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Historical Fire and *Ventenata dubia* Invasion in a Temperate Grassland☆

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ABSTRACT

Ventenata (*Ventenata dubia* L.) is an invasive annual grass that has rapidly expanded its range across temperate grassland and shrub-steppe ecosystems in western North America. However, there is little published regarding its ecology, especially its relationship with fire on rangelands. The objective of this study was to examine the effect of fire on ventenata invasion in the Pacific Northwest Bunchgrass (PNB) Prairie. Given the influence of fire on the invasion of other annual grasses such as cheatgrass (*Bromus tectorum* L.), we expected that fire would facilitate the spread and increase in abundance of ventenata. In addition, we considered that annual variation in precipitation might mask the effect of fire and drive the year-to-year variation in production of ventenata. Therefore, we resampled 56 plots in 2015 and 2016 where frequency and foliar cover of ventenata had been recorded in 2008 and where 12 of these plots had burned in the past 15 yr. We then compared ventenata abundance (frequency and foliar cover) between burned and unburned plots within each sampling yr (2008, 2015, and 2016), as well as the change in abundance over time. Our data revealed that ventenata frequency and cover increased on all plots. However, there was not significantly higher abundance in burned plots in any of the sampling years. In addition, ventenata abundance did not increase more in burned plots over time. Our findings suggest that, unlike cheatgrass, fire may not be a driving factor in the spread and increase of ventenata across the PNB Prairie. This finding has important implications for the management and control of ventenata, as well as the conservation of the PNB Prairie.

Introduction

Fire plays an important and highly variable role in the invasion success of a wide variety of exotic plant species (D'Antonio 2000; DiTomaso et al. 2006; Alba et al. 2015). Fire can promote or inhibit invasion depending on the traits of the exotic species and adaptations of the native plant community to fire disturbances (DiTomaso et al. 2006; Leffler et al. 2013; Juani et al. 2015; Porensky and Blummenthal 2016). The annual grass/fire cycle is well known for promoting and maintaining dominance of exotic annual grass invasions in arid and semiarid ecosystems (D'Antonio and Vitousek 1992; D'Antonio 2000). Annual grasses, such as cheatgrass (*Bromus tectorum* L.), can reduce fire return intervals from 30 yr to 3 or 5 yr, which favors their own lifecycle while concomitantly stressing native plant communities of sagebrush ecosystems (D'Antonio and Vitousek 1992; Chambers et al. 2007). Fire can also promote the establishment and spread of exotic species by removing or reducing competition by native species and providing a nutrient-rich environment for fast-growing ruderal species, especially annual grasses (D'Antonio 2000; Alba et al. 2015).

A relatively new exotic annual grass, ventenata (*Ventenata dubia* L.), is rapidly spreading across much of the Palouse and Pacific Northwest Bunchgrass (PNB) Prairie (Nyamai et al. 2011; Bernards and Morris 2017; Averett et al. 2020). In contrast to its common name, "North Africa grass," ventenata originated in southern

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Europe and western Asia (Alomran et al. 2019). It was first recorded in the United States in 1952 in Washington and has been documented in at least 10 states, as well as several provinces of southwestern and southeastern Canada (Scheinost et al. 2008). It is well established now in pasturelands, croplands, and a variety of ecosystems including grasslands, sagebrush steppe, ponderosa pine forests, and woodlands (Averett et al. 2016; Bernards and Morris 2017; Fryer 2017; Jones et al. 2018; Downing et al. 2019). Despite this wide ecological distribution, the basic ecology and dynamics of this annual grass are just beginning to be studied (Wallace et al. 2015; Endress et al. 2019; Averett et al. 2020; Tortorelli et al. 2020).

There are many questions about the potential fire dynamics associated with ventenata (Fryer 2017). However, there has been scant research investigating the relationships between ventenata and fire in rangelands outside of prescribed fire in the Conservation Reserve Program (CRP) seeded pastures (Mackey 2014; Fryer 2017) and summer wildfires in the forests of the Blue Mountains of Oregon (Tortorelli et al. 2020). Furthermore, there are currently conflicting published observations about the effects of fire on ventenata abundance in rangelands. For example, in landowner surveys, respondents reported higher dominance of ventenata after prescribed fire and low effectiveness as a management tool to control it (Pavek et al. 2011). There have also been anecdotal reports of ventenata density increasing after summer fires in Washington and Oregon, in years with above-average precipitation (Haferkamp et al. 1984). However, on CRP lands, there was a reduction in the density of ventenata on CRP seeded fields that prescribe burned during the fall the year before and when followed by an application of the herbicide sulfosulsuron (Mackey 2014). Wallace et al. (2015) suggest prescribed burning may reduce the litter layer (thatch) created by ventenata, which has been hypothesized to promote its own seedling survival. In the forested ecosystems of the Blue Mountains of Oregon, trace amounts of ventenata reportedly established after treatments of thinning and prescribed fire or thinning only and burn only (Youngblood et al. 2006). There were no differences in abundance or invasion between burned and unburned sites (Downing et al. 2019; Tortorelli et al. 2020). However, Tortorelli et al. (2020) reported that summer wildfires may intensify negative relationships between ventenata and species diversity and richness. Finally, this new invasive grass differs from other annual grasses in phenology and other life history traits such that closer study of the dynamics influencing its invasion success is warranted (James 2008; Bansal et al. 2014; Rinella et al. 2014; McKay et al. 2017), specifically the role that fire may play in facilitating its spread (Fryer 2017; Tortorelli et al. 2020).

The objective of this study was to examine the effect of historical fires on ventenata invasion in the PNB Prairie. Averett et al. (2020) documented an increase in ventenata across different plant communities in this grassland but did not consider historical fire. Given the substantial evidence that fire promotes the spread and increase of other annual grasses (e.g., cheatgrass) (D'Antonio 2000), we expected that fire would facilitate an increase in ventenata abundance. To test this hypothesis, we resampled nonpermanently marked plots established in 2008 where a portion had been burned in the past 15 yr. We then compared percent abundance (frequency and foliar cover) of ventenata on burned and unburned plots within the same yr (2008, 2015, and 2016) and the change in abundance between sampling periods (2008 to 2015) on burned and unburned plots. Since variation in annual precipitation is linked to the production of annual grasses and both vary widely year to year (Bradley and Mustard 2004), we also evaluated the change in abundance of ventenata between burned and unburned sites from 2008 to 2016 and 2015 to 2016 to ensure our results were not confounded by interannual differences in precipitation and temperature.

Methods

Study Site

This study was conducted within The Nature Conservancy's Zumwalt Prairie Preserve (ZPP) in northeastern Oregon (45°34′N, 116°58′W). The ZPP is a large (13 300-ha) remnant of the PNB, a grassland system that once stretched across 8 million ha of the Pacific Northwestern states in the United States and into the British Columbia region of Canada (Tisdale 1982). Today, an estimated 90% of the PNB has been converted to agriculture (Kimoto et al. 2012). Before their forced removal by the US government in 1877, the Nez Perce people (Nimiipuu) inhabited the Zumwalt Prairie seasonally for many thousands of years. The Nez Perce hunted game and gathered food plants on the prairie. After horses and cattle were acquired—in the early 18th century and mid–19th century, respectively—the Zumwalt Prairie became important for grazing (Reid 1985; Bartuszevige et al. 2012). The Nez Perce may have influenced the fire cycle by promoting fire for the purposes of hunting, food gathering, or conditioning forage for their livestock. Euro-American settlers acquired land on what is now the ZPP through the Homestead Acts of 1862 and 1909 and brought large herds of livestock with them, which in turn may have consumed much of the fine fuels for fire (Bartuszevige et al. 2012). A full fire history of the PNB and the ZPP has not been completed, but given the climate and fuel conditions, it is thought that low- to moderate-severity fires occurred every 10–20 yr in this area (Black et al. 1998; Bartuszevige et al. 2012). Fire on the ZPP and surrounding prairie grasslands has been more infrequent than this, and only The Nature Conservancy initiated a prescribed burning program on its preserve in 2004 (Morgan et al. 1996; Taylor 2014). Grazing continues on the ZPP at a stocking rate of ~4.7 AUMs (Endress et al. 2019).

The ZPP is dominated by native perennial bunchgrass species, including *Festuca idahoensis* Elmer, *Pseudoroegneria spicata* (Pursh) Á. Löve, *Poa secunda* J. Presl, and *Koeleria macrantha* (Ledeb.) Schult. (Kennedy et al. 2009) and includes a high diversity of native forbs. Soils on the ZPP consist of colluvium and loess over Basalt and are mostly classified as Xerolls (Schmalz et al. 2013). The climate of the Zumwalt Prairie is characterized by cold, moist winters and warm, dry summers. Winter (December–February) temperatures reported from the Zumwalt Weather Station, located near the center of the study area (elevation of 1 335 m), averaged −2.7°C over the 2006–2015 period and average summer (July–August) temperatures were 15.0°C (Taylor 2016). Total annual precipitation over these 9 yr averaged 34.9 cm, 14.7 cm of which fell during the main growing season (April 1–July 31). Summers are very dry with an average of only 2.7 cm of rain falling each yr. One of our sampling yr, 2015, represented the warmest yr on record and total precipitation received was 31.9 cm, ≈3 cm lower than the 2005–2008 average (Taylor 2016). Mean monthly temperatures varied but followed similar patterns over the growing season (**Fig. 1A**). However, the precipitation patterns appeared to be very different for 2016 (see Fig. 1, B), making our study time frame useful for examination of annual differences.

Study Design

The original plot selection for the 2008 survey was completed using a stratified random design to locate plots within the prairie portion of the ZPP that excluded lower-elevation canyon regions (slopes > 20% and > 1 200 m elevation; Endress et al. 2019). Placement was distributed across the ZPP by dividing the study area into quarter-quarter sections based on the US Public Land Survey System where a quarter-quarter section is 0.25 × 0.25 mi (40 acres or 16.2 ha). Within each quarter-quarter section in the prairie

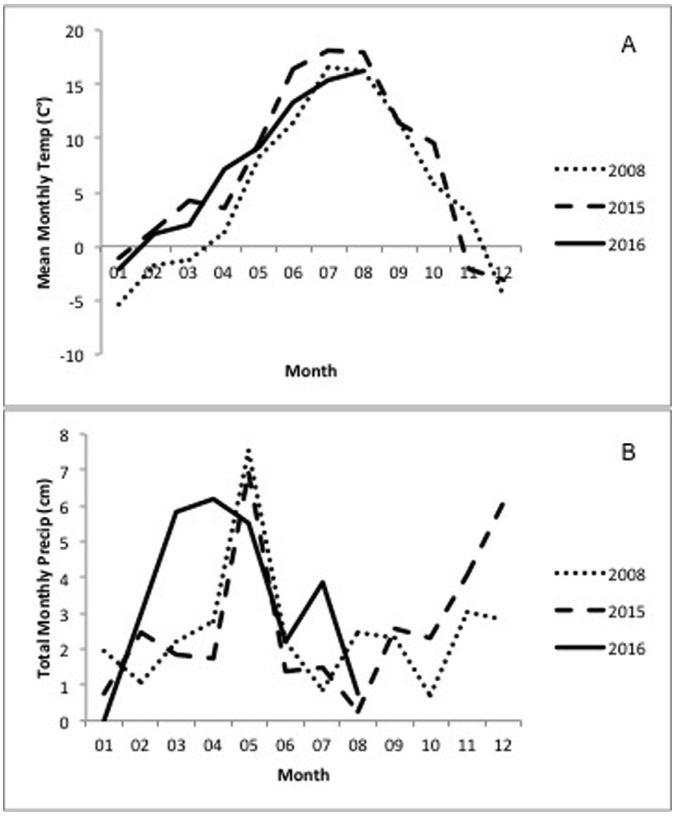

Fig. 1. A, Mean monthly temperature for the yr 2008, 2015, and 2016. **B,** Mean monthly precipitation (cm) for the yr 2008, 2015, and 2016. (The Nature Conservancy, unpublished data).

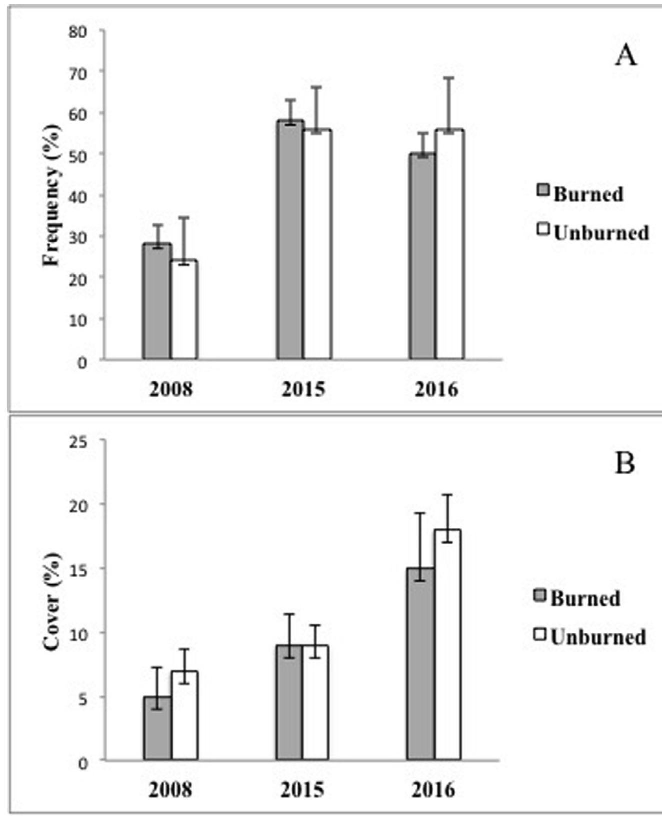

Fig. 2. Mean (± standard of error) mean frequency (**A**) and cover (**B**) of ventenata between burned and unburned plots in 2008, 2015, and 2016. Means are displayed for interpretation, but analysis was Wilcoxon rank sums. There were no significant differences.

($N = 337$), one sample point was randomly placed using ArcGIS 9.1 and frequency and foliar cover were measured along three 50-m transects arrayed at 0°, 120°, and 240° starting 5 m from the point (see Endress et al. 2019 for details). None of these plots were excluded from livestock grazing or wildlife herbivory (Endress et al. 2019).

We relocated 56 of the original 2008 survey plots in 2015 and 2016 using hand-held Global Positioning System units and followed the vegetation sampling design from the original survey (see Endress et al. 2019 for more detail). Between late June and July of both sampling years, frequency of ventenata was recorded every 5 m within a 40 × 40 cm quadrat along each transect ($N = 30$). Foliar cover of ventenata was measured using the line-point intercept method with a laser pointer every meter along each 50-m transect ($N = 150$). Of these 56 plots, several had been burned at different times starting in 2005 ($N = 3$), 2006 ($N = 1$), 2007 ($N = 5$), 2012 ($N = 1$), 2013 ($N = 1$), and 2014 ($N = 1$) for a total of 12 burned plots and 44 unburned plots. Of these 12 plots, only one was a wildfire (TNC, unpublished data) and there was not enough replication within years to test for time since fire, so historical fire was pooled across all 12 plots.

Comparisons of abundance on burned and unburned plots within the same year were completed using Wilcoxon rank sums because the data did not meet assumptions of normality for parametric testing. For comparison of change in abundance, we calculated change in percent frequency and percent cover by subtracting values in 2008 from 2015 and 2016 on burned and unburned plots. We used the same formula to calculate change in abundance between 2015 and 2016. We tested for change in mean frequency and mean foliar cover of ventenata using Student's *t*-tests between burned and unburned plots from 2008 to 2015, 2008 to 2016, and 2015 to 2016. All analysis was completed using JMP 11.0 (SAS Institute Inc., Cary, NC).

Results

There were no differences in frequency of ventenata on burned and unburned plots in the yr 2008 ($Z = -0.08$, $P = 0.9$), 2015 ($Z = 0.11$, $P = 0.9$), or 2016 ($Z = 0.27$, $P = 0.6$; Fig. 2A). Likewise, we found no differences in cover of ventenata on burned and unburned plots in the yr 2008 ($Z = -0.74$, $P = 0.5$), 2015 ($Z = 0.12$, $P = 0.9$), or 2016 ($Z = -0.82$, $P = 0.4$; see Fig. 2B). The mean change in frequency of ventenata has increased across all plots in all years regardless if they were burned and unburned (see Fig. 2A). Ventenata did not become more frequent on burned sites from 2008 to 2015 ($P = 0.9$), and this result did not change due to sampling in another yr (2008–2016) with different precipitation and temperatures ($P = 0.3$) or in just 1 yr from 2015 to 2016 ($P = 0.7$; **Fig. 3A**). Likewise, mean change in cover of ventenata increased across all plots in all years regardless if they were burned or unburned (see Fig. 2B). Ventenata cover did not increase more on burned sites from 2008 to 2015 ($P = 0.44$), and this result did not differ due to sampling in another yr (2008 to 2016) with different precipitation and temperatures ($P = 0.80$) or in just 1 yr from 2015 to 2016 ($P = 0.35$; see Fig. 3B).

Discussion

Contrary to our expectations, our findings suggest that past fires have not been a primary driver of invasion by ventenata in the ZPP from 2008 to 2016. Although ventenata abundance has increased remarkably across the PNB Prairie in both frequency and

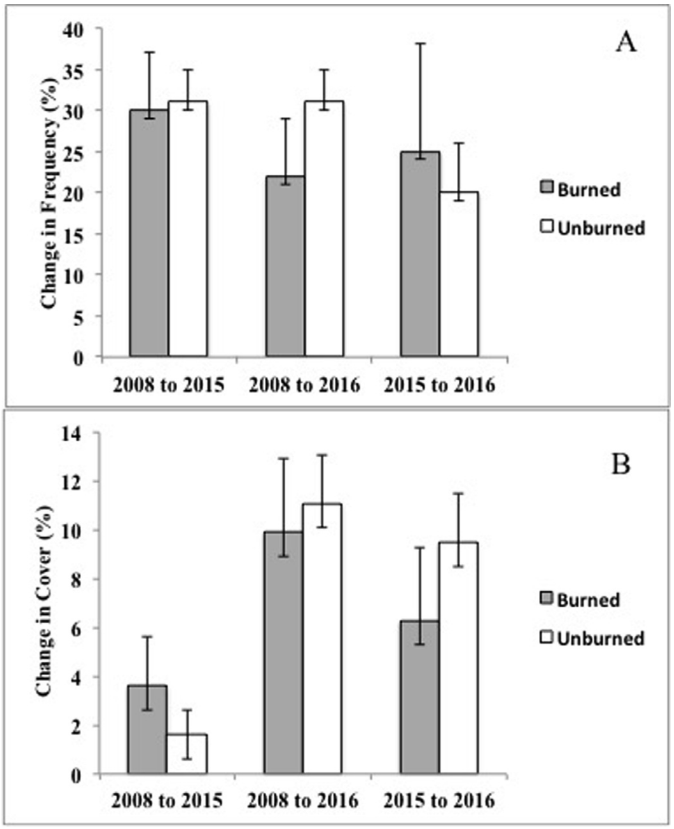

Fig. 3. Mean (± standard of error) change in frequency (**A**) and cover (**B**) of ventenata between burned and unburned plots from 2008 to 2015, 2008 to 2016, and 2015 to 2016 and 2015 to 2016. There were no significant differences.

cover (Averett et al. 2020), our data provide no evidence that fire has been facilitating this invasion since the burned plots did not have a higher abundance within any of the years sampled. Furthermore, history of fire on the sites did not create any differences in the increase of ventenata frequency or cover. The burned and unburned plots showed no significant difference in change over time (2008–2016), regardless of fire history. Our results do not appear to be driven by precipitation. Interannual differences in change of ventenata cover between burned and unburned plots did not reflect interannual precipitation differences between 2015 and 2016 like other annual grasses (Bradley and Mustard 2004; see Fig. 1). Therefore, our primary finding is that whether the area burned or not, the frequency and cover of ventenata have increased over time.

Although little has been published regarding the conditions that aid in the spread of this relatively new invasive species, our findings align with previous studies. Our findings are consistent with results from a monitoring report on the ZPP in which Taylor and Schmalz (2012) suggest the frequency of ventenata is increasing regardless of fire across a smaller number of plots. It also supports other studies documenting the ever-increasing ventenata abundance in this region including canyon grasslands (Johnson et al. 2013; Bernards and Morris 2017) and low-elevation forested systems (Averett et al. 2016). Our findings are also consistent with suggestions, based on other annual grasses, that long-term monitoring will be critical to understanding the dynamics of annual exotic species in temperate grasslands (Ashton et al. 2016). Our findings are also consistent with recent findings that high-severity fires in the dry mixed-conifer forests in the region do not appear to increase the invasibility of ventenata (Downing et al. 2019) and the suggestions that fire disturbances may not necessarily facilitate invasion (Moles et al. 2012).

Since this is the first study examining fire and ventenata in a temperate grassland ecosystem, more work should be completed to examine fire dynamics and if fire could be used as a method of management. Our study looked at historical fires that have occurred since 2005, but we did not have the replication necessary to examine the intervals since a fire. There could be a connection between the response of ventenata and the time elapsed since a fire. For example, fire may promote ventenata for a few years only. In addition, it may take more time for fire dynamics that favor ventenata to develop in the PNB Prairie since it is a fairly new invasive species. Future research should examine the effects of fire on the seed bank to see if prescribed fire has the potential to reduce ventenata abundance by reducing the seed bank. It's also possible that the lack of fire response we report here is connected to the overall abundance of ventenata, as was reported in other locations (Mackey 2014). Finally, our study does not take into account multiple fires (Porensky and Blummenthal 2016) or comparisons between wildfire and prescribed fire. Temperature, seasonal timing, and fire return interval can all either promote or inhibit invasions (Alba et al. 2015).

Our findings may not be applicable across other ecosystem types as fire and plant invasion dynamics are not only about the plant species but also the environment in which they interact (Chambers et al. 2014; Porensky and Blumenthal 2016). PNB plant communities are adapted to fire and, therefore, ventenata invasion may be favored by fire in other ecosystems adapted to longer fire return intervals like those in the Great Basin. For example, in a study examining historical fire effects in the western Great Plains steppe ecosystem, fire did not increase cheatgrass cover like it did in the Great Basin (Porensky and Blumenthal 2016). These findings were partially attributed to the native plant's evolution with and adaptation to more fire and grazing pressures, which may have allowed the perennial plants to compete with cheatgrass after a fire and reduce the chance of an invasion (Porensky and Blumenthal 2016). Hence, it could be the change in natural disturbance regime rather than fire itself that is promoting ventenata a bundance (Moles et al. 2012). Likewise, ventenata may influence fire dynamics in diverse ways across different ecosystems (Tortorelli et al. 2020). In the forested systems of the Blue Mountains in northeastern Oregon, for example, there is new concern that infilling of ventenata will provide more fine fuels that alter fire dynamics in open sites where native species ground cover is typically low (Oliver et al., 2016; Fryer 2017; Kerns et al. 2020). It is still unknown if ventenata may influence fine fuels for fire in a way that will initiate a positive feedback cycle that promotes its own invasion in the future, as other annual grasses such as cheatgrass have done (Balch et al. 2013; Kerns et al. 2020). However, a recent study suggests that summer wildfires may intensify negative impacts from *V. dubia* invasion in the Blue mountains in northeastern Oregon (Tortorelli et al. 2020).

Implications

This study represents the first to examine the spread of ventenata in association with fire on rangelands in North America. As a winter annual grass, ventenata control and management are often grouped with cheatgrass and other invasive winter annuals (Nyamai et al. 2011). Our results in the PNB support other studies where fire does not assist in the invasion of annual grasses in more fire-adapted ecosystems like the Great Plains (Brooks et al. 2004; Porensky and Blumenthal 2016). Some are beginning to question the predictive role of disturbances, arguing that multiple intrinsic and extrinsic factors interact and change over time with invasions (Dietz and Edwards 2006; Moles et al. 2012). Although fire disturbance can be an important part of invasion success, the relationship of such disturbances can be associated with study methods, habitat type, and temporal scale (Jauni et al. 2015). Better knowledge of these dynamics may help alleviate concerns over reintroducing fire as a management tool in grassland systems, like the PNB Prairie. Our findings support the idea that managers may be able to reintroduce prescribed fire to this system without high risk of conversion to ventenata where abundance is low and the native system is still intact (Taylor and Schmalz 2012; Mackey 2014). Finally, our study further documents the startling increase, in under a decade, in the overall frequency and cover of ventenata in this region and demonstrates the need to monitor and learn more about this new invasive annual grass.

Declaration of Competing Interest

None of the authors have any conflict of interest declarations to make regarding this manuscript.

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