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**Modeling the relationship between water level, wild rice abundance, and waterfowl abundance at a central North American wetland**

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**Abstract**

Recent evidence suggests wild rice, an important resource for migrating waterfowl, is declining in parts of central North America, providing motivation to rigorously quantify the relationship between waterfowl and wild rice. A hierarchical mixed-effects model was applied to data on waterfowl abundance for 16 species, wild rice (*Zizania palustris*) stem density, and two measures of water depth (true water depth at vegetation sampling locations and water surface elevation). Results provide evidence for an effect of true water depth on wild rice abundance (posterior mean estimate for the TWD coefficient, = 0.92, 95% confidence interval = 0.11—1.74), but not for an effect of wild rice stem density or water surface elevation on local waterfowl abundance (posterior mean values for relevant parameters overlapped 0). Refined protocols for sampling design and more consistent sampling frequency to increase data quality should be pursued to overcome issues that may have obfuscated relationships evaluated here.

**Keywords** hierarchical modeling, migration, waterfowl, wetlands, *Zizania palustris*

**Introduction**

Wild rice is an important resource for migrating waterfowl and other waterbirds (Moyle 1944; Webster 1964; Gonsoski et al. 2005; Longoni 2010; Marco-Méndez et al. 2015; Pernollet et al. 2016), especially in agricultural areas where residual seed serves as a valuable resource for waterfowl and other migratory birds (Stafford et al. 2006; Elphick 2010; Elphick et al. 2010; Fasola and Brangi 2010; Ibáñez et al. 2010). Wild rice (*Zizania* spp.)—a high protein food source unrelated to commercially grown rice, however, also plays an important role. In North America, wild rice commonly occurs in well-circulated shallow waters with silty or mucky bottoms (Moyle 1944) in the north-central and northeastern U.S. and adjacent areas of Canada. Wetland birds including waterfowl use wild rice as direct (seed consumption) and indirect forage (consumption of invertebrates that rice wetlands support), nesting habitat in their breeding ranges, and roosting habitat during migration (Elphick 2010). Wild rice in some areas may constitute up to 94% of the fall diet of sora (*Porzana carolina*) (Webster 1964). Wood ducks (*Aix sponsa*) forage on the flowers and geese and swans consume young shoots, germinating seeds, and mature stems and leaves (Bellrose 1980). Much of what is known, though, about the connection between rice (whether wild [e.g., *Zizania spp*] or domesticated [e.g., *Oryza spp*]) and waterfowl abundance comes from research conducted in agricultural rice fields (Greer et al. 2009) largely because relations are more readily detected in less vegetatively diverse agricultural rice fields. Clarifying the role wild rice plays in supporting waterfowl populations is an important step in managing systems of land and water for migrating waterfowl.

Waterfowl compensate for agricultural rice depletion by exploiting other vegetative or invertebrate food sources to persist in areas when rice abundance falls below the density at which waterfowl are otherwise likely to depart (Marco-Méndez et al. 2015). In fact, Greer et al. (2009) indicated that depletion of wild rice by waterfowl likely occurs at substantially lower values than previously hypothesized, suggesting that wild rice may be an important *component* of the diet of migratory waterfowl, but perhaps one that is easily replaced. If this is the case, we may not expect to see a clear signal of wild rice density on waterfowl abundance, as waterfowl would be using wild rice as only one of a number of food sources. Parsing this difference has profound consequences for heavily managed wetlands in which rice abundance is a mutable feature.

The historical presence of wild rice (specifically northern wild rice, *Z. palustris*) at Rice Lake National Wildlife Refuge (Rice Lake NWR) combined with the general declining trend of wild rice in the greater geographic area (Pillsbury and McGuire 2009) places heightened importance on identifying the relationship between wild rice availability and waterfowl abundance. Here, a Bayesian framework is applied to a hierarchical model describing effects of water level and wild rice abundance on waterfowl abundance counts for 16 species collected at Rice Lake NWR. It is especially important to include water level as it is the only variable among those considered here that can be directly manipulated by management actions.

**Methods**

**Study Area**

Rice Lake NWR is a 74 km2 preserve in east-central Minnesota, USA (46˚ 53’ N, 93˚ 34 W) surrounding a ~15 km2 lake. It is a product of glaciation; advancing and retreating glaciers provided a natural depression which captures water and facilitates nutrient cycling and plant production (USFWS 2005).

Water depth was recorded from 1990 to 2010, with gaps in 1992, 1996-2001, and 2006-2007, as the true water depth (TWD, bottom to surface) at the sampling points for wild rice stem density. Wild rice density was sampled from 1990 to 1995, 2002 to 2005, 2008, and 2009. Protocols for measuring the density of wild rice changed over the course of the data collection. From 1990 to 1995, density was calculated as the number of stems/ft2; from 2000 to 2005, and in 2008 and 2009, density was calculated as the number of stems/m2. In both cases PVC squares (with sides of one foot and one meter, respectively) were randomly placed in the wetland for sampling purposes. Measurements were converted to a common scale of stems/m2. Water depth and wild rice density were sampled simultaneously, in late summer to early autumn (late August through early October). An average of 58 samples were recorded each year (from 32 to 78, depending on plot accessibility).

Waterfowl abundance was estimated from morning (0800 CT) observations conducted weekly between April and first ice cover in the autumn from 1990 to 2012. These were flush counts from an airboat, lower water depth near the edge of the lake was surveyed first and a second pass in the deeper central portion of the lake was surveyed second. When large flocks (>5,000 individuals) were observed it was usually in the central deeper portion. In total, 13,688,812 birds were counted, representing 16 species (Table 1). Some species were only observed in a few years (*Mergus merganser*, *Bucephala albeola*), but most were present in all surveys. Abundance counts were converted to bird-use-days using the trapezoidal area-under-curve method (Millar et al. 2012, Aagaard et al. 2015) to obtain annual summaries of waterfowl presence at the lake to match the time-scale of the rice data.

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