56.8 mgO_2-O/m^2/h) had the greatest sediment oxygen demand and had 22.5 mgO_2-O/m^2/h more than the TP (-34.3 mgO_2-O/m^2/h) habitat, which had the least sediment oxygen demand, and the SWA habitat tested differently from RF ($p<0.01$), TP ($p<0.01$), and the NR ($p=0.003$) habitats (Table 6). All other habitats had similar sediment oxygen demand. At 72-h the SWA (-68.3 mgO_2-O/m^2/h) consisted of the highest sediment oxygen demand and was 46.1 mgO_2-O/m^2/h higher than the TP (-22.2 mgO_2-O/m^2/h) habitat, which was the lowest sediment oxygen demand (all, $p<0.001$). The RF (-40.2 mgO_2-O/m^2/h) had the next highest and was 28.1 mgO_2-O/m^2/h higher than the TP habitat (all, $p<0.001$). The TP and NR habitats had similar sediment oxygen demand.

Temporal trends were also observed over the inundation experiment. The SWA habitat increased in sediment oxygen demand over time. The highest was at 72-h, and was 18.6 mgO_2-O/m^2/h more than 24-h, and 11.6 mgO_2-O/m^2/h higher than 48-h. The TP habitat decreased in sediment oxygen demand over time. The highest was observed at 24-h (-39.3 mgO_2-O/m^2/h) and was 5.0 mgO_2-O/m^2/h more than 48-h and 17.1 mgO_2-O/m^2/h more than 72-h. The NR habitat has the highest sediment oxygen demand at 48-h (-41.2 mgO_2-O/m^2/h), lowest at 72-h (-23.3 mgO_2-O/m^2/h), and middle at 24-h. The RF had its highest sediment oxygen demand at 24-h (-41.1 mgO_2-O/m^2/h), lowest at 48-h (-35.5 mgO_2-O/m^2/h), and middle at 72-h.

Figure 19.

Mean Sediment Oxygen Demand Rates



Note. Bars represent mean sediment oxygen demand (mgO_2-$O/m^2/h$) rates across all habitats for each sampled time point. Error bars represent 95% confidence interval. Different letters indicate significant difference among habitat. RF represents Remnant Forest, SWA is Shallow Water Area, TP is Tree Planting, and NR is Natural Regeneration.

Structural Results

Soil Moisture

Soil moisture varied from a mean of 60% in SWA cores to 41.2% in TP cores (Figure 20, Table 7). The field soil moisture meter was unable to accurately read fully submerged soils, thus the SWA cores were assigned a soil moisture percentage of 60% based on literature values of typical soil moisture of saturated clay-dominated soils (Datta, 2017). SWA soil moisture was significantly different from all other habitats ($p<0.01$) for all habitat comparisons (Table 8). The RF (28.9%) habitat had the second highest soil moisture mean percentage, and differed significantly in soil moisture from TP (18.8%, $p<0.01$), but not NR habitat. Lastly, NR soil moisture was significantly higher than TP ($p<0.01$).

Table 7.

Soil Parameters Values

		Soil Characteristic					
Habitat		**SM**	**AFDM**	**DOM**	**VEG**	**TP**	**TOC**
RF	**Min**	17.6	41.4	50.4	0.0	629.8	17.6
RF	**Max**	36.6	202.8	222.4	28.2	1257.0	93.8
RF	**Mean**	28.9	116.2	118.5	1.2	958.9	51.4
RF	**SD**	5.5	39.5	44.3	5.3	164.6	23.0
SWA	**Min**	60.0	26.9	0.0	0.0	353.7	11.0
SWA	**Max**	60.0	198.6	218.6	221.3	994.0	34.6
SWA	**Mean**	60.0	70.1	127.3	135.1	584.6	20.3
SWA	**SD**	60.0	34.1	68.0	67.9	162.3	6.8
TP	**Min**	10.8	43.8	44.9	0.0	369.5	10.3
TP	**Max**	26.5	74.3	311.5	221.2	666.7	24.9
TP	**Mean**	18.8	57.6	124.3	41.0	512.8	17.5
TP	**SD**	4.6	8.3	71.3	66.4	64.9	4.3
NR	**Min**	14.3	5.8	14.6	0.0	326.5	8.7
NR	**Max**	35.9	74.7	292.7	312.3	748.8	24.1
NR	**Mean**	27.7	51.8	130.4	99.3	476.4	15.1
NR	**SD**	5.6	14.3	66.0	108.7	106.7	4.0

Note. Ranges (min and max), means, and standard deviations that were collected at each sampling round for soil moisture (SM, %), AFDM (mg/g), detrital organic matter (DOM, mg/cm^2), surface vegetation (VEG, mg/cm^2), total phosphorus (mg/g), and total organic carbon (TOC, mg/g). Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 8.

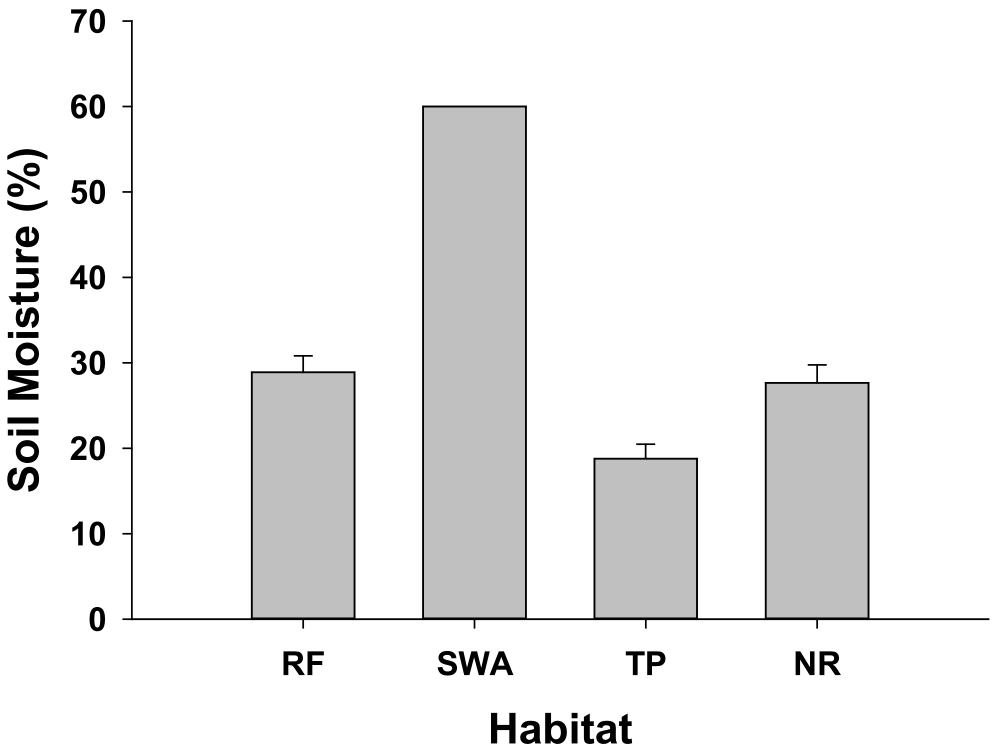
Tukey HSD Post-hoc P-values for Soil Parameters

SM		AFDM		DET		VEG		TP		TOC	
Habitat	**p-value**	**Habitat**	**p-value**	**Habitat**	**p-value**	**Habitat**	**p-value**	**Habitat**	**p-value**	**Habitat**	**p-value**
RF-NR	0.7	**RF-NR**	<0.001*	**RF-NR**	<0.001*	**RF-NR**	-	**RF-NR**	<0.001*	**RF-NR**	<0.001*
SWA-NR	<0.001*	**SWA-NR**	0.05	**SWA-NR**	0.96	**SWA-NR**	<0.001*	**SWA-NR**	0.001*	**SWA-NR**	0.37
TP-NR	<0.001*	**TP-NR**	0.84	**TP-NR**	0.56	**TP-NR**	0.04*	**TP-NR**	0.71	**TP-NR**	0.87
SWA-RF	<0.001*	**SWA-RF**	<0.001*	**SWA-RF**	<0.001*	**SWA-RF**	-	**SWA-RF**	<0.001*	**SWA-RF**	<0.001*
TP-RF	<0.001*	**TP-RF**	<0.001*	**TP-RF**	<0.001*	**TP-RF**	-	**TP-RF**	<0.001*	**TP-RF**	<0.001*
TP-SWA	<0.001*	**TP-SWA**	0.3	**TP-SWA**	0.27	**TP-SWA**	<0.001*	**TP-SWA**	0.15	**TP-SWA**	0.82

Note. Tukey HSD post-hoc test results among habitats. Habitats are Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR). * indicates significant statistical difference.

Figure 20.

Mean Soil Moisture



Note. Bars represent the mean percentage of soil moisture in each habitat. Error bars represent the 95% confidence interval on each bar. RF represents Remnant Forest, SWA is Shallow Water Area, TP is Tree Planting, and NR is Natural Regeneration.

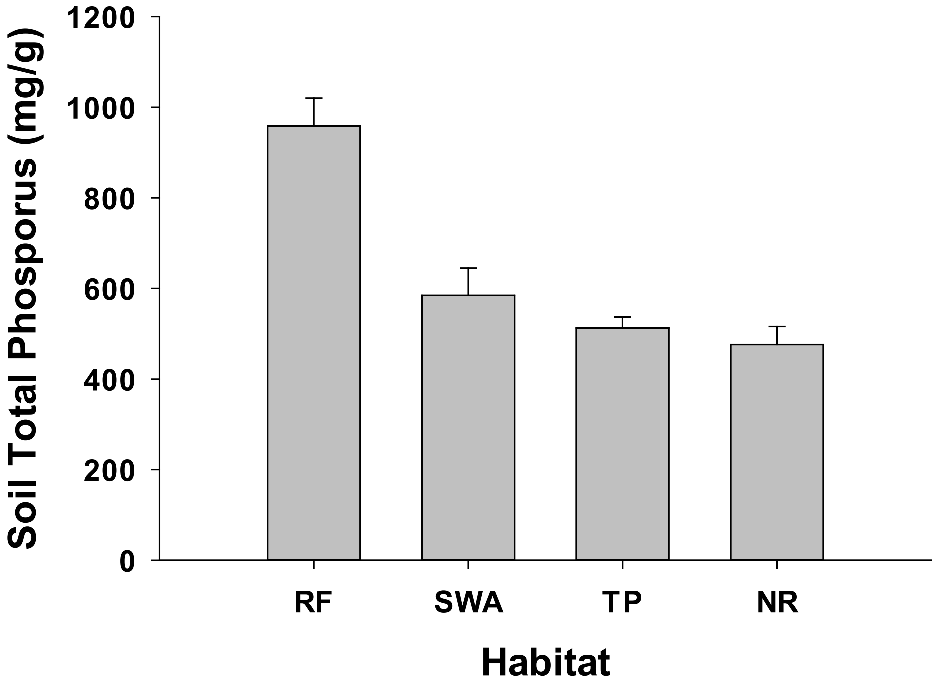
Nutrients

Soil Total Phosphorus.

Soil total phosphorus the RF habitat had the highest concentration of mean soil total phosphorus (Figure 21) at 958.9mg/g (Table 7) and was 482.5mg/g higher than the NR (476.4mg/g). The RF habitat tested significantly different from the all the other habitats ($p<0.001$, Table 8). The SWA habitat had the second highest concentration at 584.6 mg/g and tested significantly different from the NR habitat ($p=0.01$). The TP (512.8mg/g) and NR habitats were similar to each other.

Figure 21.

Mean Soil Total Phosphorus



Note. Bars represent the mean soil total phosphorus (mg/g) concentration in each habitat. Error bars represent the 95% confidence interval on each bar. RF represents Remnant Forest, SWA is Shallow Water Area, TP is Tree Planting, and NR is Natural Regeneration.

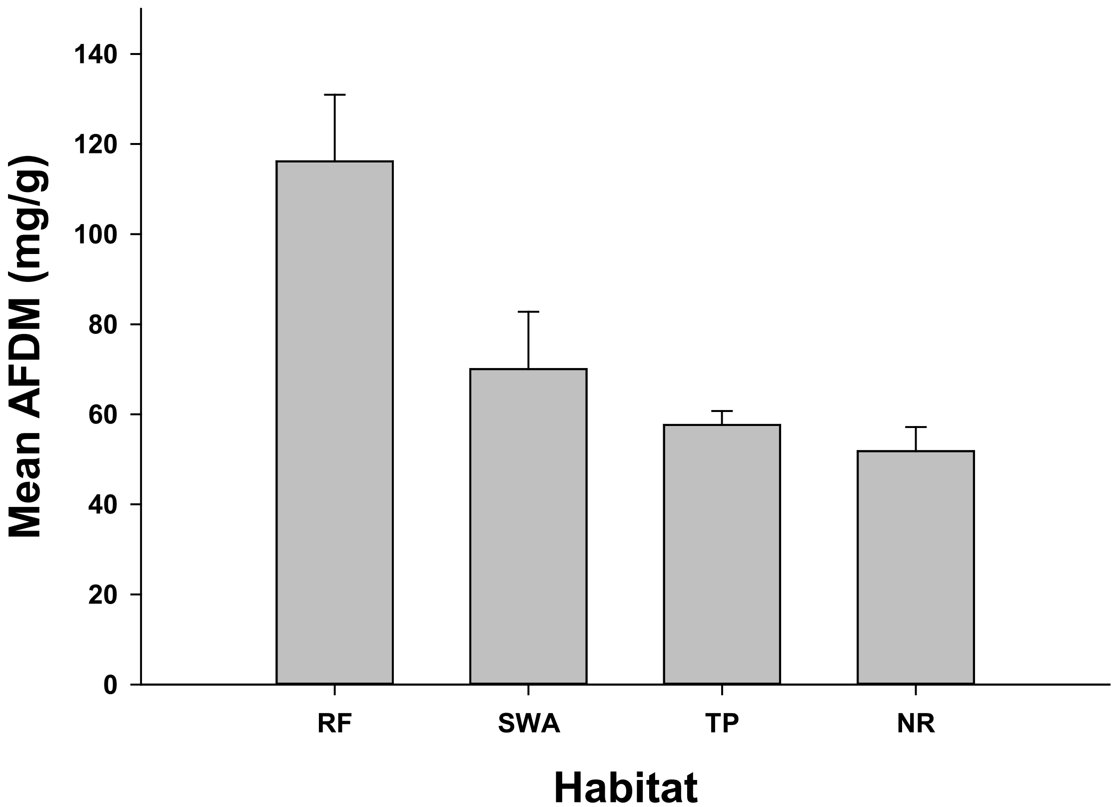
Organic Matter

AFDM.

The RF habitat displayed highest mean AFDM concentration (Figure 22) at 116.2 mg/g (Table 7), and was 64.4mg/g higher than the NR (51.8mg/g) habitat. The RF habitat was significantly different to all other habitats ($p<0.001$, Table 8). The SWA and TP had mean concentrations of 70.1mg/g and 57.6mg/g, respectively. All other habitats did not test significant among each other, as they all possessed similar mean AFDM concentrations.

Figure 22.

Mean Soil AFDM



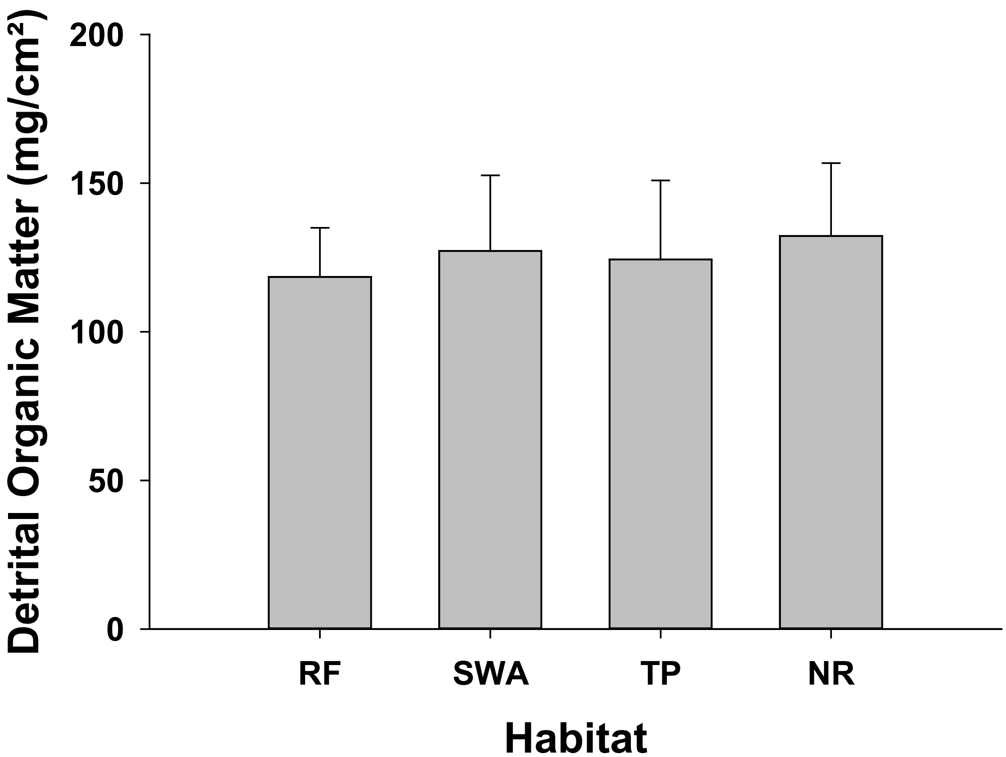
Note. Bars represent the mean subsurface soil Ash Free Dry Mass (mg/g) in each habitat. Error bars represent the 95% confidence interval on each bar. RF represents Remnant Forest, SWA is Shallow Water Area, TP is Tree Planting, and NR is Natural Regeneration.

Detritus.

The NR (130.4mg/cm²) habitat consisted of highest concentration (Figure 23) of mean detrital organic matter that was 11.9mg/cm² more than the RF habitat (118.5mg/cm², Table 7) The SWA and TP habitats had 157.2mg/cm² and 124.3mg/cm² of mean detrital organic matter, respectively. All habitats were statically similar when comparing all habitats (Table 8).

Figure 23.

Mean Detrital Organic Matter



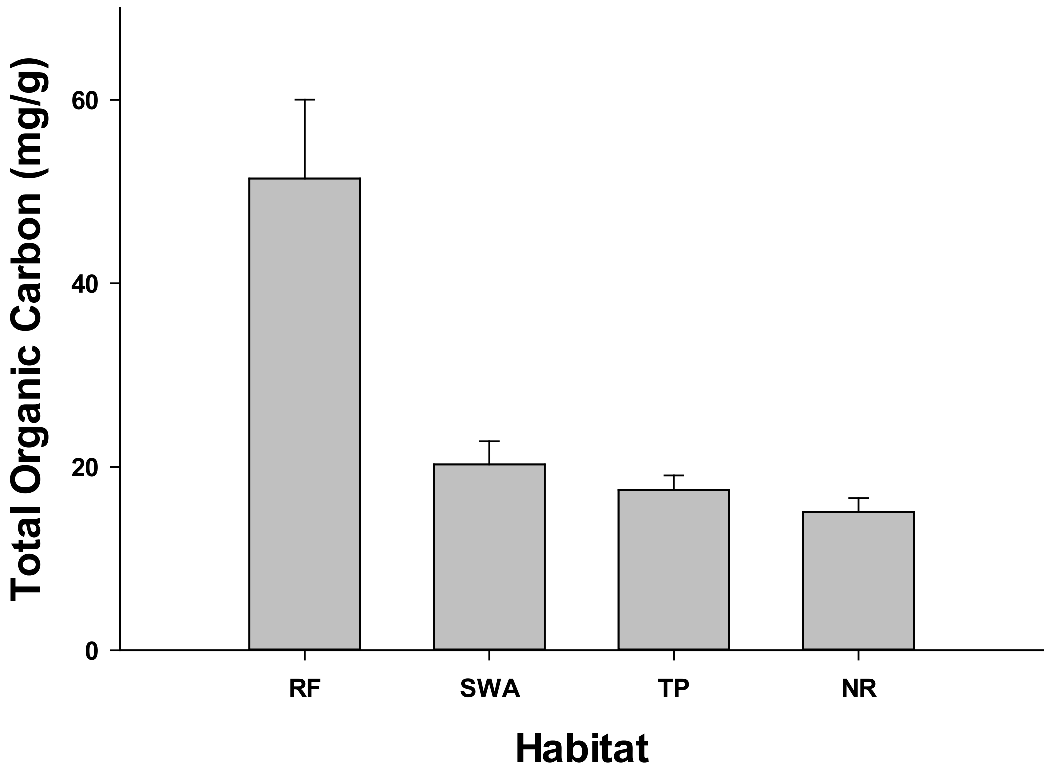
Note. Bars represent the mean surface detrital organic matter (mg/cm^2) in each habitat. Error bars represent the 95% confidence interval on each bar. RF represents Remnant Forest, SWA is Shallow Water Area, TP is Tree Planting, and NR is Natural Regeneration.

Total Organic Carbon.

The RF (51.3mg/g) habitat consisted of the highest mean soil total organic carbon concentration among all habitats (Figure 24) and was 36.2mg/g more than the NR (15.1mg/g) habitat (Table 7). This concentration tested significantly different than all other habitats (all $p<0.001$, Table 8). The SWA and TP habitats consisted of mean soil total organic carbon concentrations at 20.3mg/g and 17.5mg/g respectively. All other habitats were similar in concentration.

Figure 24.

Mean Soil Total Organic Carbon



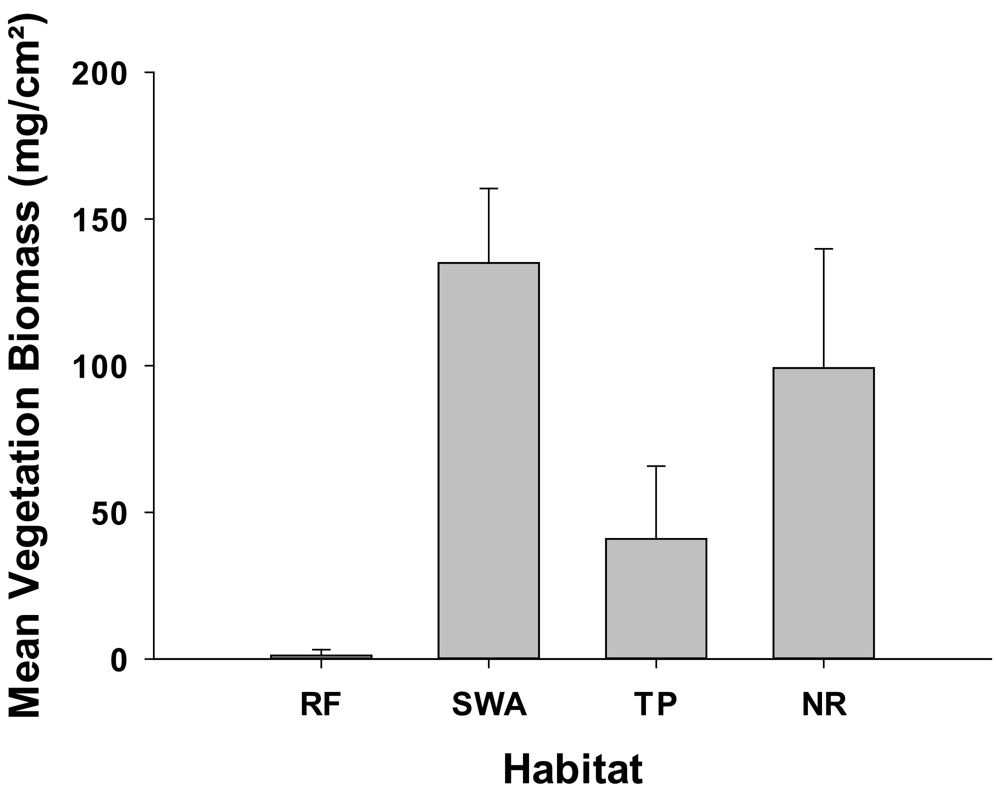
Note. Bars represent the mean concentration of soil total organic carbon (mg/g) in each habitat. Error bars represent the 95% confidence interval on each bar. RF represents Remnant Forest, SWA is Shallow Water Area, TP is Tree Planting, and NR is Natural Regeneration.

Vegetation

The SWA (135.1mg/cm²) consisted of significantly highest vegetation biomass concentration (Figure 25) and was 133.9 mg/cm² more than the RF (1.2mg/cm²) habitat (Table 7). The SWA tested statically significant to the TP and RF habitats (all $p<0.001$, Table 8). The mean vegetation biomass concentration for NR habitat was the second highest at 99.3mg/cm² mg/g, and for TP habitat it was 41.0mg/cm². The TP and NR habitats were also statistically significant between each other ($p=0.01$). In the RF habitat, only included two cores actually had vegetation biomass to measure, the other cores had zero vegetation to measure; therefore, only had a mean concentration of 1.2mg/cm².

Figure 25.

Mean Surface Vegetation



Note. Bars represent the mean surface vegetation biomass (mg/cm²) in each habitat. Error bars represent the 95% confidence interval on each bar. RF represents Remnant Forest, SWA is Shallow Water Area, TP is Tree Planting, and NR is Natural Regeneration.

Generalized Linear Modeling

Nitrate Modeling

The soil parameters most related to NO_3^- flux at 6-h were soil AFDM(p=0.04) and above ground vegetation(p=0.05), with flux rates also different among habitats (Tables 9 and 10). Vegetation correlated negatively with NO_3^- flux, and AFDM had a positive correlation with NO_3^- flux, meaning that more NO_3^- was removed from the water with more surface vegetation, and less NO_3^- was removed with more soil organic matter. The RF (p=0.03) and SWA (p<0.01) habitat NO_3^- flux was significantly different to all other the other habitats, with SWA being the lowest NO_3^- flux. The Δi difference between each AICc model was <2 so, statically, many of the 6-h models have a similar level of support. All of the higher ranked models have some combination of AFDM and vegetation. After 24-h of inundation, total phosphorus (p<0.01) was the only significant soil parameter relate to NO_3^- flux, with more soil total phosphorus leading to more NO_3^- removal from the water. At this time point, the RF habitat (p<0.001) was the only habitat included in the model. After 48-h of inundation, the initial soil moisture was the only significant soil parameter in the model (p=0.05), with higher soil moisture leading to lower NO_3^- removal from the water. The SWA habitat (p=0.02) was the only significant habitat in the 48-h model. The results of the ANOVA and Tukey HSD post-hoc tests show that different soil parameters may be important to NO_3^- flux at different time points, and changes in NO_3^- flux during a flood are occur most in the SWA and RF habitats.

Table 9.

Generalized Linear Model P-values for Individual Habitats and Soil Parameters

Nutrient	Round	RF Hab	SWA Hab	TP Hab	NR Hab	SM	AFDM	DOM	Veg	SOD	TOC	TP
NO_3^-	**6-h**	0.03*	0.004*	0.88	0.88	0.59	0.04*	0.17	0.05*	-	0.2	0.17
NO_3^-	**24-h**	p<0.001*	0.87	0.57	0.72	0.98	0.44	0.96	0.99	-	0.56	0.006*
NO_3^-	**48-h**	0.65	0.02*	0.2	0.11	0.04*	0.86	0.56	0.92	-	0.83	0.84
DIN	**6-h**	0.26	0.77	0.06	0.09	0.02*	0.32	0.51	0.17	-	0.22	0.47
DIN	**24-h**	0.18	0.61	0.36	0.78	0.81	0.5	0.83	0.65	-	0.46	0.002*
DIN	**48-h**	p<0.001*	0.1	0.96	0.3	0.15	0.74	0.8	0.007*	-	0.62	0.02*
PO_4^{3-}	**6-h**	p<0.001*	0.87	p<0.001*	p<0.001*	0.001*	0.03*	0.99	0.18	-	0.04*	0.96
PO_4^{3-}	**24-h**	0.2	0.14	0.26	0.002*	0.01*	0.61	0.06*	0.25	-	0.11	0.005*
PO_4^{3-}	**48-h**	0.32	0.1	0.99	0.87	0.14	0.29	0.93	0.26	-	0.009*	0.008*
DNF	**24-h**	0.02*	0.12	0.12	0.12	0.57	0.02*	0.98	0.15	0.001*	0.18	0.85
DNF	**48-h**	0.15	0.18	0.11	0.72	0.51	0.05*	0.92	0.15	p<0.01*	0.73	0.05*
DNF	**72-h**	0.001*	0.03	0.96	0.24	0.19	0.88	0.95	0.07	p<0.01*	0.87	0.12

Note. Generalized linear model p-value test results among habitats and soil parameters. Sampling rounds are expressed as 6-h, 24-h, and 48-h. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR). * indicates significant statistical difference at the p=0.05 level.

Table 10.

Nitrate AICc Models

Round	Model Number	Model	NO_3^- k	Log-Likelihood	AICc	Δi	wi	acc wi
6-h	1	H + AFDM + V	3	-515.01	1045.20	0.00	0.19	0.19
6-h	2	H + AFDM + DOM + V	4	-514.06	1045.60	0.45	0.15	0.34
6-h	3	H + AFDM + V + TP	4	-514.41	1046.3	1.14	0.11	0.45
6-h	4	H + AFDM + V + TOC	4	-514.43	1046.30	1.18	0.1	0.55
6-h	5	H + AFDM + DOM + V + TP	5	-514.43	1046.40	1.23	0.1	0.65
6-h	6	H + TP + TOC + V + DOM + AFDM	6	-514.43	1047.10	1.76	0.08	0.73
6-h	7	H + TP +DOM + V	4	-514.43	1047.10	1.92	0.07	0.8
6-h	8	H + TP + V	3	-514.43	1047.10	1.92	0.07	0.87
6-h	9	H + AFDM + TP + V + TOC	5	-514.43	1047.10	1.98	0.07	0.94
6-h	10	H + AFDM + DOM	3	-514.43	1047.10	1.99	0.07	1.01
24-h	1	H + TP	2	-514.43	984.20	0.00	1	1
48-h	1	H + SM	2	-514.43	977.80	0.00	0.72	0.72
48-h	2	H + SM+ DOM	3	-514.43	979.70	1.87	0.28	1

Note. Best AICc models for predicting NO_3^-. Soil parameters are as follows: H=habitat, SM= soil moisture, ADFM= sediment ash-free dry mass, DOM =Detrital organic matter, V= vegetation, TP= total phosphorus, TOC= total organic carbon. Δi = difference in AIC of model from the best model, wi = Akaike weighting, k = number of predictors, acc wi = cumulative Akaike weight.

Dissolved Inorganic Nitrogen Modeling

The soil parameters that were most related to DIN flux at 6-h was soil moisture ($p=0.03$), with habitat variability as of importance (Tables 9 and 11). Soil moisture has a negative correlation with DIN flux, meaning as soil moisture increased, more DIN was removed. The Δi difference between each AICc model is <2 so, statically, many of the 6-h models have a similar level of support. All of the higher ranked models have some combination of soil moisture. At 24-h the soil parameters that were most related to DIN flux were soil moisture and total phosphorus ($p<0.01$). Total phosphorus had a negative correlation and soil moisture has a slight positive correlation with DIN flux. As soil total phosphorus increased, DIN removal increased. As soil moisture increased, DIN removal decreased. Soil total phosphorus was in every other model listed and soil moisture was in most other models at 24-h. Lastly at 48-h, the parameter than most fits DIN flux is soil moisture, with differences within habitats. Soil moisture has a positive correlation with DIN flux, so as soil moisture increased, DIN removal decreased. The RF habitat ($p<0.001$) was the only habitat to have statistical significance in the 48-h round. Both habitat and soil moisture were both in some combination with higher ranked models. The results of ANOVA and Tukey HSD show that the soil moisture may be important to DIN flux but other parameters are also important at different time points. Changes in DIN flux during a flood occur most in RF habitat.

Table 11.

Dissolved Inorganic Nitrogen AICc Models

			DIN					
Round	**Model Number**	**Model**	**k**	**Log-Likelihood**	**AICc**	**Δi**	**wi**	**acc wi**
6-h	1	H + SM	2	-568.24	1149.30	0.00	0.34	0.34
6-h	2	H + SM + V	3	-567.43	1150.00	0.68	0.25	0.59
6-h	3	H + SM + TP	3	-567.00	1150.90	1.61	0.15	0.74
6-h	4	H + SM + AFDM	3	-568.06	1151.30	1.92	0.13	0.87
6-h	5	H + SM + DOM	3	-568.08	1151.30	1.97	0.13	1.00
24-h	1	SM + TP	2	-486.81	982.00	0.00	0.45	0.45
24-h	2	H + TP	2	-484.97	982.80	0.79	0.30	0.75
24-h	3	SM + TP + TOC	3	-486.29	983.20	1.17	0.25	1.00
48-h	1	H +SM	2	-485.34	983.50	0.00	0.27	0.27
48-h	2	H + TOC	2	-486.09	985.00	1.49	0.13	0.40
48-h	3	H+ SM + TOC	3	-484.95	985.00	1.50	0.13	0.53
48-h	4	H+ SM + AFDM	3	-485.00	985.10	1.61	0.12	0.65
48-h	5	H + SM + TP	3	-485.02	985.20	1.66	0.12	0.77
48-h	6	H + SM + DOM	3	-485.06	985.30	1.66	0.12	0.89
48-h	7	H	1	-487.39	985.40	1.66	0.11	1.00

Note. Best AICc models for predicting DIN. Soil parameters are as follows: H=habitat, SM= soil moisture, ADFM= sediment ash-free dry mass, DOM =Detrital organic matter, V= vegetation, TP= total phosphorus, TOC= total organic carbon. Δi = difference in AIC of model from the best model, wi = Akaike weighting, k = number of predictors, and acc wi = cumulative Akaike weight.

Phosphate Modeling

At 6-h sampling, the soil parameters most related to PO_4^{3-} flux include: soil moisture ($p=0.001$), AFDM ($p=0.03$), and total organic carbon ($p=0.04$) with habitat variability as importance (Tables 9 and 12). Soil moisture and total organic carbon both negatively correlate with PO_4^{3-} flux, so as both soil moisture and total organic carbon increase, then more PO_4^{3-} is removed. AFDM positively correlates with PO_4^{3-} flux, so as AFDM increased, more PO_4^{3-} is released. The NR, RF, and TP habitats all tested significant with PO_4^{3-} flux ($p<0.001$). The Δi difference between each AICc model is <2 so, statically a couple 6- models have similar level of support. At 24-sampling the soil parameters that most related to PO_4^{3-} flux were soil moisture ($p=0.01$), total phosphorus ($p<0.01$), detrital organic matter ($p=0.06$), total organic carbon, and vegetation. Soil moisture, total phosphorus, and detrital organic matter express a negative correlation to PO_4^{3-} flux, which means as these parameters got higher the more PO_4^{3-} was removed. Total organic carbon and vegetation express positive correlation with PO_4^{3-} flux, so the more of these parameters means more PO_4^{3-} is released. Even though detrital organic matter is not statistically significant, it was in most of the models at 24-h; therefore, it may still ecologically significant, as it was close to $p=0.05$. Since the Δi difference between each AICc model is <2, the other soil parameters have similar level of support at 24-h. Lastly, at 48-h sampling, the parameters that closely relate to PO_4^{3-} flux include: total phosphorus and total organic carbon ($p<0.01$). Total phosphorus had a negative correlation with PO_4^{3-} flux, so the more total phosphorus, the higher PO_4^{3-} is removed. Total organic carbon had a positive correlation with PO_4^{3-} flux, so as total organic carbon increases more PO_4^{3-} is released. The results of the ANOVA and Tukey HSD post-hoc tests show that different soil parameters may be important to NO3- flux at different time points.

Table 12.

Phosphate AICc Models

Round	Model Number	Model	PO_4^{3-} k	Log-Likelihood	AICc	Δi	wi	acc wi
6-h	1	H + SM + AFDM + TOC	4	-338.55	694.60	0.00	0.38	0.38
6-h	2	H + SM + AFDM + V + TOC	5	-337.53	694.90	0.30	0.32	0.70
6-h	3	H + SM + V	3	-340.66	696.50	1.60	0.15	0.85
6-h	4	H + SM	2	-341.81	696.50	1.88	0.15	1.00
24-h	1	SM + DOM + V + TP + TOC	5	-278.39	571.90	0.00	0.18	0.18
24-h	2	H + SM + DOM + V + TP + TOC	6	-276.13	572.10	0.21	0.25	0.43
24-h	3	SM + TP + TOC + V	4	-280.03	572.90	0.99	0.17	0.60
24-h	4	H + SM + DOM + TP + TOC + V	6	-275.35	573.00	1.11	0.16	0.76
24-h	5	SM + DOM + TP + TOC	4	-280.23	573.30	1.39	0.14	0.90
48-h	1	TOC + TP	2	-295.01	598.40	0.00	0.48	0.48
48-h	2	AFDM + TP + TOC	3	-294.50	599.60	1.20	0.27	0.75
48-h	3	TOC +TP + V	3	-294.56	599.70	1.31	0.25	1.00

Note. Best AICc models for predicting PO_4^{3-}. Soil parameters are as follows: H=habitat, SM= soil moisture, ADFM= sediment ash-free dry mass, DOM =Detrital organic matter, V= vegetation, TP= total phosphorus, TOC= total organic carbon. Δi = difference in AIC of model from the best model, wi = Akaike weighting, k = number of predictors, acc wi = cumulative Akaike weight.

Denitrification Modeling

At 24-h sampling AFDM ($p=0.02$), and sediment oxygen demand ($p<0.01$) were all soil parameters that best related to denitrification (Tables 9 and 13), with differences within a habitat. Sediment oxygen demand and AFDM both had a negative correlation to denitrification, which means that as both these parameters increased then so did denitrification rates. The RF ($p=0.02$) was the habitat that was significant for the habitat parameter. The Δi difference between each AICc model is <2 so, statically, many of the 6-h models have a similar level of support. All of the higher ranked models have some combination of AFDM and sediment oxygen demand. At 48-h AFDM ($p=0.04$), sediment oxygen demand ($p<0.001$), and total phosphorus ($p=0.05$) were all soil parameters that related most to dentification rates, the importance in habitat variability. Sediment oxygen demand and AFDM had negative correlations with denitrification, which means as these parameters increased denitrification rates were higher. Total phosphorus had a positive correlation with dentification, so total phosphorus decreased denitrification rates. The Δi difference between each AICc model is <2 so, statically, many of the 6-h models have a similar level of support. All of the higher ranked models have some combination of AFDM and sediment oxygen demand. At 72-h the soil parameters that relate to denitrification sediment oxygen demand ($p<0.001$), soil moisture, total phosphorus, and vegetation with differences among habitats. Sediment oxygen demand had a negative relationship with denitrification, thus increased denitrification rates. Soil moisture, vegetation, and total phosphorus all expressed positive correlations with denitrification, so all these parameters decreased denitrification rates. The habitat parameters RF ($p<0.001$) habitat, SWA ($p=0.02$) habitat were the significant parameters. The results of the ANOVA and Tukey HSD post-hoc tests show that sediment oxygen demand and AFDM are likely major factors for denitrification occurring in an ecosystem. Changes in denitrification rates during a flood event most occur in the RF habitat.

Table 13.

Denitrification AICc Models

Round	Model Number	Model	DNF k	Log-Likelihood	AICc	Δi	wi	acc wi
24-h	1	H + AFDM + SOD	3	-261.94	539.00	0.00	0.28	0.28
24-h	2	H + AFDM + V + SOD	4	-260.00	539.30	0.25	0.24	0.52
24-h	3	H + AFDM + SOD + TOC	4	-261.16	539.80	0.78	0.19	0.71
24-h	4	H + AFDM + V + SOD + TOC	5	-260.00	539.90	0.84	0.18	0.89
24-h	5	H + SOD	2	-263.98	540.80	1.79	0.11	1.00
48-h	1	H + AFDM + SOD + TP	4	-266.91	551.30	0.00	0.24	0.24
48-h	2	H + AFDM + V + SOD + TP	5	-265.73	551.30	0.02	0.24	0.48
48-h	3	H + AFDM + SOD	3	-268.74	552.60	1.30	0.12	0.60
48-h	4	H + AFDM + V + SOD	4	-267.74	553.00	1.64	0.11	0.71
48-h	5	H + SM + AFDM + V + SOD + TP	6	-265.33	553.00	1.66	0.10	0.81
48-h	6	H + SM + AFDM + SOD + TP	5	-266.57	553.00	1.69	0.10	0.91
48-h	7	H + SM + AFDM + SOD + TP	6	-266.68	533.20	1.92	0.09	1.00
72-h	1	H + SM + SOD + TP + V	5	-286.47	592.80	0.00	0.20	0.20
72-h	2	H + SOD + TP + V	4	-288.00	593.50	0.69	0.14	0.34
72-h	3	H + SM + SOD + V	4	-288.02	593.50	0.69	0.14	0.48
72-h	4	H + SOD + TP	3	-289.24	593.60	0.69	0.14	0.62
72-h	5	H + SM + SOD + TP	4	-288.33	594.10	0.69	0.10	0.72
72-h	6	H + SOD	2	-290.75	594.30	0.69	0.10	0.82
72-h	7	H + SOD + TP	3	-289.66	594.50	0.69	0.09	0.91
72-h	8	H + SM + SOD	3	-289.68	594.50	0.69	0.09	1.00

Note. Best AICc models for predicting denitrification. Soil parameters are as follows: H=habitat, SM= soil moisture, ADFM= sediment ash-free dry mass, DOM =Detrital organic matter, V= vegetation, TP= total phosphorus, TOC= total organic carbon. Δi = difference in AIC of model from the best model, wi = Akaike weighting, k = number of predictors, acc wi = cumulative Akaike weight.

Kriging Models

Nitrate

The easement was dividing into two sites for kriging analysis because of discontinuity among samples locations (Figure 3). Site 1 included cores from the RF, NR, and TP habitats on the east side of the easement, and Site 2 included TP and NR habitats on the west side. The SWA habitats were not included in kriging models as the transects were too close together for evaluation and would have produced inaccurate predictions for rates. Site 1 NO_3^- kriging model fits became better the longer cores were inundated with a model R^2 of 0.17, 0.25, and 0.42 for the 6-h, 24-h, and 48-h time points, respectively (Table 14). The major range distance (the maximum distance apart where samples are spatially correlated) for the 6-h, 24-h, 48-h models were 228 m, 423 m, and 41 m, respectively.

On site 1, the NO_3^- 6-h model showed the majority of removal occurred in the southern RF habitat, and the northern RF, TP, and NR areas mainly released NO3- (Figure 31). After 24-h of inundation, the areas there was a shift in removal and release zones, where areas that initial removed NO3- (negative flux) began releasing NO3-, and areas the initially released NO3- into the water (positive flux) began to remove NO_3^- (Figure 32). Zero flux rates, i.e., no release or removal, were predicted to occur in the majority of the central and southern forest region. In the 48-h model more sporadic flux rates occurred throughout Site 1. The northern RF, all of TP, and part of the NR habitat experienced removal rates, while the southern RF experiences mostly release rates and central RF and east NR habitats experience close to zero rates (Figure 33). However, the release rate prediction in the northern RF was driven by two cores with very high removal rates.

Table 14.

Kriging Model Values Site 1

Nutirent	Hour	R^2	Major Range (m)	Root-mean Square	Root Mean Square Standardized	Average Standard Error
NO_3^-	6	0.165	228.536	0.015	0.980	0.016
NO_3^-	24	0.250	423.265	0.024	1.092	0.021
NO_3^-	48	0.423	41.096	0.018	0.969	0.017
PO_4^{3-}	6	0.544	36.602	0.007	0.969	0.008
PO_4^{3-}	24	0.154	187.471	0.004	0.969	0.003
PO_4^{3-}	48	0.225	495.661	0.003	0.969	0.003
DNF	24	0.311	176.254	0.003	0.969	0.003
DNF	48	0.314	223.229	0.003	0.969	0.003
DNF	72	0.237	273.693	0.004	0.969	0.004

Note. Site 1 statistical values for each nutrient parameter and sampling round for the kriging models. Included are the R^2, major range distance (m), Root-Mean Square, Root- Mean Square Standardized, and Average standard error.

Site 2 included cores from the TP and NR habitats only. According to the NO_3^- 6-h model, most of Site 2 released NO_3^- across both habitats, with a small area predicting NO_3^- removal. Small areas of near zero flux rates in the north central region of the TP habitat are predicted in areas between neighboring cores that have opposite flux rates (Figure 34). The Site 2 NO_3^- 24-h model showed NO_3^- removal from the water throughout both habitats (Figure 35). With the 48-h model most rates across both habitats are predicted to have removed NO_3^-, with a small area northeast corner of the NR habitat releasing NO_3^- (Figure 36). As with Site 1, Site 2 NO_3^- kriging model fits became better the longer cores were inundated with a model R^2 of 0.12, 0.18, and 0.44 for the 6-h, 24-h, and 48-h time points, respectively (Table 15). The major range distance for the 6-h, 24-h, 48-h models were 77 m, 72 m, and 91 m, respectively.

There were similar temporal NO_3^- flux patterns over time in both Sites 1 and 2, with an initial release of NO_3^-, followed by more removal at 24 hours, and then more heterogeneous flux rates after 48-h. Additional model fits were similar at each time point suggesting the longer the easement is flooded, the closer areas (i.e., neighboring core samples) behave more similarly. However, over time, hotspots of nutrient flux within and between habitats also become more evident.

Table 15.

Kriging Model Values Site 2

Nutirent	Hour	R^2	Major Range (m)	Root-Mean Square	Root Mean Square Sandardized	Average Standard Error
NO_3^-	6	0.115	76.696	0.059	1.148	0.015
NO_3^-	24	0.182	71.912	0.012	1.074	0.011
NO_3^-	48	0.437	90.519	0.014	1.053	0.013
PO_4^{3-}	6	0.345	82.086	0.006	1.012	0.006
PO_4^{3-}	24	0.079	195.146	0.002	1.006	0.002
PO_4^{3-}	48	0.278	101.209	0.001	1.036	0.001
DNF	24	0.115	238.847	0.002	1.017	0.002
DNF	48	0.269	105.772	0.002	0.936	0.002
DNF	72	0.007	425.289	0.002	1.008	0.002

Note. Site 1 statistical values for each nutrient parameter and sampling round for the kriging models. Included are the R^2, major range distance (m), Root-Mean Square, Root- Mean Square Standardized, and Average standard error.

Phosphate

The model for Site 1 PO_4^{3-} 6-h flux rates showed PO_4^{3-} removal throughout the RF habitat and near zero or release from the TP and NR habitats (Figure 37). The 24-h model for predicted similar PO_4^{3-} removal in the RF habitat, and approximately half the PO_4^3 release in the NR and TP habitats relative to 6-h (Figure 38). The 48-h model showed that after 2 days of inundation, all habitats were removing PO_4^3, with only a small area in the northeast corner of the NR habitat still showing a PO_4^3 release (Figure 39). Site 1 PO_4^3 kriging model fits were best at 6-h and became worse the longer cores were inundated with a model R^2 of 0.54, 0.15, and 0.23 for the 6-h, 24-h, and 48-h time points, respectively (Table 14). The major range distance for the 6-h, 24-h, 48-h models were 37 m, 187 m, and 496 m, respectively.

The model for Site 2 PO_4^{3-} 6-h (Figure 40) showed that all areas measured were releasing PO_4^{3-} with lower (10.57mg/m²/h) release rates in the TP habitat and higher (16.42mg/m²/h) in the NR habitat (Table 3). According to the model for Site 2 PO_4^{3-} 24-h (Figure 41), the TP and NR habitats were still releasing PO_4^{3-}, but mean flux rates were lower in the NR (0.44mg/m²/h) habitat and in the TP (0.24mg/m²/h) habitat, than at 6-h. By 48-h of inundation, the TP habitat is removing PO_4^{3-} , while the NR habitat is still releasing in all locations (Figure 42). As with Site 1, Site 2 PO_4^3 kriging model fits were best at 6-h and became weaker the longer cores were inundated with a model R^2 of 0.35, 0.08, and 0.28 for the 6-h, 24-h, and 48-h time points, respectively (Table 15). The major range distance for the 6-h, 24-h, 48-h models were 82 m, 195 m, and 101 m, respectively.

The RF habitat was consistently removing of PO_4^{3-} over time. When comparing the NR and TP habitats from both sites we see a general pattern of an initial release of PO_4^3 during rewetting, across both habitats, and then a switch to PO_4^{3} removal at 48-h in all but the Site 2 NR habitat.

Denitrification

The denitrification model for Site 1 24h predicts lower rates in the RF habitat and higher rates in the TP and NR habitats (Figure 43). The 48h model shows high denitrification rates across all habitats with only small pockets of low rates in the southern TP habitat and northeast corner of the RF habitat (Figure 44). The 72h model predicts the TP and NR habitats with high rates and the RF shows mostly low predicted rates (Figure 45). The best statistical kriging models for the 24 and 48h models were both equal (R^2=0.31 for both), and worse at 48-h (R^2=0.24, Table 14). The major ranges for 24h, 48h, and 72h are 176m, 223m, and 174m, respectively.

Site 2 denitrification 24h model predicted higher values in the NR habitat and the central-eastern edge of the TP habitat, with only the northwestern corner of the TP habitat predicting low rates (Figure 46). The 48h model predicts higher rates in the center of both habitats and as it moves out to the edges the prediction rates become less (Figure 47). The 72h model has lower rates throughout both habitats but the rates are more consistent than other sampling rounds (Figure 48). The best kriging model statistically is the 48h model (R^2=0.27), the 24-h and 72-h are worse at R^2=0.16 and R^2=0.01, respectively (Table 15). The major range for 24h, 48h, and 72h models is 239, 106, and 425m, respectively.

These predictions fit with the mean denitrification rates in both sites: the RF, NR, and TP habitats over time, because over time mean rate in these three habitats all decline. At 72-h sampling the RF habitat had low denitrification occur, and this trend is also shown in Site 1.

Discussion

The primary hypothesis of this project is that soil nutrient retention would be similar in areas that are closer together, but the spatial relationship would not cross habitat boundaries. Thus, distance between cores would be influential for predicting retention rates, but habitat type would be a better predicator of soil nutrient retention. For example, the RF habitat did not remove N, but consistently removed P. The second hypothesis that standing water presence will increase nutrient removal, was also supported, as the SWA had the highest nutrient removal earlier in the inundation experiment. Examining the differences within and among habitats over the course of a flood also added important information regarding spatial variability of nutrient retention in this wetland. Habitats responded differently the longer they were inundated, increasing or decreasing their nutrient removal capacity, and some switching between being sinks and sources. The third hypothesis predicted soil properties would be correlated to nutrient flux rates. The soil parameters that were best correlated to flux rates were not consistent across time points. For example, the soil parameters that were most related to NO_3^- flux were AFDM and vegetation at 6-h inundation, TP at 24-h, and initial soil moisture at 48-h. However, initial soil moisture was included in many of the top ranked flux models, suggesting it was a strong driver of nutrient flux. Kriging analysis showed low correlation of core distance and nutrient flux rates across the wetland. This suggests that (1) nutrient retention will not be predicted well based on distance between locations, (2) soil parameters can also vary substantial across habitats, and (3) sample number may be more important than sample location to assess nutrient flux rates within a habitat.

Nutrient Retention

Nitrogen

Nitrate.

Habitat type was more important in predicting NO_3^- retention than distance between sampling locations (i.e., cores), but removal trends changed over time for all habitats. The data suggest that NO_3^- retention increased during at least the first 24-h, switching from a net release to a net retention in the NR and TP habitats. The increased interaction time between sediment and standing water can allow for more microbial, plant, and/or soil uptake of NO_3^- to occur (Powers et al., 2012; Wollhiem et al., 2014). The results suggest that three out of four habitats (SWA, NR, and TP) studied retain NO_3^- during a flood, whereas the RF may not retain NO_3^- during floods.

Hydrologic residence time of standing water on sediment (Wollhiem et al., 2014) can play a significant role in NO_3^- retention. The importance of long-term standing water on the site is exemplified by the high SWA initial uptake rates. Although the SWA exhibited the highest NO_3^-removal rates, NO_3^- uptake decreased over time, but removal of NO_3^- still occurred after 24-h. Denitrification also increased with time in the SWA habitat as NO_3^- removal decreased. NO_3^- removal and denitrification rates are often linked in aquatic ecosystems (Forshay, 2005), as NO_3^- is reduced to N_2 in low redox conditions. Low redox increased dentification rates in the SWA and sediment oxygen demand may have increased from increased decomposition of organic matter in the SWA. Decomposition rates may have been increased from the rewetting of fully saturated soil (Dijkstra, 2007). Additionally, the wetland will continue to remove NO_3^- from the ecosystem (at a lower rate), as the water continues to pool over the sediment (Rückauf, 2004).

Another possibility to explain NO_3^- uptake involves changes in water NO_3^- concentration. Lower rates of NO_3^- uptake may be indicative of lower concentration in the water due to the high rates of removal, and/or via denitrification occurring as a result of hydrologic residence time

(Zarnetske et al., 2011). However, since the cores had a continuous supply of high NO_3^- water, it is more likely that NO_3^- either saturated the demand, or other resources may have become limited. For example, denitrification (an anoxic respiration pathway) also requires an organic carbon source to occur.

With the TP and NR habitats increasing uptake as the simulated flood progressed, the TP habitat removed NO_3^- gradually over 48-h of inundation. This result supports my hypothesis that as hydrological residence time increases, so does NO_3^- uptake (Powers et al., 2012). The NR habitat exhibited a similar pattern of NO_3^- uptake increasing over time. After 24-h the NR habitat consistently removed NO_3^- from the water. This pattern suggests the TP and NR habitats are also effective in removing NO_3^- from the ecosystem, but require more time to begin this process; therefore, this trend suggests soil moisture may be a large contributor because the more time to allow for higher the soil moisture, microbial activity increases (Schimel, 1989). The RF did not remove NO_3^- over 48 hours of inundation. This trend may be influenced by nitrogen demand by the microbes and vegetation. If N is not a limiting nutrient in the RF habitat, then NO_3^- is not in high demand by vegetation (Rennenberg, 2015). The RF vegetation may have satisfied the N requirements for vegetation from NH_3^+. The results show that the RF habitat increases NH_3^+ removal; thus, suggesting that the NH_3^+ may be removed by the vegetation in the RF, and NO_3^- is not removed by the vegetation.

Dissolved Inorganic Nitrogen.

NO_3^- composes the majority of DIN (NO_3^-, NO_2, and NH_3^+); therefore, results were similar to NO_3^- flux rates. All habitats expressed DIN flux rates that closely resembled NO_3^- flux rates; however, at 6-h and 48-h the RF habitat had mean removal of DIN. The RF habitat expressed all mean release rates for NO_3^-, but had high NH_3^+ mean removal rates during every sampling round. NH_4^+ is preferentially taken up by microbes and plants as it requires less energy to convert to organic N components, since dissimilatory reduction of NO_3^- to NH_4^+, and then assimilation of NH_4^+ to organic N takes two steps (Li, 2013). Additionally, NH_4^+ is oxidized to NO_2^- and then NO_3^- in oxic conditions through the nitrification process. All habitats consistently released NO_2^-, suggesting nitrification was occurring, but NO_2^- was not a significant contributor to DIN flux, as it was at least an order of magnitude lower in concentration relative to NO_3^-. Initially, at 6-h of inundation the RF habitat was releasing more NO_2^-, and at 24-h and 48-h of inundation the TP habitat release more NO_2^-. Since the TP habitat is removing more NH_3^+ and releasing more NO_2^- at 24-h, indicating that the start of the nitrification process was highest at 24-h of inundation. In the RF habitat, the trend between NH_3^+ and NO_2^- is different than in the TP habitat: the highest removal of NH_3^+ occurred at 48-h and highest release of NO_2^- occurred at 6-h. This result suggests that nitrification process did not occur in the RF habitat as it occurred in the TP habitat. The removal of NH_3^+ occurred mostly for vegetation uptake of N in the RF and nitrification occurred less (Li, 2013).

Phosphate

PO_4^{3-} retention had a similar pattern as NO_3^- retention, and habitat type was a better predicter of PO_4^{3-} retention than distance between cores. In the RF, PO_4^{3-} removal occurred in all sampling periods and PO_4^{3-} removal increased up to 24-h. The results suggest that, during a flood, the RF may be effective at removal of PO_4^{3-} from the ecosystem and that there is a relationship between flood duration and PO_4^- uptake. In addition to flood duration, annual flood patterns have previously been found to influence forest nutrient fluxes more than vegetation (which the habitats are defined by) (Peterson and Rolfe, 1982; Kreiling, 2015).

Microbial activity is often correlated with soil moisture in wetlands (Qu, 2020; Yin, 2019), and results yielded a correlation between pre-flood mean soil moisture and PO_4^- uptake. The relationship between soil moisture and PO_4^- uptake is shown in the RF, TP, and SWA habitats. The RF removed PO_4^- every sampling time over 48 hours of inundation. The TP habitat increased in mean PO_4^- removal over 48 hours of inundation. In the SWA the initially at 6-h of inundation removed a high amount of PO_4^-. The correlation between biotic PO_4^{3-} removal and soil moisture in the RF habitat may be related to the inundation of the cores, as introducing water can cause a reduction in the P sorption in soil (Sawhney, 1975; Wright, 2001). The bicarbonate buffering system property of water may cause the soil pH to become more alkaline and result in concentration of metals to decrease (Indraratna, 2002). This may then result in less Al and Fe cations for P to adsorb to; moreover, biological removal of PO_4^- may increase. A study in Illinois on a Mississippi River temperate forest floodplain concluded that large concentrations of PO_4^- were sequestered in the floodplain soil, and that microbial P biomass was greater in the floodplain soil when compared to biomass in less frequently flooded upland soils (Arenburg et al., 2020). Another potential reason for PO_4^- removal is forests can provide large clusters of root systems that stabilize the soil, and reduce soil erosion. Since PO_4^{3-} is commonly sorbed to soil particles, forests retain the PO_4^{3-} that was removed from the ecosystem, and prevents soil (with PO_4^-) from eroding into the nearby streams (Alewell et al., 2020). A similar affect may be observed with the TP habitat. The TP habitat is essentially a restored wetland habitat that, in the future, will mimic the current RF habitat. Over time, the TP habitat is predicted to become just as effective as the RF at removing PO_4^{3-} from the flood water. In the SWA, the high removal of PO_4^{3-} initially at 6-h, from areas with pooling water over the sediment, has a similar result as NO_3^- at 6-h. Another study had similar results of quick uptake of PO_4^{3-}

from sediment in areas where water can pool (Noe, 2003). The NR habitat was more effective at PO_4^{3-} uptake after 24 hours; although, every sampling period had a mean release rate. In the NR habitat, wetting dry soil increased uptake but some release may still occur. Here inundation may not be the main focus in terms of maximizing uptake potential from a management standpoint.

Other parameters such as trace metal cations (Fe^{3+}, Al^{3+}, Ca^{2+}) that PO_4^{3-} can adsorb with (Fink, 2016) and soil pH may be more important factors affecting biological removal of PO_4^{3-} , as was the outcome of a study looking at P loss based on mobility of topsoil P under flood irrigation events (Sinaj et al., 2002). The data suggests that PO_4^{3-} removal will eventually occur in the RF, SWA, and TP habitats, with RF habitat the consistently removing PO_4^{-}.

Denitrification

Denitrification occurred across all habitats, and differences among habitats were not as great as with NO_3^- and PO_4^{3-} fluxes. Denitrification rates were highest at 24-h in the RF, TP, and NR habitats and decreased over the next 2 days, while SWA rates remained relatively constant over time. Since cores were exposed to a continuous source of fresh, high nutrient water, differences in these maximum potential rates were due to soil properties rather than the overlying water. Denitrification is the respiration of organic matter in anoxic (low redox) environments that used NO_3^- as the final electron acceptor instead of oxygen. Denitrification is an anerobic process; therefore, is carried out by obligate anerobic or facultative anerobic microbial species. Hypoxic/anoxic conditions in the soil/sediment will trigger microbial denitrification activity to increase; thus, as is suggested by the trends in the data (Caffrey, 2018; Knowles, 1981). Wetland soil denitrification rates are thus often limited by nitrate availability, redox potential (i.e., oxygen concentration), and labile organic matter (Surey, 2020). There was a strong correlation between denitrification and sediment oxidation demand for all the habitat types, with an increase in oxygen demand correlated to a simultaneous increase in denitrification rates. Sediment oxygen demand stayed high in the SWA cores, but less oxygen was consumed in the other habitats over time. This suggests that organic matter respiration continued at similar rates in the SWA, but may have decreased in the other habitats. Additionally, our study found significant relationship between AFDM and denitrification rates at 24-h and 48-h of inundation, i.e., AFDM was included in the highest AICc models at both of those time points.

One other factor that could influence the small increase of mean denitrification rate in the SWA, involves the hydrologic residence time between the sediment to water interface. The longer the sediment is inundated, denitrification may increase, as microbial activity has more time to taking up NO_3^- from the water (Song et al., 2010; Roley et al., 2012). This increased time to take up NO_3^- may result in the removal of N by soil microbes through denitrification.

Reasons that may influence the RF, TP, and NR habitats with denitrification rate dropping in the 72-h time interval may include lower microbial denitrification activity in the soil due to lower organic carbon availability and potentially higher redox, or other methods of nitrate uptake (soil, plants). The RF is an interesting habitat, in that, the first two sampling periods have consistent mean denitrification rates, but the last sampling period has much lower mean denitrification. Our results suggest that the RF is more efficient for sequestering PO_4^- than NO_3^-; therefore, denitrification may occur at a less mean rate. Gallardo and Schlesinger (1994), found similar results in a North Carolina temperate forest. Their results suggested that microbial biomass in a temperate forest ecosystem soil is not a major sink of NO_3^- and this conclusion may further suggest that temperate forests are not effective in the removal of NO_3^- through the denitrification process. For the TP and NR habitats the mean denitrification rate gradually decreases after 24-h, which suggests that these two habitats reached maximum denitrification rates before 24-h due to inundation of cores. A study done by Sextone (1985) had similar results; after simulated flood this study found maximum denitrification rates after 3-5 hours and within about 12 hours the rates fell back to pre-flood levels. So, the simulated flood event in the TP and NR habitats that increases soil moisture may drastically accelerate microbial activity within a few hours until it reaches maximum rates. Just as with nutrient retention, increased soil moisture again is an important driver for microbial population involved in NO_3^- removal through the denitrification process (Pinay, 2007). Even with three of the habitats resulting in a decrease of denitrification over time, all four habitats are effective with denitrification.

Role of Soil Structure in Nutrient Retention

The soil parameters that best correlated to nutrient flux rates varied some across the 6-h, 24-h, and 48-h time points. However, there was a few parameters that were consistently in the top models; soil moisture, AFDM, TP, and vegetation, with SOD also important for denitrification, signifying the water, labile carbon, and nutrients were important in regulating soil nutrient fluxes. Unfortunately, soil nitrogen could not be analyzed to include in this assessment. As habitat was included in each of the best models, it is evident that the nutrient flux and soil characteristic relationships vary among habitat types. This suggests that soils composition may also vary substantially across habitats as would be predicted by the different vegetation and hydrologic conditions.

The RF also had the highest soil organic matter (both AFDM and total organic carbon) concentrations. Temperate forests often have high soil carbon (Adams, 2019), which can result from increased vegetation photosynthesis and microbial sequestration of soil carbon, and high amount of decomposition occurrence from heavy woody debris and fallen leaves (Liski, 2002). The RF habitat had little vegetation during sampling, but had noticeable detritus from leaves and flood residue, as well as substantial large woody debris. Arenburg (2020) found that soil in a stream flood plain consisted of large concentrations of PO_4^- were sequestered in the soil of the floodplain, and that microbial P biomass was greater in the floodplain soil. According to the data as total organic carbon increased PO_4^{3-} uptake also increased. The data suggests that soil total organic carbon may have an effect on biological uptake of phosphorus by reducing the adsorption of phosphorus ions to metal cations and even increasing the rate at with phosphorus desorbs from soil and metal cations (Yang, 2019).

Soil moisture was strongly related to nutrient flux rates. As expected, SWA had higher soil moisture than all other habitats, which may have contributed to the high nutrient removal rates of NO_3^- and PO_4^{3-} observed at 6-h. As compared to the dry habitats, the already saturated soil in the of the SWA cores may have provided an initial boost in the capacity of soil microbes to remove nutrients from the water column (Stark, 1995; Torbert, 1992) and plant uptake (Dijkstra, 2008). This may be explained by the soil of the RF, TP, and NR habitats being highly aerobic during the initial inundation (i.e., flooding), which means the microbes of these three habitats may be facilitative aerobic microbes that prefer oxygen for respiration. Rückauf (2004) found that as wetland soil becomes more saturated over time and NO_3^- is taken up quickly and efficiently, initially, during reflooding event; however, the soil will continue to remove NO_3^-, albeit at a lower rate, as the water continues to pool over the sediment. As the results suggest this may be a similar story for the RF, SWA, and NR habitats as they all have mean NO_3^- flux rates that get near zero after 24 hours.

At 6-h vegetation and AFDM, played a large role in regulating NO_3^- flux from the cores showing both above and below ground organic matter is important in N cycling here. As surface vegetation increased the NO_3^- uptake increased, but as soil AFDM increased NO_3^- uptake decreased. These trends suggest there may be an interaction between soil moisture and other soil parameters in nutrient removal during initial flooding, with more nutrient removal occurring when herbaceous vegetation is present.

After 24-h total phosphorus was the best explanatory soil parameter for NO_3^- flux regulation. The increase of NO_3^- uptake as total phosphorus increases may be due to limitation of organic P in the soil of the cores. If soil N:P molar ratios are higher than ~16, then organic P is more limited in the soil and microbes are more likely to assimilate organic N rather than organic P for plant absorption of organic N (Rufty Jr., 1993). In the 48-h sampling round the best soil parameters that explained NO_3^- flux rates were initial soil moisture. Over time as soil moisture increases, NO_3^- uptake decreases. For PO_4^{3-} flux rates the best AICc model soil parameters during the 24-h sampling round include: detrital organic matter, soil moisture, total organic carbon, total phosphorus, and vegetation. The soil moisture increases as PO_4^{3-} uptake increases. This result is probably due to the same reason that soil moisture was a key parameter in the 6-h sampling round. As total phosphorus increases so does PO_4^{3-} uptake, according to the data. Total phosphorus is a consistent fitting parameter because the organic P of total phosphorus concentration in the soil is important to drive the biological removal of PO_4^{3-} of the ecosystem. As detrital organic matter increased so did PO_4^{3-} uptake. This result is probably due to increased carbon and decreased oxygen concentrations in the soil as a result of the decomposing organic matter. With total organic carbon, as it increases PO_4^{3-} uptake decreases. The data suggests that total organic carbon in soil may be explanatory with other variables such as habitat, total soil phosphorus, or detrital organic matter, because when compared to phosphate flux rate individually, soil total organic carbon has really low correlation.

The soil parameters that best fit the AICc model for 24-h sampling period of denitrification were AFDM and sediment oxygen demand, with TP also becoming important at 48-h, and soil moisture and vegetation at 72-h. Denitrification rates increased as sediment oxygen demand increased. Denitrification occurs due to anoxic organic matter respiration where nO3- is the final electron acceptor in the absence of oxygen. NO_3^- is thus reduced to N_2O and then N2 gas and released into the atmosphere; therefore, this process provides the only complete removal of N pollution from the wetland. As AFDM increased in the soil denitrification rates decreased. This result is unexpected as organic matter is needed for denitrification to occur. Total phosphorus was also important as total phosphorus increased denitrification rates. Mehnaz (2016) had a similar result in a study where added P increased N_2O production and potential denitrification. As soil moisture increased so did denitrification rates. The longer the sediment is inundated with no flush occurring, the higher the denitrification rate, as microbial activity has more time to taking up NO_3^- from the water and soil (Song et al., 2010; Roley et al., 2012). According the data, denitrification rates increased as vegetation biomass increased. Vegetation and sediment oxygen demand are both parameters that are important for denitrification as photosynthesis production of oxygen can decrease denitrification rates (Veraart 2010). Type of vegetation presence can also affect denitrification rates either through vegetation cover or algal cover of submerged aquatic vegetation in aquatic systems (Veraart 2010; Wenzhi 2011).

Spatial Patterns of Nutrient Retention

The semivariogram R^2 values that evaluated the kriging models were relatively low (R^2=0.94 is a high value for semivariogram from a spatial wetland study by Nkheloane, 2012), indicating that the predictability of the models is very low. As a result, more sample points may need to be collected from the whole easement at further distances apart, so the kriging models have more data to more efficiently predict and examine the spatial relationship between flux rates. With very few other studies on flux rates with kriging, comparable studies are difficult to find. At site one, which included RF, NR, and TP habitats, NO_3^- had the highest R^2 at 6-h, whereas PO_4^{3-} had the highest at 48-h. Denitrification model fits were similar across time points. The data suggests that NO_3^- flux rates are more spatially correlated (i.e., closer cores have similar flux rates) soon after flooding, soil PO_4^{3-} fluxes become more spatially correlated during the two days of inundation, and soil denitrification fluxes were relatively consistent across this time period. There is less spatial correlation among denitrification rates in soils, and this lack of a relationship continues over at least two days of flooding.

The major range distance of NO_3^- flux for Site 1 was lowest in the 48-h model, 41 m, whereas the 6-h and 24-h models were 229 m and 423 m, respectively, which does not compare to a study done by Hu, 2019, that had a major range of 18,000-23170m for soil total nitrogen. Thus, in Site 1, the minimum distance for spatial autocorrelation can change during a single flood. So, the longer a flood occurred, the higher variability at a shorter minimum distance occurred. Site 2 only included the TP and NR habitats. Here the NO_3^- flux major range was an order of magnitude less, signifying more heterogeneous nitrate fluxes on average. Site 2 spatial autocorrelation distance did not change drastically during the flood simulation. PO_4^{3-} flux rates in both sites had the shortest minimum distance for spatial autocorrelation at 6-h. The other two time point models had of range above 100 meters. This result suggests that over time PO_4^{3-} flux rate variability under flood simulations decreases as the soils flux rates become more similar.

For denitrification rates in Site 1 the lowest minimum distance at which rates are variable is in the 24-h model with a minimum distance equaling 176 meters and other models being over 200meters. As with PO_4^{3-} flux in Site 1, denitrification rates in Site 1 start out with spatial variability occurring at shorter distance, early in the flooding simulation. Over time the minimum distance for spatial variability in rates increases, indicating more consistency in the denitrification rates. For Site 2 spatial variability minimum distance was shortest in the 48-h model at 106 meters between cores. The minimum distance is so high for dentification rates in Site 2 that little spatial variability across habitats occurs in Site 2. In order to obtain spatial independence in dentification rates in cores from these habitats, during a flood event, that cores must be sampled at least 106 meters apart.

The results suggest that kriging models may be a better tool to visualize a temporal trend of NO_3^- flux rates over time than the mean can show. The models show better the spatial variability between cores over time. In order to obtain independent spatial variability in NO_3^- flux rates in cores from these habitats, during a flood event, it is best cores are sampled after 24 hours at a range of approximately 40-70 meters apart. In order to obtain spatial variability in PO_4^{3-} flux rates in cores from these habitats, during a flood event, it is best cores are sampled around 6 hours at a range of approximately 40-80 meters apart, which is much less than Hu, 2019 measured for soil total phosphorus at 2330-2390m.

Management Implications

There is significant variability within and across habitats. The SWA was the most effective habitat at consistently removing NO_3^- and the RF most effective at consistent PO_4^{3-} removal; although other habitats were effective at nutrient removal during various points of the simulated flood. Denitrification rates were greatest in the NR habitat, followed closely by the SWA; however, all habitats had measurable denitrification. Another specific takeaway from this research is that RF habitats were mainly sources of N rather than sinks. Forests are a primary management endpoint for NRCS restoration, and N pollution removal is a key functional response of restoration; therefore, there may be trade-offs in restoration vegetation reestablishment and N removal. An important caveat to this assessment is that the forests measured were dry. This work also showed that water presence increases N removal, so wet forests may provide the desired N removal. In summary, these results suggest that a multihabitat approach may be best at providing consistent nutrient removal, and specifically incorporating a focus on constructing areas where water can pool. Wetlands with multiple installment and management of these habitat types in future wetlands will be key in western Tennessee.

Future Research

Intact soil/sediment cores have been shown to effectively evaluate nutrient uptake across various constructed habitat types for restored wetlands in west Tennessee. Though, there are limitations of cores to explain the spatial variability in the wetland easement as a whole. Future studies utilizing cores should consider collecting enough cores at longer, but continuous distances across habitat boundaries to better assess spatial autocorrelation, and the evaluation of temporal variability through seasonal core collections. Additionally, temperature and soil moisture influences on the biotic and abiotic factors that regulate nutrient uptake rates should be investigated to understand how a changing climate will influence nutrient cycling pathways.

I analyzed how organic matter on the soil surface and subsurface impacted nutrient rates in the cores. In this aspect, further research should investigate more specific parameters within the subsurface microbial communities and the relationship between the mycorrhizal-plant community. A better understanding of the biological communities that play major roles in nutrient pathways will improve our understanding of how complex hydrological manipulations may benefit nutrient removal in these habitats on restored wetland easements.

APPENDIX A. TABLES

Table 16.

Nitrate Flux Rates

	Habitat											
	RF			SWA			TP			NR		
Core	**6-h**	**24-h**	**48-h**	**6-h**	**24-h**	**48-h**	**6-h**	**24-h**	**48-h**	**6-h**	**24-h**	**48-h**
1	15.59	-4.29	13.90	-86.31	-107.63	-13.72	34.52	-18.06	-20.75	15.73	-25.57	-3.46
2	16.68	9.24	4.31	-51.43	-40.61	-96.67	15.88	-25.24	-28.86	20.23	-23.49	2.37
3	0.69	20.50	12.12	-155.82	-28.90	3.34	17.60	-25.79	-23.52	10.39	-27.93	-14.09
4	10.07	-28.09	35.19	-132.38	8.17	5.22	29.88	-20.65	-28.72	6.09	-31.91	-13.06
5	4.18	15.72	-73.94	-178.70	-8.50	68.23	19.75	-20.90	-20.21	5.51	-39.29	-39.19
6	10.25	-20.08	-1.56	-44.07	-85.43	-	25.57	-14.98	-17.80	25.11	-20.14	-5.76
7	13.25	0.14	-20.48	-215.71	-92.02	-0.24	25.31	-34.47	-17.97	20.77	-26.61	0.39
8	12.71	-52.62	-75.07	-119.47	-20.13	-25.00	24.14	-24.02	-21.77	18.40	-24.02	-7.07
9	-11.10	24.25	2.52	-154.89	-17.26	-13.60	-	-23.88	-33.71	-23.08	-27.69	-7.87
10	13.30	52.67	-11.42	-28.21	-66.66	-59.77	24.06	-27.72	-37.63	9.97	-37.65	-22.44
11	-1.76	69.26	-4.42	-215.58	-105.48	-1.70	33.25	-17.49	-17.10	22.58	-44.73	0.74
12	25.13	-57.09	-6.35	-220.26	-13.11	-18.34	18.70	-25.68	-17.42	-9.99	-	-18.71
13	-	-	-4.48	-224.15	-4.58	-26.63	28.66	-19.48	-14.95	24.20	-37.03	-1.48
14	-11.40	36.62	15.28	-173.41	-2.96	-90.68	35.06	-4.87	-14.16	-52.18	-29.05	1.47
15	8.41	5.44	-0.77	-127.65	-3.30	-17.28	-	-30.08	-48.08	27.02	-27.63	1.04
16	12.98	18.30	-3.36	-213.24	-15.80	6.20	14.14	-16.13	-17.58	16.76	-17.55	4.82
17	18.83	10.65	-13.49	-211.34	-27.24	-49.26	31.77	-10.19	-48.79	25.06	-14.45	4.59
18	6.36	48.92	3.89	-102.28	-44.35	41.81	-36.42	-15.90	-4.15	16.24	-6.63	10.18
19	3.46	-12.20	-5.52	-83.65	-30.71	-10.76	-15.51	-25.55	-23.57	26.80	-15.86	-23.89
20	36.87	13.22	3.80	-241.71	-29.13	-57.51	18.11	-14.77	-26.43	19.30	-13.18	-7.96
21	5.91	12.03	0.76	-208.23	-4.97	-12.55	29.69	-11.93	-26.01	29.62	-17.81	-5.86
22	10.55	-4.35	32.56	-153.73	-1.58	-29.73	33.32	-7.76	-21.30	-	-23.64	-4.23

Table 16. (Continued)

	Habitat											
		RF			SWA			TP			NR	
Core	6-h	24-h	48-h	6-h	24-h	48-h	6-h	24-h	48-h	6-h	24-h	48-h
23	-5.56	2.21	22.99	-209.99	-43.74	-21.86	30.49	-7.45	-49.92	24.48	-18.65	-2.47
24	-1.79	-7.16	18.25	-217.03	9.22	-49.71	21.63	-12.97	-	19.59	-	-
25	-36.16	-15.77	10.84	-225.80	-0.03	-62.48	23.78	-10.17	-18.86	23.58	-19.90	-0.62
26	-	63.38	14.39	-244.82	-4.05	5.83	35.14	-5.77	-21.81	18.55	-18.27	-2.89
27	-39.14	13.49	31.43	-228.88	-9.14	-26.48	28.38	-16.42	-12.93	-23.75	-21.37	13.89
28	-3.13	38.84	21.02	-252.45	-13.85	-59.57	19.37	-74.60	-11.66	21.54	-18.28	15.36
29	-3.16	24.76	83.05	-247.64	-9.29	-31.98	22.90	-32.72	-41.92	21.48	-14.28	13.93
30	-25.77	89.49	2.17	-224.05	34.15	-6.92	24.95	-9.14	-18.21	14.39	-12.68	-2.92

Note. All calculated NO_3^- flux rates for each core, from all habitats. Negative rates mean removal of nitrate and positive flux rates mean release of nitrate. Values are expressed as mg/m²/h. Sampling rounds are expressed as 6-h, 24-h, and 48-h. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 17.

Nitrite Flux Rates

	Habitat											
	RF			SWA			TP			NR		
Core	6-h	24-h	48-h	6-h	24-h	48-h	6-h	24-h	48-h	6-h	24-h	48-h
1	0.51	0.38	0.21	0.02	0.40	0.13	0.07	0.70	-0.25	0.08	0.30	0.45
2	0.29	0.17	0.08	0.02	-0.19	0.26	0.06	-0.18	-0.09	0.04	-0.31	-0.46
3	0.06	0.13	0.07	0.06	-0.15	0.79	0.05	-0.08	-0.27	0.16	-0.21	-0.12
4	0.27	0.25	0.07	0.01	-0.02	0.21	0.19	0.07	-0.63	0.30	1.08	3.67
5	0.53	0.50	0.13	0.00	0.04	0.08	0.11	0.72	0.98	0.42	4.03	9.87
6	0.32	0.21	0.07	0.02	-0.03	-	0.01	-0.33	-1.06	0.02	-0.32	-0.60
7	0.42	0.59	0.85	0.09	0.08	0.16	0.01	-0.29	-0.89	0.02	-0.17	0.01
8	0.43	0.21	0.23	0.01	0.22	0.33	0.01	-0.36	-0.73	-0.02	0.48	0.19
9	0.25	0.15	0.22	0.02	0.07	0.37	-	1.68	1.97	-0.05	0.03	2.21
10	0.03	0.15	0.16	0.04	-0.03	0.11	0.17	-0.15	8.64	0.09	2.44	0.84
11	0.56	0.40	0.33	0.10	-0.01	0.12	0.10	-0.06	2.95	0.16	3.01	0.15
12	0.41	0.43	0.33	0.12	0.07	0.17	-0.01	-0.25	-0.94	0.10	-	1.18
13	-	-	0.34	0.12	-0.18	0.31	0.07	-0.01	-0.82	0.14	3.74	0.86
14	0.61	0.31	0.22	0.04	-0.04	0.22	0.20	-0.16	-0.98	-0.07	-0.29	-0.16
15	0.03	0.13	0.13	0.03	-0.03	0.03	-	-0.29	-0.24	0.07	2.40	1.29
16	0.92	0.35	0.25	0.04	0.03	0.23	0.12	0.36	-0.68	-0.01	-0.35	-0.85
17	0.28	0.19	0.17	0.08	0.10	0.34	0.18	-0.27	-0.49	0.05	0.58	-0.45
18	0.65	0.58	0.45	0.04	0.04	0.37	0.11	1.48	2.45	0.06	0.24	-0.33
19	0.24	0.42	0.36	0.02	-0.15	0.26	0.08	1.11	0.34	0.20	1.40	-0.02
20	0.30	0.21	0.11	0.16	-0.06	0.06	0.74	5.14	2.08	0.14	1.19	0.32
21	0.44	0.30	0.20	0.05	-0.15	0.76	0.16	0.39	0.03	0.11	2.49	0.46
22	0.80	0.36	0.67	0.07	-0.19	0.22	0.49	0.20	0.00	-	11.59	5.66

Table 17. (Continued)

Core	6-h	24-h	48-h	6-h	24-h	48-h	6-h	24-h	48-h	6-h	24-h	48-h
23	0.42	0.14	0.48	0.05	-0.15	0.49	0.27	1.81	0.40	0.09	1.26	-0.11
24	0.41	0.43	0.76	0.05	0.00	0.02	0.18	0.53	-	0.88	-	-
25	0.34	0.20	0.16	0.07	0.02	0.10	0.13	0.04	-0.55	0.10	1.08	2.35
26	-	0.24	0.14	0.12	0.23	0.38	0.12	0.10	-0.96	0.00	-0.19	-0.94
27	0.06	0.29	0.28	0.09	0.21	0.39	0.13	0.00	-0.63	0.07	-0.07	0.62
28	0.08	0.11	0.07	0.10	0.33	0.48	-0.01	-0.23	-0.95	0.05	-0.24	0.32
29	0.06	0.06	0.38	0.05	0.18	0.96	0.20	11.50	8.81	-0.04	-0.14	-0.88
30	0.08	0.12	0.40	0.12	-0.18	0.76	0.15	0.06	-0.32	0.05	-0.06	-0.40

Note. All calculated NO_2^- flux rates for each core, from all habitats. Negative rates mean removal of nitrite and positive flux rates mean release of nitrite. Values are expressed as mg/m²/h. Sampling rounds are expressed as 6-h, 24-h, and 48-h. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 18.

Ammonia Flux Rates

	Habitat											
		RF			SWA			TP			NR	
Core	**6-h**	**24-h**	**48-h**	**6-h**	**24-h**	**48-h**	**6-h**	**24-h**	**48-h**	**6-h**	**24-h**	**48-h**
1	-12.25	-10.91	-29.50	-8.61	-2.39	-21.40	-163.10	-6.79	-18.47	-134.11	1.90	-6.00
2	-11.33	-6.23	-36.43	-10.59	-4.22	-21.45	-158.87	-1.59	-6.25	-68.83	-1.95	6.08
3	-11.88	-8.78	-32.92	-6.06	-2.03	-19.74	-159.96	-4.31	-14.16	-96.97	13.59	0.66
4	1.36	3.37	-10.58	-9.13	-2.92	-19.33	-146.65	9.37	-16.20	-89.88	3.65	20.04
5	-13.27	-10.77	1.33	-12.47	-1.55	-19.57	102.66	-6.21	-9.15	-59.34	-1.10	-0.98
6	-4.69	-10.92	-2.69	-10.65	-2.22	-	71.22	-6.53	-1.71	-26.55	-0.03	1.24
7	-11.21	-6.17	-7.87	-11.13	0.35	-18.18	-4.77	-1.28	-16.18	-45.98	-7.84	9.62
8	-9.05	-12.02	4.92	-10.18	-1.91	-20.13	-2.47	-7.73	4.52	-10.42	-9.63	4.43
9	-5.26	-15.86	-1.96	3.69	-1.10	-20.10	-	-12.14	0.59	-35.21	-7.83	7.70
10	-11.47	-11.95	5.23	-10.63	-2.10	-18.62	77.34	-7.19	-2.28	-187.59	-8.57	5.85
11	-8.13	-14.35	-0.96	-10.90	2.16	-19.33	22.85	-9.29	-6.12	-21.84	-7.31	51.15
12	-6.52	-5.14	-1.59	-6.57	1.94	-18.67	-8.35	-0.18	-8.79	-34.84	-	25.29
13	-	-	-16.50	-8.28	2.12	-17.06	74.77	-5.94	-16.84	8.89	-4.98	12.21
14	-8.25	-8.75	-12.95	-10.92	0.59	-18.12	91.65	-4.72	-6.13	-30.28	-7.63	16.30
15	-10.31	-9.73	-6.62	-8.95	0.38	-18.62	-	-5.31	-1.61	-63.92	-6.78	22.91
16	-8.22	-18.20	-15.80	-12.35	0.47	-18.76	38.89	-14.89	-5.35	-62.99	-7.90	35.22
17	-13.03	-11.67	-6.80	-11.29	-0.29	-17.17	32.13	-7.93	-17.46	-88.26	-3.30	10.75
18	-9.32	-6.85	-10.65	-7.70	-1.66	-16.88	-211.37	-3.04	-14.03	-23.26	-2.50	5.22
19	-10.02	-13.71	-12.85	-7.05	-0.93	-16.60	45.19	-10.49	-14.76	-42.25	-3.16	12.61
20	-8.98	-11.61	13.20	-10.32	-1.59	-16.45	22.60	-7.57	-4.88	-20.70	-4.71	12.90
21	-9.67	-9.97	-12.44	-8.40	-1.29	-15.74	8.40	-5.49	5.86	-18.81	-5.21	30.05
22	-8.77	-13.07	-8.29	-5.86	-0.39	-17.19	119.13	-8.97	16.16	-	-4.47	8.09

Table 18. (Continued)

	Habitat											
	RF			SWA			TP			NR		
Core	6-h	24-h	48-h	6-h	24-h	48-h	6-h	24-h	48-h	6-h	24-h	48-h
23	-8.60	-15.92	-44.85	-8.49	-1.31	-15.64	37.18	-11.74	6.34	-37.97	-6.10	13.96
24	-3.48	-7.85	-43.38	-4.42	-1.67	-13.52	-177.79	-3.63	-	-25.06	-	-
25	-4.39	-10.36	-13.97	-5.82	-2.09	0.99	42.81	-6.18	6.36	-44.36	-6.85	26.07
26	-	-4.21	-14.04	-6.30	-1.00	-12.41	36.34	0.68	11.09	-66.63	-7.55	24.76
27	-3.48	-5.78	-17.44	-4.38	-1.81	-9.05	57.51	-2.51	3.92	-31.19	-7.26	26.85
28	-5.24	-1.29	-8.10	-5.81	-1.68	-7.33	33.09	3.93	12.34	-1.71	-6.06	26.45
29	-8.76	2.36	-10.18	-4.59	-1.71	-6.79	84.19	7.66	0.44	-32.21	-6.92	22.74
30	-3.79	-3.23	-7.48	-0.21	1.68	-5.84	81.16	1.78	19.14	-33.45	-7.70	19.07

Note. All calculated NH_3^+ flux rates for each core, from all habitats. Negative rates mean removal of ammonia and positive flux rates mean release of ammonia. Values are expressed as mg/m²/h. Sampling rounds are expressed as 6-h, 24-h, and 48-h. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 19.

Dissolved Inorganic Nitrogen Flux Rates

	Habitat											
	RF			SWA			TP			NR		
Core	**6-h**	**24-h**	**48-h**	**6-h**	**24-h**	**48-h**	**6-h**	**24-h**	**48-h**	**6-h**	**24-h**	**48-h**
1	-10.26	-49.81	-31.74	-94.89	-75.85	-21.15	-99.18	-16.24	-53.67	-90.35	-15.65	-23.02
2	-8.48	-31.81	-48.40	-62.01	-11.25	-104.01	-113.25	-19.10	-49.58	-23.41	-17.84	-6.21
3	-25.24	-23.15	-37.07	-161.82	0.36	-2.72	-112.97	-22.47	-51.96	-58.48	-7.83	-26.83
4	-1.37	-56.87	9.54	-141.50	36.68	-1.01	-87.24	-3.31	-59.94	-55.55	-19.48	-3.37
5	-23.19	-30.84	-89.44	-191.17	21.44	61.63	151.86	-18.48	-41.66	-25.47	-28.65	-44.14
6	-8.75	-67.08	-21.13	-54.70	-55.06	-	126.49	-13.74	-35.33	24.43	-12.67	-19.13
7	-12.17	-41.72	-44.47	-226.75	-61.31	-5.85	49.89	-28.12	-49.43	2.06	-27.11	-3.44
8	-10.56	-100.70	-86.88	-129.64	10.79	-31.43	49.62	-24.00	-32.37	35.20	-25.66	-16.10
9	-30.22	-26.45	-15.58	-151.19	14.32	-19.96	-	-26.53	-45.17	-30.40	-27.79	-11.61
10	-12.78	4.59	-22.99	-38.80	-38.51	-65.87	130.91	-27.45	-44.74	-150.29	-36.26	-29.39
11	-23.96	19.02	-22.01	-226.38	-71.88	-8.02	84.14	-19.52	-33.18	28.85	-41.32	38.39
12	4.39	-98.09	-24.58	-226.71	21.50	-23.48	38.27	-18.40	-41.16	-20.28	-	-5.15
13	-	-	-38.21	-232.31	27.65	-30.96	132.14	-17.92	-46.81	59.78	-30.95	-1.69
14	-33.16	-6.81	-13.80	-184.29	27.87	-96.16	154.85	-1.25	-36.39	-54.95	-29.25	3.96
15	-15.45	-37.87	-23.00	-136.57	27.34	-23.46	-	-28.56	-63.58	-8.89	-24.30	11.23
16	-8.44	-34.54	-35.27	-225.55	16.15	0.57	83.90	-22.75	-37.99	-18.31	-18.18	25.53
17	-8.04	-35.83	-36.47	-222.55	4.02	-53.20	94.82	-10.18	-81.49	-35.20	-9.45	0.87
18	-15.38	10.25	-21.46	-109.94	-14.53	38.20	-216.94	-9.15	-30.48	7.71	-3.54	2.90
19	-19.91	-59.18	-33.76	-90.68	-1.51	-14.68	58.40	-27.02	-52.39	11.30	-10.11	-25.33
20	14.07	-33.16	0.76	-251.87	0.66	-61.01	70.09	-9.29	-42.51	26.69	-9.39	-8.02
21	-17.96	-33.93	-28.44	-216.58	23.87	-15.10	67.59	-8.92	-34.50	38.87	-12.82	10.63
22	-11.53	-52.05	8.59	-159.52	29.29	-33.81	181.58	-8.81	-19.53	-	-9.80	-3.76

Table 19. (Continued)

	Habitat											
	RF			SWA			TP			NR		
Core	**6-h**	**24-h**	**48-h**	**6-h**	**24-h**	**48-h**	**6-h**	**24-h**	**48-h**	**6-h**	**24-h**	**48-h**
23	-27.85	-48.56	-37.74	-218.43	-12.59	-23.64	95.19	-9.87	-57.02	13.85	-15.58	-2.82
24	-18.44	-48.27	-40.12	-221.40	37.83	-50.81	-128.74	-8.36	-	24.05	-	-
25	-54.33	-60.91	-19.32	-231.55	29.34	-48.49	94.66	-8.40	-26.71	7.26	-17.77	13.78
26	-	24.42	-15.87	-251.00	27.80	7.17	100.95	3.22	-26.43	-19.43	-18.09	6.91
27	-53.01	-17.92	2.16	-233.16	21.87	-21.76	115.36	-12.99	-24.03	-26.92	-20.79	26.96
28	-21.88	3.96	-2.75	-258.16	18.58	-52.58	82.83	-62.79	-15.40	47.13	-16.87	28.11
29	-26.50	-9.10	56.29	-252.17	21.78	-24.45	135.93	-5.84	-45.21	16.47	-13.72	22.50
30	-43.59	51.39	-21.26	-224.13	65.94	0.42	136.30	0.80	-14.15	8.94	-12.53	1.73

Note. All calculated DIN flux rates for each core, from all habitats. Negative rates mean removal of DIN and positive flux rates mean release of DIN. Values are expressed as mg/m²/h. Sampling rounds are expressed as 6-h, 24-h, and 48-h. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 20.

Phosphate Flux Rates

	Habitat											
	RF			SWA			TP			NR		
Core	6-h	24-h	48-h	6-h	24-h	48-h	6-h	24-h	48-h	6-h	24-h	48-h
1	-3.21	-0.52	-1.26	-7.33	-7.35	-7.94	24.32	0.64	-0.97	-	0.38	-0.14
2	1.61	-4.77	-2.49	-7.13	-6.83	-7.68	15.15	-1.04	-1.43	9.09	-1.65	-0.11
3	-1.76	-9.44	2.72	-12.23	-7.20	-5.20	11.34	-2.69	-3.09	-	-0.22	-1.24
4	-1.62	-8.20	-3.29	-12.60	-8.56	-3.99	20.91	-2.16	-4.29	-8.14	-0.70	-1.48
5	-3.35	24.34	-9.15	-15.74	-7.09	-3.66	32.90	0.35	-3.94	9.57	-1.65	-0.93
6	-1.76	-6.99	-5.49	-3.16	-7.20	-4.24	13.35	-3.93	-3.64	12.01	-2.85	0.41
7	-0.34	-3.60	-3.61	-19.41	-9.48	-3.44	6.93	-2.81	-3.11	22.39	0.96	0.16
8	-3.28	-9.81	-8.25	-13.00	-6.15	-3.27	3.67	-4.32	0.11	20.24	1.53	-0.33
9	-2.36	-4.19	-6.10	-15.67	-8.01	-2.28	11.26	1.72	-2.04	20.34	0.69	-0.36
10	-0.66	-5.93	-1.66	-6.96	-5.64	-4.58	15.19	-3.89	-1.77	-	2.56	0.62
11	-4.49	-6.83	-7.17	-19.93	-8.67	-2.49	2.75	-1.21	-1.09	10.72	0.39	0.26
12	-3.11	-9.82	-8.35	-18.71	-3.93	-2.20	-1.37	0.84	-2.74	12.14	0.51	0.27
13	-	-	-4.55	-20.86	-5.86	-4.21	10.00	-0.25	-3.73	29.58	1.59	1.75
14	-0.26	-5.92	-2.96	-15.71	-6.45	-2.93	10.68	1.98	1.37	19.03	0.42	0.76
15	-2.31	-5.10	-5.02	-12.82	-6.61	-1.33	4.90	-1.00	0.32	29.10	2.69	0.68
16	0.01	-3.95	-3.02	-21.09	-6.37	-2.58	8.90	0.92	0.30	8.59	-2.35	0.34
17	-2.32	0.40	-3.11	-18.91	6.20	-0.83	12.57	1.42	-3.40	15.84	1.27	1.13
18	0.84	-6.93	-4.35	-12.13	-5.96	-1.76	-	1.14	-0.48	10.75	1.32	0.57
19	0.55	-4.13	-4.57	-10.19	-6.52	-1.21	10.06	1.89	-1.94	22.88	0.56	1.17
20	-3.37	-4.50	-6.62	-23.65	-6.15	-4.18	11.54	3.01	0.20	29.06	1.54	0.40
21	-5.42	-8.85	-5.26	-17.91	-4.52	-0.98	1.28	2.09	0.69	32.97	0.53	0.96
22	-1.26	-4.05	-6.52	-15.87	-4.42	-2.01	18.36	0.25	0.44	25.69	2.71	1.55

Table 20. (Continued)

	Habitat											
		RF			SWA			TP			NR	
Core	**6-h**	**24-h**	**48-h**	**6-h**	**24-h**	**48-h**	**6-h**	**24-h**	**48-h**	**6-h**	**24-h**	**48-h**
23	-2.13	-3.10	-6.35	-19.13	-3.16	-4.85	12.18	4.02	0.34	23.32	1.27	-0.23
24	-3.02	-2.27	-5.07	-22.41	-5.44	-5.26	-	-1.25	-0.92	22.80	3.18	2.51
25	-1.01	-2.19	-5.59	-21.91	-2.89	30.23	7.36	1.94	-1.12	17.80	1.98	1.41
26	-	-2.74	-2.45	-22.51	-6.73	2.20	-1.91	1.05	-1.36	4.68	0.51	1.03
27	-1.88	-4.36	14.47	-21.16	-6.96	-1.56	5.81	1.17	-1.57	5.38	0.34	0.93
28	-0.97	-4.22	-3.66	-21.16	-5.91	-3.13	4.63	1.91	-0.30	13.17	0.42	-0.04
29	-3.89	-2.58	-1.29	-21.16	-5.69	-0.23	15.19	1.91	-1.40	11.22	-0.43	0.66
30	-1.80	-6.05	-2.91	-21.16	-7.05	-1.20	7.87	1.91	0.97	13.14	-4.25	0.01

Note. All calculated PO_4^{3-} flux rates for each core, from all habitats. Negative rates mean removal of phosphate and positive flux rates mean release of phosphate. Values are expressed as mg/m²/h. Sampling rounds are expressed as 6-h, 24-h, and 48-h. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 21.

Denitrification Rates

	Habitat											
	RF			SWA			TP			NR		
Core	**24-h**	**48-h**	**72-h**	**24-h**	**48-h**	**72-h**	**24-h**	**48-h**	**72-h**	**24-h**	**48-h**	**72-h**
1	3.56	-0.98	-6.12	-14.31	-11.48	-6.07	4.45	1.65	4.54	8.09	8.14	4.17
2	1.97	-8.82	-12.13	-24.67	-17.41	-13.46	5.81	2.27	4.14	6.85	6.76	9.36
3	-5.77	1.06	-2.22	1.38	3.90	7.82	1.28	-0.57	6.41	5.60	7.34	6.72
4	0.58	1.06	-3.38	-6.04	-3.30	-3.40	4.70	0.70	0.79	10.01	9.94	13.00
5	6.65	3.51	2.15	2.13	2.03	2.56	2.75	1.17	-0.29	13.37	12.45	9.19
6	3.73	5.05	0.78	-0.28	1.15	7.56	2.11	1.22	0.26	6.44	3.14	0.08
7	4.35	4.24	5.85	3.04	3.09	2.16	4.39	0.11	1.55	8.07	6.77	9.15
8	1.50	4.69	-1.26	4.27	14.76	8.79	4.62	-0.54	0.02	11.43	8.82	4.48
9	1.48	4.22	1.90	5.09	9.27	4.14	7.34	6.40	8.78	9.02	6.39	2.84
10	2.63	4.10	-0.49	2.38	4.36	5.36	5.01	8.87	15.49	8.59	7.58	5.58
11	5.89	7.25	4.28	2.55	4.68	1.83	4.93	5.36	4.82	9.79	6.93	1.89
12	5.86	6.00	2.41	5.82	7.44	6.96	6.82	1.67	5.37	8.48	6.47	3.06
13	3.54	5.62	2.49	2.46	0.73	12.89	17.48	8.84	2.18	10.54	8.57	22.72
14	3.30	3.07	-0.10	1.67	-0.20	11.92	5.30	1.21	5.94	8.30	6.12	1.45
15	3.70	5.15	3.11	2.66	1.85	0.25	3.81	3.73	3.41	8.65	9.14	6.56
16	3.90	2.31	-0.48	2.67	2.59	1.91	4.70	0.80	2.41	5.30	2.55	-0.03
17	4.66	3.84	0.48	5.93	9.93	9.07	4.06	5.15	0.79	6.76	5.95	2.21
18	2.39	1.80	1.85	1.06	1.84	0.60	5.92	6.07	3.72	3.06	2.22	3.18
19	1.67	2.32	-0.76	1.37	0.81	3.09	5.38	2.60	4.16	7.38	9.17	7.32
20	4.19	2.27	-0.67	2.75	0.87	1.28	3.45	1.54	4.53	5.08	5.96	2.35
21	4.64	7.14	2.13	4.73	7.98	8.19	4.80	2.51	3.32	4.78	5.21	3.96
22	8.33	6.69	3.27	3.35	2.63	4.26	5.43	5.24	4.20	8.55	9.71	8.79

Table 21. (Continued)

	Habitat											
		RF			SWA			TP			NR	
Core	**24-h**	**48-h**	**72-h**	**24-h**	**48-h**	**72-h**	**24-h**	**48-h**	**72-h**	**24-h**	**48-h**	**72-h**
23	3.96	3.77	3.64	4.56	2.34	-1.18	5.10	5.15	-0.25	6.90	6.56	0.92
24	2.18	2.64	3.22	4.28	3.80	-1.54	11.28	8.25	2.99	-	-	10.83
25	5.88	3.91	0.77	2.03	4.65	5.01	5.50	2.82	6.52	10.51	5.43	4.19
26	3.03	2.54	-1.05	7.68	12.59	9.35	6.53	2.58	1.22	6.12	2.12	2.89
27	2.49	1.32	0.00	7.21	11.51	10.24	4.46	2.97	0.87	6.26	5.87	4.24
28	2.78	1.87	-1.75	11.11	12.82	11.01	4.38	1.94	-0.13	5.58	5.39	2.56
29	3.19	5.59	0.46	7.58	17.76	12.61	5.80	3.27	6.59	4.69	2.90	1.65
30	3.62	2.15	-0.03	3.62	4.79	6.59	6.11	3.93	4.62	4.92	5.45	1.85

Note. All calculated denitrification rates for each core, from all habitats. Positive rates indicate denitrification occurrence and negative rates indicate no occurrence. Values are expressed as $mgN_2\text{-}N/m^2/h$. Sampling rounds are expressed as 24-h, 48-h, and 72-h. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 22.

Sediment Oxygen Demand

	Habitat											
	RF			SWA			TP			NR		
Core	**24-h**	**48-h**	**72-h**	**24-h**	**48-h**	**72-h**	**24-h**	**48-h**	**72-h**	**24-h**	**48-h**	**72-h**
1	-71.27	-57.71	-58.29	-48.73	-53.27	-70.30	-32.59	-29.13	-20.65	-48.91	-49.48	-31.30
2	-37.74	-24.07	-38.44	-20.91	-42.38	-68.97	-57.54	-43.41	-29.77	-33.02	-45.87	-13.32
3	-23.00	-19.43	-31.38	-49.35	-69.87	-86.56	-37.81	-38.20	-25.62	-26.01	-36.56	-10.20
4	-43.12	-22.62	-29.32	-42.75	-55.05	-65.24	-32.07	-37.71	-17.52	-50.22	-44.30	-46.12
5	-57.56	-27.73	-27.43	-32.60	-47.40	-46.72	-49.48	-41.97	-27.40	-76.47	-61.88	-43.54
6	-46.28	-37.51	-39.94	-27.49	-44.09	-73.64	-2.51	-1.56	9.50	-16.19	-28.41	-8.21
7	-70.59	-53.58	-71.45	-32.81	-40.88	-63.49	-12.12	-13.90	0.80	-30.00	-41.84	-22.95
8	-37.93	-29.16	-39.52	-48.13	-59.30	-76.78	-21.86	-26.53	-7.35	-44.42	-57.90	-20.85
9	-45.72	-49.10	-50.36	-44.67	-83.38	-73.35	-45.73	-59.89	-52.66	-36.58	-43.44	-8.47
10	-24.08	-24.93	-28.34	-37.14	-45.30	-57.76	-53.93	-63.88	-64.24	-46.57	-45.78	-16.79
11	-49.36	-52.74	-59.61	-44.07	-41.70	-49.38	-38.84	-45.97	-45.81	-46.00	-41.77	-18.53
12	-62.82	-59.87	-67.83	-69.49	-72.08	-77.18	-12.33	-24.12	-14.51	-45.24	-50.91	-42.54
13	-44.00	-37.30	-52.04	-41.22	-54.22	-50.60	-12.11	0.23	-17.47	-38.87	-44.31	-38.68
14	-38.12	-37.64	-33.94	-13.87	-23.88	-25.35	-22.77	-21.84	0.69	-36.77	-41.40	-24.64
15	-26.41	-19.96	-19.04	-20.17	-40.64	-51.99	-38.48	-43.76	-37.13	-34.47	-47.96	-34.90
16	-39.00	-30.19	-19.14	-41.16	-48.67	-62.14	-36.59	-19.89	-18.23	-19.43	-26.07	-10.08
17	-39.70	-38.42	-33.42	-71.48	-85.91	-93.08	-15.81	-17.35	6.72	-30.56	-28.28	-0.65
18	-45.34	-39.97	-74.43	-32.25	-41.26	-54.06	-74.88	-60.64	-42.95	-23.38	-35.59	-33.66
19	-27.72	-19.67	-21.34	-31.59	-46.22	-58.80	-38.12	-25.29	-20.83	-36.43	-28.24	-44.96
20	-35.37	-32.84	-43.75	-36.90	-33.29	-57.67	-47.50	-35.25	-37.65	-34.74	-38.51	-14.84
21	-43.25	-47.98	-52.62	-65.16	-65.56	-76.46	-32.86	-36.48	-16.31	-46.81	-38.56	-17.61
22	-71.60	-55.10	-60.45	-38.38	-41.42	-60.43	-47.61	-34.09	12.36	-54.89	-48.92	-32.81

Table 22. (Continued)

	Habitat											
	RF			SWA			TP			NR		
Core	**24-h**	**48-h**	**72-h**	**24-h**	**48-h**	**72-h**	**24-h**	**48-h**	**72-h**	**24-h**	**48-h**	**72-h**
23	-32.53	-40.49	-57.36	-49.92	-22.31	-63.37	-52.97	-39.74	-24.62	-41.03	-37.93	-6.33
24	-30.92	-32.02	-56.11	-42.63	-52.68	-66.00	-61.98	-41.60	2.74	-	-	-55.40
25	-45.14	-47.06	-50.55	-60.07	-62.83	-82.09	-63.80	-39.55	-62.83	-57.24	-57.45	-39.77
26	-34.14	-24.97	-28.52	-78.04	-83.67	-98.09	-20.92	-21.91	-8.07	-12.68	-22.27	-8.44
27	-25.28	-24.91	-31.54	-99.70	-99.37	-96.62	-39.74	-30.38	-14.69	-43.44	-45.73	-30.36
28	-19.84	-18.60	-24.70	-98.23	-109.18	-110.39	-32.05	-22.59	-1.17	-31.39	-44.09	-11.66
29	-27.82	-28.11	-48.04	-119.80	-111.94	-119.01	-69.79	-59.15	-54.39	-21.67	-16.52	-4.42
30	-36.88	-29.96	-46.38	-53.21	-25.69	-12.75	-74.59	-54.79	-37.84	-34.84	-45.94	-7.95

Note. All calculated SOD rates for each core, from all habitats. Negative numbers indicate higher oxygen demand. Values are expressed as mgO_2-O/m²/h. Sampling rounds are expressed as 24-h, 48-h, and 72-h. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 23.

Soil Moisture

	Habitat			
Core	**RF**	**SWA**	**TP**	**NR**
1	28	60	21	33
2	18	60	19	24
3	37	60	23	32
4	32	60	24	35
5	22	60	14	29
6	34	60	25	36
7	27	60	24	31
8	30	60	24	29
9	35	60	13	21
10	31	60	23	27
11	28	60	19	25
12	28	60	19	32
13	32	60	19	27
14	34	60	19	25
15	30	60	19	33
16	26	60	19	36
17	20	60	19	30
18	27	60	19	28
19	29	60	19	24
20	19	60	19	23
21	25	60	19	14
22	36	60	19	19
23	21	60	19	20
24	26	60	19	23
25	32	60	19	23
26	31	60	19	33
27	33	60	19	34
28	30	60	19	24
29	36	60	19	35
30	32	60	19	24

Note. Percentage of soil moisture for each core. Core is the core number. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 24.

AFDM

	Habitat			
Core	**RF**	**SWA**	**TP**	**NR**
1	98	106	53	40
2	146	93	67	59
3	68	199	67	51
4	148	152	64	69
5	184	59	48	72
6	121	82	51	46
7	203	77	49	53
8	106	72	52	52
9	98	53	45	59
10	106	87	74	63
11	107	64	62	52
12	107	74	61	64
13	173	53	55	72
14	132	68	51	59
15	106	70	62	50
16	114	60	57	6
17	167	51	65	54
18	113	74	73	62
19	82	55	57	49
20	92	39	67	75
21	98	49	60	64
22	85	27	61	41
23	149	64	46	46
24	118	33	64	26
25	79	47	58	35
26	58	67	47	45
27	195	73	57	47
28	103	48	44	50
29	41	67	49	43
30	87	37	61	51

Note. AFDM (mg/g) for each core. Core is the core number. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 25.

Detrital Organic Matter

	Habitat			
Core	**RF**	**SWA**	**TP**	**NR**
1	3527	9153	4728	4955
2	4590	8864	4695	8886
3	3774	6469	5727	6953
4	2427	6835	14205	10135
5	2298	6199	4772	3173
6	5585	1883	2048	5629
7	10142	5611	13486	8505
8	5288	6564	8494	2980
9	5561	7060	6239	10692
10	7331	6731	3473	4344
11	5342	1282	3778	3262
12	5760	2239	2307	4991
13	4612	2135	10552	4038
14	5170	8551	2712	667
15	6287	3631	4008	1667
16	9678	8850	3426	5672
17	5469	2403	4894	7916
18	4187	7411	2480	4569
19	2680	2505	3479	7708
20	6770	2962	4069	4187
21	7009	9693	4917	13350
22	9251	7247	3770	3736
23	6555	5410	6447	7045
24	2799	9076	3263	6065
25	5599	9885	7096	9053
26	4926	7386	7475	3383
27	2519	8089	2942	10753
28	4678	0	12503	3748
29	6633	0	5904	4455
30	5647	9969	6231	8420

Note. Detrital organic matter (mg/g) for each core. Core is the core number. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 26.

Vegetation Organic Matter

	Habitat			
Core	**RF**	**SWA**	**TP**	**NR**
1	0	588	104	6430
2	340	1239	2100	356
3	0	9181	5987	4491
4	0	8407	0	0
5	0	0	4750	2346
6	1288	7505	0	175
7	0	7672	0	0
8	0	7052	0	6723
9	0	5269	0	0
10	0	1052	797	9160
11	0	7990	0	7292
12	0	8715	7293	6995
13	0	408	0	14241
14	0	5902	2013	339
15	0	794	0	13603
16	0	5522	1764	0
17	0	7900	0	13599
18	0	6785	9932	3399
19	0	4112	0	0
20	0	5405	5357	4998
21	0	8718	0	4989
22	0	8120	0	10282
23	0	8250	602	0
24	0	6349	0	14015
25	0	6968	261	9292
26	0	10093	0	209
27	0	9120	965	2458
28	0	9255	4026	398
29	0	8674	10086	0
30	0	7749	0	0

Note. Organic Vegetation (mg/g) matter for all cores. Core is the core number. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 27.

Total Organic Carbon

	Habitat			
Core	**RF**	**SWA**	**TP**	**NR**
1	50.07	33.82	14.23	10.50
2	90.57	31.03	16.46	16.66
3	17.59	18.52	22.16	11.92
4	52.65	15.70	14.71	21.13
5	72.64	16.14	13.84	21.06
6	28.51	22.00	10.80	8.74
7	93.78	25.30	11.97	14.60
8	42.37	26.66	13.08	11.35
9	34.65	16.33	10.31	15.91
10	41.61	24.21	24.87	18.04
11	31.16	13.30	23.82	14.96
12	28.28	16.35	19.07	19.39
13	81.56	10.97	14.74	24.08
14	49.39	16.32	16.81	16.83
15	31.19	17.14	18.85	15.18
16	43.30	17.71	24.45	13.25
17	93.78	14.79	20.50	14.54
18	57.33	26.52	14.55	21.46
19	41.91	23.21	15.88	12.83
20	51.16	13.91	20.14	16.73
21	50.41	23.69	20.14	20.68
22	37.41	11.28	20.14	12.57
23	92.48	16.25	20.14	12.80
24	64.88	12.86	20.14	8.95
25	38.36	18.76	20.14	9.26
26	29.76	28.19	20.14	12.91
27	88.04	34.60	20.14	13.93
28	50.61	18.13	20.14	15.58
29	20.28	30.24	20.14	11.20
30	37.30	13.66	20.14	15.49

Note. Total Organic Carbon (mg/g) for all cores. Core is the core number. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

Table 28.

Total Phosphorus

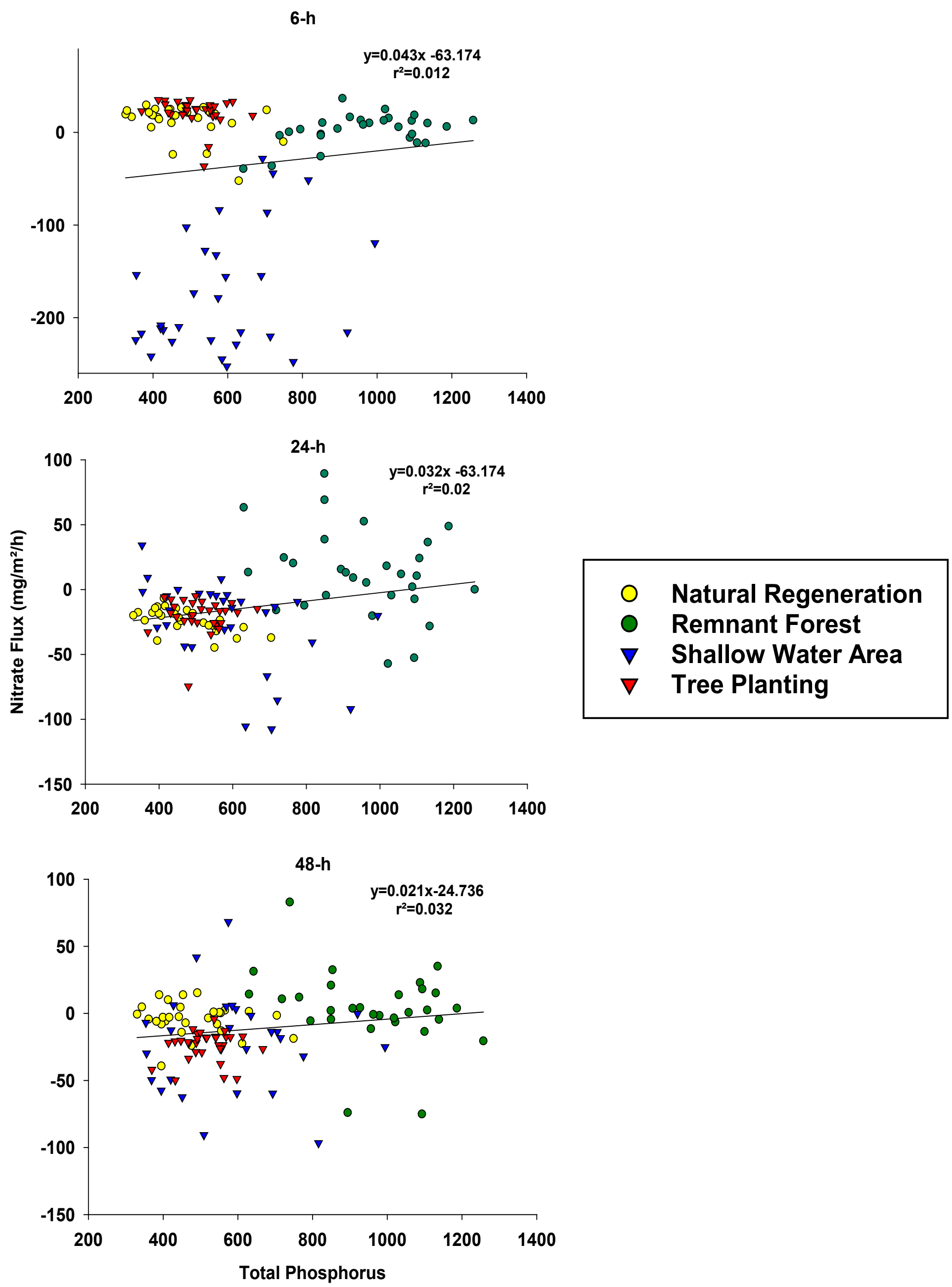
	Habitat			
Core	**RF**	**SWA**	**TP**	**NR**
1	1031	705	431	520
2	927	816	503	565
3	764	595	560	449
4	1135	569	487	555
5	894	574	447	395
6	979	721	514	406
7	1257	920	541	554
8	1093	994	489	460
9	1107	690	468	544
10	956	693	553	611
11	849	635	613	550
12	1021	714	568	749
13	1138	555	491	704
14	1130	509	499	629
15	963	539	563	535
16	1018	427	580	343
17	1100	420	580	446
18	1186	489	580	413
19	794	577	580	476
20	907	577	580	395
21	1057	577	580	382
22	854	577	580	361
23	1088	577	580	442
24	1094	577	580	327
25	718	577	580	330
26	630	577	580	399
27	642	577	580	399
28	849	577	580	399
29	739	577	580	399
30	849	577	580	399

Note. Total phosphorus (mg/g) for all cores. Core is the core number. Habitats are abbreviated including Remnant Forest (RF), Shallow Water Area (SWA), Tree Planting (TP), and Natural Regeneration (NR).

APPENDEX B. FIGURES

Figure 26.

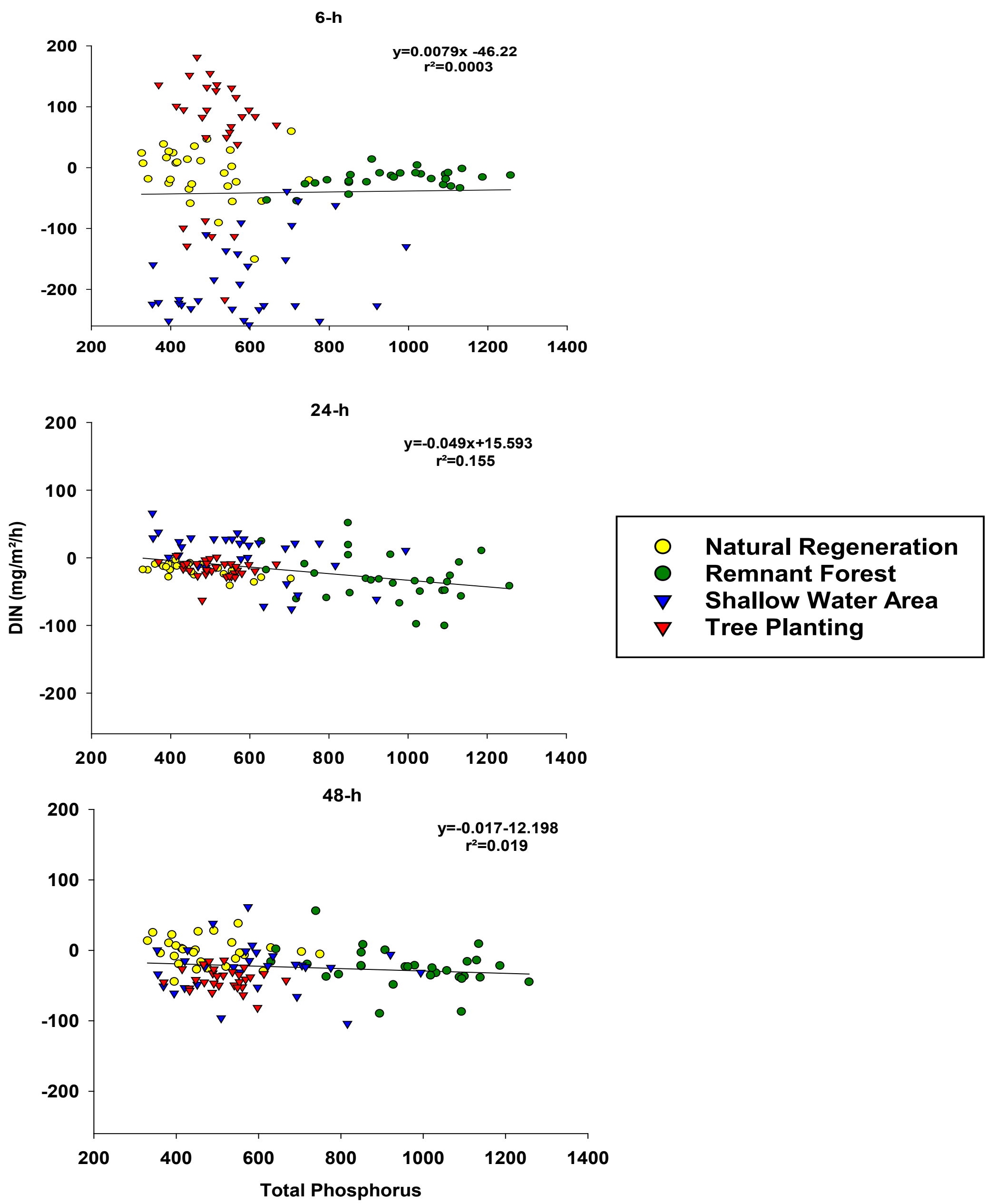
Nitrate Flux and Total Phosphorus



Note. Linear regression of nitrate flux rates for each habitat (color coded) with soil total phosphorus for each core. Slope equation and R^2 are given in top right corner of graphs. Negative values indicate nitrate removal from the ecosystem and positive values indicate nitrate release into the ecosystem.

Figure 27.

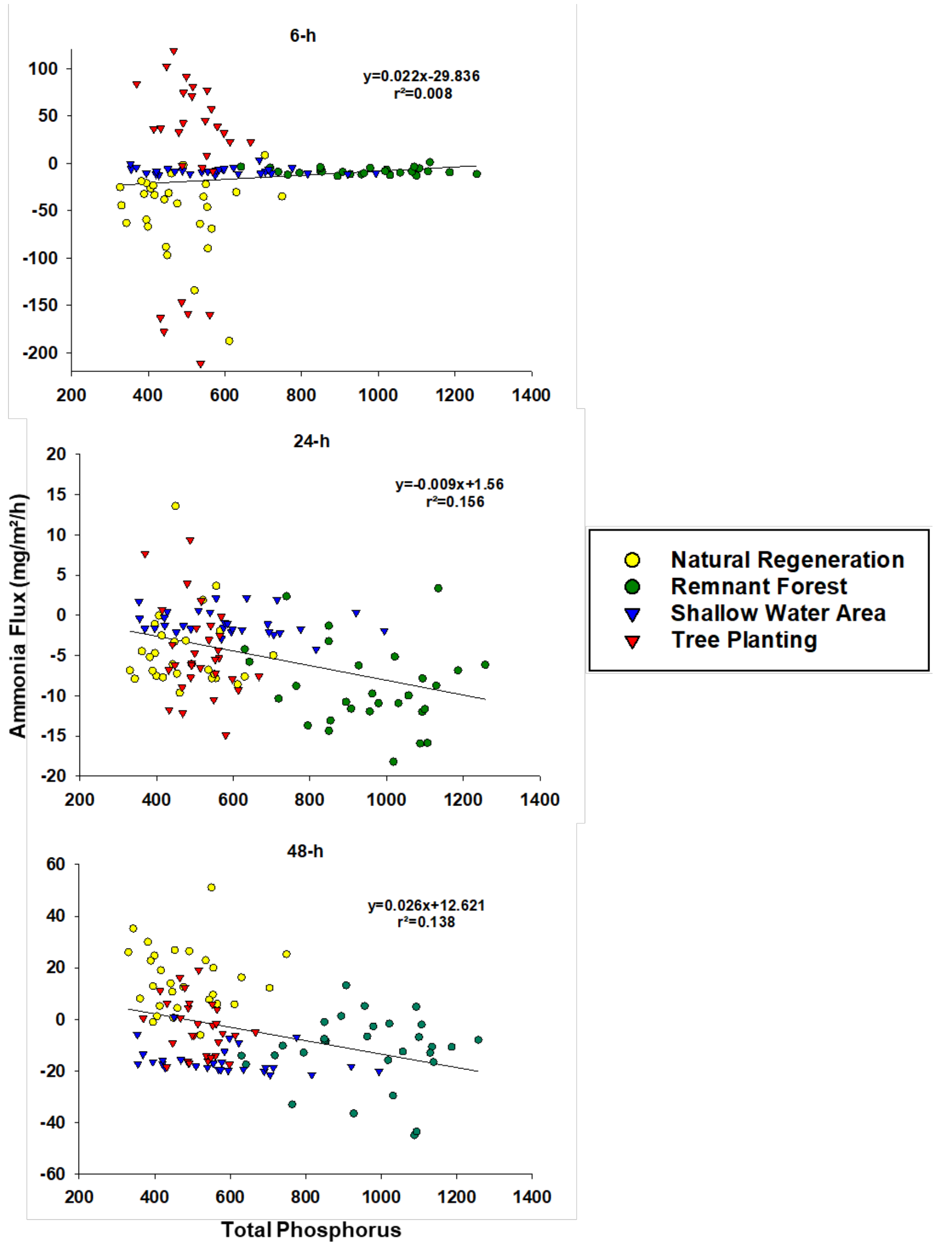
Dissolved Inorganic Nitrogen Flux and Total Phosphorus



Note. Linear regression of DIN flux rates for each habitat (color coded) with soil total phosphorus for each core. Slope equation and R^2 are given in top right corner of graphs. Negative values indicate nitrate removal from the ecosystem and positive values indicate nitrate release into the ecosystem.

Figure 28.

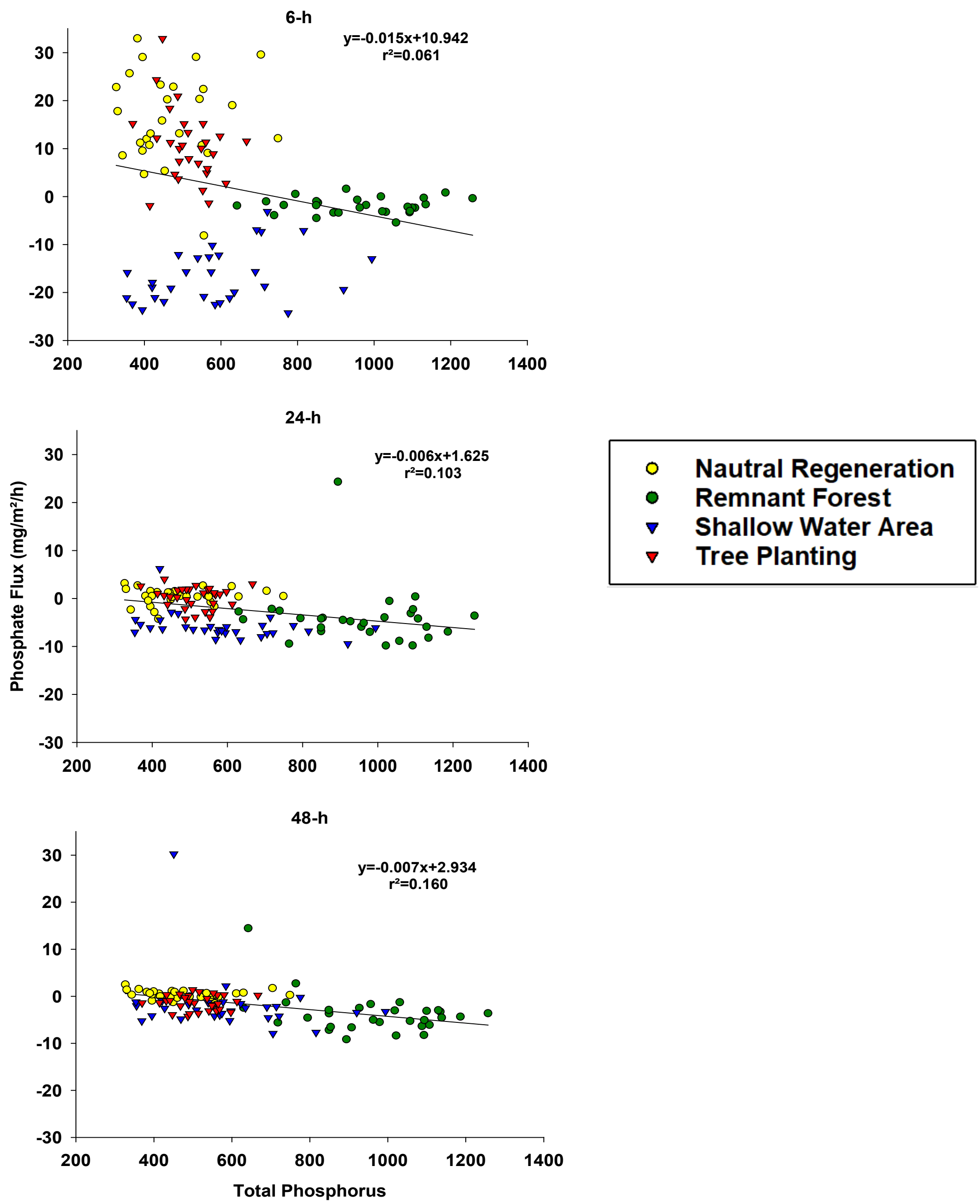
Ammonia Flux and Total Phosphorus



Note. Linear regression of ammonia flux rates for each habitat (color coded) with soil total phosphorus for each core. Slope equation and R^2 are given in top right corner of graphs. Negative values indicate nitrate removal from the ecosystem and positive values indicate nitrate release into the ecosystem.

Figure 29.

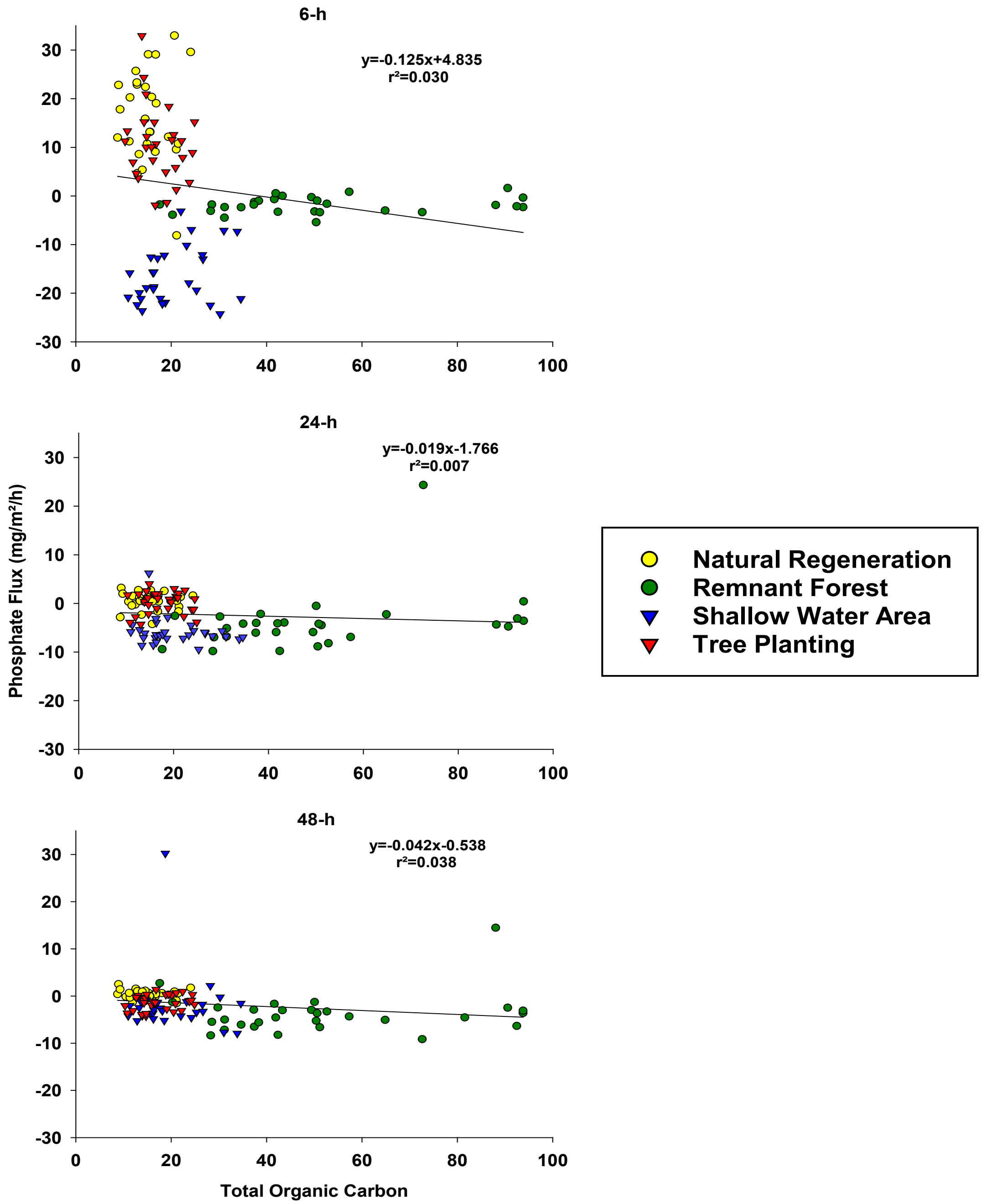
Phosphate Flux and Total Phosphorus



Note. Linear regression of phosphate flux rates for each habitat (color coded) with soil total phosphorus for each core. Slope equation and R^2 are given in top right corner of graphs. Negative values indicate nitrate removal from the ecosystem and positive values indicate nitrate release into the ecosystem.

Figure 30.

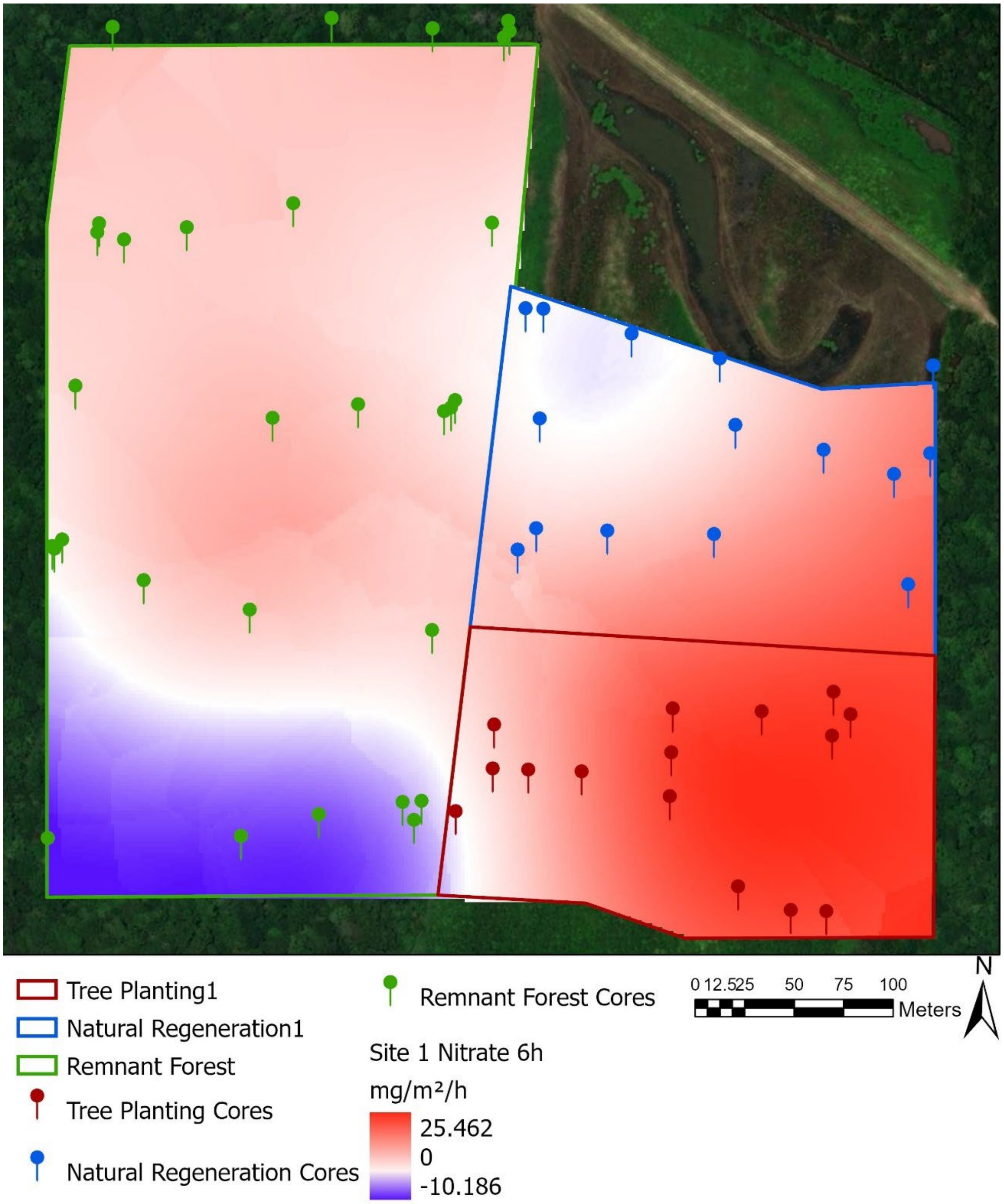
Phosphate Flux and Total Organic Carbon



Note. Linear regression of phosphate flux rates for each habitat (color coded) with soil total organic carbon for each core. Slope equation and R^2 are given in top right corner of graphs. Negative values indicate nitrate removal from the ecosystem and positive values indicate nitrate.

Figure 31.

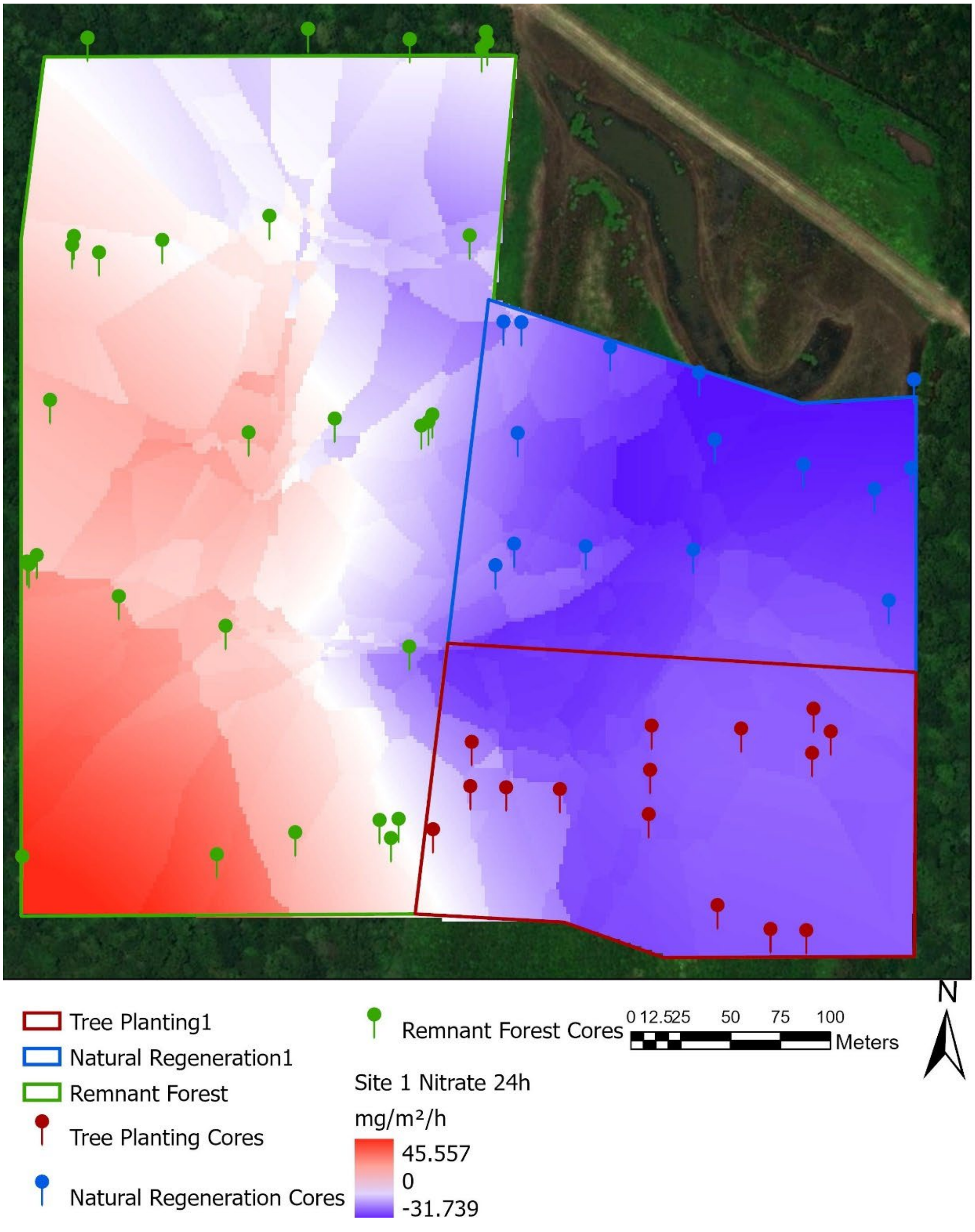
Kriging Model Site 1 Nitrate 6h



Note. Kriging Model for Site 1 NO_3^- flux rate prediction values (mg/m²/h) for the 6-h sampling round. Blue values represent removal, white equals zero flux, and red represents release. Core pins and borders are color coded to indicate habitat type.

Figure 32.

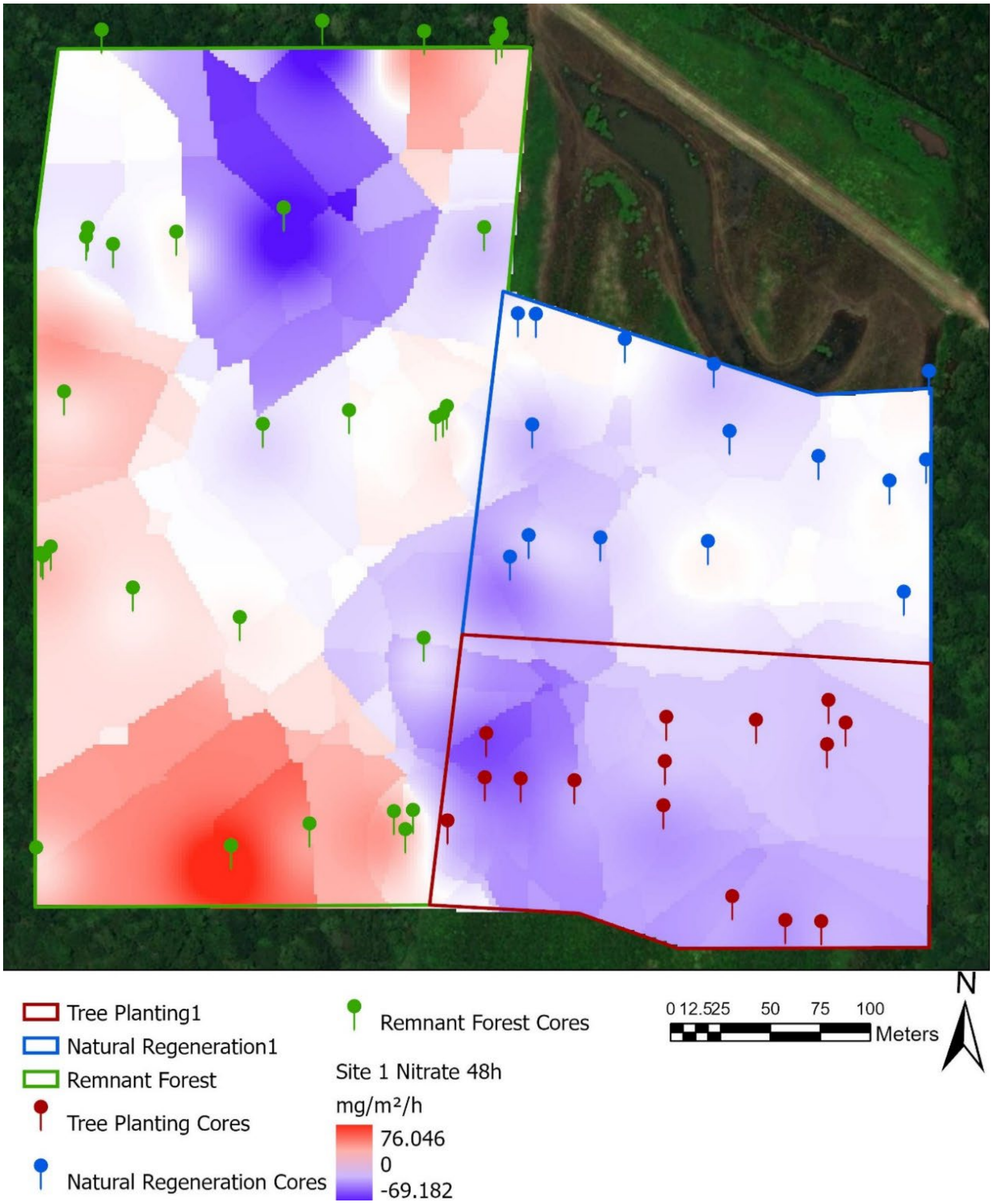
Kriging Model Site 1 Nitrate 24h



Note. Kriging Model for Site 1 NO_3^- flux rate prediction values (mg/m²/h) for the 24-h sampling round. Blue values represent removal, white equals zero flux, and red represents release. Core pins and borders are color coded to indicate habitat type.

Figure 33.

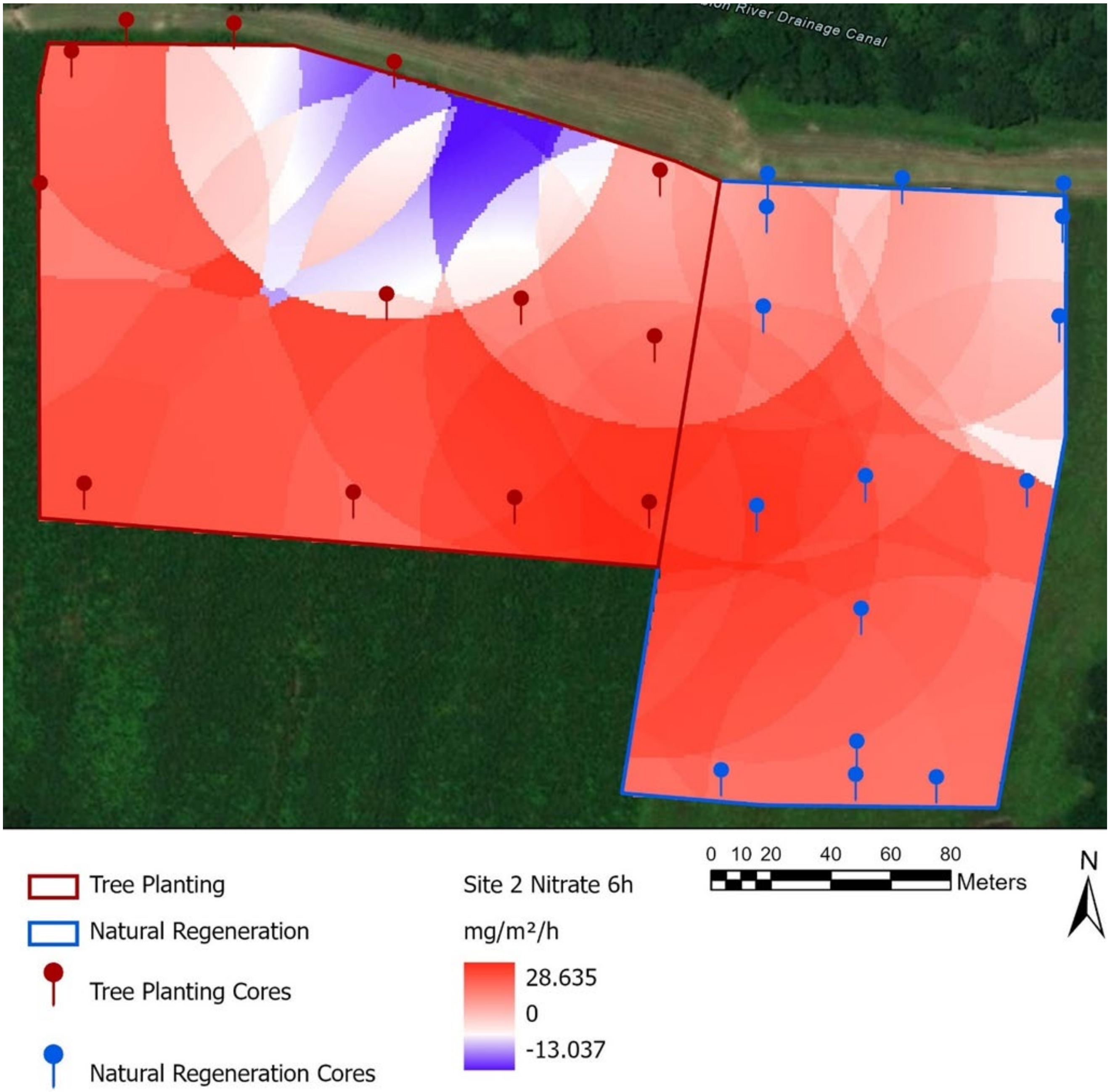
Kriging Model Site 1 Nitrate 48h



Note. Kriging Model for Site 1 NO_3^- flux rate prediction values (mg/m²/h) for the 48-h sampling round. Blue values represent removal, white equals zero flux, and red represents release. Core pins and borders are color coded to indicate habitat type.

Figure 34.

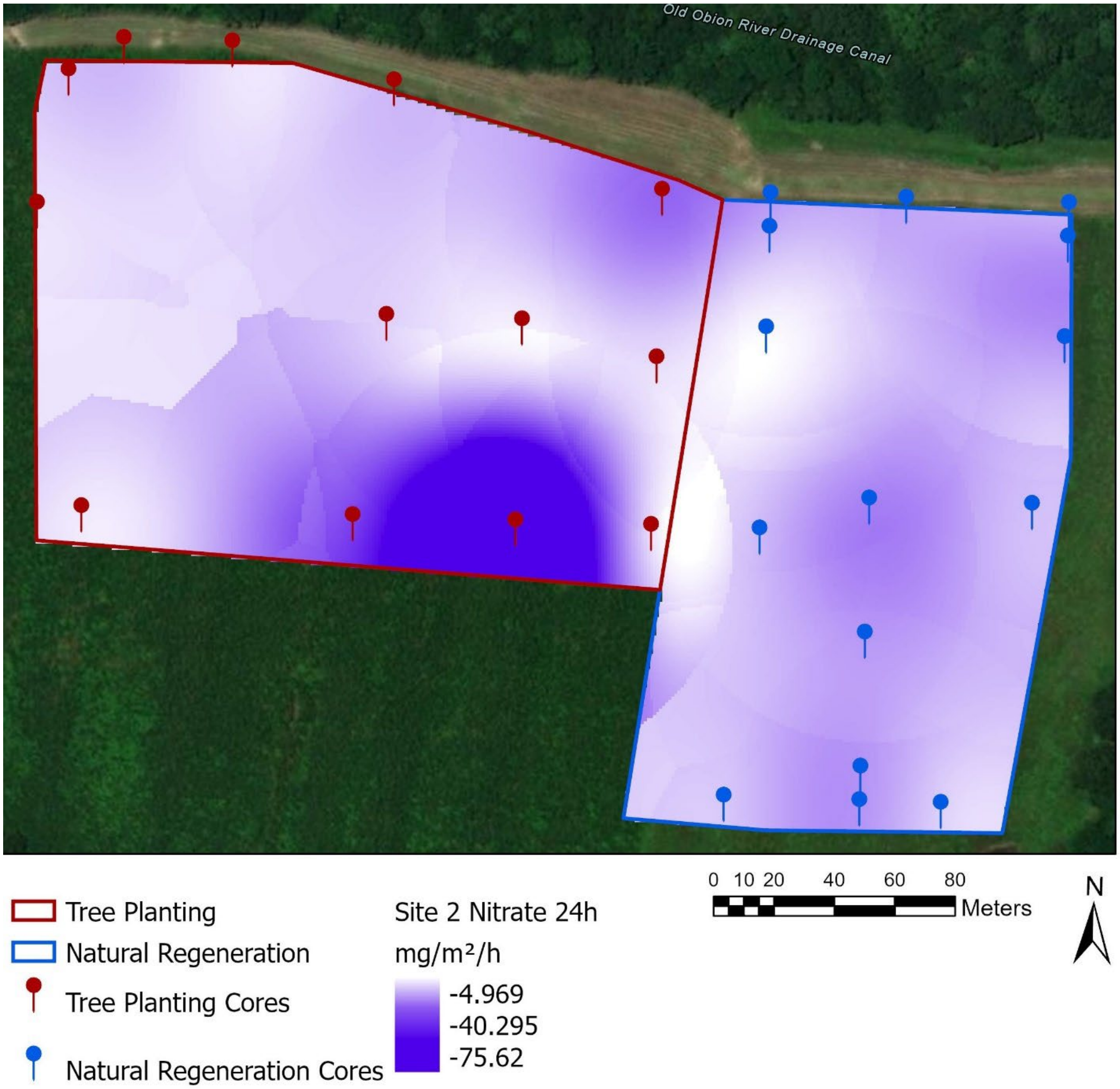
Kriging Model Site 2 Nitrate 6-h



Note. Kriging Model for Site 2 NO_3^- flux rate prediction values (mg/m²/h) for the 6-h sampling round. Blue values represent removal, white equals zero flux, and red represents release. Core pins and borders are color coded to indicate habitat type.

Figure 35.

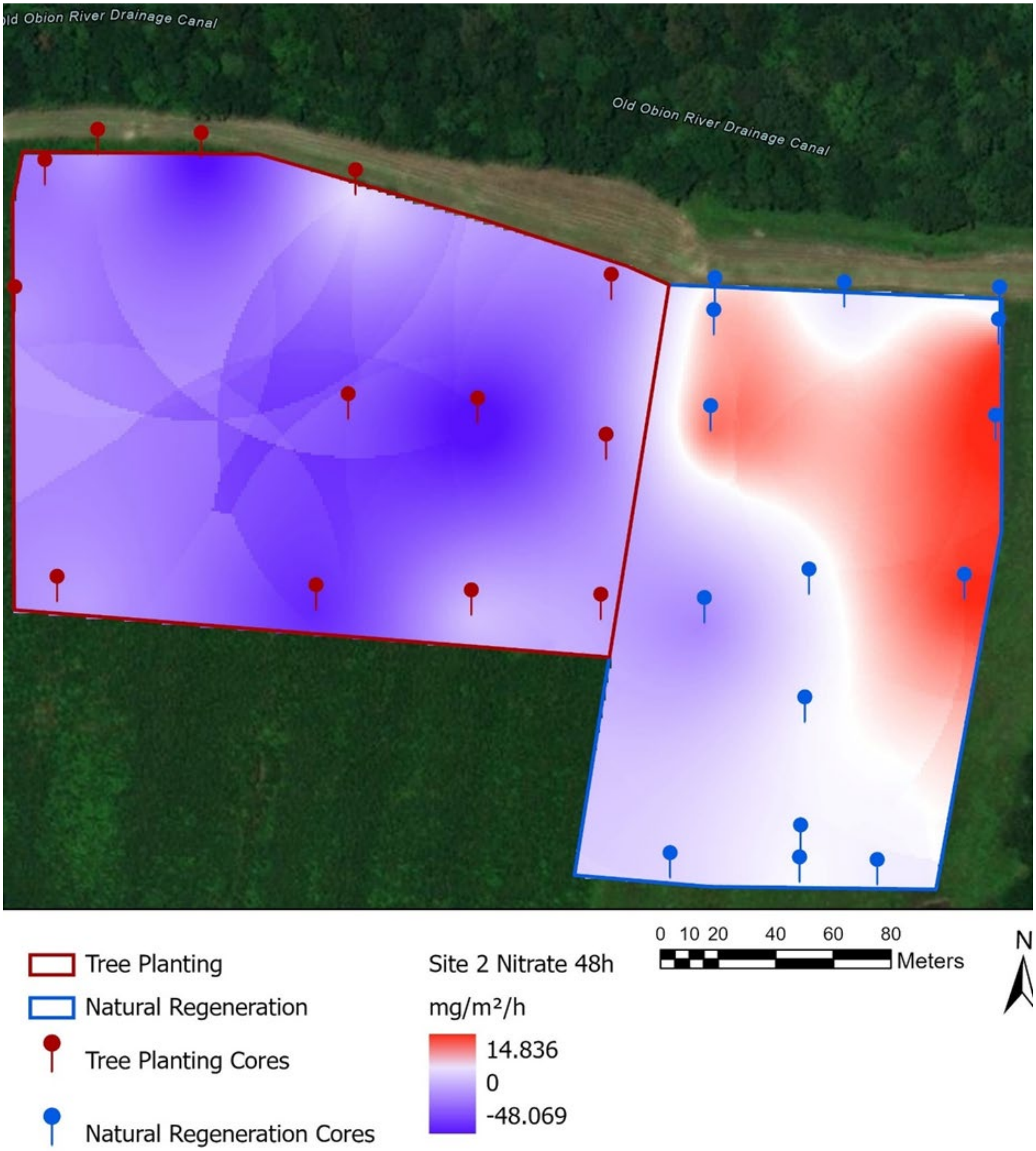
Kriging Model Site 2 Nitrate 24-h



Note. Kriging Model for Site 2 NO_3^- flux rate prediction values (mg/m²/h) for the 24-h sampling round. All values represent removal rates. White are values nearest zero and purple/blue are increasing in removal rates. Core pins and borders are color coded to indicate habitat type.

Figure 36.

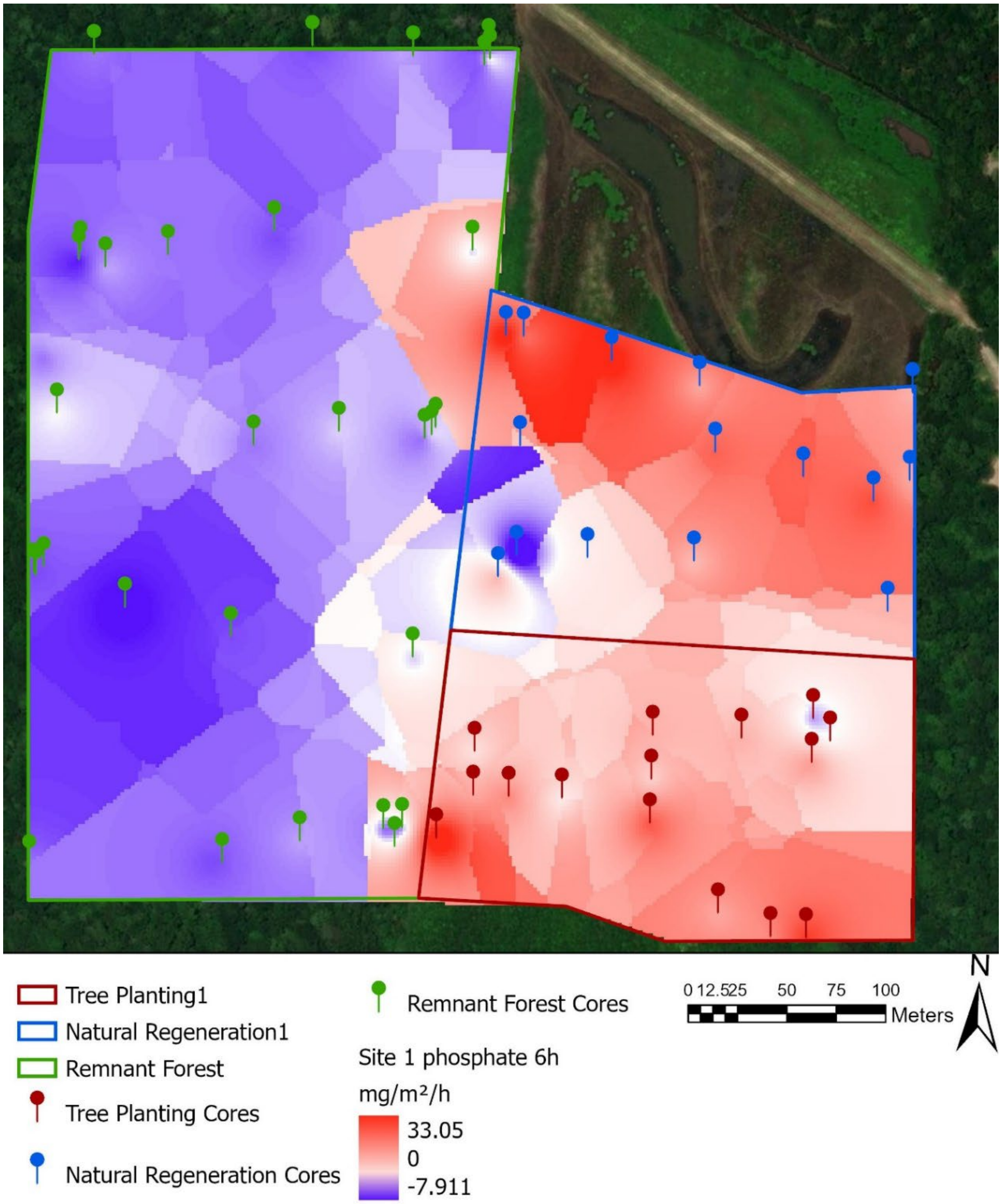
Kriging Model Site 2 Nitrate 48-h



Note. Kriging Model for Site 2 NO_3^- flux rate prediction values (mg/m²/h) for the 48-h sampling round. Blue values represent removal, white equals zero flux, and red represents release. Core pins and borders are color coded to indicate habitat type.

Figure 37.

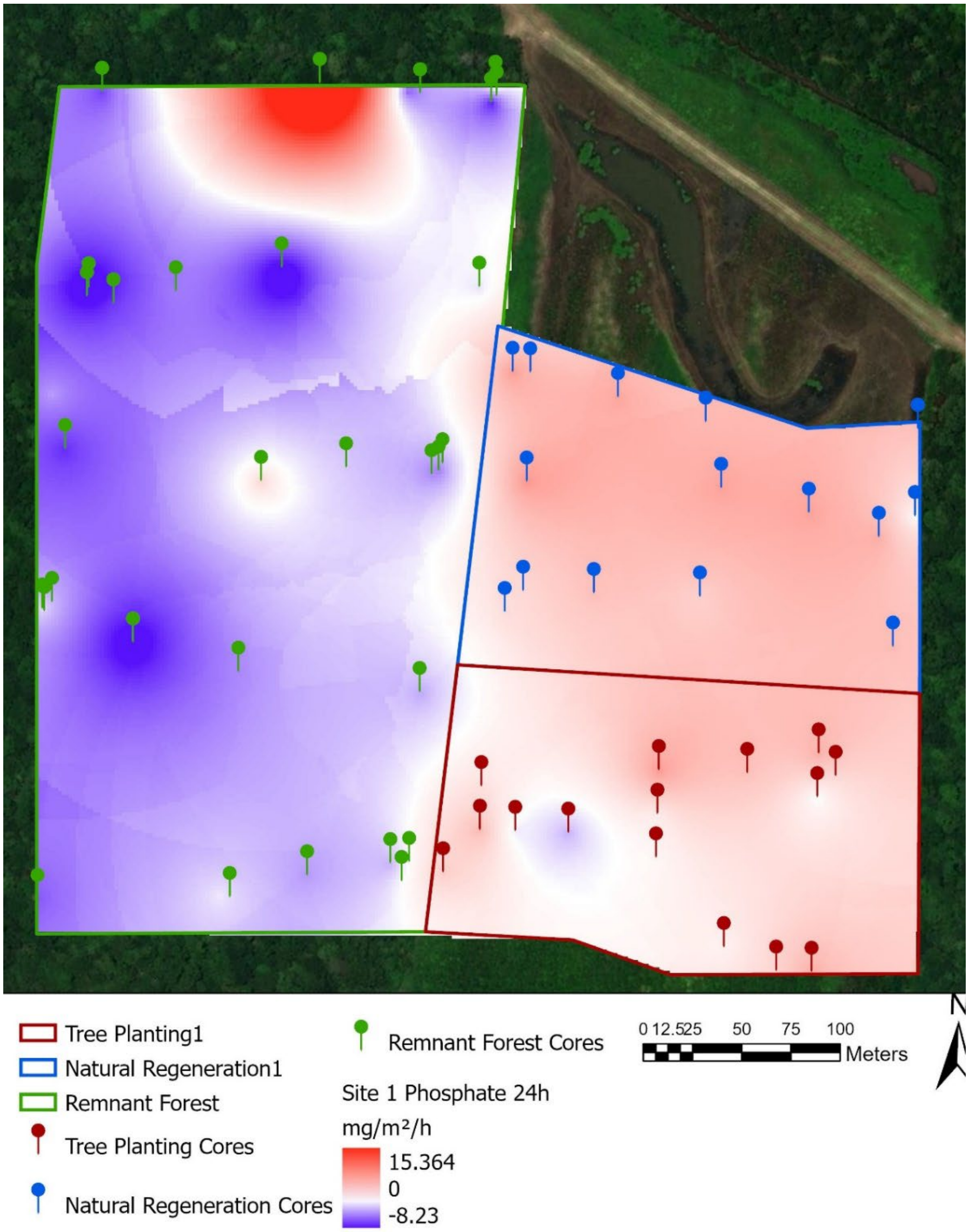
Kriging Model Site 1 Phosphate 6-h



Note. Kriging Model for Site 1 PO_4^{3-} flux rate prediction values (mg/m²/h) for the 6-h sampling round. Blue values represent removal, white equals zero flux, and red represents release. Core pins and borders are color coded to indicate habitat type.

Figure 38.

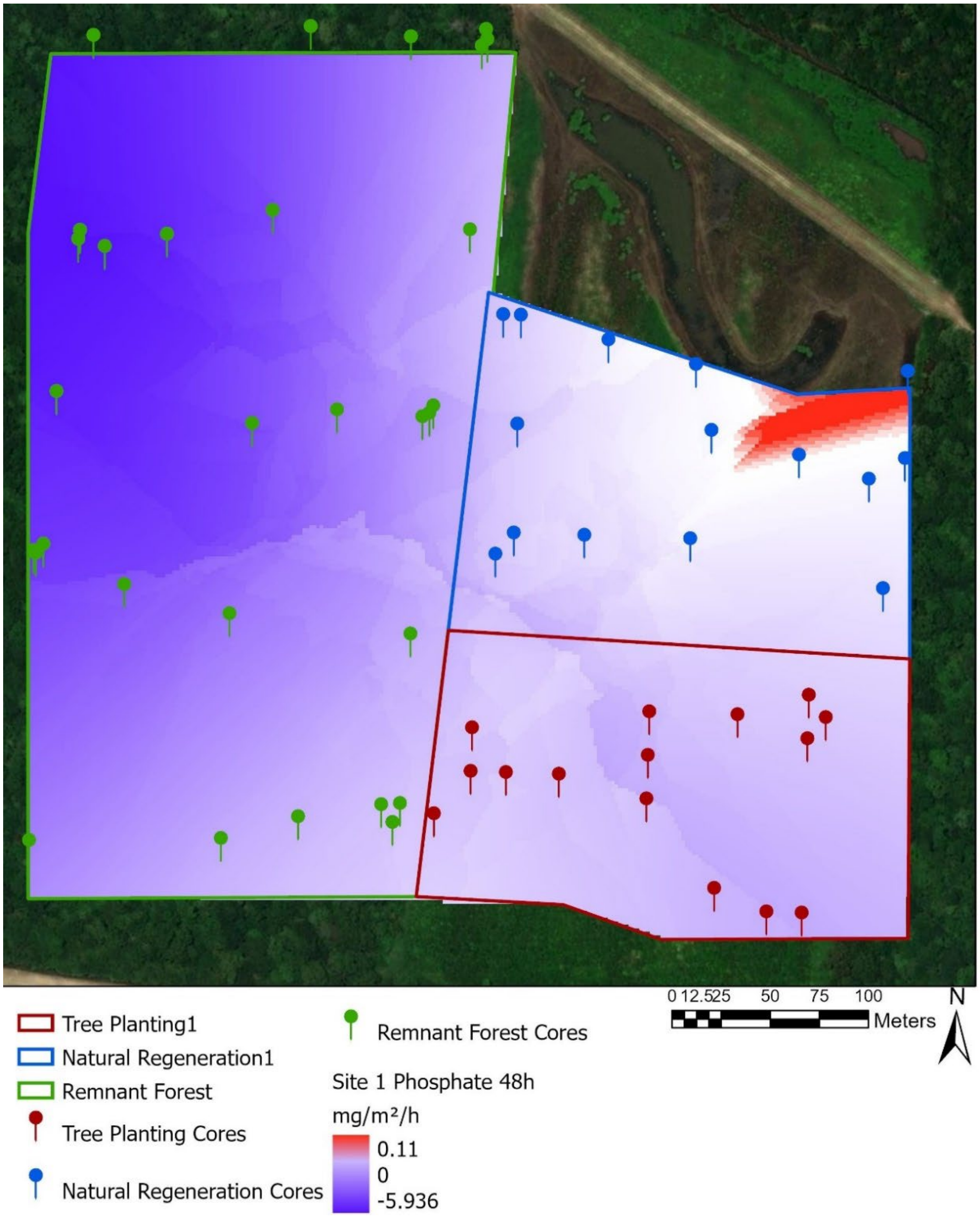
Kriging Model Site 1 Phosphate 24-h



Note. Kriging Model for Site 1 PO_4^{3-} flux rate prediction values (mg/m²/h) for the 24-h sampling round. Blue values represent removal, white equals zero flux, and red represents release. Core pins and borders are color coded to indicate habitat type.

Figure 39.

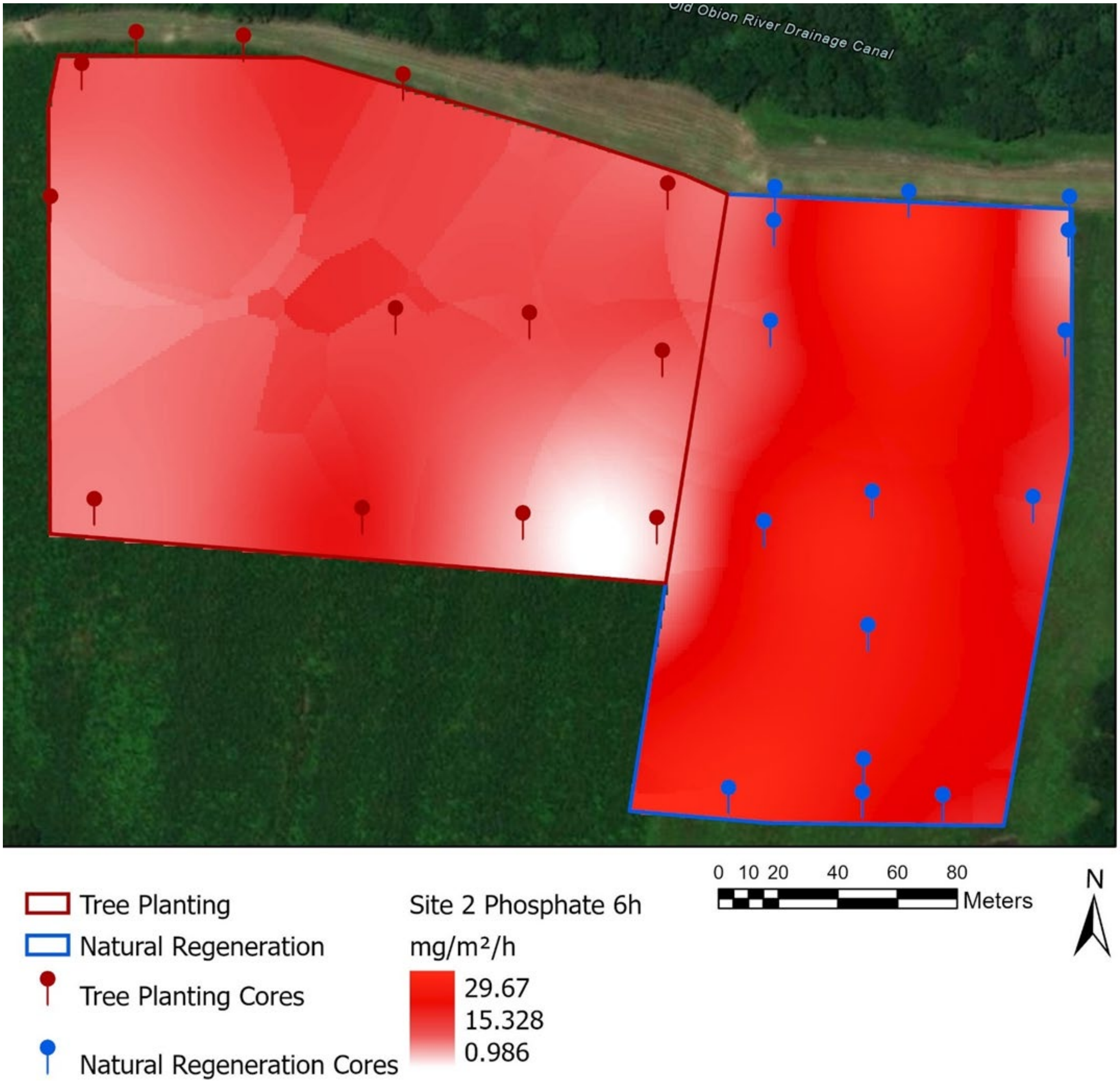
Kriging Model Site 1 Phosphate 48-h



Note. Kriging Model for Site 1 PO_4^{3-} flux rate prediction values (mg/m²/h) for the 48-h sampling round. Blue values represent removal, white equals zero flux, and red represents release. Core pins and borders are color coded to indicate habitat type.

Figure 40.

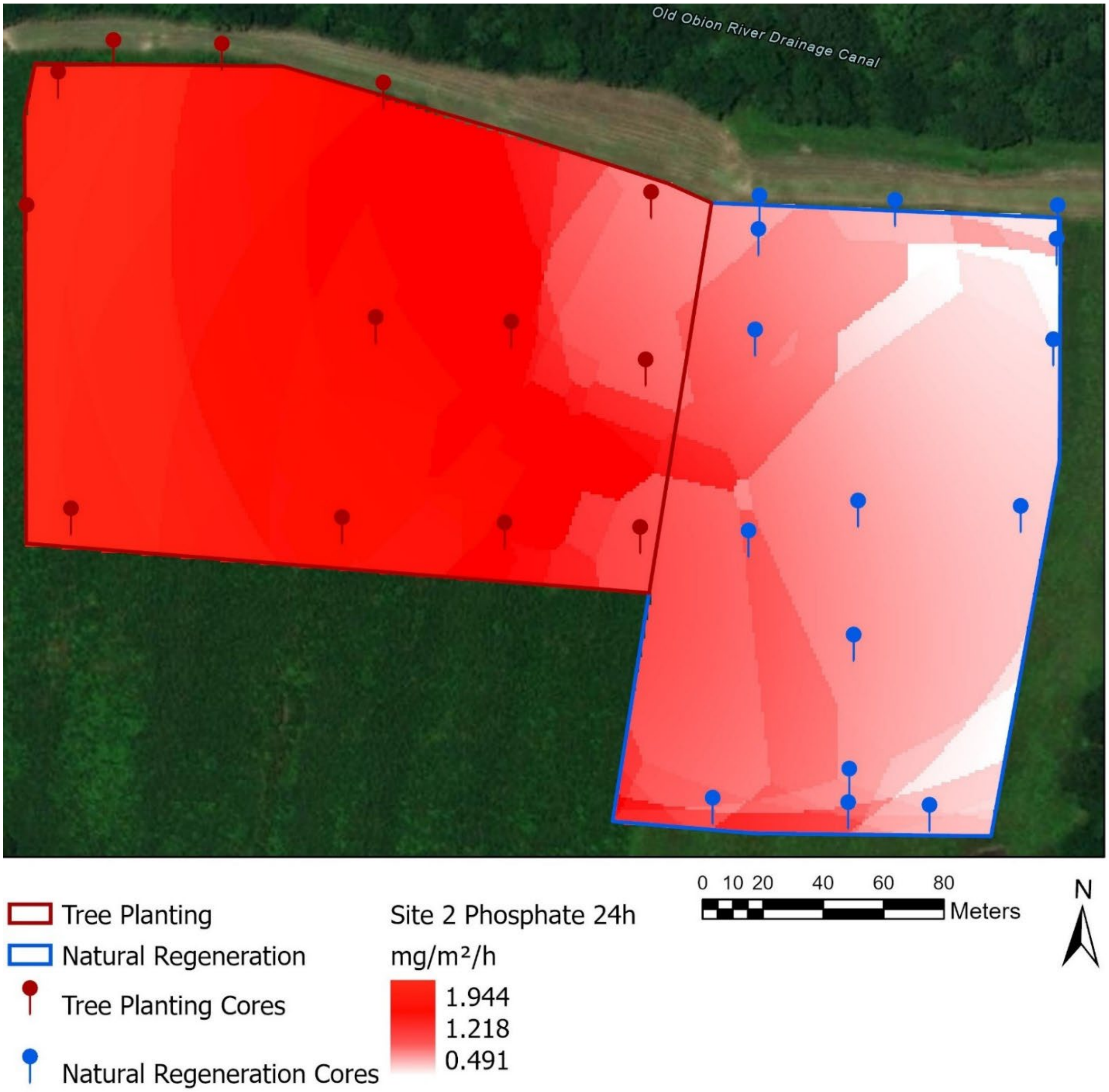
Kriging Model Site 2 Phosphate 6-h



Note. Kriging Model for Site 2 PO_4^{3-} flux rate prediction values (mg/m²/h) for the 6-h sampling round. All colors represent release rates. White are rates nearest to zero and red is increasing release rates. Core pins and borders are color coded to indicate habitat type.

Figure 41.

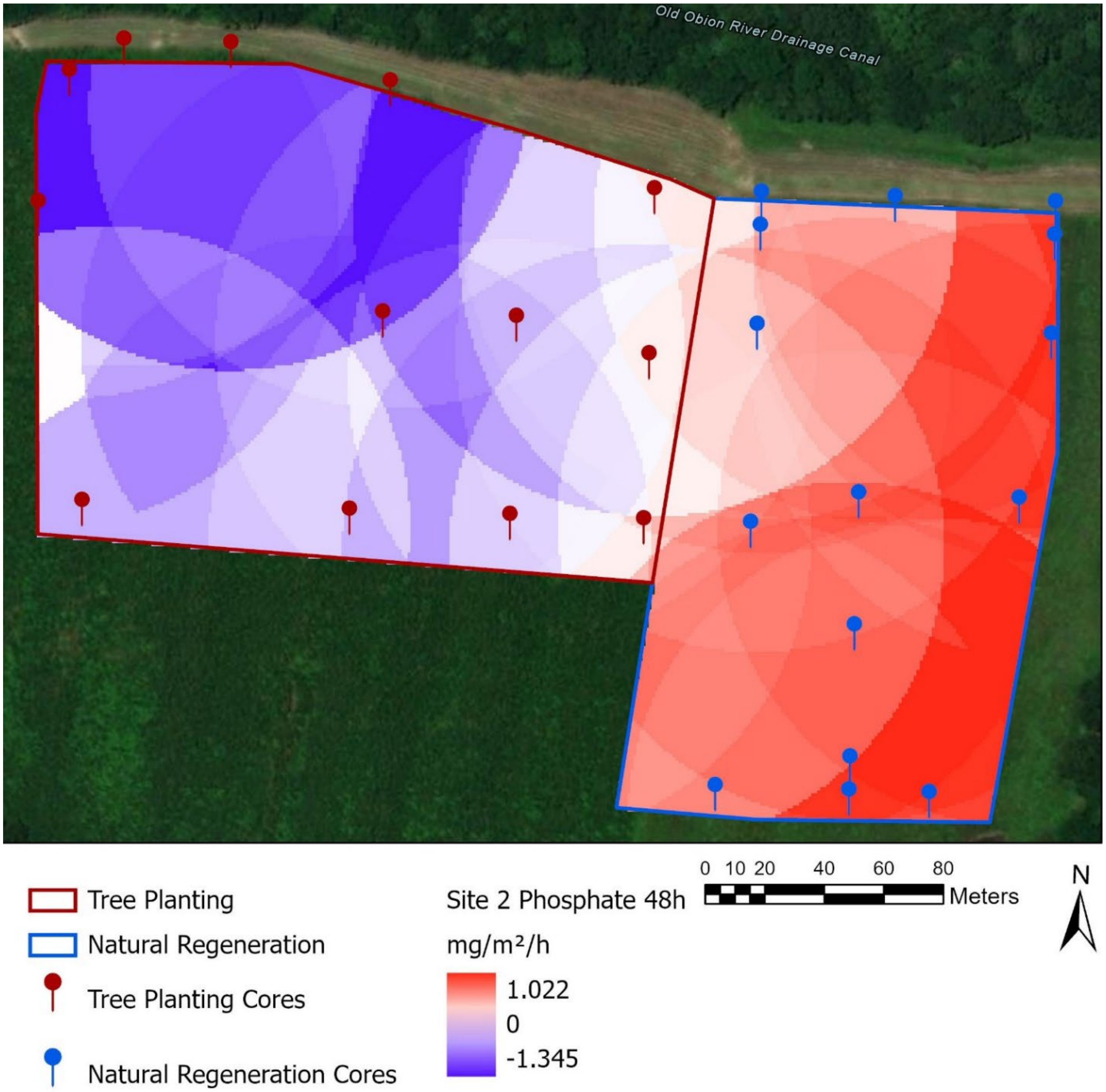
Kriging Model Site 2 Phosphate 24-h



Note. Kriging Model for Site 2 PO_4^{3-} flux rate prediction values (mg/m²/h) for the 24-h sampling round. All colors represent release rates. White are rates nearest to zero and red is increasing release rates. Core pins and borders are color coded to indicate habitat type.

Figure 42.

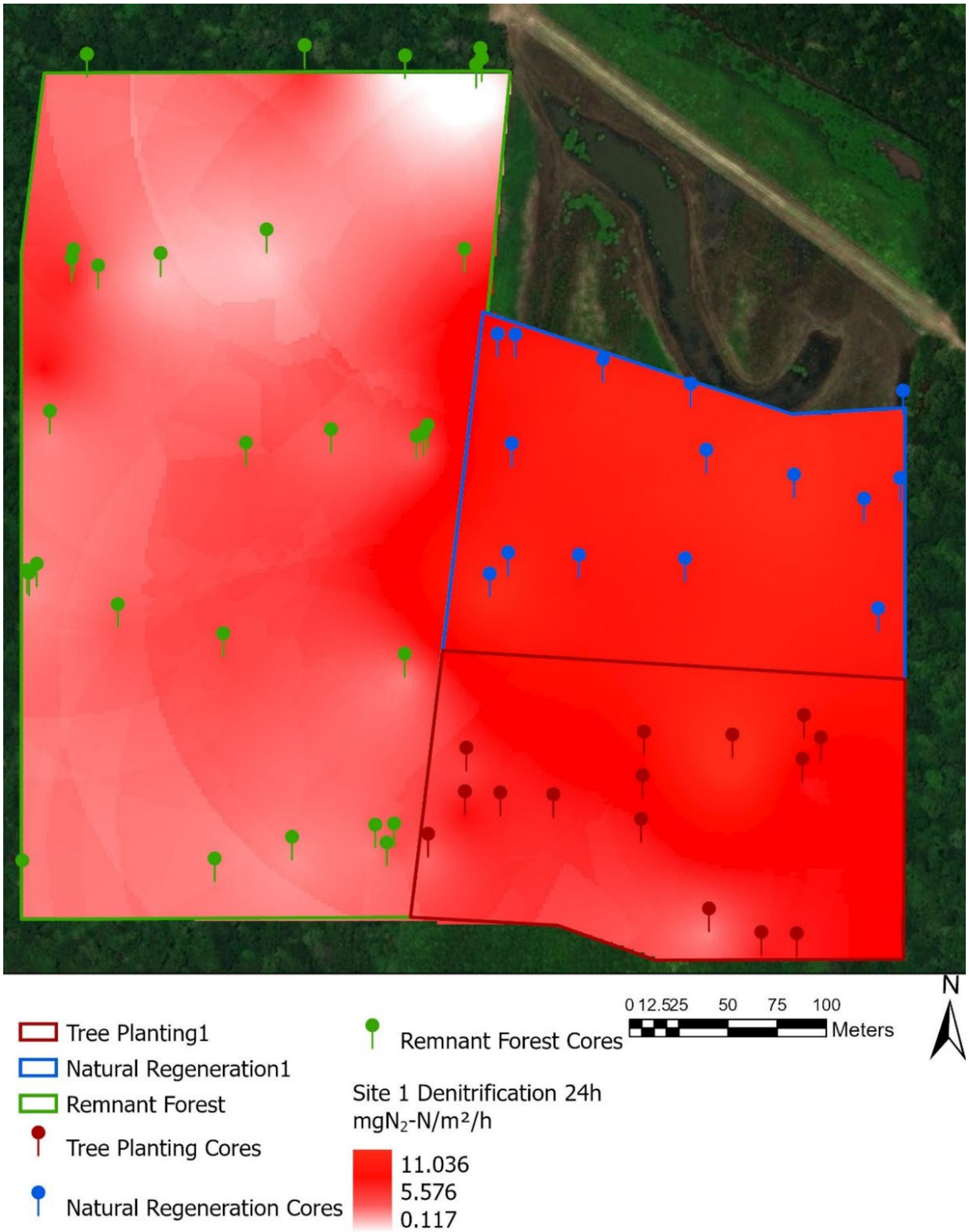
Kriging Model Site 2 Phosphate 48-h



Note. Kriging Model for Site 2 PO_4^{3-} flux rate prediction values (mg/m²/h) for the 48-h sampling round. Blue values represent removal, white equals zero flux, and red represents release. Core pins and borders are color coded to indicate habitat type.

Figure 43.

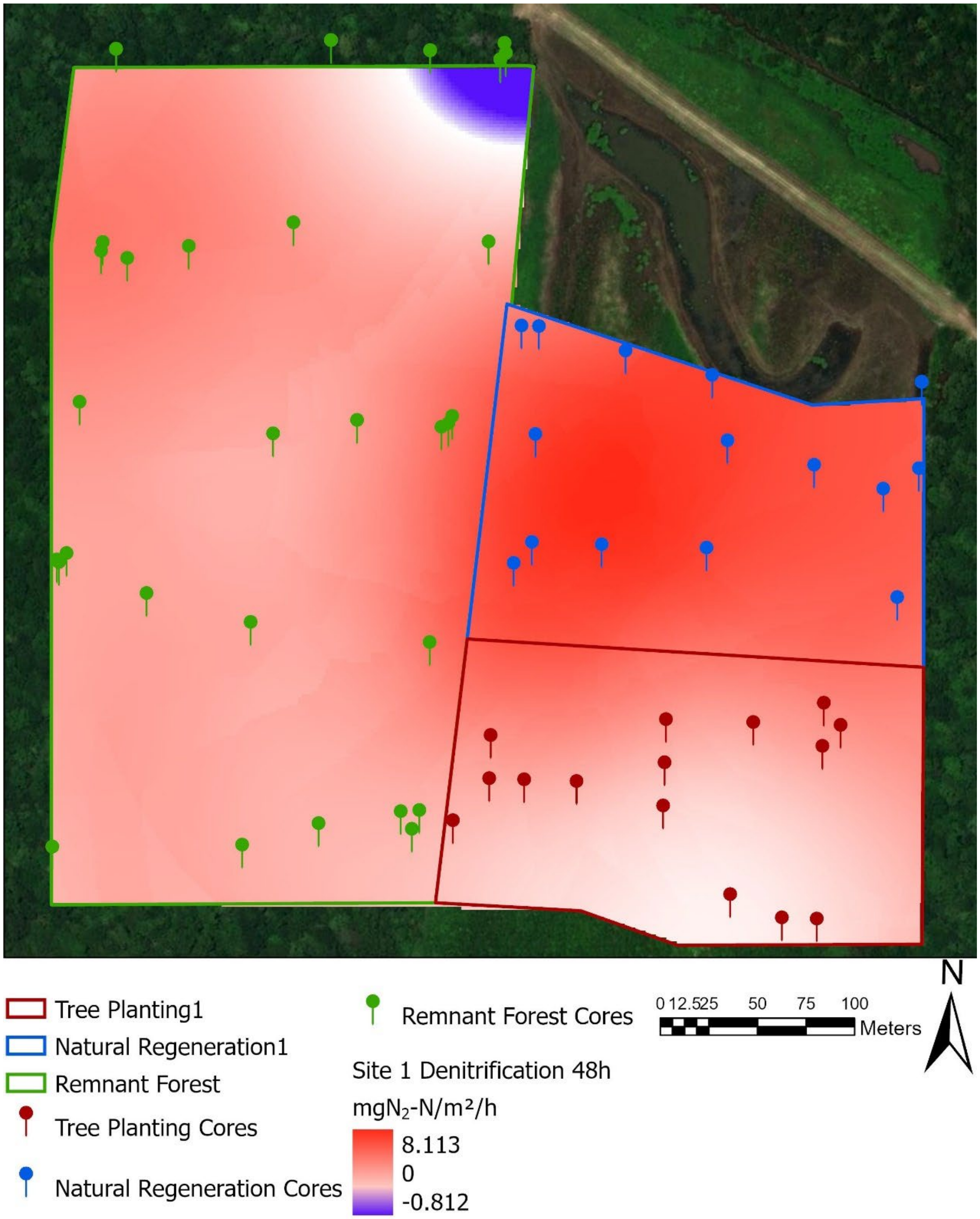
Kriging Model Site a Denitrification 24-h



Note. Kriging Model for Site 1 Denitrification rate prediction values (mgN_2-$N/m^2/h$) for 24-h sampling round. Red values are high denitrification and white represents rates nearest to zero. Core pins and borders are color coded to indicate habitat type.

Figure 44.

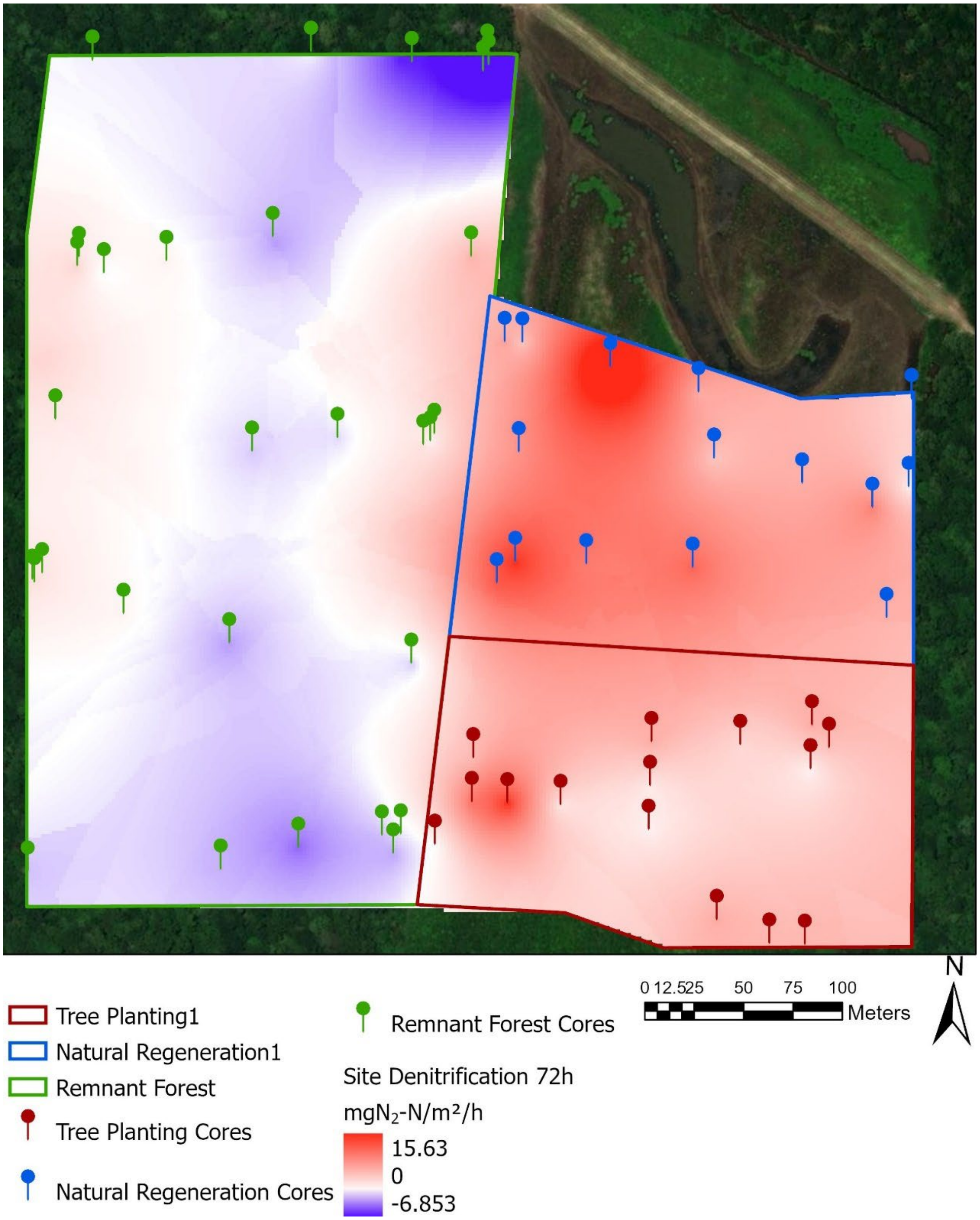
Kriging Model Site a Denitrification 48-h



Note. Kriging Model for Site 1 Denitrification rate prediction values (mgN_2-N/m²/h) for 48-h sampling round. Red values indicate denitrification rates, white are zero rates, and blue are negative rates (nitrification). Core pins and borders are color coded to indicate habitat type.

Figure 45.

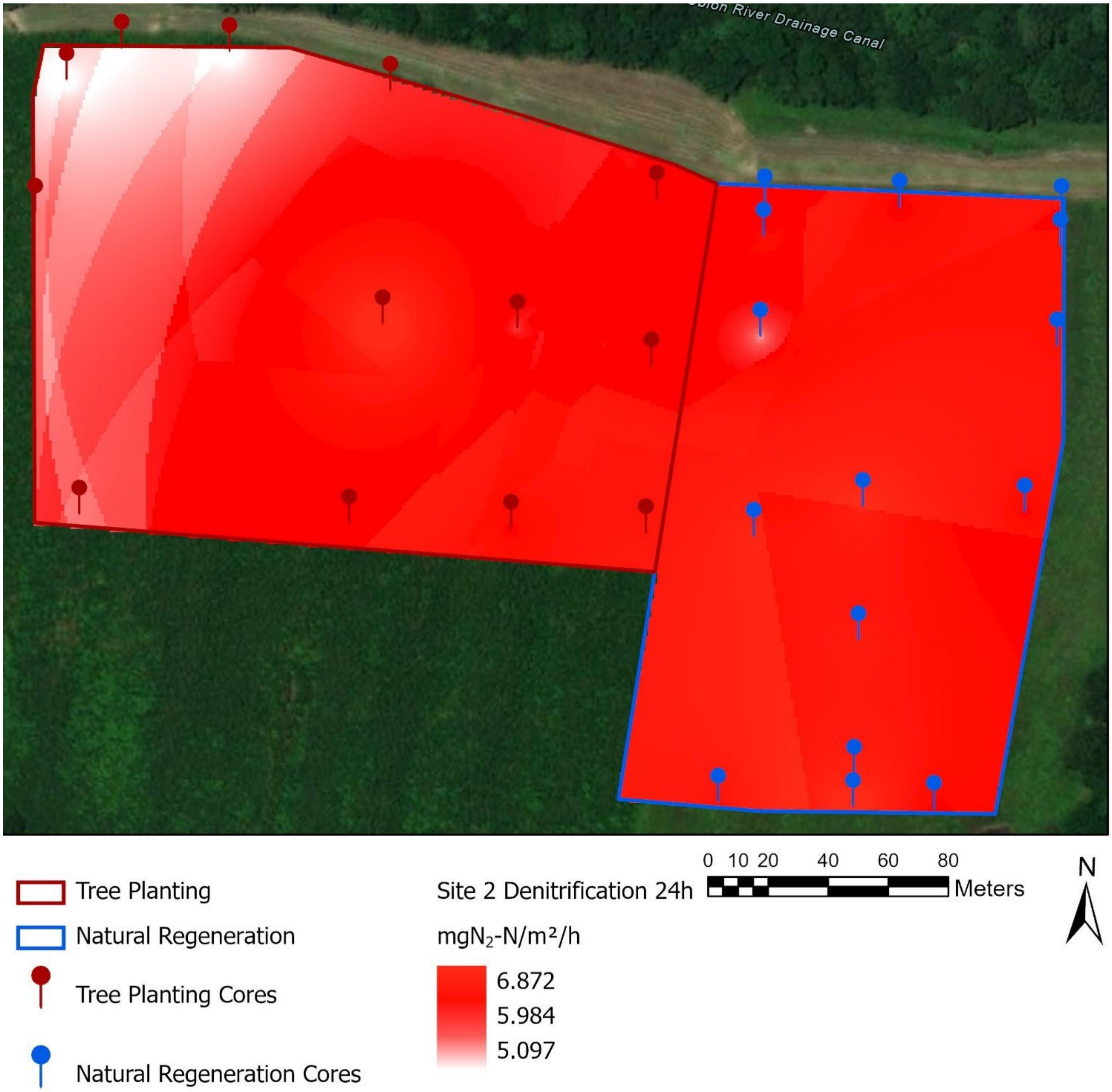
Kriging Model Site 1 Denitrification 72-h



Note. Kriging Model for Site 1 Denitrification rate prediction values (mgN_2-$N/m^2/h$) for 72-h sampling round. Red values indicate denitrification rates, white are zero rates, and blue are negative rates (nitrification). Core pins and borders are color coded to indicate habitat type.

Figure 46.

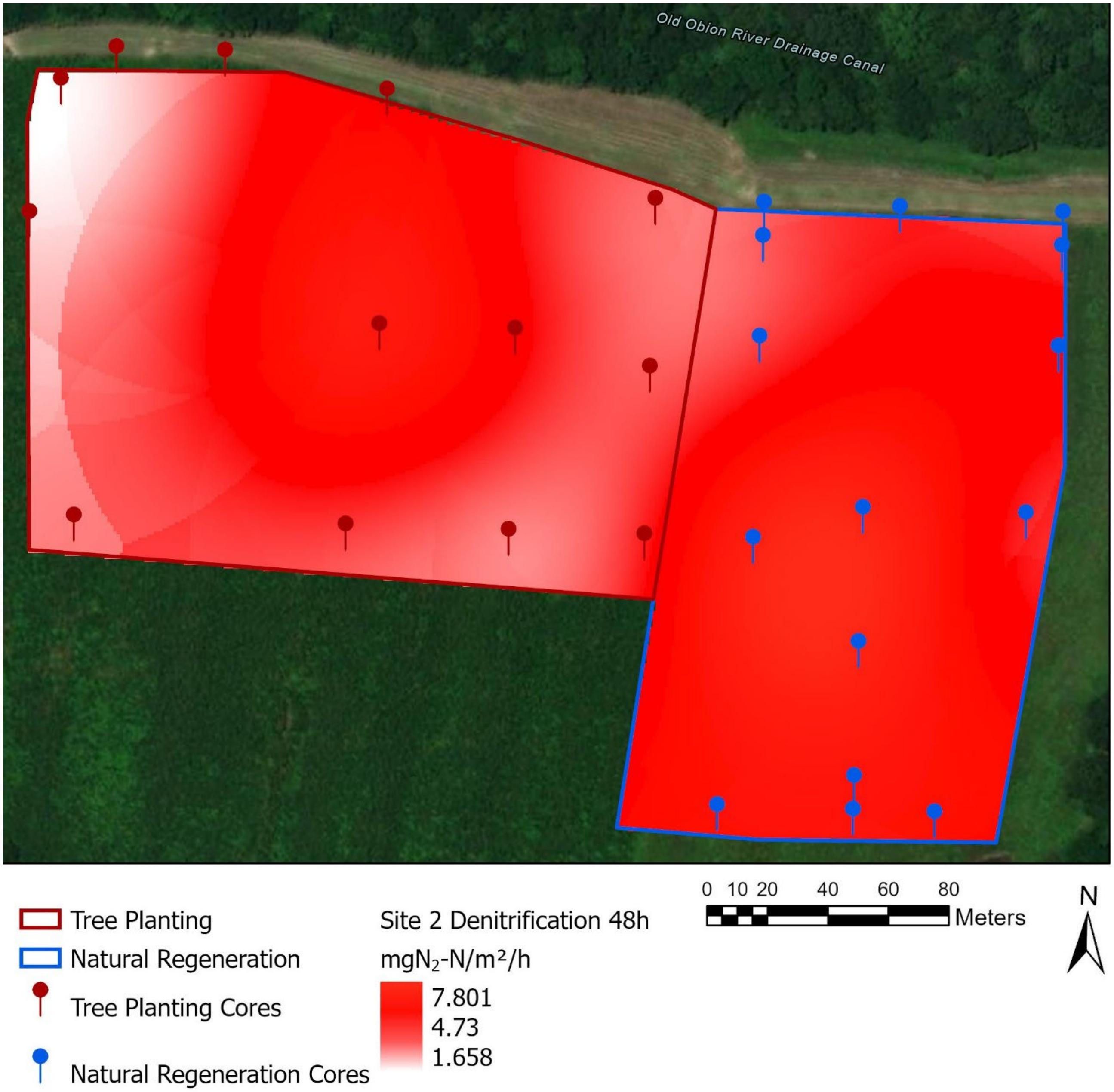
Kriging Model Site 2 Denitrification 24-h



Note. Kriging Model for Site 2 Denitrification rate prediction values (mgN_2-$N/m^2/h$) for 24-h sampling round. All rates are denitrification rates. More red values are higher rates and white values are nearest to zero. Core pins and borders are color coded to indicate habitat type.

Figure 47.

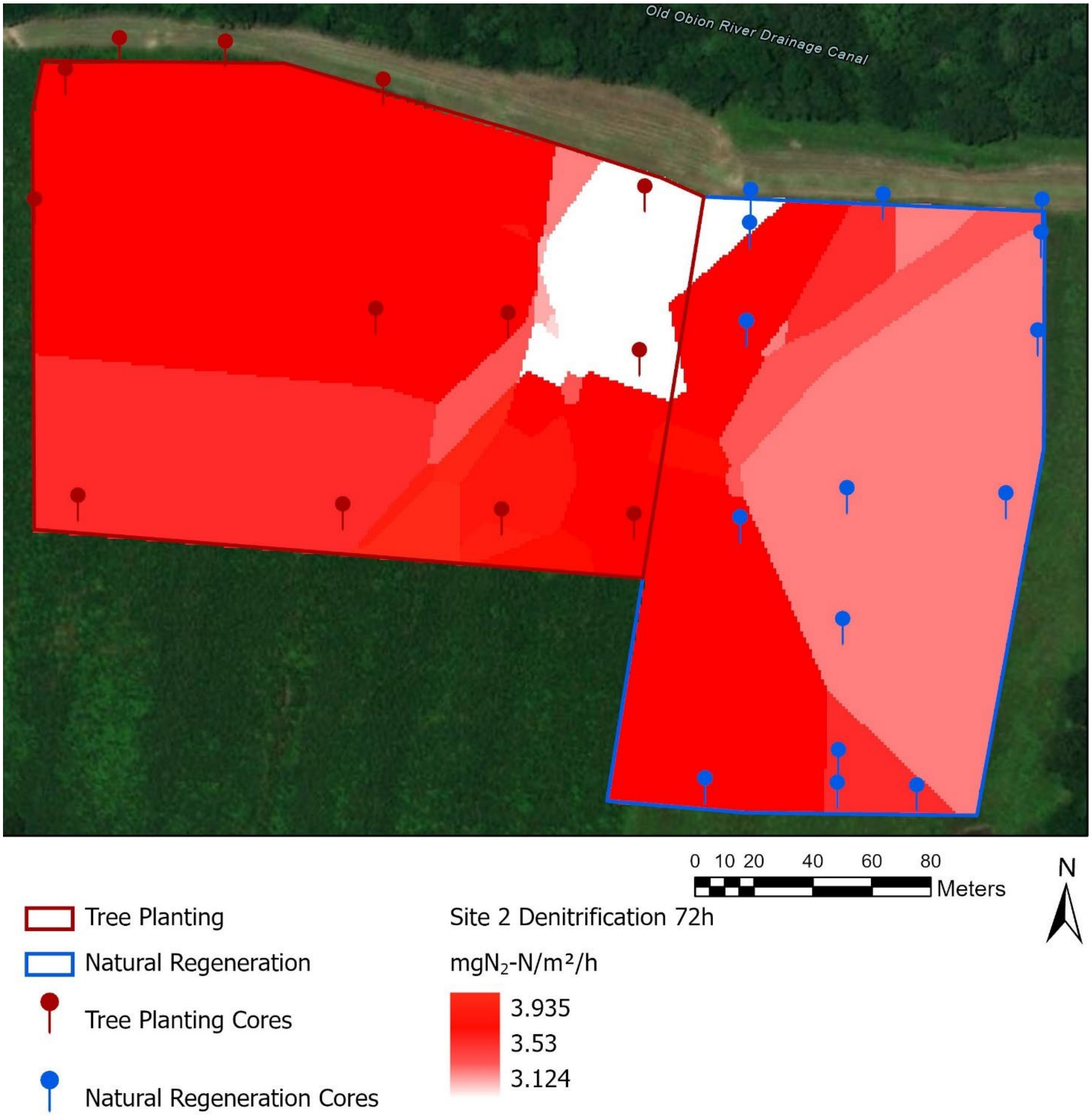
Kriging Model Site 2 Denitrification 48h



Note. Kriging Model for Site 2 Denitrification rate prediction values (mgN_2-$N/m^2/h$) for 48-h sampling round. All rates are denitrification rates. More red values are higher rates and white values are nearest to zero. Core pins and borders are color coded to indicate habitat type.

Figure 48.

Kriging Model Site 2 Denitrification 72h



Note. Kriging Model for Site 2 Denitrification rate prediction values (mgN_2-$N/m^2/h$) for 72-h sampling round. All rates are denitrification rates. More red values are higher rates and white values are nearest to zero. Core pins and borders are color coded to indicate habitat type.

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