

Monitoring Greater Yellowstone Ecosystem Wetlands: Can Long-term Monitoring Help Us Understand Their Future?

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Photo 1. Wetlands near Cygnet Lakes Trail off Norris Canyon road.

In the Greater Yellowstone Ecosystem (GYE), changes in the drying cycles of wetlands have been documented (McMenamin et al. 2008, Schook 2012). Wetlands are areas where the water table is at or near the land surface and standing shallow water is present for much or all of the growing season (photo 1). We discuss how monitoring data can be used to document variation in annual flooding and drying patterns of wetlands monitored across Yellowstone and Grand Teton national parks, investigate how these patterns are related to a changing climate, and explore how drying of wetlands may impact amphibians. The documented declines of some amphibian species are of growing concern to scientists and land managers alike, in part because disappearances have occurred in some of the most protected places (Corn et al. 1997, Drost and Fellers 1996, Fellers et al. 2008). These disappearances are a recognized component of what is

being described as Earth's sixth mass extinction (Wake and Vredenburg 2008).

In Yellowstone and Grand Teton national parks, depressional wetlands (i.e., those lacking flowing water, including ponds, wet meadows, and marshes bordering lakes and rivers) are the most prevalent wetland type and constitute approximately 3% of the landscape (Gould et al. 2012). Despite limited representation, 38% of all of Yellowstone's 1,200 documented plants species and 70% of Wyoming's 400 bird species are associated with wetlands (Elliot and Hektner 2000, Nicholoff 2003). Wetland-associated birds include obligate species (e.g., trumpeter swans and sandhill cranes) and upland-nesters that use wetlands for feeding (e.g., tree swallows). All five native species of amphibians (boreal chorus frogs, boreal toads, Columbia spotted frogs, plains spadefoot, and western tiger salamanders) occurring in Yellowstone

are dependent on wetlands for breeding. Many of Yellowstone's mammals live in or regularly use wetlands (e.g., beavers, muskrats, otters, and moose). Aquatic invertebrates and wetland-breeding insects provide critical food resources for many species of wildlife.

Freshwater wetlands are equally important outside of this region, covering approximately 4% of the Earth's surface (Prigent et al. 2001). Worldwide, wetlands provide crucial habitat for a diversity of plants and animals, function as carbon sinks, and are widely used for outdoor recreation. Wetlands are often described as "keystone habitats" because their influence on ecosystem function and structure is disproportional to their size. Despite their natural value, wetlands have been drained, filled, or manipulated by humans for centuries (Mitsch and Gosselink 2007, Zedler and Kercher 2005). Over half of the wetland acres in the conterminous United States have been lost since 1780, including > 25% in Montana and nearly 40% in Wyoming (Dahl 1990). Because of these historic and widespread losses, wetlands in the United States are protected under the Clean Water Act. Even with current regulatory protections, low-elevation wetlands in Wyoming are still vulnerable to land use and climate change (Copeland et al. 2010).

Although periodic and regular drying is an important component of most wetland ecosystems (Prigent et al. 2001), a recent report by the International Panel on Climate Change (IPCC) stated wetlands and shallow ponds are among the most vulnerable to changes in climate (IPCC 2008). Many wetland-dependent species have adaptations allowing them to cope with these highly variable environments (Williams 1997), but permanent drying of wetlands or significant changes in flooding patterns could cause profound changes to productivity and biodiversity across the globe and throughout Yellowstone and Grand Teton national parks (Copeland et al. 2010, Junk et al. 2006, Ray et al. 2014).

Amphibian Monitoring in the Greater Yellowstone Ecosystem

Annual amphibian monitoring has been conducted in the wetlands of Yellowstone and Grand Teton national parks since 2000 by the NPS Greater Yellowstone Inventory and Monitoring Network, the U.S. Geological Survey's Amphibian Research and Monitoring Initiative, university and non-governmental cooperators (Gould et al. 2012). The parks were divided into 3,370 catchments, or discrete land units connected by surface water flows,

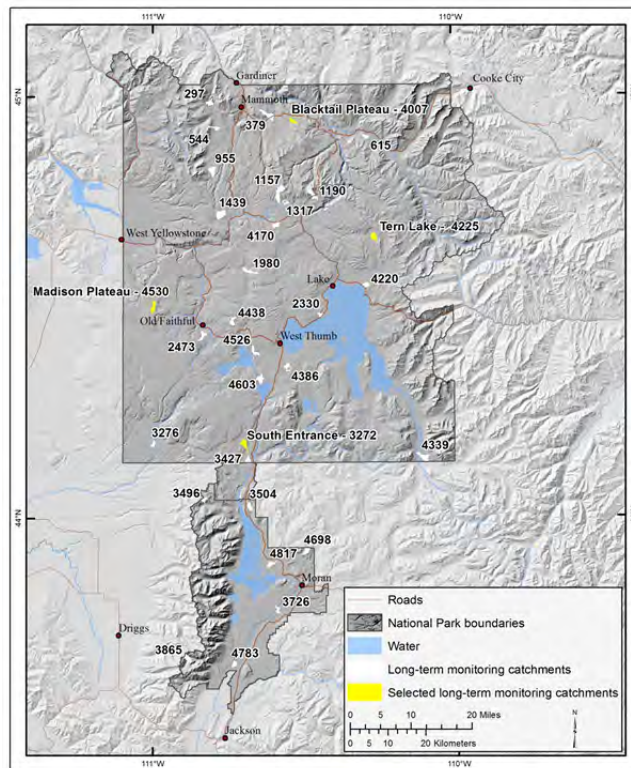


Figure 1. Long-term monitoring catchments in Yellowstone and Grand Teton national parks where annual wetland visits occurred and amphibian surveys were completed.

averaging 200 hectares (approximately 495 acres) in size. A random subset of catchments across both parks was selected to serve as the basis for long-term monitoring (figure 1). Wetlands within these catchments were visited annually in mid-summer. During the annual field visit, amphibian surveys were conducted; and size, depth, and vegetative coverage were documented.

To understand how observed variation in wetland flooding affects amphibians and other wetland-dependent taxa, we examined the relationships between weather data, surface runoff, and wetland inundation from 2005 to 2012 (figure 2). Wetland inundation is the presence of surface water observed during annual summer surveys. Sites without surface water were described as 'dry', while sites with even a minimal expanse of surface water were described as 'inundated'. Generally, the amount of surface water on the landscape that is available to fill or inundate wetlands and support amphibian breeding is related to air temperature, precipitation, and site-specific characteristics like soil and topography. Higher air temperatures contribute directly to increased evaporation and soil drying; this in turn affects how much precipitation infiltrates the landscape and sustains wetlands.

Temperature and precipitation data were used in a water balance model (see Thoma et al., this issue) to calculate annual runoff (the amount of water available to fill wetlands after evaporation and other pathways are accounted for) using daily estimates in monthly time steps. Average maximum and minimum air temperatures, and average regional precipitation for calendar years 2005 to 2012 were compared to the 30-year average (1982–2012, figure 2). Maximum and minimum air temperatures both influence wetland inundation. Maximum temperatures have a greater influence on evaporation rates, desiccating soils and contributing to wetland drying, while minimum temperatures reveal important information about conditions important for maintaining snow. Snow is a critical source of water for wetlands located at high elevations (Corn 2003).

Amphibian monitoring records from 2005 through 2012 were compiled, and photographs were taken in the field to describe and document annual wetland inundation status. Additionally, we assessed the relationship between annual runoff and percentage of wetlands inundated across all catchments in Yellowstone and Grand Teton and for four catchments representing four geographically and hydrologically distinct regions of Yellowstone: the Northern Range (Blacktail Plateau), the Madison Plateau, the South Entrance, and the Tern Lake area (figure 1). Precipitation, air temperature, soil, and topography vary among these catchments; as a result, each watershed contains wetlands with different sensitivities to annual runoff.

Finally, we explored how annual variations in wetland inundation affected the occurrence of breeding boreal chorus frogs. Chorus frogs may be most vulnerable to wetland drying due to breeding habitat preference for seasonal pools, wet meadows, and shallow portions of permanent wetlands (Koch and Peterson 1995). Previous analyses of chorus frog breeding occurrence in the parks indicated a sharp reduction at both seasonal and permanent wetlands in the dry year 2007 (Gould et al. 2012).

Annual Runoff & Amphibian Occurrence

Maximum and minimum air temperatures since 2005 are generally warmer than the 30-year average, but minimum air temperatures exhibit the strongest departure from the longer-term average (figure 2a). Annual precipitation and annual runoff have varied around the 30-year average during this period (figure 2b and 2c). Notable among the monitoring years were 2007 and 2011. In 2007, maximum air temperatures were high, and precipitation

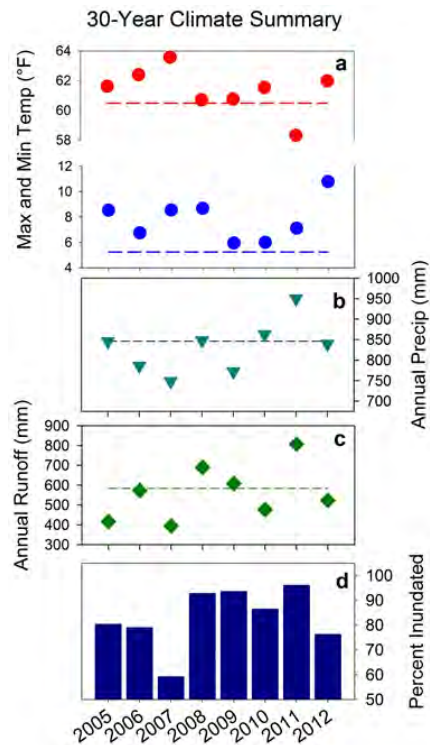


Figure 2. Summary of average annual maximum (red circles) and minimum (blue circles) air temperatures (a), total annual precipitation (b), total annual runoff (c), and the percentage of monitored wetlands inundated annually (d). Maximum and minimum air temperatures for years 2005 to 2012 are presented in degrees Fahrenheit (circles) and are shown along with the 30-year (1982–2012) average (dashed line) to highlight differences between a given year and the longer-term average. Similarly, 2005 to 2012 estimated annual precipitation (triangles) and runoff (diamonds) totals are shown along with the 1982–2012 average (dashed line) for each parameter.

and runoff were low. Conversely, maximum air temperatures were low, and precipitation and runoff were high in 2011. The percent of monitored wetlands inundated also varied among years, with a lower percentage (59%) of wetlands inundated in 2007 and higher percentage (96%) inundated in 2011 (figure 2d).

Across all Yellowstone and Grand Teton national park catchments, a strong relationship between the amount of runoff per year and the number of inundated wetlands was found (figure 3) but varied by catchment. Percentage of wetlands inundated within catchments 3272 (South Entrance), 4530 (Madison Plateau), and 4007 (Blacktail Plateau) generally increased with available runoff, while the percentage of wetlands inundated in catchment Y4225 (Tern Lake area) appeared to be unrelated to annual runoff (figure 4).

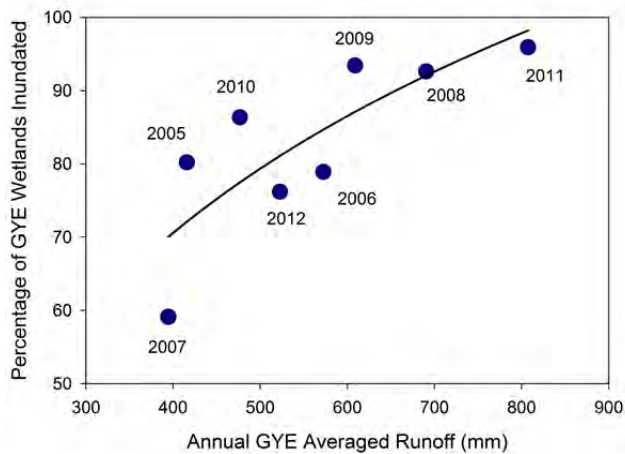


Figure 3. Percentage of monitored wetlands in Yellowstone and Grand Teton national parks (collectively GYE) inundated yearly and relationship to annual estimated runoff for the entire GYE in that same year. The relationship is statistically significant and explains nearly two-thirds of the variation documented in wetland flooding ($R^2 = 0.65$). GYE runoff estimates represent an average across all wetlands monitored in the GYE.

The annual variation in flooding described above is apparent in a series of photos taken of wetland site 3 in catchment 4007 located on the Blacktail Plateau (photo 2). This isolated wetland was dry by early July in 2005, 2006, 2007, and 2010. Although the wetland was inundated in other years (2008, 2009, 2011, and 2012), the amount of water varied. When this site is inundated, western tiger salamanders and boreal chorus frogs breeding was documented. Even though wetlands in southern Yellowstone are expected to be less tied to annual weather patterns because of greater runoff, they exhibited similar drying during years with low precipitation and warm temperatures (see site 2-3272 in photo 3).

Chorus frog occurrences in monitored catchments were strongly related to annual runoff (figure 5). The lowest number of documented occurrences of chorus frog breeding was in 2007, the driest year within our monitoring record and a year when > 40% of monitored wetlands were dry. During that year, chorus frog breeding was documented in only 60 wetlands across both parks. In contrast, surveys in 2011, when approximately 96% of all monitored wetlands were inundated, documented chorus frog breeding occurred in 110 wetlands.

Impacts of Climate Change on Wetlands of the GYE

Wetlands within parts of the GYE, specifically Yellowstone's Northern Range, are shrinking or drying as a consequence of recent temperature and precipitation

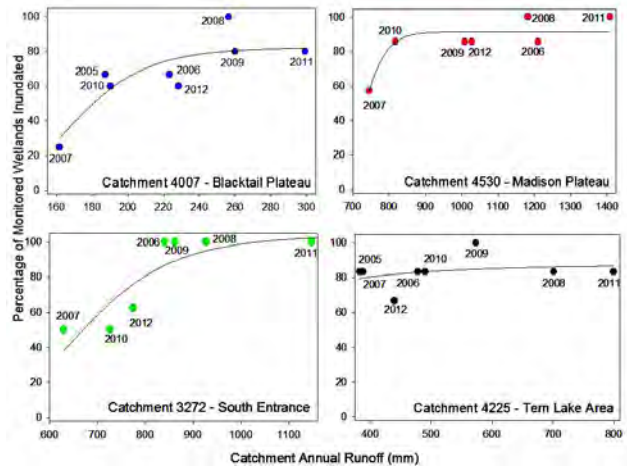


Figure 4. Percentage of monitored wetlands inundated annually for 4 distinct regions (Blacktail Plateau, Madison Plateau, South Entrance, and Tern Lake area) of Yellowstone National Park and the relationship with catchment-level estimates of runoff. Estimates of runoff vary dramatically by location (see individual x-axes for annual variations in runoff). Curves represent best fit curves using a logistic function.

trends (Schook 2012). In the Northern Range, McMenamin et al. (2008) found the number of inundated wetlands declined from the early 1990s to late 2000s. Our data confirmed wetland inundation in the Northern Range and elsewhere in the GYE are vulnerable to annual variations in temperature and precipitation, and long-term trends in climate. Our annual monitoring data suggest chronic repetition of dry, warm years, like in 2007, could lead to a decline in upwards of 40% of the region's wetlands. This decline could ultimately reduce the distribution and abundance of wetland-dependent taxa, including boreal chorus frogs. Chorus frogs may be the most vulnerable of the GYE's amphibian species to climate because they prefer shallow, ephemeral wetland habitats. The negative response described between boreal chorus frog breeding habitat and dry, warm years underestimates the effects of wetland drying on this species. Even if breeding was documented, we have informally observed the drying of some sites after our annual surveys are conducted but prior to completion of amphibian metamorphosis which can cause reproductive failure. The strong relationship between annual runoff, wetland inundation, and chorus frog breeding occurrence foretell rough times for amphibians if projected drought increases occur.

Declines in water-levels and drying of wetlands could affect a number of other species (e.g., moose, beaver, trumpeter swans, and sandhill cranes) dependent on inundated wetlands for survival (Bilyeu et al. 2008, NRC 2002, White et al. 2011). Although the link be-

tween wetland loss and biodiversity is somewhat predictable, changes to other ecosystem services (i.e., benefits and experiences humans obtain from wetlands such as groundwater recharge, pollution filtration) have not been carefully considered. Generally, wetland loss is expected to reduce plant productivity, which limits the carbon sequestration potential of landscapes, affect hydrologic flow paths and water storage within floodplains and uplands, alter soundscapes, and affect wildlife viewing opportunities (Pijanowski et al. 2011, Turner and Daily 2008, Zedler 2003). Loss of wetlands due to drying could also remove natural fire breaks important for managing low to moderate intensity wildfires (Swanson 1981).

Wetlands in Yellowstone's Northern Range may be particularly vulnerable to drying because this region has relatively low amounts of precipitation, elevated temperatures, limited runoff, and declining snowpack and ground water levels (McMenamin et al. 2008, Ray et al. 2014, Schook 2012, Wilmers and Getz 2005). Combined, these conditions have already led to wetland drying and shrinking in the last few decades (McMenamin et al. 2008, Schook 2012). The Northern Range has unique characteristics, but may serve as an indicator for other parts of Yellowstone (e.g., Bechler Meadows) and Grand Teton (e.g., Antelope Flats) where high temperatures lead to high evaporative losses and reduced runoff. More troubling, the region as a whole is projected to experience continued warming over the next century (possibly 5.4° F in the next 50 years; Hansen et al. 2014). Given these projections, widespread changes to wetlands are expected.

Our monitoring data indicated in the driest years, approximately 40% of Yellowstone's and Grand Teton's monitored wetlands were dry by June or mid-July (figure 2). In years with reduced precipitation, high temperatures, and limited runoff, wetland drying was widespread but not uniform across the region (figure 4). In some monitored catchments, no change was detected in the number of wetlands present across years. These wetlands may be hydrologically connected to permanent water bodies (e.g., Yellowstone River or Yellowstone Lake) or exist at higher elevations or locations receiving more snow (e.g., high in the Tetons). In contrast, catchments monitored in Yellowstone's Northern Range in 2007 supported only half ($\leq 50\%$) of the wetlands present in wet years (Ray et al. 2014). The inundation response of Northern Range wetlands to annual variations in surface runoff highlights the importance of runoff contributions, but indicates

these hydrologically-isolated glacial wetlands (e.g., kettle ponds) are also strongly influenced by regional groundwater levels and long-term climate conditions (McMenamin et al. 2008). Documenting relationships between air temperature, precipitation, runoff, and wetland inundation is a necessary first step to identifying which regions, catchments, and wetlands are most susceptible to drying and, in turn, which taxa and ecosystem services will be lost.

During our monitoring record, calendar years 2005, 2007, and 2010 all represented low runoff years. These years had variable amounts of annual precipitation, but temperatures during these years were higher than the 30-year average (figure 2). We emphasize this latter point because it demonstrates the influence of air temperature on annual runoff estimates and forecasts for this region's continued warming (Pedersen et al. 2011, Hansen et al. 2014). Higher air temperatures contribute directly to soil drying which, in turn, affects how much precipitation infiltrates rather than runs off the landscape. We believe signs of future warming will continue shrinking and drying of wetlands throughout some regions of the GYE. Our annual monitoring is critical to both documenting and predicting how climate will continue to influence wetlands of this region.

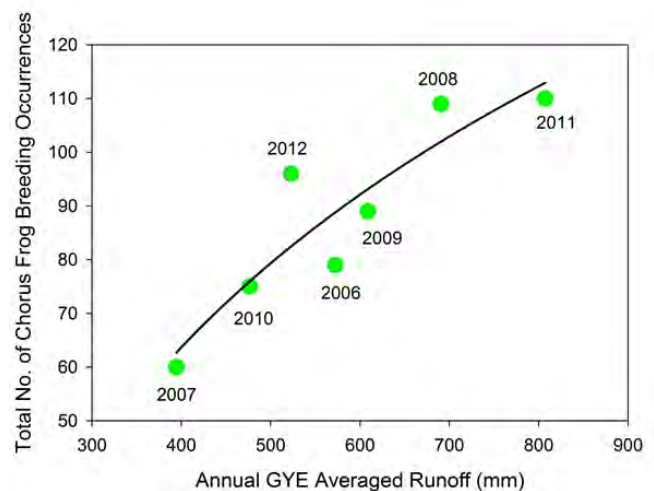


Figure 5. Total number of boreal chorus frog breeding occurrences documented annually in the GYE study area and average annual runoff for the region. Runoff was averaged across all wetlands monitored as part of the long-term monitoring effort. Relationship is statistically significant and explains more than 80% of the documented variation in chorus frog occurrences ($R^2 = 0.82$).

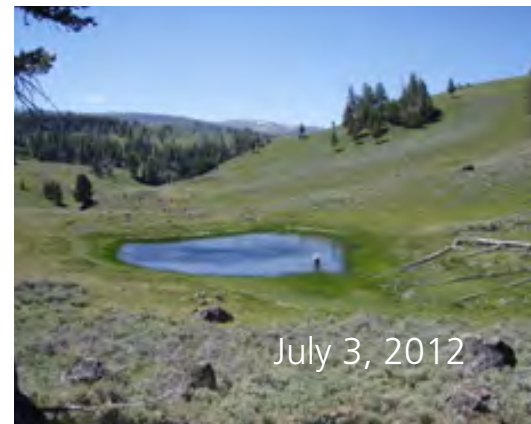


Photo Series 2. Photographic history of site 3 from Yellowstone Catchment 4007 located on the Blacktail Plateau in Yellowstone's Northern Range. Note that the location where the photo was taken changed between 2007 and 2008, but 2007 does depict dry conditions at this site.*

**Although photo dates vary among years, all photos in Photo Series 2 & 3 were taken prior to amphibian metamorphosis when amphibian larvae (e.g., tadpoles) are dependent on standing surface water for survival.*



Photo Series 3. Photographic history of site 2 from Yellowstone Catchment 3272 located near the South Entrance Station.*

The Continued Need for Wetland Monitoring

In Yellowstone and Grand Teton national parks, annual amphibian and wetland habitat monitoring (see Gould et al. 2012) has greatly increased the understanding of wetland vulnerability and links between annual wetland drying and climate. Additionally, monitoring information will inform conservation decisions by providing annual, spatially balanced evidence about the distribution and occurrence of wetlands and amphibians across the GYE. Monitoring data also reduce uncertainty surrounding wetland resources and strengthens opportunities to make informed, science-based decisions that will benefit wetlands and wetland-dependent taxa in a changing climate.

Given our results and the NPS's commitment to wetland protection (Director's Order #77-1) through a goal of 'no net loss of wetlands,' we present four themes to consider. We believe these measures may contribute to the future protection of valuable wetland resources in the Greater Yellowstone Ecosystem:

1. Consider expanding and prioritizing wetland inventories to ensure proper protection, management, and planning around existing wetland resources. Conservation planning would benefit from knowledge of the location, extent, and description of major biological features and ecosystem services of existing wetland resources. This up-to-date information could be combined with temperature, precipitation, and runoff data to identify wetlands most vulnerable to climate change.
2. Identify degraded or disturbed (e.g., through the introduction of nonnative fish) wetlands that could be restored to 'pre-disturbance conditions.' Recent work confirms restoration activities can benefit wetland-dependent taxa, including amphibians, by increasing habitat complexity, re-connecting wetlands, and removing nonnative species (Green et al. 2013, Hossack et al. 2013, Shoo et al. 2011).
3. Recognize the importance of the beaver to sustaining and creating wetlands. Wetlands, amphibians, and other wetland-dependent taxa are strongly linked to the presence of beaver in the Northern Rockies (Bilyeu et al. 2008). Natural and management-related changes in beaver abundance during the 20th century resulted in lower water tables and fewer streamside and floodplain wetlands (Bilyeu et al. 2008, Marshall et al. 2013, Persico and Meyer 2013).

4. Increase public and visitor awareness about the importance of wetlands and vulnerability to climate change. Increased awareness through existing interpretation and education programs (see Wetlands in the National Parks¹ and NPS Response to Climate Change² for more information) or through alternative education models. Regardless, the information collected through our on-going monitoring efforts could be used to deliver compelling information about the effects of climate change on wetland resources and engage some of the 3.5+ million people who visit Yellowstone and Grand Teton national parks annually.

¹Wetlands in the National Parks: <http://www.nature.nps.gov/water/wetlands/aboutwetlands.cfm>

²NPS Response to Climate Change: <http://www.nps.gov/subjects/climatechange/response.htm>

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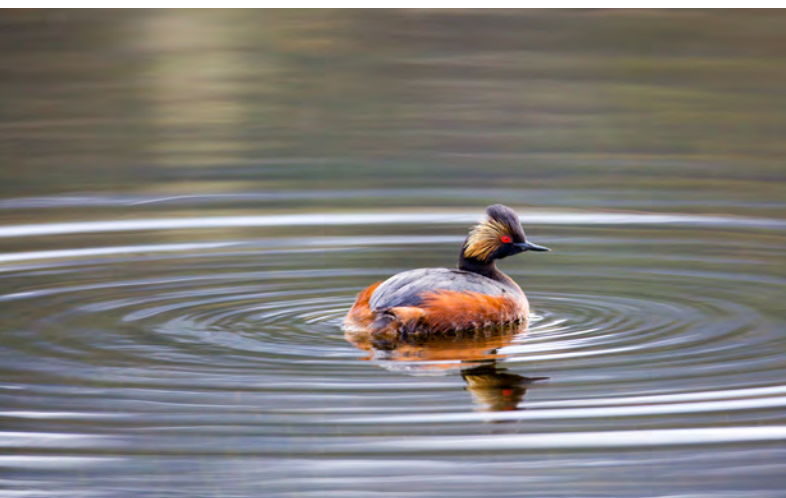
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Photo by: Kristen Inbody, Great Falls Tribune

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