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Use of vegetated drainage ditches and low-grade weirs for aquaculture effluent mitigation: I. Nutrients

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ABSTRACT

Implementation of water management practices could be a strategy for reducing mass discharge from aquaculture production. Of greatest concern is the delivery via discharge of excess loads of nitrogen and phosphorus to downstream systems and their effects on ecological impairments. This study assessed effects of consecutive low-grade weirs on chemical retention of aquaculture pond effluent in a single, vegetated drainage ditch. Two control (without weirs) and nine treatment (with weirs) discharges were conducted September to October 2012 at the Mississippi State University South Farm Aquaculture Facility. From discharge to drainage ditch outlet, control discharges had a 154% increase in soluble reactive phosphorus (SRP) load, whereas total phosphorus (TP), total ammonia nitrogen (TAN), and nitrate (NO_3^--N) loads decreased (47%, 43%, and 63%, respectively). Additionally, concentrations of TP ($F = 4.59$, $P = 0.02$) and TAN ($F = 6.70$, $P < 0.001$) in control discharges were significantly decreased. In treatment discharges, nutrient mass loads decreased across all analytes (80% SRP, 86% TP, 89% TAN, 89% NO_3^--N). Treatment discharges' concentrations of TP, nitrite, and NO_3^--N ($F = 4.95$, $P = 0.01$; $F = 2.91$, $P = 0.06$; $F = 5.18$, $P = 0.01$, respectively), were significantly reduced while SRP concentrations increased significantly ($F = 12.60$, $P < 0.001$). Changes in concentration were further analyzed with additional fixed effects of distance to weir 1, number of discharges prior, initial effluent concentration, and flow rate; initial effluent concentrations were shown to have a significant negative effect on TP ($F = 4.28$, $P < 0.001$) and NO_3^--N ($F = 2.41$, $P = 0.02$) concentration decrease. Results of this study indicate utilizing a ubiquitous landscape feature such as a vegetated drainage ditch with installed low-grade weirs has the potential to reduce nutrient mass loads moving downstream and can be added as a promising effluent mitigation strategy for aquaculture.

1. Introduction

Basin-wide increases in fluxes of nitrogen and phosphorus to aquatic systems have been linked to ecological impairments such as seasonal hypoxia in the Gulf of Mexico (Alexander et al., 2008). At a more local scale, catfish aquaculture in the Mississippi Alluvial Valley encompasses 16,000 ha, whose discharge eventually flows into the Gulf of Mexico (USDA/NASS, 2013). In the past, embankment ponds that dominate catfish culture in Mississippi have been targeted as nutrient sources to receiving systems. As part of the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) classifies concentrated aquatic animal production as a point source and establishes pollutant monitoring and reporting requirements (EPA, 2013). Currently, however, due to facility size and/or frequency of discharge, catfish production facilities are exempt from NPDES permitting. Even with permit exemptions, producers proactively integrate best management practices (BMPs) that aim to minimize or treat effluent from embankment ponds. Some effluent-treatment BMPs, which include settling basins and constructed wetlands, take land out of production, warranting consideration for innovative BMPs that can be integrated into established landscape features (e.g., ditches) where effluent drainage already occurs.

Little work has been done on the use of vegetated ditches to mitigate aquaculture effluent. The majority of research into vegetated ditches has focused on row-crop agriculture; however, the technology is transferable and the scientific foundations for their use still hold true when applied to aquaculture. Vegetated ditches are

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a ubiquitous feature on any aquaculture landscape and serve as a primary intercept between ponds and receiving waters. Vegetated ditches possess hydric soils, hydrophytes, and fluctuating hydroperiods that are characteristic of wetland ecosystems (Kröger, 2008), and have been shown to remove nutrients, even through multiple exposures (Cooper et al., 2004; Kröger et al., 2008a, 2012; Moore et al., 2010). Kröger et al. (2007, 2008a) reported vegetated ditches were able to decrease 57% of dissolved inorganic nitrogen and decreased 45% of total phosphorus (TP) loads in effluent. Moore et al. (2010) reported that drainage ditch vegetation can decrease soluble reactive phosphorus (SRP) concentration up to 52%. With management constantly looking to improve mitigation capacity while maintaining integration into production landscapes, introducing a controlled drainage practice into ditches may further improve water quality by decreasing flow velocities within the system.

Similar to drainage ditches, low-grade weirs show promise for mitigating nutrient concentrations and loads hydrologically through increased chemical residence time, as well as biogeochemically by creating conditions conducive for nutrient transformations. Low-grade weirs are controlled drainage structures which increase hydraulic residence time (HRT) by reducing velocities throughout the system (Kröger et al., 2008b, 2012). Multiple, in-series low-grade weirs create multiple stages for biogeochemical transformations, potentially lowering nutrient mass loads before effluent reaches downstream receiving waters. Kröger et al. (2008b, 2011) found that chemical retention time was altered significantly by installation of low-grade weirs and further concluded weirs significantly decreased outflow loads and concentrations of nitrate ($NO_3{}^-$-N), SRP, and TP. The objective of this study was to assess effects of multiple low-grade weirs on nutrient mass load and concentration of aquaculture pond effluent. There is a need, and a paucity of BMP effectiveness information for mitigating nutrients from aquaculture effluent. It was hypothesized that weirs installed in aquaculture drainage ditches would increase nutrient retention and thus improve water quality downstream.

2. Materials and methods

2.1. Experimental system and discharge

In September and October 2012, 11 experimental embankment aquaculture ponds (0.05 ha) were intentionally discharged at the Mississippi State University South Farm Aquaculture Facility (Mississippi State, MS) into a 292-m vegetated ditch fitted with three pre-cast concrete low-grade Cipoletti weirs (hereafter “weirs”) with removable riser boards to manipulate flow (Fig. 1). With riser boards removed, the ditch functioned as a conventional drainage ditch. Water height behind weirs without riser boards in place was 0.17 m, 0.15 m, and 0.34 m, respectively. With boards installed, weir height was 0.35 m, 0.24 m, and 0.55 m, respectively. Ditch channel width averaged 3 m with a 0.25% slope. In channel volunteer vegetation primarily consisted of cutgrass (*Leersia oryzoides*) and cattail (*Typha latifolia*), while ditch sides were covered by native grass. Discharge events were categorized as control (conventional drainage) or treatment (controlled drainage with weirs). Two control discharges (riser boards removed) and nine treatment discharges (riser boards installed) were conducted allowing assessment of weir function. Randomly assigned ponds were unstocked ($n = 2$), stocked with freshwater prawns (*Macrobrachium rosenbergii*) (n = 7), or stocked with channel catfish fry (*Ictalurus punctatus*) ($n = 2$). Order of discharge was randomly assigned. Prior to discharge events, initial water samples were collected from the pond ($n = 2$) and each ditch sample site ($n = 4$). Distance from initial effluent to weir 1 was measured and initial ditch volume was calculated. Volumes of each reach of the ditch were calculated as pyramidal volume calculation of ditch area above each weir by water depth at the corresponding weir, and summed for all reaches for the total in-ditch volume.

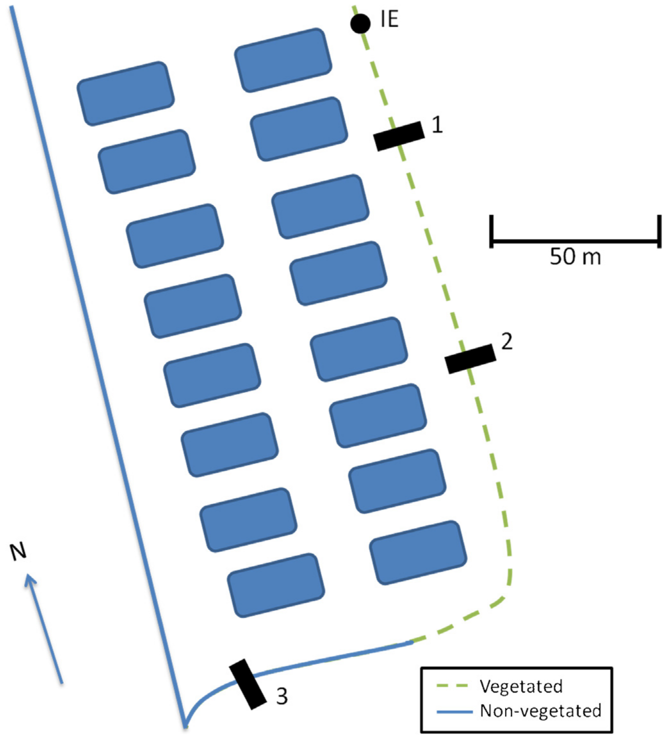

Fig. 1. Experimental site – South Farm Aquaculture Facilities on the campus of Mississippi State University, Starkville, MS. The 292-m treatment ditch had three low-grade weirs installed in a stair-step fashion. The ditch was sampled September – October 2012. The effluent from the 11 adjacent ponds was pumped by PTO pump to initial effluent (IE) location and flowed over weirs 1–3. Flow was downstream from the IE location through the weirs in sequential order. Sample sites are referred to by weir number within the ditch. Sample sites are referred to by weir number within the ditch.

Ponds were drained using a hydraulic PTO tractor pump (custom fabrication, Starkville, MS) to simulate overflow. Nutrient mass load entering and leaving the system was calculated for one control discharge and four treatment discharges (concentration × flow rate). To account for varying distances of individual discharge and reaches in the system, all loads were normalized by dividing load by the wetted ditch area. Change in depth of pond was monitored using a rugged troll level logger (InSitu, Inc., Ft. Collins, CO) mounted at the deepest point of each pond. Rate of flow entering the system was calculated as the change in pond depth over time. Pumping ranged from 4 h to 8 h. Rate of flow leaving the system was determined by taking a three-sample average of the time it took to fill a 21-L bucket behind the last weir, hourly (at water sampling event), throughout each drainage event.

To determine HRT and system turnover, one control and two treatment discharges were randomly selected to which a salt slug was introduced to the system when pumping began and when pumping ended. The salt solution was created in a mixing chamber using 18.14 kg of 99% pure NaCl, Diamond Crystal® pool salt (Cargill, Inc., Wayzata, MN), dissolved in 125 L of pond water. Specific conductivity (μS) was measured above each weir using a Hydrolab Minisonde 5 Multiprobe SE (Hach, Loveland, CO) to monitor the salt slug movement through the system. Hydraulic residence time and system turnover were recorded as the difference in peak specific conductivity time and the time the salt slug was administered. At maximum weir capacity, volume of the ditch was additionally