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## About

The Scholarly Review is an open-access, quarterly journal dedicated to publishing academic research in the natural sciences, social sciences and humanities. Our independent editorial board is made of highly accomplished professors and academics in corresponding fields who review student submissions and select pieces for publication.

## Editorial Board

Dr. Roger Worthington (Chair) has a PhD in philosophy from the State University of New York (Buffalo) and an MA in medical ethics from Keele University (UK). Specializing in medical education and global health, he works as an independent researcher, running workshops for doctors in the National Health Service and mentoring young scholars from around the world. He previously held academic positions in the UK, honorary positions at Yale University (USA) and Bond University (Australia), and advisory roles for various public bodies. He is an associate editor for BMC (Springer) *Globalization and Health* and has served on a number of editorial boards. He is currently a UN Sustainable Development Publishers Compact Fellow.

Dr. Bailey Brown completed her PhD in sociology at Columbia University. At Columbia, Dr. Brown was named Paul F. Lazarsfeld Fellow and a Ford Foundation Predoctoral Fellow. She holds a bachelor's degree in sociology with minors in urban education and Africana studies from the University of Pennsylvania. Dr. Brown was a Ronald E. McNair Scholar, a Leadership Alliance Fellow and received top departmental honors for her senior thesis at Penn. For the 2020-2021 academic year Dr. Brown joined the Department of Sociology at Princeton University as a Presidential Postdoctoral Research Fellow and she will join the Department of Sociology and Anthropology at Spelman College as an Assistant Professor of Sociology in the fall of 2021. Dr. Brown researches and teaches on urban sociology, race and ethnicity, and education.

Dr. Hima Vangapandu is a technology licensing specialist at UTHealth San Antonio. Dr. Vangapandu received a PhD in experimental therapeutics from MD Anderson Cancer Center. She has over 10 years of experience in cancer research. She published in journals such as *Molecular Cancer Research* and received multiple awards throughout graduate training and postdoctoral fellowships. Dr. Vangapandu now works at the intersection of science and business and plays a major role in evaluating technologies emerging from cutting edge research by assessing their commercial potential, protecting these ideas and marketing them for commercialization.

Dr. Vladimir Petrovic is a historian researching mass political violence and strategies of confrontation with its legacy. He is a Senior Researcher at the Institute for Contemporary History of Serbia and a Core Curriculum faculty member at Boston University. He also teaches at the Harvard Extension School and CEU's Invisible University for Ukraine. He studied history at College of Philosophy, Belgrade University, graduating from comparative history at Central European University, Budapest and completing postgraduate specialization at NIOD Institute for

War, Holocaust and Genocide Studies in Amsterdam. He has published extensively on foreign policy of socialist Yugoslavia and on the history of ethnic cleansing (*Etničko čišćenje: geneza koncepta*, Arhipelag, 2019). His latest book in English, *The Emergence of Historical Forensic Expertise: Clio takes the Stand* (Routledge, 2017) examines the role of historians and social scientists as expert witnesses in some of the most dramatic legal reckonings with the violent past.

Dr. Ana-Maria Piso-Grigore is an independent scientist and researcher with over 10 years of experience in applying data science and artificial intelligence techniques to astrophysics problems. She holds two bachelor degrees in Physics and Math from M.I.T. (2010), and a Ph. D. in Astronomy and Astrophysics from Harvard University (2016). Her doctoral research has focused on theoretical studies and modeling of extrasolar planet compositions. She held two postdoctoral positions at UCLA and CSUN, where she continued my exoplanet research studying planet formation and protoplanetary disk evolution. At that time, she also became highly interested in artificial intelligence and data science, to which end she completed a 6-month internship as a data scientist at a medical device company. In 2019, she returned to her home country, Romania, where she is currently working as Project Manager and Science Data Processing Engineer at a private company in the space sector. Here, she is managing and coordinating internal activities for upgrading SST tools for optical telescopes using AI capabilities. In parallel, she is leading business development activities for science missions related advances, with the goal of developing novel tools and solutions to facilitate exoplanet data processing using AI. She has four peer-reviewed publications in the *Astrophysical Journal* as lead author with over 300 citations in total.

Ms. Avi-Yona Israel is an accomplished academic scholar and lawyer with a JD from University of Pennsylvania Law School, including the Exceptional Pro Bono Service Award (200+ hours). She has studied at the University of Oxford, the Wharton School at Penn, and she received her undergraduate degree from Colgate University. Among other roles she serves as a director of advocacy and mentor to dozens of young scholars.

Dr. Ganesh Mani is an adjunct faculty member at Carnegie Mellon University. Ganesh co-founded Advanced Investment Technology (combining investment management and machine learning), which was acquired by State Street Corporation, creating its Advanced Research Centre for helping manage multibillion-dollar institutional portfolios. Ganesh has contributed to other AI start-ups, including an entity that's now part of Nasdaq-listed iCAD, employing machine learning techniques for early cancer detection. Ganesh has an MBA in finance and a PhD in AI from the University of Wisconsin-Madison. He is a board member of The Indus Entrepreneurs (TiE.org), Pittsburgh chapter, and on the advisory board of the FDP Institute. Ganesh's work has been patented and featured in a Barron's cover story and in academic journals.

The editorial board also acknowledges the support of our valued student and graduate board members, including for this issue:

Minghui Zhang, who received her Bachelor of Science degree in Biotechnology from Sun Yat-sen University, Guangzhou, China, in 2020. She is currently pursuing a Master of Health Science degree in Epidemiology at Johns Hopkins Bloomberg School of Public Health. Her research interests include control and prevention of infectious disease, molecular and genetic mechanisms of disease transmission, and global health promotion.

## **Editorial: SR Issue 4 Oct 2022**

Welcome to the 4th issue of Scholarly Review, a multi-disciplinary journal, providing emerging scholars with a platform where they can share their work and enjoy the benefits of having an online peer-reviewed journal publication. The editors have been impressed by the high standard of submissions, and readers should expect to find stimulating essays to read on a broad range of topics. We hope that readers share our enthusiasm and enjoy the journal and that it may help to inspire future contributions from young scholars.

This issue contains seven papers. V Fan explores links between ecology and climate in the Amazon rain forest, identifying the steps that need to be taken to maintain forest health, using satellite imagery to consider the effects of El Nino. D Sriram discusses concerns over the use of Selective Serotonin Re-uptake Inhibitors in adolescents and how combination therapy can be applied with cognitive behavioral therapy to treat major depressive disorders. S Zhang writes about dissociative amnesia and Post Traumatic Stress Disorder, commenting that while the two conditions differ, they can manifest at the same time, making it difficult for clinicians to diagnose and identify causes of memory loss. W Jiang's paper focuses on the Northeast Siberian Tundra and the impact of global warming, using satellite imagery to assess the evidence that soil quality is deteriorating, with negative consequences for both plant and wildlife.

Y Xiao's paper examines team artistic gymnastic performance, using modeling techniques such as RStudio to evaluate the chances of competitive success, extending the debate about performance to include socioeconomic and demographic considerations. CN Nguyen wrote a literature review studying research papers on gambling, linking pharmacology, neurotransmission, and addictive behaviors; analyzing neurobiological bases of addictive behavior could help identify pharmacological interventions for pathological patterns of gambling. T Catalano has done a literature review on a very different topic, re-examining roles in Shakespeare's Macbeth in relation to sexual orientation and prevailing religious values about good and evil (against the backdrop of political tensions between Tudor England and Scotland).

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# Using Remote Sensing to Analyze the Effect of the 2015-2016 El Niño Drought on the Forest Health in the Lower Tapajós Region of the Amazon Rainforest

By Valerie Fan

## Author Bio

Valerie Fan is a senior at Aragon High School. At school, she pursues her passion for engineering as vice-captain of her school's underwater robotics team and as president of Aragon's Technology Student Association. In order to understand how to engineer for humanity, she explores topics such as the sinking of the Titanic and gets involved in impact-focused initiatives, such as an Amazon Expedition – which encouraged her to explore the Amazon Rainforest even further using remote sensing.

## Abstract

Preserving the Amazon rainforest is crucial for maintaining its biodiversity, protecting local communities, and slowing down global warming. Deforestation and anthropogenic climate change have been interfering with the natural ecosystem dynamics and degrading the health of the rainforests. This study seeks to understand the impacts of deforestation on forest health and the effectiveness of restoration efforts in sustaining the rainforests. Leveraging publicly available satellite data, we compared the short-term changes in forest health of intact forests, areas of forest loss, and areas of forest gain in the Lower Tapajós region following the 2015-2016 El Niño. Particularly, a combination of the Normalized Difference Vegetation Index and the Normalized Difference Water Index representing vegetation greenness and water content, respectively, were used as proxies for forest health. We found that intact forests are significantly less vulnerable to drought, with smaller disturbance magnitudes and faster recovery rates compared with most areas of forest gain and forest loss. We also observed that a few areas of forest gain and forest loss showed patterns similar to that of intact forests. Our analyses affirm the importance of preserving intact rainforests to maintain their resilience. Furthermore, our study suggests that carefully managing reforestation efforts and levels of deforestation can improve forest health.

*Keywords:* Remote Sensing, Deforestation, Reforestation, Anthropogenic climate change, Vegetation Index, Forest Health.

## 1. Introduction

The Amazon is the world's largest tropical rainforest, consisting of more than 50 percent of all remaining tropical rainforests on earth (Butler, 2020). Not only is it home to an immense amount of biodiversity, but it also provides a critical cooling effect on the planet (National Geographic, n.d.). As a major player in the world's oxygen and carbon cycle (Houghton et al., 2000), the preservation of the Amazon Rainforest is crucial to fighting anthropogenic climate change.

In the Amazon, forests play an important role in maintaining the ecosystem's water cycle. However, deforestation in the Amazon rainforest has directly contributed to worsening drought (Staal et al., 2020). Several extreme droughts have occurred on a much more frequent basis in recent decades, specifically in 2005, 2010, and 2015. In the future, the warmer climate may lead to more frequent and/or intense dry seasons and may also increase the risk of fires, impacting the ecosystem and communities in the Amazon (Staal et al., 2020).

In response to the increasing degradation of the Amazon Rainforest, measures such as early warning systems (Boulton et al., 2013), land-use surveillance (Mainville, 2017), as well as analyses of the resilience of the Amazon (Boulton et al., 2022) have been implemented in order to understand its conditions and slow down further degradation. Particularly, remote sensing through satellite monitoring has long been used to observe the Amazon rainforest (Boulton et al., 2022, Torres et al., 2021, Fragal et al., 2016). Remote sensing techniques make it feasible to quasi-synchronously monitor forest health, an indicator of forest degradation, through the variations in vegetation indices over large spatial and temporal scales. Thus, remote sensing offers efficient complementaries to field and in situ monitoring.

Vegetation greenness – a composite of canopy cover, leaf area, and chlorophyll content – and water content are often used to gauge forest health and stress (Wilson & Norman, 2018; Joiner et al., 2018). The Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), and Normalized Difference Water Index (NDWI) are proxies of vegetation greenness and water content. They have been previously used in tropical forests

to assist land-cover classifications, detect seasonal phenological changes, assess forest disturbance, and predict forest resilience (Reiche et al., 2018; Zhu et al., 2021; Liu et al., 2021). NDVI measures vegetation greenness via the multispectral reflectance properties of chlorophyll and plant leaves. Specifically, red wavelengths are absorbed by chlorophyll A and B, while near-infrared (NIR) wavelengths are scattered by plant leaves (Costa et al., 2021). EVI is similar to NDVI, but “corrects for some atmospheric conditions and canopy background noise and is more sensitive in areas with dense vegetation.” (US Geological Survey, n.d.). NDWI measures vegetation water content through a combination of Short-Wave Infrared Wavelength (SWIR1: 1.55 -1.75  $\mu\text{m}$ ) reflectances and NIR reflectances (Joint Research Centre, 2011).

Leveraging publicly available satellite data and user-friendly data mining and analysis tools, we sought to gain insight into the effects of deforestation on forest health and understand forest restoration efforts in sustaining the Amazon rainforest. Particularly, this study evaluates how extreme drought may affect vegetation greenness and water content in the Amazon rainforest and compares the way in which intact forests (IFs), areas with forest loss (FL), and areas of forest gain (FG), respond to the extreme drought conditions. We hypothesized that the health of areas of FL suffer greater impacts from extreme drought conditions than that of intact forests and areas of FG. In addition, we hypothesize that areas of FG may have the ability to recover to health resembling that of intact forests.

## 2. Material and Methodology

### 2.1 Study Region

The Lower Tapajós region in the eastern Brazil area was the Amazonian epicenter of the 2015-2016 El Niño (Berenguer et al., 2021). The extreme drought and wildfires led to the death of around 2.5 billion trees and plants in the area (Hernandez, 2021). A study has also revealed that the mortality of trees in the drought and fire-affected forests continued to be higher than normal for up to 3 years after the extreme drought (Berenguer et al., 2021).

The Lower Tapajós region consists of the Tapajós National Forest, representing the IFs, areas with FL, and FG as shown in Figure 1A. The type of forests was determined using the University of Maryland’s Global Forest Change tool (Hansen et al., 2013). A total of 12 sites, 4 of each for IF, FL, and FG, were chosen to observe the effect of the 2015-2016 El Niño on vegetation indices. Their locations and types of each site are listed in Figure 1B.

The Global Forest Change tool defines areas of forest gain as the “inverse of loss, or a non-forest to forest change entirely within the period 2000–2012” (Hansen et al., 2013). Forest cover loss is defined as “a stand-replacement disturbance, or a change from a forest to non-forest state, during the period 2000–2021” (Hansen et al., 2013). Using the forest loss year indicator, we verified that the forest loss in our chosen sites occurred near the year 2000.

## 2.2 Data Acquisition

Climate Engine is an online platform built from Google Earth Engine in 2014. It is a “no-code” user interface that allows users to easily perform cloud-based computing of climate and remote sensing data, create maps, and generate graphs to visualize various variables. Climate Engine was used to obtain climate data, NDVI, EVI, and NDWI time series.

The mean time series of precipitation (PPT), Climate Water Deficit (CWD), and Palmer Drought Severity Index (PDST) of the study regions were obtained using the TerraClimate-monthly dataset as shown in Figure 2. These environmental variables are commonly used indicators of drought.

The NDVI and NDWI time series were obtained based on the Landsat 5, 7, 8, and 9 surface reflectance satellite images available in Climate Engine. EVI time series were also extracted and used to compare with NDVI. These indices were extracted from a small polygon around each site in order to reduce noise. This study evaluated data from January 1st, 2015 to December 31st, 2017.

The equation for NDVI is as follows,

$$NDVI = \frac{NIR - R}{NIR + R} \quad (\text{Equation 1})$$

where NIR and R are the reflectances of the NIR band (750–850 nm) and the Red band (680 nm), respectively.

The equation for NDWI is as follows,

$$NDWI = \frac{NIR - SWIR}{NIR + SWIR} \quad (\text{Equation 2})$$

where NIR and SWIR are the reflectances of the NIR band (750–850 nm) and the SWIR1 band (1.55 -1.75 μm), respectively.

## 2.3 Data Processing

The NDVI, EVI, and NDWI time series obtained from Climate Engine were downloaded as comma-separated value (csv) files and replotted using Google Sheets. The pre-disturbance NDVI and NDWI values from around January to August of 2015 were averaged and used as the baseline. This baseline is sometimes referred to as the pre-disturbance mean value. In order to understand the differential effects of El Niño on various types of forests, as illustrated in Figure 2, the Disturbance Magnitude (DM) from the baseline and the Recovery Time (RT) from the lowest point to a level consistently close to baseline were estimated from the NDVI and NDWI time series data.

## 3. Results

The PDSI drought index measures the average soil moisture conditions, with positive and negative values representing wet and dry conditions, respectively. A PDSI value between -0.5 and 0.5 represents normal soil moisture conditions, while PDSI > 4 represents very wet conditions, and PDSI < -4 represents an extreme drought (Climate Citation Internet Team, 2005). As shown in Figure 3A, from 2015 to 2016, the PDSI values for the study region were < -2 for about 13 months, with four months staying below -4. The annual PPT was lower for 2015 (~1700 mm) compared to other years between 2010 to 2018 (~1900 to 2000 mm), with very low monthly PPT from August to December 2015 (4-43 mm/month) (Figure 3B). The CWD, another measure of dry season intensity, was high in the study region during the time period (Figure 3C).



Figure 4 shows the NDVI and NDWI time series for the 4 IF sites in the Tapajós National Forest. A drop in NDVI value from a pre-disturbance mean value of  $\sim 0.8$  to below 0.6 was consistently observed around Nov-Dec, 2015. The NDVI values recovered to  $>0.6$  within 1 month. For IF2 and IF4 plots, the NDVI returned to the previous mean value within 1 month. For IF1 and IF3, it fluctuated for a few months before consistently returning to the pre-disturbance mean values. The NDWI values were generally close to the pre-disturbance mean values, with only a transient minor decrease for IF2.

Figure 5 shows the NDVI and NDWI time series for 4 sites of FL. The NDVI values consistently dropped from  $\sim 0.8$  to below 0.6 around Nov-Dec, 2015. It first returned to  $>0.6$  in about a month but fluctuated before consistently returning to the previous mean values. For FL1 and FL3, the NDVI fluctuated for 4 to 6 months, while the NDVI of FL2 and FL4 fluctuated for  $\sim 18$  months. The NDWI values for FL1, FL2, and FL4 had a substantial negative deviation from the pre-disturbance mean values. Specifically, the NDWI value of FL2 and FL4 began deviating around December 2015, bottoming in June-July of 2016, and returning close to the baseline around 18 months later (although never fully recovering). The NDWI value for FL1 began deviating around September 2015, bottoming in January 2016, and returning to the baseline in September 2016. The NDWI value for FL3 generally remained close to the pre-disturbance mean values.

Figure 6 shows the NDVI and NDWI time series for 4 sites with forest gain. A drop in NDVI value from  $\sim 0.8$  to below 0.6 was generally observed around Nov-Dec, 2015. The NDVI values generally recovered to  $>0.6$  within a month. For FG1 and FG3, the NDVI returned to previous mean values in about 6 months. For FG2, the NDVI returned to previous mean values in about 3 months. For FG4, the NDVI values first returned to previous mean values after 6 months, but seemed to have more fluctuation compared to other sites of FG. The NDWI values deviated from the mean values and generally bottomed in December 2015, excluding FG2. The NDWI of FG1 and FG4 began deviating around September to December 2015, returning close to the pre-disturbance mean value in July. Compared to FG1 and FG4, FG2 and FG3 returned close to the baseline relatively faster.

## 4. Discussion

The time series drought index PDST, monthly PPT, and CWD (Figure 3) clearly illustrate that during the 2015-2016 El Niño, the chosen study region had an extended period of extreme drought.

In this study, we used NDVI as the primary index to monitor vegetation greenness and photosynthesis capacity. The NDVI time series was also compared to EVI (data shown in Appendix 1), another commonly used vegetation greenness index. In general, both indices showed similar trends. However, on a few occasions when the NDVI data exhibited a major drop, the EVI data showed a positive spike, which exceeded the normal EVI range of -1 to 1 and are likely artifacts (EOS Data Analytics, 2022). Along with major drops in NDVI values starting from around November to December 2015, we also generally observed drops in NDWI. The NDWI reductions sometimes occurred earlier and often were more pronounced compared to the corresponding NDVI values, suggesting NDWI is more sensitive to dry conditions in the study region. We hypothesized that this is likely because the loss of chlorophyll and leaves from trees is relatively a slower process compared to water loss during drought. The observation seems to corroborate with other studies (Joiner et al., 2018).

Our NDVI results show that the greenness of IF sites in the Tapajós National Forest generally returned to the pre-disturbance mean values faster compared to the areas of FG or FL. The consistent nature of the NDWI results indicates that the overall water content of the IF sites were barely affected by the drought. These observations are likely because the highly developed ecosystems in intact forests confer their stability and resilience against perturbations. For example, the diverse and fully functioning units of the ecosystems, consisting of both drought-tolerant and drought-sensitive trees, allow forests to maintain their soil moisture (Thompson et al., 2009). In times of drought, drought-tolerant trees that rely on a deeper water supply are able to hold onto their greenness for the longest period of time, protecting the moisture in the topsoil that other drought-sensitive plants rely on (Haberstroh & Werner, 2022). Areas of FG and FL, on the other hand, often have decreased biodiversity and altered ecosystems. Moreover, significant deforestation reduces overall evapotranspiration and disrupts the

natural water cycle in the rainforests, likely leading to less rainfall and ultimately increased drought within the microclimates. Even modest deforestation could affect local precipitation patterns and likely cause the remaining forest to experience a significant change in water and light availability. The effects can be manifested by vegetation index changes.

The results from this study cannot conclusively establish the general difference between areas of FG and FL. Although our results seem to suggest that the sites of FG tend to have faster recovery rates compared to most sites of FL, there is an exception. The NDVI and NDWI time series of FL3 show patterns similar to that in intact forests. The inconsistencies may be explained by the heterogeneous nature of areas with FL or FG. The sites of FL and FG could vary significantly in terms of types and ages of trees, biodiversity, level of deforestation, and other conditions. We were unable to obtain these detailed characteristics of each chosen site. As such, it is unclear which factors are affecting the results. Furthermore, since only 4 sites of each were selected in this study, our results may not represent areas of FG/FL as a whole.

During the 2015-2016 El Niño, although areas of FL and FG generally showed a higher negative deviation of vegetation indices relative to IFs, some studied areas (e.g. FL3 and FG4) seemed to be relatively resilient. The results suggest that it is feasible to improve forest health by carefully managing the level of deforestation and/or establishing healthy ecosystems via reforestation.

This study is limited to assessing the short-term changes of rainforests in the study region based on vegetation greenness and water content, which are often used to evaluate the health of the forests. NDVI and NDWI cannot accurately assess the long-term resilience of rainforests as they can not assess parameters such as vegetation structure and variation in tree stem thickness (Boulton et al., 2022). Additionally, NDVI has been shown to saturate in dense vegetation cover (Huete et al., 1997). However, since clear decreases were consistently observed in our data, we believe our data was within the dynamic range and thus, this limitation should not affect our analysis. Furthermore, other studies (Boulton et al., 2022) have used the Vegetation Optical Depth (VOD) index, a microwave-derived product with a wider

dynamic range, to assess forest resilience (Moesinger et al., 2020). We did not have the capacity to compare our data with the VOD index in order to understand the long-term resilience of the selected sites. During the data mining process, we also noticed gaps between data points likely due to cloud cover, which, in a few cases, made it difficult to determine exactly when the NDVI or NDWI results returned to the pre-disturbance mean.

To our knowledge, this is the first time the combination of NDVI and NDWI has been used to assess forest health and stress in the Lower Tapajós region. This study also takes advantage of the diverse statuses of the forests in the region and conducts an in-depth assessment of the difference between IFs, areas of FG, and areas of FL. In the future, other remote sensing techniques such as Sun Induced chlorophyll fluorescence (SIF) can also be used to track canopy photosynthesis and assess forest health (Hernández-Clemente et al., 2017). In addition, a combination of field-work and satellite data could provide information on the characteristics of each site and mechanistically pinpoint specific factors affecting the health of forests.

Conclusion

This study investigated short-term forest health by monitoring the changes of NDVI and NDWI in the Lower Tapajós region, Brazil, after the 2015-2016 El Niño. After comparing the short-term resilience of NDVI and NDWI in IFs, areas of FG and FL, we observed that the IFs are significantly less vulnerable to drought based on smaller disturbance magnitudes and faster recovery rates. Although a general distinction between areas of FG and FL was unable to be made, our data suggests that carefully managing reforestation efforts and levels of deforestation can improve forest health. Ultimately, the superior conditions of IFs affirm the necessity of preserving the Amazon to maintain its resilience. Doing so would not only maintain the livelihood of the Amazon, but would also benefit the world on a much larger scale by repressing global climate change.

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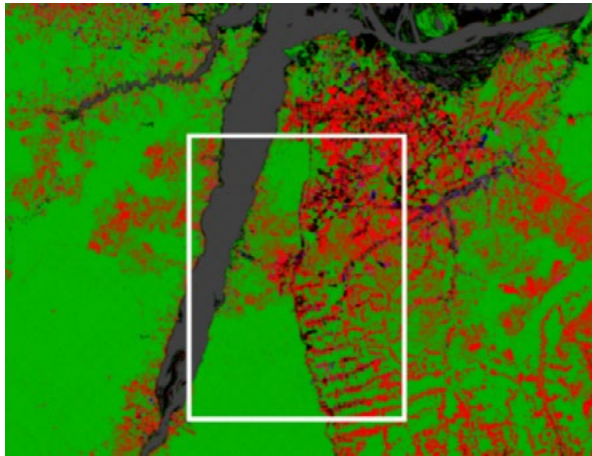
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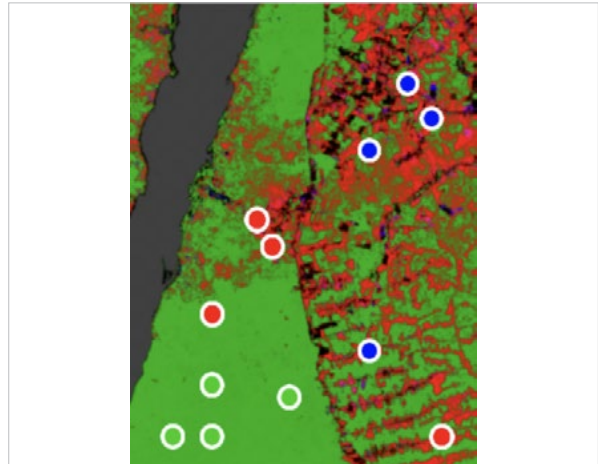
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**Figure 1. Study Region and Study Sites**

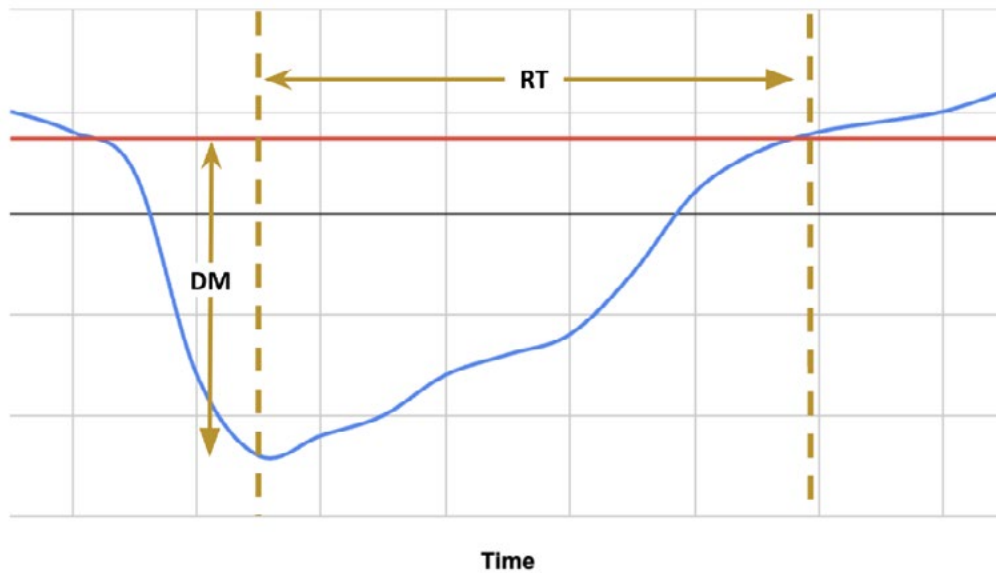
**A:** Study Region within the Lower Tapajós. Green = Intact Forest; Red = Forest Loss; Blue = Forest Gain



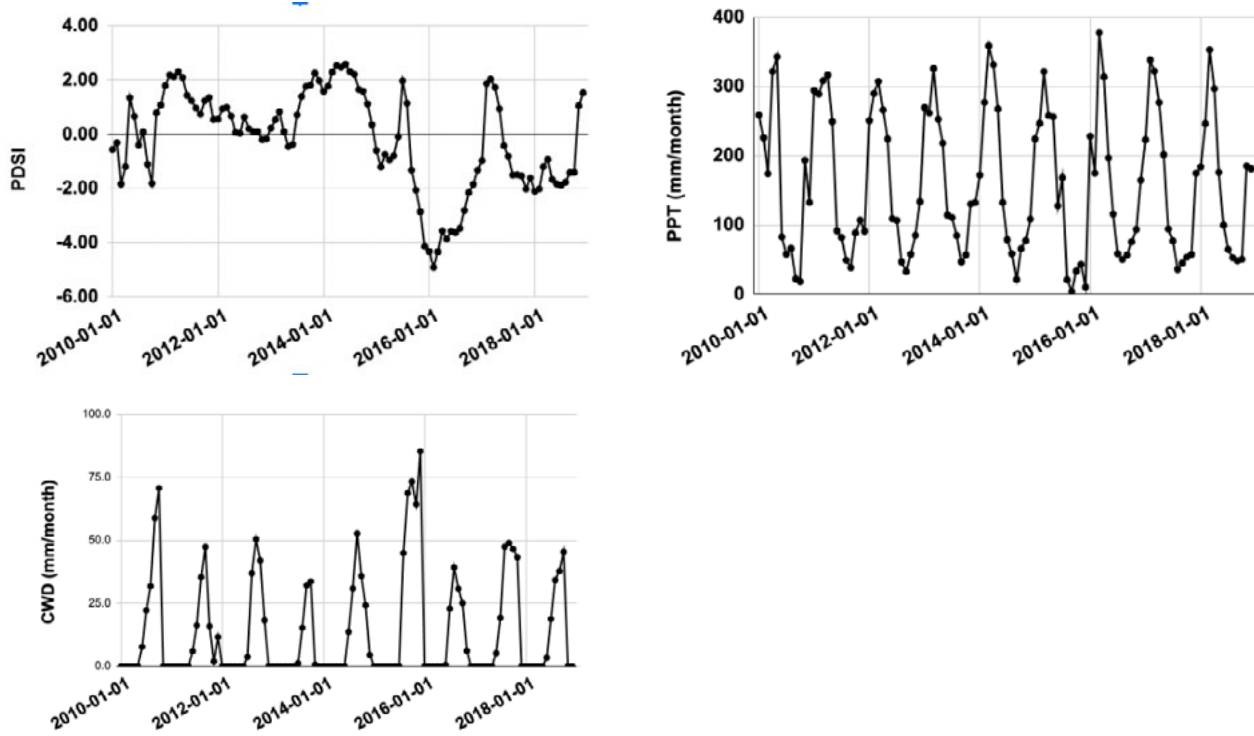
**B:** 12 chosen sites of study. Green = Intact Forest; Blue = Area of Forest Gain; Red = Area of Forest Loss.



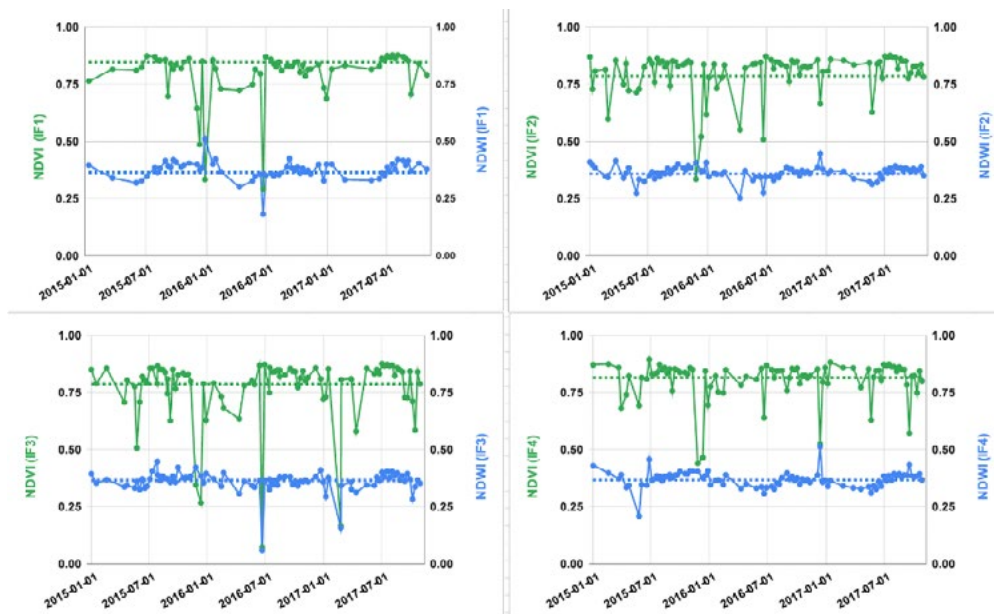
**Figure 2. Schematic Representation of Effects of Climate Disturbance on NDVI and NDWI.**  
RT = Recovery Time; DM = Disturbance Magnitude; Red Line = Pre-disturbance Mean.



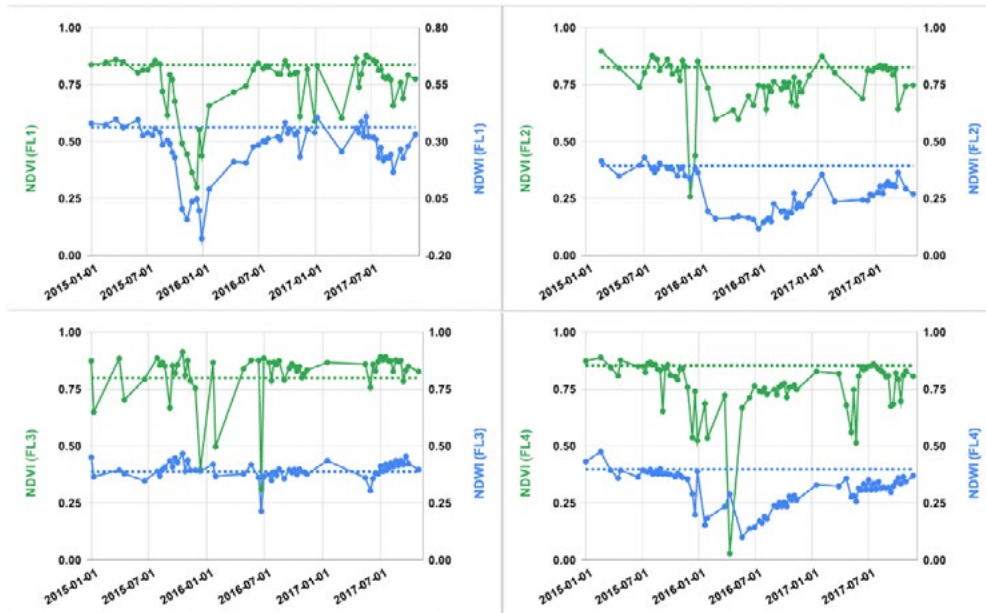
**Figure 3.** Time Series of the Three Environmental Indices (PDST, PPT, and CWD) Analyzed in the Study Region from January 2010 to December 2018



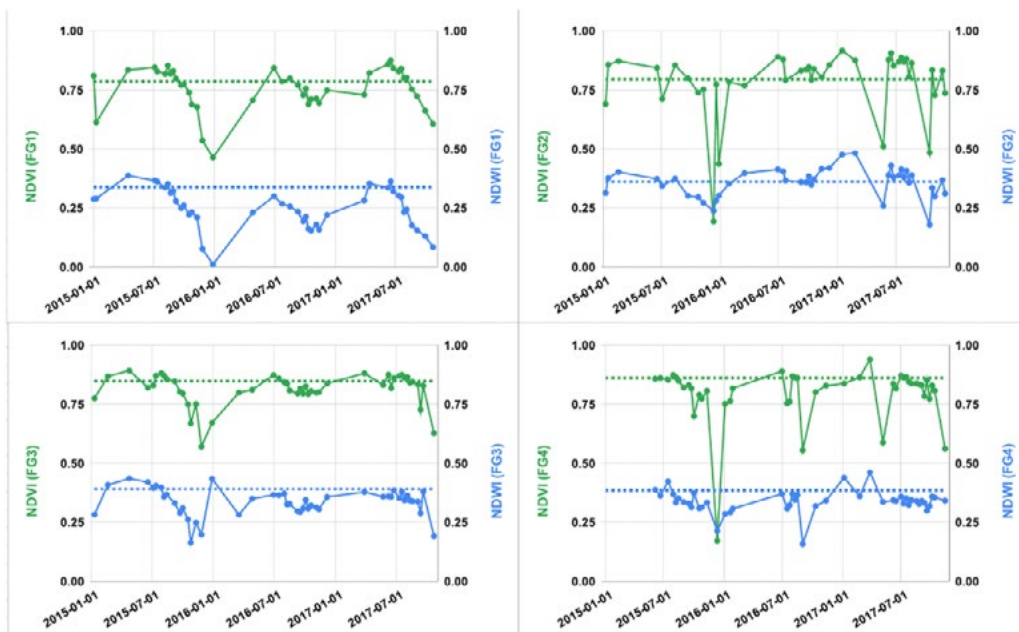
**Figure 4.** NDVI and NDWI for the Intact Forests in the National Forest Area. Green (NDVI); blue (NDWI); dash lines represent pre-disturbance mean values.



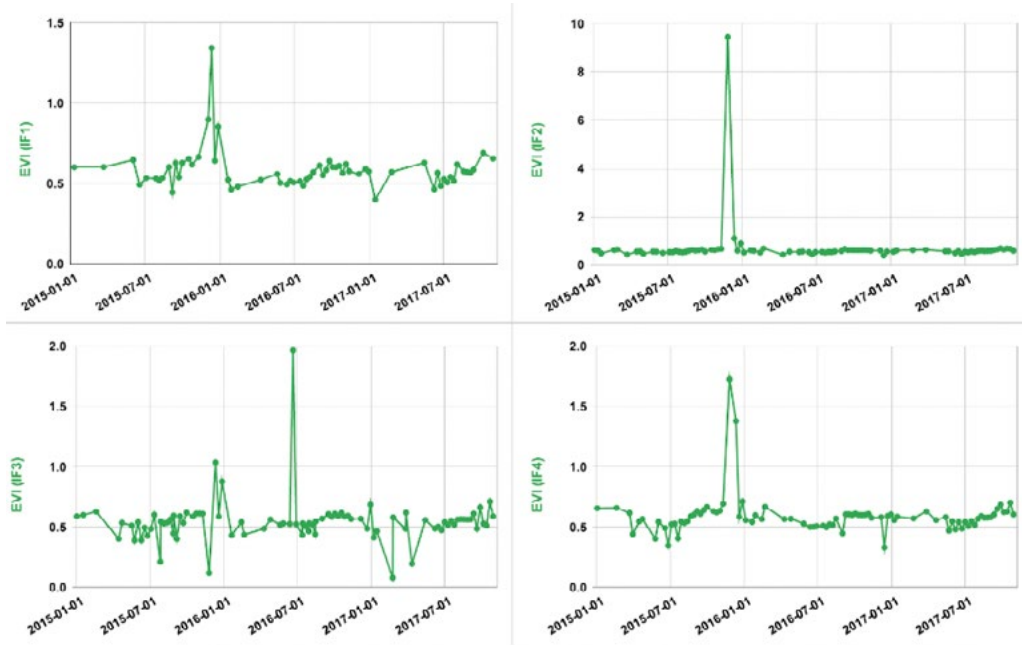
**Figure 5.** NDVI and NDWI for Areas with Forest Loss. Green (NDVI); blue (NDWI); dash lines represent pre-disturbance mean values.



**Figure 6.** NDVI and NDWI for Areas with Forest Gain. Green (NDVI); blue (NDWI); dash lines represent pre-disturbance mean values.



**Appendix 1. EVI Time Series for the Intact Forests in the National Forest Area**

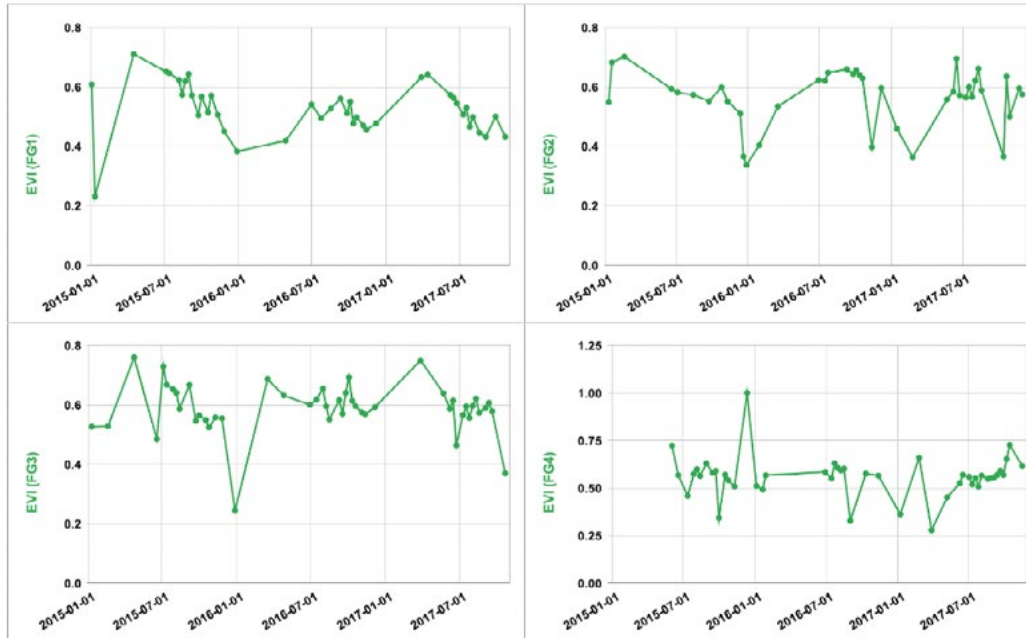


**Appendix 2. EVI Time Series for Areas with Forest Loss**





**Appendix 3. EVI Time Series for Areas with Forest Gain**



# A Detailed Review of the Safety and Efficacy of Selective Serotonin Reuptake Inhibitor Treatment for Adolescents with Major Depressive Disorder

By Diksha Sriram

## Author Bio

Diksha Sriram is currently a senior at the Massachusetts Academy of Math and Science who plans to study neuroscience in the future. She has always been passionate about mental health and would like to work specifically in optimizing personalized medicine and treatment for various mental illnesses based on factors such as age, gender, etc. Her interest was initially sparked by her middle and high school experience, where she decided that she wanted each person to be aware of their options when struggling with mental health and feel safe and comfortable reaching out for help. In her free time, she enjoys singing and songwriting as well as public speaking through the National Speech and Debate Association.

## Abstract

Major depressive disorder (MDD) is a serious mental illness consisting of at least one discrete depressive episode in which patients may feel sad, irritable, or empty, lose interest and pleasure in activities, have poor concentration, and/or feel excessive guilt, or low self-worth. According to the National Institute of Mental Health (NIMH), 12.8% of the US adolescent population (12-17 years old) was diagnosed with at least one depressive episode in 2016, with suicide being the 2nd leading cause of death for adolescents. Currently, it is advised to prescribe Selective Serotonin Reuptake Inhibitor (SSRI) medication to moderate to severe cases of adolescent depression after psychological methods have been applied. However, people concern about the safety and efficacy of SSRIs, leading to a drop in antidepressant prescriptions and sales for adolescents. This literature review discusses the functionality of SSRI medication and assesses its benefits and adverse effects. SSRIs increase serotonin levels at synapses, hence easing depressive symptoms caused by the deficiency of serotonin. On the other hand, SSRIs can negatively affect learning, memory, and cognitive function. The review also investigates the effectiveness of the combination of SSRI treatment with other forms of treatment.

*Keywords:* Major depressive disorder, depression, Selective Serotonin Reuptake Inhibitors, SSRI, adolescent mental health, effects of SSRIs, adolescent psychiatry, cognitive behavioral therapy

## Section 1: An overview of Major Depressive Disorder

### 1.1: Symptoms, effects, and the external triggers of major depressive disorder

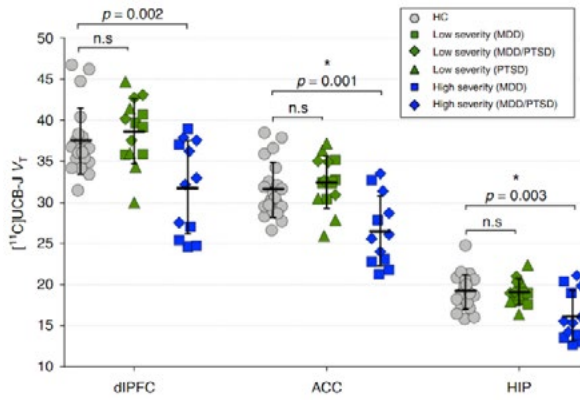
Major depressive disorder (MDD) is a pleomorphic and serious mental illness that consists of at least one discrete depressive episode that lasts two or more weeks (Otte et al., 2017). During a depressive episode, patients may feel sad, irritable, or empty, lose interest and pleasure in activities, have poor concentration, and/or feel excessive guilt, or low self-worth. They may also experience disrupted sleep, or excessive tiredness or low energy, and thoughts about dying or suicide. In fact, according to the World Health Organization, an estimated 50% of the approximate 800,000 worldwide suicides per year happen during a depressive episode (*Depression, n.d.*). Furthermore, patients with MDD are 20-fold more likely to die from suicide than a healthy patient (*Depression, n.d.*). The World Mental Health survey indicated that major depressive disorder affects 1 in every 6 adults. MDD leads to many other symptoms as well: changes in appetite and weight, cardiac arrhythmias and dyspnea, changes in body temperature, and more. There is an increased risk of diabetes mellitus, heart disease, stroke, hypertension, obesity, cancer, cognitive impairment, and Alzheimer disease associated with MDD. Thus, it is the second leading contributor to the global chronic disease burden (Otte et al., 2017). The average duration of a depressive episode is between 13-30 weeks and 70-90% of patients recover within one year with therapy and/or pharmaceutical treatment. However, residual symptoms and functional impairment often remain after MDD remission (Otte et al., 2017).

There are many external factors that contribute to MDD such as sexual, physical, or emotional abuse during childhood (Otte et al., 2017). Cognitive changes and emotional dysregulation in the brain's response to fear and stress after experiencing childhood trauma may lead to depression (*Depression | NAMI: National Alliance on Mental Illness, n.d.*). A history of childhood trauma leads to a two-fold increase of developing MDD with higher symptom severity, poorer course, and less response to treatment than patients without childhood trauma. It is important

to note that there is a positive correlation between the number and severity of traumatic life events and the severity and chronicity of MDD (Otte et al., 2017). Other contributors can include life circumstances (marital status, relationship changes, financial status), co-morbidities (sleep disturbances, medical illness, chronic pain, anxiety, attention-deficit hyperactivity disorder), or drug and alcohol misuse (*Depression | NAMI: National Alliance on Mental Illness, n.d.*).

### 1.2: Proposed mechanisms of major depressive disorder

There is no single mechanism that can explain every aspect of MDD. fMRI imaging studies have shown that synaptic density decreases as a result of depression (Holmes et al., 2019). Figure 1 displays the radioligand [11C]UCB-JVT as a readout for synaptic density (Holmes et al., 2019). A radioligand is a radioactive biochemical compound that aids in diagnosis and research on receptor systems in the body (*Radioligand - an Overview | ScienceDirect Topics, n.d.*). The graph in Figure 1 provides evidence that that the level of synaptic density for healthy volunteers and patients with low severity of depression are about the same. However, there is a major deficit in patients with high severity depression (Holmes et al., 2019). In general, it is associated with smaller hippocampal volume, as visible by smaller synaptic density shown in Figure 1 (Holmes et al., 2019), and changes in activation or connectivity of neural networks. These networks include the cognitive control network, which influences executive functions like selective attention, working memory, stimulus-response mapping, and performance monitoring, and the affective salience network, which is a collection of regions in the brain that consider which stimuli are deserving of attention (Otte et al., 2017). Depression is further associated with changes in how the pituitary gland and hypothalamus respond to hormone stimulation (*Depression | NAMI: National Alliance on Mental Illness, n.d.*).



**Figure 1:** [11C]UCB-JVT readings in the Prefrontal Cortex (PFC), Anterior Cingulate Cortex (ACC), and Hippocampus (HIP), indicating synaptic density (Holmes et al., 2019).

One of the most researched biological systems in MDD is the hypothalamic-pituitary-adrenal (HPA) axis. It serves as a neurobiological model that explains the long-lasting consequences of early trauma. Early-life stress produces an increase in the activity of neural circuits containing corticotropin-releasing hormone (CRH). CRH is then released in the paraventricular nucleus and affects the response to stress and addiction. This effect is caused through the creation and release of the adrenocorticotropic hormone from the pituitary gland (*Corticotropin-Releasing Hormone (CRH)*, 2019). In addition, CRH is the primary regulator of the HPA axis. Individuals who were sexually or physically abused in childhood demonstrated the hyperactivity of the HPA axis when they are exposed to social stressors again in adulthood (Otte et al., 2017).

The dysfunction of monoamine neurotransmitters, their metabolites, as well as the maladaptive alterations of their receptors in the Central Nervous System (CNS) are involved in the pathogenesis of depression as well. Monoamine neurotransmitters include noradrenaline, dopamine, and serotonin. Selective serotonin reuptake inhibitors (SSRIs) are targeted toward serotonin stabilization (Otte et al., 2017).

### 1.3: Major depressive disorder in adolescents

Adolescence is defined as the developmental period starting with physical and observable signs

of puberty and ending with the addition of adult responsibilities and social roles to one's life (Rice et al., 2019). According to the National Institute of Mental Health (NIMH), 12.8% of the US adolescent population (12-17 years old) was diagnosed with at least one depressive episode in 2016. In fact, suicide is the second leading cause of death for adolescents. The Center for Disease Control and Prevention records that after puberty, females are more frequently diagnosed with depression. Adolescents with depression usually display increased irritability and impulsivity; decreased grades and school performance; disturbed sleep an appetite; and suicidality (Mullen, 2018). Somatic symptoms are also more common in adolescents with depression (Rice et al., 2019).

A study conducted by Rice et al. (2019) investigated 335 adults with MDD and assessed them and their offspring with clinical interviews on three separate occasions. Depressive symptoms in adolescents were assessed using the Child and Adolescent Psychiatric Assessment (CAPA). The interviews were used to determine which symptoms may or may not be more common in adolescents. For example, loss of interest/anhedonia was more observed in adults. Table 1 displays a full list of symptoms as well as the percentage of MDD cases in adults and adolescents with those symptoms. In general, symptoms such as loss of energy (97.2% of participants), depressed mood (94.6% of participants), insomnia (at least 2 less hours of sleep every night; 86.5% of participants), and worthlessness/guilt (81.1% of participants) were observed to be the most common in adolescents. It is important to note however that irritability rather than depressed mood is more commonly used as a diagnostic factor of depression (Rice et al., 2019).

		Percentage of MDD cases with symptoms	
		Adults	Adolescents
Core symptoms	Depressed mood	98.2	94.6
	Loss of interest/anhedonia	88.1	70.3
	Irritability	46.8	29.7
Vegetative	Change in appetite	56.0	78.4
	Weight gain	3.7	40.5
	Weight loss	7.4	31.4
	Hypersomnia	22.9	22.9
	Insomnia	63.3	86.5
	Psychomotor retardation	30.3	35.1
Cognitive symptoms	Loss of energy	70.6	97.2
	Worthlessness/guilt	85.2	81.1
	Loss of concentration	74.3	38.9
	Suicidality	65.4	50.0

**Table 1:** The percentage of adults and adolescents with MDD that display certain symptoms (Rice et al., 2019)

Early intervention of MDD is vital, making it crucial to find the right treatment for adolescents in order to avoid impairment to educational, occupational, and social functioning (Mullen, 2018). Evidence for the effectiveness of antidepressants in the treatment of adolescent MDD is less than adult MDD. SSRIs, in particular, are shown to have smaller effects in treatment for depression in adolescents (Rice et al., 2019). An FDA warning on the SSRI paroxetine was issued in June 2003, warning against suicide, worsening depression, agitation, and mania (Hamrin & Scahill, 2005). Therefore, people concern about the safety and efficacy of SSRIs, leading to a drop in antidepressant prescriptions and sales for adolescents (Cousins & Goodyer, 2015). The following review will investigate the functionality as well as the efficacy of SSRI usage for adolescents with MDD.

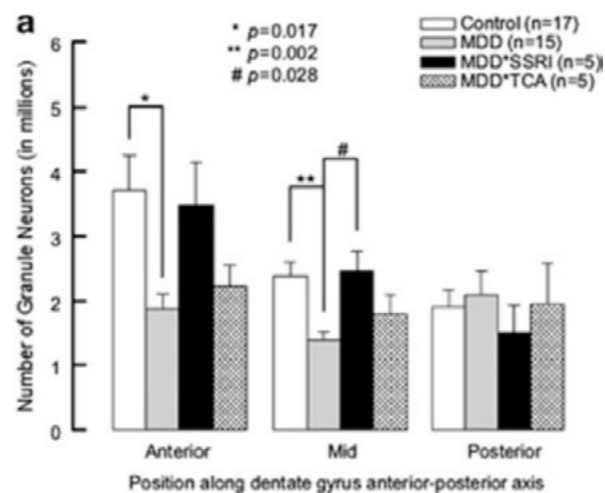
## Section 2: The use of SSRIs to treat major depressive disorder

### 2.1: Functionality in the adolescent brain

Currently, it is advised to only prescribe SSRI medication to moderate to severe cases of depression in adolescents, after psychological methods have been applied (Cousins & Goodyer, 2015). As mentioned earlier, serotonin is a neurotransmitter in the central nervous system that deals with physiological and behavioral functions including control of sleep and wakefulness, motor function, emotional responses, and more (Hamrin & Scahill, 2005). Serotonin is also involved in synaptic development (Cousins & Goodyer, 2015). Since MDD is associated with reduced serotonin levels in limbic regions of the brain, SSRIs, as the name suggests, block the reuptake of serotonin at the presynaptic transporter site, which results in the increase of serotonin at the synapse. The increase of serotonin at the synapse eventually results in a net increase of serotonin in the brain (Hamrin & Scahill, 2005).

SSRIs have also been shown to increase neurogenesis in the hippocampus, as MDD is associated with lower hippocampal volumes (Cousins & Goodyer, 2015). Boldrini et al. (2013) looked at the right hippocampus of 17 healthy volunteers, 15 patients with untreated MDD, and 10 patients

who were being treated for MDD (5 with tricyclics and 5 with SSRIs). The SSRI-treated group had an amount of granule neurons (GN) in the dentate gyrus (DG) closer to control subjects rather than untreated subjects, as observable in Figure 2. The DG is a part of the hippocampal formation. The observation was only statistically significant in mid DG ( $p < 0.028$ ). Furthermore, mid DG was bigger in treated patients compared to untreated patients and controls ( $p = 0.002$ ). The direct correlation between the number of GN and DG volume indicates that patients on SSRI treatment have larger mid hippocampal volume than unmedicated patients and controls (Boldrini et al., 2013).



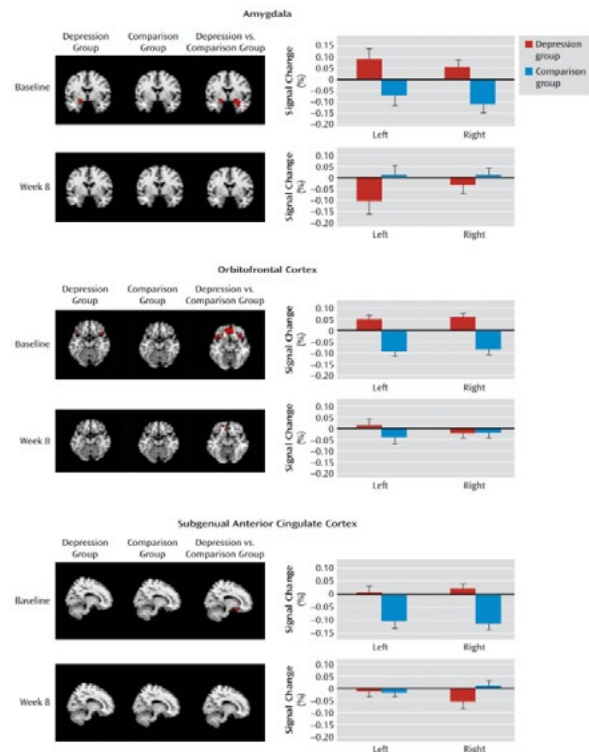
**Figure 2:** The number of granule neurons in the anterior-posterior axis of the dentate gyrus for healthy volunteers, patients with untreated MDD, and patients with MDD being treated with SSRIs or tricyclic medication.

Certain SSRIs induce the hippocampal neurogenesis by blocking the acid sphingomyelinase (ASM)-ceramide system. Ceramide is involved in oxidative stress. ASM is expressed everywhere to release ceramide from sphingomyelin (Cousins & Goodyer, 2015). A study conducted on mice by Gulbins et al. (2013) showed that when ASM is over-expressed, there is less hippocampal neurogenesis, while antidepressants like the SSRI fluoxetine induced hippocampal neurogenesis. The increase of ceramide independent of ASM also led to the reduction of neurogenesis and the increase of depressive symptoms, which could be corrected by antidepressants (Gulbins et al., 2013).

## 2.2: Benefits of SSRI usage to treat MDD

Tao et al. (2012) conducted a study using fMRI to determine the effects of antidepressant treatment with fluoxetine in adolescents. The study used a voxel-wise whole brain analysis to look at differences in fMRI activation to emotional faces before and after treatment, hypothesizing that there is an association between treatment and normalization of activation in the amygdala. Participants included 23 depressed adolescents and 22 healthy adolescents. Black and white fearful and neutral facial expressions were selected from the Picture of Facial Affect collection. Participants were randomly presented 10 faces at the baseline, and then again 8 weeks later. Adolescents with depression received 8 weeks of fluoxetine treatment after the initial scan. 60% of the depressed adolescents reported to have responded to the treatment after the 8th week (Tao et al., 2012).

After the initial scan, adolescents with MDD had greater activations than the healthy controls for fear>neutral contrast in the left and right frontal lobe, temporal lobe, putamen, insula, and cingulate gyrus in the right amygdala, right hippocampus, and right occipital cortex. The baseline also showed that adolescents with MDD responded almost the same to fearful or neutral faces. However, by week 8, adolescents with MDD and the control group responded almost the same as each other to neutral and fearful faces. Figure 2 displays activations at baseline and week 8 in the amygdala, orbitofrontal cortex, and subgenual cingulate cortex in adolescents with MDD and healthy control subjects. The post hoc revealed that there was more activation for depressed adolescents in the left and right amygdala at the baseline, which was then normalized by the treatment by week 8. The same phenomenon was observed with the right orbitofrontal cortex and subgenual anterior cingulate cortex. However, only the left amygdala, right orbitofrontal cortex, and right subgenual anterior cingulate cortex reached statistical significance (Tao et al., 2012).



**Figure 3:** Activations at baseline and week 8 in the amygdala, orbitofrontal cortex, and subgenual cingulate cortex in adolescents with MDD and healthy control subjects.

The study conducted by Tao et al. (2012) concluded that brain activity in adolescents with depression became normalized to levels observed in healthy control patients, which can relieve any concerns about SSRI usage in the pediatric population (Tao et al., 2012). Ambrosini et al. (1999) also studied the effect of the SSRI sertraline in a ten-week open-label trial. The outcome was measured using the Hamilton Depression Rating Scale and the Clinical Global Inventory. The study described a 55% improvement on the scale by week 6 of the experiment and a 76% improvement at the conclusion of week 10. 55% of the 47 adolescents in the study reduced their depression scores by at least 50% from the beginning to the end of the 10 weeks (Ambrosini et al., 1999).

## 2.3: Adverse effects of SSRI usage to treat MDD

Although SSRIs are efficacious to treat MDD in adolescents, there are some potential adverse effects. Sass & Wörtwein (2012) studied the effects of fluoxetine treatment on learning and

memory in adolescent rats. 24 male Wistar rats were administered fluoxetine and assessed through open field, object recognition (OR), behavioral, and spatial memory tests. The open field test consisted of two trials of 15 minutes given to each rat over the period of two consecutive days. The trial started when the experimenter released the rat facing the arena, and the total distance moved (cm) as well as the percentage of total distance moved was determined and recorded. During both sessions, fluoxetine-treated rats entered the center of the field less and moved shorter distances in the center, indicating higher levels of anxiety ( $p < 0.05$  and  $p < 0.01$ , respectively). OR tests consisted of one 15-minute exploration trial where two identical objects were placed in two square areas. Then, there was a 3-minute discrimination trial in which two new objects were placed in the same square areas, one being identical to the original two objects. The amount of time that the rats' center of gravity entered each square area during each trial was measured and recorded. Fluoxetine-treated rats explored the objects more during the discrimination period and displayed less discrimination between the new and familiar object, indicating their inability to recognize objects from memory. The spatial memory test gave rats 5 swims for 5 consecutive days through a water maze. A computer was used to mark the rats' position in the arena from the start to the end of the maze. The trial was terminated after 60s of swimming. The rats were tasked with remembering the position of the platform during the original trial. Analysis of the tests showed that rats treated with fluoxetine swam significantly shorter distances when trying to locate the position of the original platform ( $p < 0.01$ ), suggesting that rats treated with fluoxetine were less able to recall the location of the platform. The study concluded that there are subtle acute and long-term effects dealing with learning and memory (Sass & Wörtwein, 2012). Similar to the open field test, a study by Oh et al. (2009) showed that treatment with fluoxetine in two different strains of adolescent mice resulted in an anxiogenic response, which again disappeared when the medication was discontinued (Oh et al., 2009). It must be taken into account that these studies have been conducted on animal models, thus making it hard to conclude how these effects of antidepressants translate to the human brain (Tao et al., 2012).

Shehab et al. (2016) conducted a 12-week study on the neurocognitive changes from fluoxetine treatment in 24 adolescents with MDD and 25 healthy

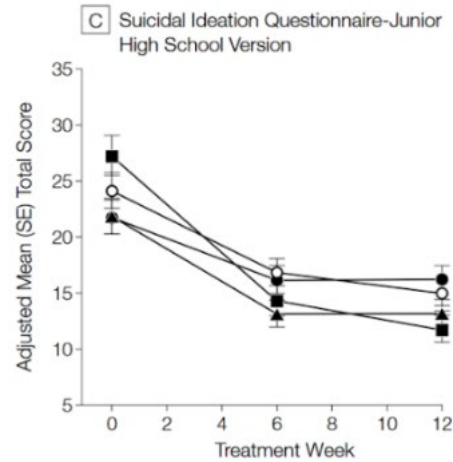
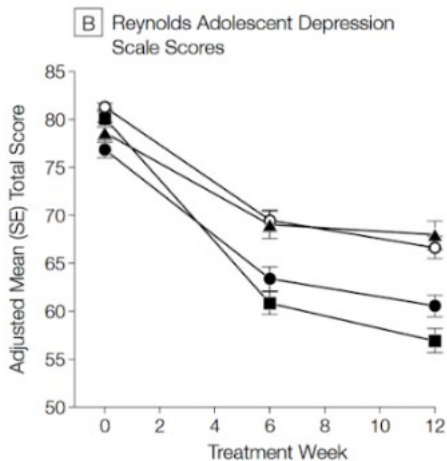
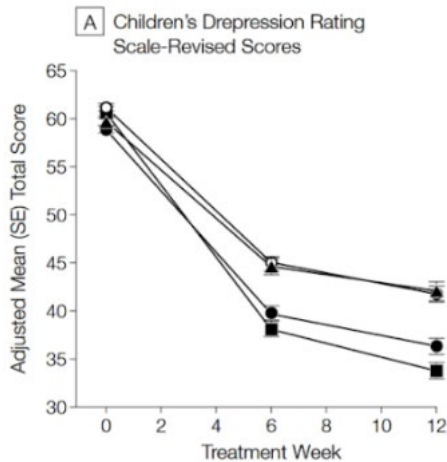
controls. Adolescents with MDD started on 20 mg of fluoxetine, with the option of increasing to 50 mg at the 5th week and 60mg at the 8th week if the score on the Clinical Global Impressions Improvement Scale was 3 or greater. Participants were first given a delayed matching to sample test where they were shown a complex visual pattern and were told to choose the one identical to it from 4 other patterns that were presented simultaneously or with a delay of 0, 4, or 12 seconds. Patients with MDD performed more poorly than healthy controls with less percent correct across assessment times. Participants were also given a rapid visual processing test where they were presented the digits 2 to 9 randomly at 100 digits/minute. They were then told to press the touchpad when they detected a pattern such as 2-4-6 or 3-5-7. Post hoc t-tests revealed a significant difference in total hits between healthy controls and patients with MDD during the 12th week ( $p = 0.008$ ), while there was no significant difference at the baseline. Finally, participants were shown two sets of stacked colored balls, one displayed higher than the other. They were instructed to use a specific number of moves to move the balls one at a time in the lower display to match the balls in the upper display. The average amount of moves for the healthy controls decreased overtime, but it remained high for patients with MDD. Shehab et al. also observed that visual memory in SSRI treated adolescents with MDD is less than healthy controls for up to 12 weeks after the end of treatment. In conclusion, healthy controls were better at finding patterns and sequences while adolescents with MDD were more impulsive and struggled with attention deficits (Shehab et al., 2016).

#### 2.4: Combination treatments with SSRIs

While SSRIs have been a mainstay treatment for adolescents with MDD, there are other options available. Cognitive behavioral therapy (CBT) is a treatment that aims to seek out and change discordant beliefs, attitudes, and behaviors that can contribute to emotional distress (Reinecke et al., 1998). It is a talking therapy that aims to help deal with overwhelming problems by breaking them down to view them in a more positive light (*Overview - Cognitive Behavioural Therapy (CBT)*, 2021). March et al. (2004) conducted a randomized multisite controlled trial of 439 adolescents in which participants were randomly assigned to fluoxetine, CBT, a combination of both, or combination of BT and

the matching placebo of fluoxetine. The combination was the most successful with a 71% response rate whereas placebo only had a 35% response rate. Furthermore, fluoxetine alone only had a 61% response rate and only CBT had a 43% response rate. Figure 3 shows the effects of the various treatments through their scale scores on the Children’s Depression Rating Scale-Revised (CDRS-R), Reynolds Adolescent Depression Scale, and the Suicidal Ideation Questionnaire-Junior High School Version. The figure displays the combination of fluoxetine and CBT as the most effective in decreasing the mean scale scores on each scale (March et al., 2004). This study provides evidence that SSRIs are most effective when used in combination with CBT.

○ Placebo    ▲ CBT Alone    ● Fluoxetine Alone    ■ Fluoxetine With CBT



**Figure 4:** Mean scale scores for participants in the depressed adolescent treatment study (March et al., 2004)

Brent et al. (2008) conducted a similar experiment dealing with the treatment of SSRI-resistant depression in adolescents (TORDIA). Participants were adolescents who were currently only on SSRI treatment for at least 8 weeks and who were not currently receiving CBT. Participants in the experiment were then randomized into 1 of 4 treatments: a different SSRI, venlafaxine, a different SSRI and CBT combo, venlafaxine and CBT combo. Participants were first assessed with the CSRS-R and Clinical Global Impressions-Severity subscale and tested again after 2 weeks of being on an SSRI regimen. Participants whose score decreased less than 30% were enrolled in the study. In this study, a greater number of participants showed an adequate clinical response to CBT (54.8%). Switching to a combination of CBT and another antidepressant was the most effective for patients who were nonresponsive to their current SSRI treatment (Brent et al., 2008). Taken together, CBT is a beneficial add-on therapy for MDD.

## Conclusion

MDD is a serious mental illness and must be treated appropriately, particularly in adolescents. SSRIs are a mainstay treatment for adolescents with MDD. While they can greatly aid in stabilizing serotonin levels in the brain and lowering the overall activation levels in critical brain regions, as shown by Tao et al. (2012), as well as reducing depressive symptoms (Ambrosini et al., 1999), they can also have adverse



effects on learning, memory, and cognitive function (Sass & Wörtwein, 2012; Shehab et al., 2016). Results of studies that have used a combination of CBT and SSRIs have proven that method to be the most effective, suggesting that CBT could be a beneficial add-on therapy with no drug-related adverse effects (Mullen, 2018). Identifying the safety and efficacy of treatment options is a step closer in informing patients of their options and finding the most effective treatment for each individual patient.

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# A Comparison Between Dissociative Amnesia and PTSD after Traumatic Experiences

By Sophia Zhang

## Author Bio

Sophia Zhang is a junior at Mountain Lakes High School in New Jersey. She hopes to continue researching in both psychology and biology in college and further education. Sophia is the captain of her high school debate team and has participated in it since freshman year. It is because of debate that sparked Sophia's interests in philosophical questions. Sophia has also been interested in analyzing connections between humans and pondering the causes of various mannerisms. Additionally, she also enjoys finding patterns in both mathematical equations and nature. Sophia has also participated in many volunteer efforts to spread her love of learning to others. In her free time, Sophia's hobbies include playing tennis, reading books, and cooking.

## Abstract

Dissociative amnesia occurs when a person is unable to recall autobiographical memory due to a traumatic event. Post traumatic stress disorder (PTSD) stems from similar causes, but it is the periodic re-experiencing of the stressor. These two conditions share similar neurological functions such as state-dependent memory. However, other processes such as retrieval inhibition and motivated forgetting are attributed more to dissociative amnesia. As a result of war trauma and childhood abuse, it can lead to any combination of dissociative amnesia and PTSD. Numerous studies look into the likelihood a trauma survivor will experience one of these conditions and which factors may contribute to it. There have been limited studies regarding this issue because there has been doubt on the validity of recovered memories from someone who has experienced dissociative amnesia. Similarly, few studies are able to research and document the impact of child abuse on psychological conditions in adulthood. This study aims to shed light on the similarity and differences in the dissociative amnesia and PTSD.

## The History and Development of Dissociative Amnesia

Johann Herbart first (1806) defined “repression” as a term to describe thoughts beneath the “threshold of consciousness”. Sigmund Freud, one of the most prominent figures in this field, however, in 1893, expanded the terms as a defense mechanism to protect painful memories. With more research, Sigmund Freud popularized the theory of repressed memories from trauma. A simple definition of this concept is that people use defense mechanisms, such as “the automatic and unconscious repression” of the memories, to forget the traumatic experience. This belief has been supported in recent studies as people who have experienced abuse and have this condition face less anxiety and depression than those who are not afflicted. However, it is important to note that Freud’s idea does not explain how repression occurs, only the base idea for it.

As more research has been done on the field, there is more contradictory evidence. Beginning from the 1990s, a term coined the “memory wars” to describe the controversy surrounding repressed memory. Especially in more modern settings, people have become more skeptical about the reliability of these memories. The debate began after the 1990s when many professionals questioned the accuracy of uncovered repressed memories; this research exposing this problematic concept began to be hotly debated, especially with its use in courtrooms. Even with confusion regarding the validity of these memories, studies have shown that an overwhelming majority of clinical psychologists agree that traumatic memories can be unconsciously blocked, and a smaller majority of them believe that these memories can be accessed. The main debate is framed between practitioners and scientists. Additionally, there have been doubts on the validity of recovered memories. In a review of 128 case studies, scientists found that there is often ambiguity in each case. Because of this, there are multiple explanations that could explain symptoms which dilutes the likelihood of the alleged memory loss.

Because of the controversy, the term “dissociative amnesia” has gained more traction, and the concept of repressed memory is rarely defended. Dissociative amnesia is defined by the American

Psychiatric Association as “the inability to recall autobiographical information that is usually of a traumatic or stressful nature”. Also, it is different from ordinary forgetting. The information should be successfully stored, but it involves a period of time when there is an inability to recall that information. Despite this, the condition is always potentially reversible. This condition is not caused by a substance or neurological condition. However, dissociative amnesia is just as ambiguous as repressed memory. For example, there is no way to determine falsifiability because to know a memory, is through a report that automatically disproves that the memory cannot be accessed. As a result, it is difficult to implement experiments involving this topic, and many use studies researching similar phenomena to compare.

## The Development of Post Traumatic Stress Disorder (PTSD)

Post traumatic stress disorder (or PTSD) is one of the most well known psychological conditions that stems from experiencing or witnessing a traumatic event. This condition has been known spanning across written human history such as the first major epic, the tale of Gilgamesh. The concept became much more prevalent after modern warfare. The use of artillery battles in World War I and the following total war in World War II led to large numbers of veterans and civilians facing PTSD. This burst of conflict and thus people affected by PTSD coincided with more work being done on this field. After decades of research into PTSD, there has been a consensus on the definition and symptoms of it. There are three possible groups of symptoms that occur: re-experiencing the event in dreams (oftentimes distressing), emotional numbness or avoiding stimuli similar to the trauma, and a permanent state of anxiety from the trauma. Additionally, these symptoms must occur for at least one month to qualify under the disorder.

There are many conditions that can affect the likelihood of having PTSD after a traumatic event. For example, studies have found that genetics are highly influential in predicting if family members will be similarly affected. Furthermore, women are more likely to have PTSD compared to men under the same circumstances; this also means that women face higher levels of severity as well. Currently, there has not been enough research to determine the reason for this.

On the other hand, the nature of the trauma will also affect the probability. There has been a consensus that if the traumatic event occurs earlier in life or involves a physical injury, there will be a greater chance of receiving PTSD as a result.

## Compare and Contrast the Two Concepts

In a broader aspect, forgetting occurs either because the memory is compromised (it is degraded so only fragments or nothing of the original memory remains) or access to the memory is compromised, which more relates to dissociative amnesia where a patient is unable to retrieve traumatic events. The specifics of dissociative amnesia often stems from three main concepts: retrieval inhibition, motivated forgetting, and state-dependent remembering.

Retrieval inhibition is “an automatic cognitive effect induced by partial recall” which prevents people from accessing memories. The theory of retrieval-induced forgetting does not mean that a memory is forgotten permanently. Access to a specific memory can be regained if specific cues are given, allowing the person to “remember” once more. A memory’s accessibility can be influenced by the retrieval cue itself and other memories with similar retrieval cues. These two aspects are considered together because one memory can overpower the other which would make the other memory more difficult to retrieve. The concept of inhibiting this process occurs to suppress some memories during retrieval, so another memory can be retrieved. This is more commonly understood as blocking irrelevant information in favor of accessing needed memories. In the case of dissociative amnesia, inhibition is attempting to suppress traumatizing memories as a defense mechanism to prevent a person from reliving that memory.

Another possibility is motivated forgetting, also known as intentionally forgetting which is defined exactly as the term: there is sufficient motivation to actively forget something learned or experienced that is generally unpleasant. Previous experiments that used the think-no-think paradigm showed individuals can intentionally forget memories using pairs of words and cues to remember or suppress specific ones. While this is possible in a laboratory setting, there is limited evidence showing its effectiveness. As a

result, an experiment was conducted to see if children actively attempt to forget math learned in school while on break because of its stress-inducing content. The findings suggested that there were similar defensive adaptations that students used to forget these lessons. This concept can also be applied in traumatic and stressful settings where someone may actively attempt to forget the experience.

State-dependent memory is something that is actively used in everyday life; this function is defined as “information that was learnt in a particular mental or physical state to be [remembered more easily] in a similar state... as when the memory was initially formed”. This idea has been examined and tested numerous times throughout history. For example, when testing the conditioned reflex in dogs, scientists found that the dogs would not only react to the stimulus when certain conditions were met. This suggests that the memory of the dogs could be triggered in one condition, and it would be more difficult or even impossible to remember in another setting. This relates to dissociative amnesia because in some extreme cases of state-dependent memory, there is a “complete amnesic barrier” where the memory cannot be retrieved at all under normal conditions. While this was found true in rats, tests involving humans have not been conducted. Furthermore, drugs were used to simulate similar effects. Therefore, it is difficult to assume which of the causes, retrieval inhibition, motivated forgetting, or state-dependent remembering, or which combination of the causes is most likely the cause of dissociative amnesia.

On the other hand, for cases involving PTSD, studies have been conducted to consider the role of state-dependent memory. For example, sexual assault victims who were intoxicated during the traumatic event causes “involuntary recollection of trauma” when drinking in another instance. Sensory cues are another possibility for resurfacing traumatic memories. State-dependent memory is heavily involved in research for both dissociative amnesia and PTSD. These traumatic memories are often formed in a condition of state-dependent learning which causes the memories to be hidden until a similar trigger is experienced. This would also lead to flashbacks of the traumatic memory when provoked. In other words, state-dependent memory can simultaneously hide memories in normal conditions and resurface them when certain triggers are met. Furthermore, memories

when involved in either dissociative amnesia or PTSD are not stored in the same pathways as normal memories. A study conducted at Northwestern found that when mice were under a drug (the stressor) memories formed in different ways which allowed the mice to react only when that stress is met. This further proves that memories lost due to dissociative amnesia or recovered from PTSD symptoms are not just regular forgetting and remembering.

While PTSD is the repeated involuntary remembering of the stress, dissociative amnesia is reduced voluntary remembering of the stress. Despite the paradoxical symptoms, the underlying cause of both of these conditions is incomplete processing of the traumatic event and the need for defense mechanisms to protect the consciousness. There has been recent evidence suggesting that these memory disorders are not two different paths but can intersect with each other. Studies have seen that people can experience a flashback of the traumatic event then immediately forget it afterwards. Furthermore, it is commonly believed that incomplete, fragmenter, or not integrated memories would cause PTSD. This can affect the person in two ways. First, shallow processing of the memories prevents the memories from being integrated into a time frame, so it overcomes the person's focus. With a group of people who have PTSD, it was found that they perceive their trauma to be central in their lives. The second way involves shallow processing when the memories are being encoded. This causes memories to be fragmented, which seems similar to a mix between PTSD and dissociative amnesia. Overall, a recent study has found that because of the similarity in the science behind these memory disorders, they are more connected than previously imagined. In generalized cases, it is difficult to separate what would cause PTSD versus what would lead to dissociative amnesia.

## PTSD Associated with War

One of the most common areas where PTSD and dissociative amnesia is present is in war veterans. It is clear that the severity of conflicts seen in war can determine the likelihood the veteran will have this condition. Studies have found veterans with a combination of all three primary factors, "prewar experience or psychological vulnerability, combat exposure, and involvement in harming civilians or

prisoners," had the greatest percentage of experiencing PTSD, something that is often correlated with dissociative amnesia, as detailed in the earlier. These conditions for prewar vulnerability often correlate with adverse childhood experiences, potentially traumatic events in childhood. On the other hand, civilians living in a war zone faced similar degrees of PTSD. It was found that in countries with active war zones, such as Afghanistan, Cambodia, Palestine, and many others, who live in war zones, its citizens experienced many symptoms of PTSD and depression.

Based on different countries, these psychological effects of conflict are seen in different proportions depending on numerous variables such as the nature, type, or severity of conflict. PTSD can occur beyond facing conflict in a war zone but emotional stress and indirect stressors as well. These include the most drastic such as war-related activities or stress through economic hardships and the safety of loved ones. In both war veterans and civilians living in a war zone, the more exposure to trauma causes the symptoms to be more clear.

## Post-war PTSD and Dissociative Amnesia Development

This cycle of trauma which forms in the presence of extreme war conditions continues after war as well. In the aftermath of war, there are often higher levels of family violence both against children and against women. Similarly, there have been reports that in Sri Lanka and Uganda alcohol consumption increased after a parent's exposure to war. This would not only affect the generation experiencing war but future generations as well because alcoholism and trauma can carry on from one generation to the next through the negative impacts an alcoholic passes on to their children. Darlene Lancer, an author and licensed family therapist explains the mentality alcoholics' children face. She lists many roles children often adopt to cope with an alcoholic parent; however, when adults, these personalities often become fixed, preventing them from healing. Furthermore, Lisa Frederikson, a daughter of an alcoholic, explains the term "Second Hand Drinking" as "the negative impact an alcoholic has on other people in the form of 'toxic stress'". It is clear that trauma can cause cyclical behaviors that continue between generations.

While children are often the focus of the impacts of trauma because their developmental stage is affected, there are also differences between gender. In a study examining responses to war-related trauma for refugees from the Democratic Republic of Congo, it was found that although there was no significant difference between the amount of trauma exposed, male participants faced more imprisonment while female participants witnessed more trauma from rape. Furthermore, a higher percentage of women had PTSD and women had higher amounts of symptoms. This indicates that the type of trauma faced affects the severity of PTSD experienced.

## Dissociative Amnesia Caused by Abuses in Childhood

Childhood abuse experiences are the cause of dissociative amnesia for many. In a participant group taken from posttraumatic stress and dissociative disorders, over 80% reported physical and sexual abuse during childhood. Symptoms of childhood abuse included both partial and complete amnesia. Furthermore, the younger the age that abuse was first witnessed or experienced, correlated with a higher degree of amnesia. However, this difference may be contributed by infantile amnesia, limited explicit memory of childhood events. Despite this discrepancy, many studies account for it by not considering subjects under the age of four. Infantile amnesia also does not explain memories that were eventually recovered in later life. Additionally, sources say that gender plays a large role in dissociative amnesia for children who were sexually assaulted since males are less likely to remember the abuse. This is less likely to be attributed to gender, but it is caused by social stigma causing males to be less willing to talk about the situation. This is supported in other cases where children are encouraged to speak about their experience more which reduces likelihood of amnesia. Moreover, the child's relationship with the perpetrator is likely a factor in dissociative amnesia. Many modern studies support Freud's "Betrayal Trauma Theory" which states that dissociative amnesia is more likely to occur if there is a close relationship between the victim and the aggressor. These studies judge the closeness of a relationship either based on familial connection or perceived emotional closeness. While these factors contribute to the likelihood of having dissociative amnesia, there are always certain cases where

dissociative amnesia is more likely to occur because of the person itself rather than any environmental conditions.

Additionally, there is reason to believe that dissociative amnesia is more prominent in children who face chronic abuse. This contrasts those who face limited abuse since they often do not experience extreme levels of amnesia and can recall the abuse in precise detail. Furthermore, in some of these extreme cases, the subjects of a study had lost memory for a portion of their lives, including negative, neutral, and positive moments. This also suggests that dissociative amnesia may not be a defense mechanism against traumatic experiences but an entire rewiring of mechanisms for processing and storing memories. This new thought process in analyzing memories after traumatic experiences also brings the plausibility of recovered memories.

Due to the "memory wars" and the following debate, it is extremely important to consider this with children. False memories can easily occur even without a traumatic instance causing amnesia. In one case, a two-year-old infant vividly remembered that someone had tried to kidnap him, but it was revealed that the story told to the child was fabricated. As a result, studies considering the memories of children (especially younger ones) may contain pseudomemories. Furthermore, this idea is supported by a study using information from parents to test college students. The study found that 6% of the college students created vivid pseudomemories. While this is true for ordinary circumstances, it was found that memories recovered from children with severe cases of dissociative amnesia are even more likely to be distorted.

## Conclusion

While dissociative amnesia and post traumatic stress disorder both stem from the same place — often caused by trauma — it has widely different symptoms. Dissociative amnesia, originally referred to as repressed memories, is the active forgetting of the trauma. By referring to this condition as active does not indicate that a person voluntarily attempts to forget, but it is rather a distinction from regular forgetting on an everyday basis. On the other hand, PTSD is the involuntary remembering of the

stressor either after certain triggers. Because these two conditions can occur simultaneously, it is difficult to categorize them to certain traumas. Both war and childhood trauma can lead to both dissociative amnesia and PTSD. Recent research has studied which conditions would lead to a higher likelihood of the manifestation of either dissociative amnesia and/or PTSD. However, there continues to be debate about the validity of recovered memories from dissociative amnesia.

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# Potential Effects of Permafrost Melt on Plant Health in the Northeast Siberian Tundra: A Review

By William Jiang

## Author Bio

William Jiang is currently a junior in high school with a great interest in environmental science. He has recently been involved with the Sunrise Movement and has experience teaching biology to younger children. He has a wide understanding of plants and nature, as well as a passion for ecological sciences and wildlife. He has participated in a wide variety of activities related to the outdoors, including fishing and gardening. William is also a competitive runner, being involved in both the track and cross-country teams at his school, and he also enjoys astronomy, video games, and cooking in his free time.

## Abstract

The Northeast Siberian Tundra is a complex ecosystem home to many species of plants that have adapted over time to survive in the Arctic's cold environment. In recent years, global warming caused by anthropogenic actions has resulted in the melting of the permafrost layer underground in locations throughout the polar regions. As permafrost begins to melt due to global warming, the effects caused by the thawing of the ground disrupts the plant cover and changes the biodiversity of the region. Many plant and animal species that inhabit the grasslands of the Northeast Siberian Tundra have been affected detrimentally by permafrost melt. Much of the permafrost in the soil has thawed, resulting in the permafrost layer receding into the ground. Without the hardened permafrost layer to keep water near the surface, water is allowed to drain through the ground with ease. Visual inspection of satellite image products from NASA's Soil Moisture Active Passive satellite from 2015-2021 revealed a clear decrease in moisture contained in the soil. The surface soil has become drier and less suitable for the grasses and other plants growing in the soil, which are adapted to thrive in moist, cooler soil. As a result, other plant species that are adapted to drier soil begin to replace the original grasses, causing a large shift in the ecosystem's balance.

*Keywords:* Northeast Siberian Tundra, Permafrost, Active Layer, Qinghai-Tibetan plateau, Degradation, Soil moisture, Soil composition, Biodiversity

## Introduction

Over the past few decades, permafrost has been melting in various Arctic regions at an increasing rate, due to rising global temperatures and climate change. Recent investigations indicate that this degradation of permafrost has caused a domino effect that results in changes in various other factors of the ecosystem. Decreases in the amount of water stored in the ground is a direct consequence of permafrost melt. In the Northeast Siberian Tundra, soil moisture observed from space gradually decreased by about 0.270 m<sup>3</sup> of water per m<sup>3</sup> of soil from 2015 to 2021 in certain Siberian tundra regions. Consistent increases in the depth of the layer of yearly ice thaw, also known as the active layer, is caused by global warming resulting in faster heating of the earth, resulting in the degradation of permafrost (Serban et al., 2021). Permafrost melt in the Arctic regions has caused the permafrost layer in the ground to recede each year, resulting in a deeper permafrost limit. The permafrost limit is defined as the upper extent of the permafrost layer, the depth at which permafrost is first found. In addition, the larger active layer allows water to drain out of the ground at higher rates than frozen soil, causing dryer soil near the surface as permafrost melts (Xue et al., 2009). Each year, the soil moisture in the Northeast Siberian Tundra gradually decreases through drainage as the active layer continues to grow due to permafrost melt.

Siberia's northern coastal tundras are diverse ecosystems which support various plant species that are very well suited to survival in the harsh environment. Several species of grasses, sedges, and dwarf bushes, including *Salix polaris*, are some of the few types of plants that are able to grow on the tundra, having small roots intended to grow within the limited active layer, many of which requiring moist soil to grow in as well. These species are able to handle cold winters and large amounts of snow. Due to their adaptation to the extreme tundra environment, many of the different species of plants require these very specific conditions in order to grow. Even small changes in the climate of the northeastern Siberian tundra can put these plant species at increased risk (Liu et al., 2017, Yang et al., 2010). The changing soil regime in these regions will potentially cause changes in the tundra ecosystem's plant biodiversity. With the active layer becoming deeper and the soil moisture

decreasing across the region, many of the native plants struggle to gain enough water. These species, especially trees, are better suited to larger active layers and are able to survive with less water in the soil, especially trees and other larger plants which normally cannot be found in the tundra. If these species are able to survive and expand into the tundra, animal species relying on certain plants for food will be affected as well, affecting the entire tundra ecosystem.

Based on our review of recent literature, we have found that melting permafrost in Northeast Siberian Tundra has resulted in decreased soil moisture, which has consequently increased the size of the active layer. In this article, we will discuss the effect of the changing surface layer on plant biodiversity, comparing the situation with many similar changes occurring on the Qinghai-Tibetan plateau, and we will discuss how these changes further influence the populations of large mammal species, namely reindeer and moose, and other animal species that inhabit the tundra. Currently, the primary large herbivorous mammal in the tundra is the reindeer. *Rangifer Tarandus Sibiricus* is the main subspecies of the reindeer population found in tundras across northern Siberia. During the summer, these reindeer generally travel in massive, well-documented herds whose population can number in the hundreds of thousands. This subspecies of reindeer relies primarily on plants common to the tundra, which include grasses and dwarf shrubs. Due to the gradual decline in these species caused by permafrost melt, reindeer populations and behavior will potentially be impacted. By contrast, moose populations could spread into the tundra due to the increased abundance of several tree species, including dwarf birches, willow, juniper, and alder (van der Kolk et al., 2016), some of which are species that moose feed on.

## Methodology

The Northeast Siberian Tundra is a region found in northeast Russia, and is divided into several ecoregions, the Northeast Siberian Coastal Tundra and the Taimyr-Central Siberian Tundra. These ecosystems are characterized by their cold temperatures, wide grasslands, lack of large plants, and also by the permafrost located underneath the soil. Permafrost found in these regions is generally continuous and widespread, found in about 90% of the soil across the Arctic. Due to various factors, including climate change, global warming, and anthropogenic activities, permafrost in these areas have been melting at a steady rate.

The temperature and moisture contained within the soil was measured in 5 different locations found within the Northeast Siberian Tundra (Fig. 1). These locations were selected due to a noticeably large increase in soil temperature and decrease in soil moisture from 2015-2021.



Fig. 1. The location within the northeastern Siberian tundra and the coordinates of the 5 locations measured for soil temperature and moisture. (Google Earth).

For the past few decades, the temperature of the soil throughout Siberia has increased significantly (Chen et al., 2020). Satellite observed temperature data gathered using Atmospheric Infrared Sounder (AIRS) equipment on NASA's Aqua satellite shows slight increases in the average soil temperature from 2015-2021 throughout the northeastern Siberian tundra (Fig. 2.) in the 5 locations where soil temperature was measured. From 2015-2021, the average temperature at point B during the summer months increased by 4.2 K, from 284.3 K (11.3°C) to 288.5 K (15.5°C). At point C, the temperature increased by 4.2 K as well, from 279.5 K (6.5°C) to 283.7 K (10.7°C)(Table 1). Other studies have shown similar increases in soil temperature in the northeastern Siberian tundra (Pollack et al., 2003).

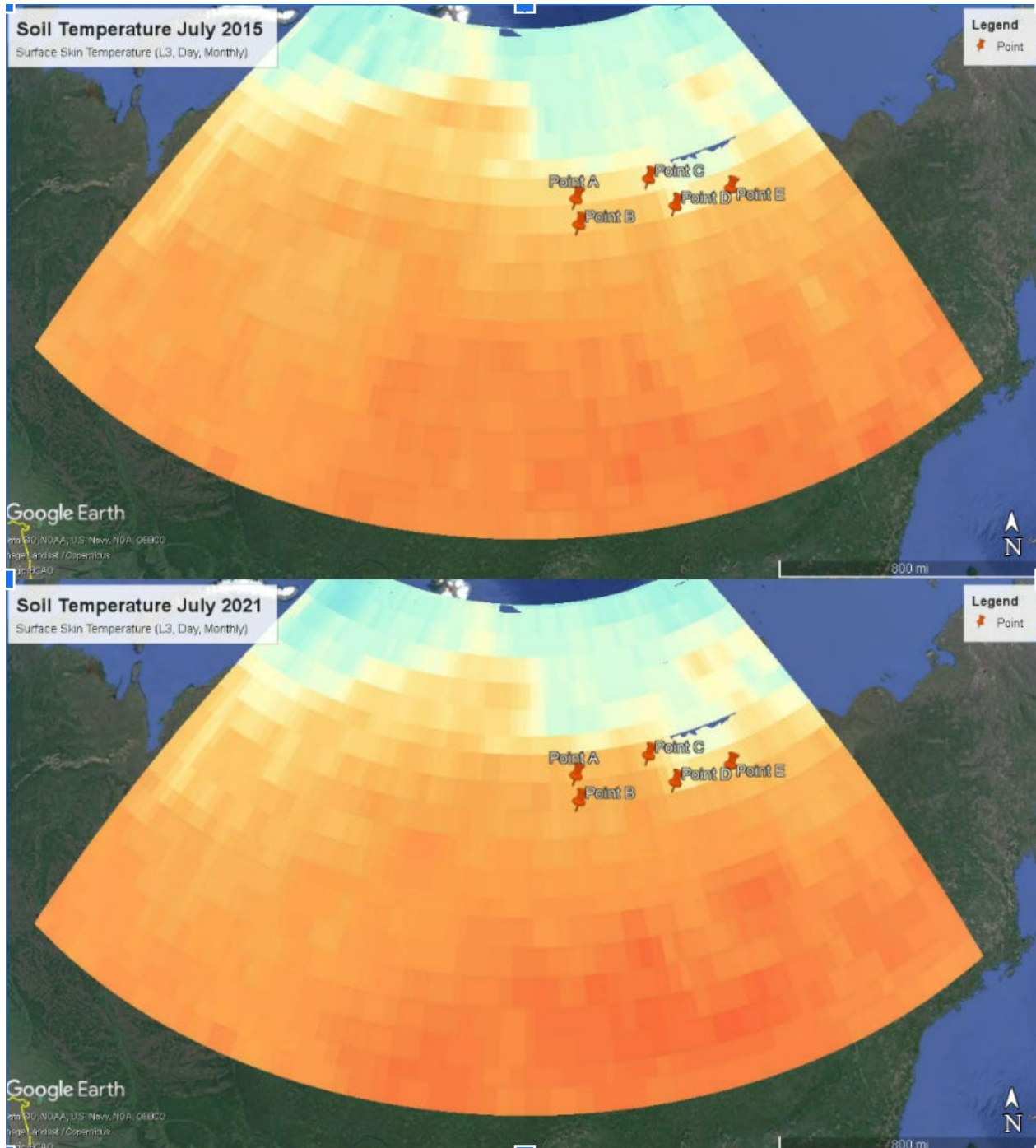


Fig. 2. Observed soil temperature (K) in the Siberian tundra and taiga from 2015-2020. Soil temperature was measured using the Surface Skin Temperature (L3, Day, Monthly) layer. Soil temperature is scaled from purple (very cold), to yellow (moderate temperatures), to red (warm temperatures). From 2015 to 2020, the soil temperature appears to increase, due to a shift in color from a yellow/orange to a deeper orange color. (NASA Worldview).

Point A		Avg. Soil Temp.	$\Delta$ Temp.	Net $\Delta$ Temp.	Avg. Soil Moisture	$\Delta$ Moisture	Net $\Delta$ Moisture
	June 2015	289.1			0.1734		
	July 2015	290.9	1.8	1.8	0.1785	0.0051	0.0051
	August 2015	286.7	-4.2	-2.4	0.1654	-0.0131	-0.008
	June 2017	290.3	3.6	1.2	0.1922	0.0268	0.0188
	July 2017	289.7	-0.6	0.6	0.1845	-0.0077	0.0111
	August 2017	287.9	-1.8	-1.2	0.1648	-0.0197	-0.0086
	June 2019	296.3	8.4	7.2	0.1666	0.0018	-0.0068
	July 2019	293.3	-3	4.2	0.14875	-0.01785	-0.02465
	August 2019	291.1	-2.2	2	0.1268	-0.02195	-0.0466
	June 2021	293.9	2.8	4.8	0.1792	0.0524	0.0058
	July 2021	293.3	-0.6	4.2	0.13725	-0.04195	-0.03615
	August 2021	289.1	-4.2	0	0.1022	-0.03505	-0.0712

Point B		Avg. Soil Temp.	$\Delta$ Temp.	Net $\Delta$ Temp.	Avg. Soil Moisture	$\Delta$ Moisture	Net $\Delta$ Moisture
	June 2015	284.3			0.3896		
	July 2015	287.3	3	3	0.3905	0.0009	0.0009
	August 2015	286.7	-0.6	2.4	0.3796	-0.0109	-0.01
	June 2017	286.7	0	2.4	0.3974	0.0178	0.0078
	July 2017	290.9	4.2	6.6	0.388	-0.0094	-0.0016
	August 2017	286.4	-4.5	2.1	0.353	-0.035	-0.0366
	June 2019	293.3	6.9	9	0.3582	0.0052	-0.0314
	July 2019	292.1	-1.2	7.8	0.32425	-0.03395	-0.06535
	August 2019	292.1	0	7.8	0.2982	-0.02605	-0.0914
	June 2021	293.3	1.2	9	0.3738	0.0756	-0.0158
	July 2021	292.1	-1.2	7.8	0.32025	-0.05355	-0.06935
	August 2021	288.5	-3.6	4.2	0.2954	-0.02485	-0.0942

Point C		Avg. Soil Temp.	$\Delta$ Temp.	Net $\Delta$ Temp.	Avg. Soil Moisture	$\Delta$ Moisture	Net $\Delta$ Moisture
	June 2015	279.5			0.1804		
	July 2015	281.9	2.4	2.4	0.15975	-0.02065	-0.02065
	August 2015	283.1	1.2	3.6	0.1598	0.00005	-0.0206
	June 2017	281.3	-1.8	1.8	0.2044	0.0446	0.024
	July 2017	284.3	3	4.8	0.18125	-0.02315	0.00085
	August 2017	280.7	-3.6	1.2	0.1674	-0.01385	-0.013
	June 2019	286.4	5.7	6.9	0.146	-0.0214	-0.0344
	July 2019	284.9	-1.5	5.4	0.12125	-0.02475	-0.05915
	August 2019	284.3	-0.6	4.8	0.1082	-0.01305	-0.0722
	June 2021	287.3	3	7.8	0.1642	0.056	-0.0162
	July 2021	289.7	2.4	10.2	0.133	-0.0312	-0.0474
	August 2021	283.7	-6	4.2	0.1152	-0.0178	-0.0652

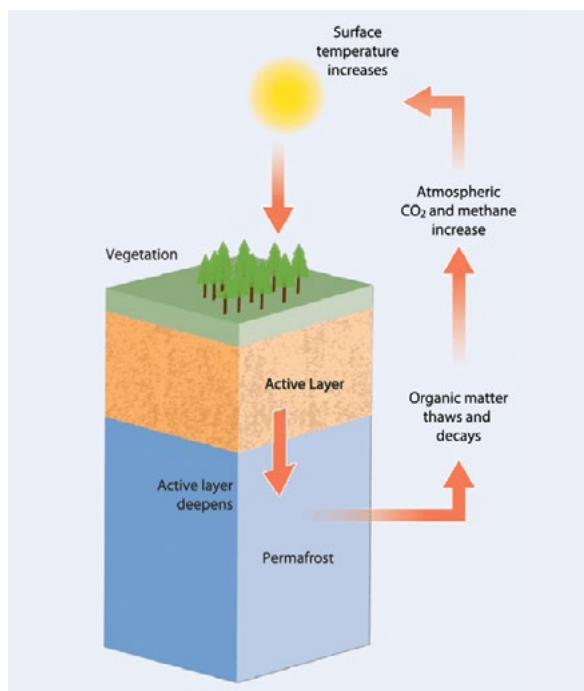
Point D		Avg. Soil Temp.	$\Delta$ Temp.	Net $\Delta$ Temp.	Avg. Soil Moisture	$\Delta$ Moisture	Net $\Delta$ Moisture
	June 2015	281.9			0.2726		
	July 2015	284.9	3	3	0.25375	-0.01885	-0.01885
	August 2015	284.3	-0.6	2.4	0.259	0.00525	-0.0136
	June 2017	281.9	-2.4	0	0.2762	0.0172	0.0036
	July 2017	286.1	4.2	4.2	0.257	-0.0192	-0.0156
	August 2017	283.7	-2.4	1.8	0.2416	-0.0154	-0.031
	June 2019	288.5	4.8	6.6	0.26	0.0184	-0.0126
	July 2019	286.1	-2.4	4.2	0.23425	-0.02575	-0.03835
	August 2019	284.9	-1.2	3	0.2174	-0.01685	-0.0552
	June 2021	289.7	4.8	7.8	0.2684	0.051	-0.0042
	July 2021	289.1	-0.6	7.2	0.2405	-0.0279	-0.0321
	August 2021	287.3	-1.8	5.4	0.226	-0.0145	-0.0466

Point E		Avg. Soil Temp.	Δ Temp.	Net Δ Temp.	Avg. Soil Moisture	Δ Moisture	Net Δ Moisture
	June 2015	278.3			0.2136		
	July 2015	283.7	5.4	5.4	0.19075	-0.02285	-0.02285
	August 2015	281.9	-1.8	3.6	0.2042	0.01345	-0.0094
	June 2017	277.1	-4.8	-1.2	0.2662	0.062	0.0526
	July 2017	281.9	4.8	3.6	0.23825	-0.02795	0.02465
	August 2017	281.9	0	3.6	0.2158	-0.02245	0.0022
	June 2019	283.1	1.2	4.8	0.1802	-0.0356	-0.0334
	July 2019	281.3	-1.8	3	0.15025	-0.02995	-0.06335
	August 2019	284.9	3.6	6.6	0.1356	-0.01465	-0.078
	June 2021	284.3	-0.6	6	0.1758	0.0402	-0.0378
	July 2021	284.9	0.6	6.6	0.18025	0.00445	-0.03335
	August 2021	283.7	-1.2	5.4	0.1792	-0.00105	-0.0344

Table 1. Observed soil temperature (K) and soil moisture (m3 water/m3) at 5 different locations in the Taimyr-Central Siberian Tundra ecoregion. Data was used from NASA Worldview, from NASA’s Aqua and Soil Moisture Active Passive (SMAP) satellites. Data was recorded every 7 days over 3 months each year during the summer, from 2015-2021. A clear increase in the soil temperature and decrease in the average soil moisture was observed from 2015-2021.

As soil temperature increases, the maximum depth of ice thaw, also known as the active layer, increases accordingly. In many cases, increasing soil temperature allows the active layer to reach the permafrost layer underneath (Fig. 3.), leading to higher rates of permafrost melt (Callaghan et al., 2021). Permafrost melt results in the permafrost layer being pushed deeper into the ground, as it is replaced by the active layer. Unlike the permafrost layer, the active layer is not permanently frozen, but regularly freezes in from late fall to early spring. During the summer months, any ice in the active layer thaws due to rising temperatures, reverting the active layer to normal soil.

Fig. 3. Diagram of the cycle of permafrost degradation. Rising surface temperatures due to global warming result in an increase in the active layer, and thus an increase in the permafrost thaw depth, causing more permafrost to melt each year. This results in a lower permafrost limit (Schaefer et al. 2014).

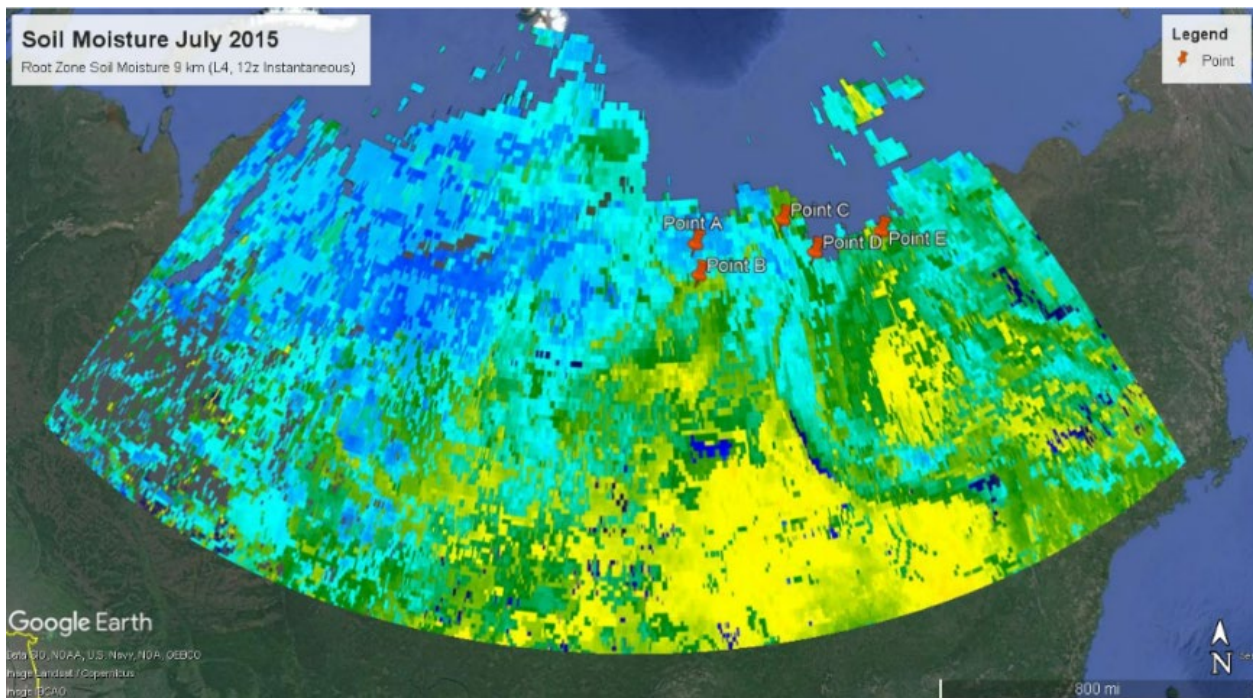




As a result of the permafrost melting and regressing, the soil humidity in the region has also decreased. When the permafrost layer is intact, moisture is retained near the surface. Permafrost hardens the soil below and prevents any water from draining, locking the water near the surface and keeping the soil wet and soft. When permafrost melts, the ice present in the soil melts away, causing the permafrost soil to lose its rigidity and the structure formed from the ice.

This leaves the soil softer and more porous due to the absence of ice in between the gaps of soil that binds the soil together. Once the soil becomes porous, water gathered near the surface is able to drain at higher rates through the soil into deeper sections of the ground, causing the soil to dry at faster rates and decreasing the average amount of moisture in the soil, as observed in permafrost located in northeastern China (Serban et al., 2021). At the 5 locations in the northeastern Siberian tundra, we used soil moisture data gathered by NASA's Soil Moisture Active Passive (SMAP) satellite (Fig. 4).

Over the course of the time period from 2015-2021, the soil moisture decreased noticeably. From 2015-2021, the average soil moisture at point B decreased from  $0.3896 \text{ m}^3 \text{ water/m}^3$  to  $0.2954 \text{ m}^3 \text{ water/m}^3$ , a decrease of about  $0.0942 \text{ m}^3 \text{ water/m}^3$ . At point C, the average soil moisture decreased from  $0.1804 \text{ m}^3 \text{ water/m}^3$  to about  $0.1152 \text{ m}^3 \text{ water/m}^3$ , a decrease of about  $0.0652 \text{ m}^3 \text{ water/m}^3$ . Among all 5 locations where data was measured, soil moisture generally decreased by  $0.03 \text{ m}^3 \text{ water/m}^3$  or greater (Table 1). Soil in the Northeast Siberian Tundra is showing to be significantly drier than 5 years ago, owing to permafrost melt.



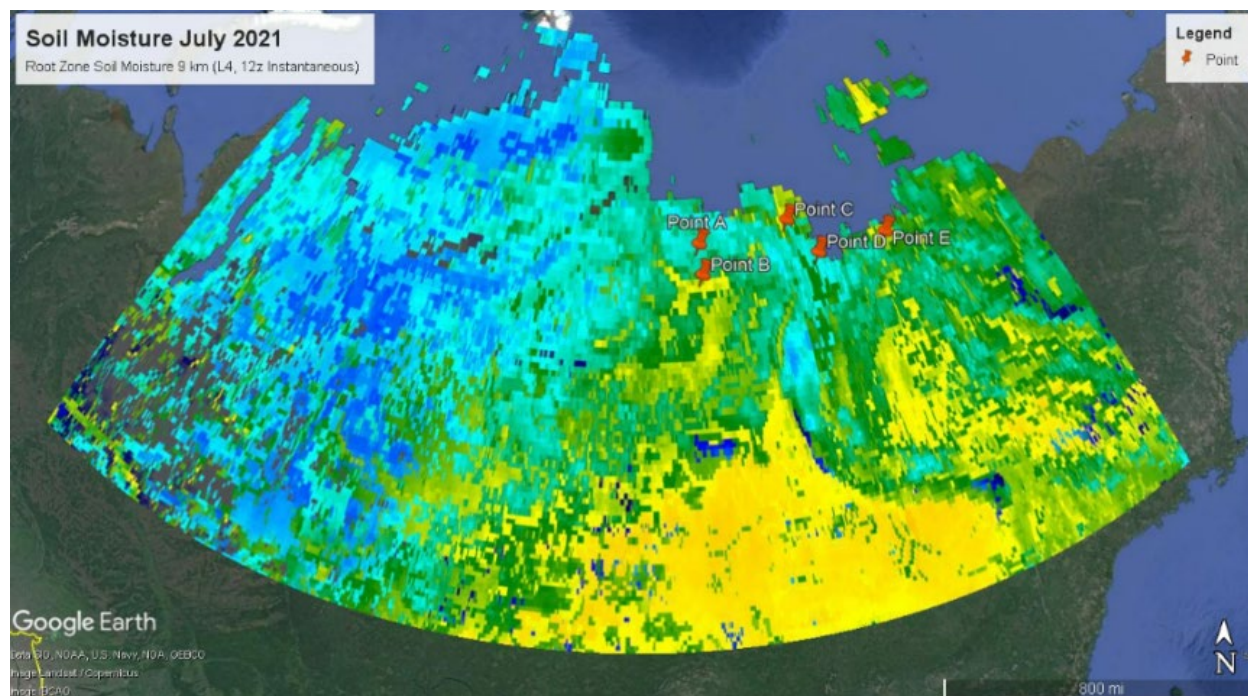


Fig. 4. Observed soil moisture (m<sup>3</sup> water/m<sup>3</sup>) in the Siberian tundra and taiga in 2015 and in 2021. Moisture was measured using the Root Zone Soil Moisture 9 km (L4, 12z Instantaneous) layer. Soil moisture is scaled from yellow (lowest moisture) to blue (highest moisture). From 2015 to 2021, more green and yellow appear on the map in the northern tundra, indicating a general decrease in soil moisture across Siberia. (NASA Worldview).

Furthermore, in areas where permafrost is beginning to degrade and melt, water availability could become the chief constraint on plant growth. In locations with stable permafrost at low risk of degradation and melting, the primary constraint on plant growth is the amount of energy and heat available. In studies conducted on the Qinghai-Tibetan plateau, areas with unstable permafrost and only seasonal ground frost, constraints on plant growth switch from energy to water (Zhou et al., 2015, Yi et al., 2011), shifting the hydrology of the region. Similarly, as permafrost melts in the Northeast Siberian Tundra, plant species would also become constrained by the decreasing water supply. With water scarcity increasing due to greater soil water drainage, constraints on available water supply will increase. Vulnerable plants in these regions will struggle to absorb sufficient water for growth.

## Discussion

Lack of soil moisture has a detrimental effect on plant species found in the Northeast Siberian Tundra. The Northeast Siberian Tundra is characterized by its long and harsh winters, short growing seasons, and by flora capable of surviving within the thin layer of soil above the permafrost. Plant species found on the tundra are well adapted to freezing conditions, able to survive under several feet of snow. However, if changes occur to either the climate or soil composition of the tundra, these plant species would be at high risk due to their narrow range

of adaptability. One change that could severely impact flora of the Northeast Siberian Tundra is decreasing soil moisture. When soil drainage increases, wetlands and bogs found in the tundra can gradually drain into the ground and disappear, and many lakes slowly lose water through drainage (Smith et al., 2005). Several sedge and shrub species, including *Eriophorum vaginatum* and *Rhododendron tomentosum*, are found within wetlands and bogs on the tundra. These species require high volumes of water and peat located in these bogs in order to grow. Without these peat bogs, these plants would not have adequate access to water and nutrients, potentially destabilizing the ecosystem.

Additionally, the potential degradation of grassland plants throughout the region could result in a domino effect (Liu et al., 2017). As observed during a study on the Qinghai-Tibetan plateau, grassland degradation from decreased soil moisture could in turn impact the soil composition, causing decreases in the amount of nitrogen, phosphorus, and potassium typically present in the soil (Liu et al., 2017). These nutrients are essential to grassland ecosystems of the Northeast Siberian Tundra. Without phosphorus, for instance, plant cells would be unable to divide, slowing plant growth and increasing the severity of plant damage. Another observed effect of grassland degradation on the Qinghai-Tibetan plateau is the increase of soil pH by about 0.66 (Liu et al., 2017), causing the soil to become more basic. Due to the similarities between the Tibetan plateau and the Northeast Siberian Tundra ecosystems, it is likely that these changes in soil composition could also occur in the Northeast Siberian Tundra. Since many plant species in the Northeast Siberian Tundra, including *Eriophorum angustifolium*, *Betula nana*, and *Vaccinium uliginosum* thrive in acidic soil, decreases in these essential nutrients and soil acidity would result in further degradation of grassland ecosystems in the Northeast Siberian Tundra.

As a result of the negative impact permafrost melt has on soil moisture and composition, many animal species which rely on impacted plant species for food will also be affected. The major herbivorous animal species in the Northeast Siberian Tundra are the caribou, willow ptarmigan, and several species of lemmings and waterfowl. These species rely on plants that are highly vulnerable to the impacts of permafrost melt, such as sedges, shrubs, and berries. Populations of these species will likely decrease due to the increased scarcity of food, and many will be forced to migrate farther north where permafrost melt is not as severe due to cooler summer temperatures. This will affect the biodiversity of impacted regions in the tundra, causing higher concentrations of animal species in the north, placing more stress on northern plant species, and also decreasing the amount of herbivorous animals in the southern tundra. These changes will consequently force predators such as arctic foxes and wolves to migrate with them. By contrast, warmer temperatures and larger active layers could cause plant species from the Siberian taiga to expand into the tundra, potentially attracting animals from the taiga along with them. Moose, deer, elk, and various bird species would begin to enter the tundra,

changing the biodiversity and essentially shifting the biome from tundra to taiga, leaving tundra species at risk of habitat loss. Further research on possible benefits of a deeper active layer on plant life would lead to more accurate predictions on the effects of global warming in Northeast Siberian Tundra. Future research efforts should also be directed towards the ability of plant species from the Siberian taiga to spread into the tundra in order to determine the future threat of habitat loss on the tundra.

## Conclusions

Permafrost melt in the Northeast Siberian Tundra has detrimental effects that cause a domino effect, potentially affecting the entire tundra ecosystem. Due to increasing soil temperatures caused by global warming and climate change, the active layer has expanded and caused permafrost to recede deeper into the earth. Without permafrost in the surface layer of the soil, water drains through the soil at higher rates, causing soil moisture to decrease and causing many wetlands and bogs to dry out. There has been clear evidence to support decreasing soil moisture and rising soil temperatures in the majority of Northeast Siberian Tundra regions, shown through both satellite data and research studies. In the Qinghai-Tibetan plateau, a region similar to the Northeast Siberian Tundra, many investigations on the quality of the soil after permafrost melt have uncovered many troubling trends. Decreasing soil moisture and disappearing wetlands could potentially constrain plant growth and affect much of the plant population. Degradation of grasslands would likely follow, and as a result could possibly cause soil content of nitrogen, phosphorus, and potassium to decrease, as well as increasing soil pH, all of which would be detrimental towards plant growth. Loss of plant life would result in migrations of animal species, and changing soil conditions would allow new plant and animal species from the southern taiga to encroach on the Northeast Siberian Tundra. This could potentially lead to the shrinking of the tundra biome, resulting in the loss of habitat for many tundra species, calling for the need to slow the effects of global warming and climate change.

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# Examining How Region and Individual Competency Affect Team Performance in Artistic Gymnastics Using RStudio

By Yuhan (Jennifer) Xiao

## Author Bio

Yuhan Xiao is currently a senior student at Saratoga High School. Through participating in math competitions, she became interested in problem-solving and applications of mathematics. She started to get involved in research in 2021, with her first project centered around the applications of Bayes Theorem in Olympic Gymnastics participation. After learning about statistical measures and RStudio computing and modeling further, she now looks forward to conducting research with a combination of mathematical theory, modeling, and data analysis. Beginning with investigating gymnastics and team sports, she aims to employ quantitative methods to offer insights on and help make decisions under social and economic contexts in the future.

## Abstract

Artistic gymnastics has been widely known for the amount of uncertainty involved in competitions, such as falls on the balance beam. However, there might be factors consistently contributing to team competition results. Previous research on gymnastics primarily focused on individual physical fitness, sports medicine, or educational aspects and were mostly qualitative investigations. This study collects NCAA women's artistic gymnastics data from the Road To National database and employs RStudio modeling to analyze how regional background and individual strength play a role in college gymnastics team competitions. Both pre-pandemic and post-pandemic seasons are taken into consideration. Contrary to common assumptions, our results suggest that average team score varies from region to region, and the average of top three scores from each team have a significant impact on its performance, while variance between top scoring individuals cannot predict team performance. These differences can be possibly attributed to local financial situations and Olympic-level gymnasts' participation, offering potential directions for further research on artistic gymnastics and team sports.

*Keywords:* Artistic Gymnastics, Team Sports, RStudio, Regional Difference, Individual Strength, ANOVA, Linear Regression, NCAA

## Introduction

Gymnastics, one of the most watched sports in America, has been known for the uncertainty of athletes' performances and scoring. However, this paper asserts that gymnastics is no different from other competitive sports and predictive models based on fixed independent variables can predict competition outcomes.

For instance, though sports has become more and more accessible to the global population, studies have shown that geographic background and socioeconomic status still make an impact on the performance of a country, narrowing down to athletes, in major competitions (Wang et al.). Despite the strong presence of millions of gymnastics participants in the United States, many gymnasts who come from less privileged schools and regions either cannot receive top-tier coaching or do not have sufficient space and equipment for practice, negatively influencing their gymnastics performance. Therefore, the first goal of this project is to analyze whether regional background plays a role in team performance, using region as a proxy for resources. The second goal of this paper is to examine the specific format of team competitions to determine how extremely competitive or consistent individuals impact a team's performance.

## Background & Research Questions

The term Artistic Gymnastics (AG) emerged as early as the 1800s and grew in Europe through the 1880s. The term was used to describe events at competitions and clubs. As the sport evolved during the last century, modern AG now includes athletes performing their own routines on one or more apparatuses, and AG competitions have a variety of individual and team events. Since different branches of AG follow different systems of scoring, in order to eliminate biases and discrepancies in scoring, this project will solely focus on NCAA Gymnastics, more specifically women's AG team performances. There are four apparatuses in women's AG: Vault, Uneven Bars, Balance Beam, Floor Exercise. In a competition, six athletes from each team perform two routines on each apparatus and the lowest score is dropped. The starting value for every gymnast is 9.5; with difficulty bonuses, the maximum potential score is 10.0 (NCAA.org).

The research questions this paper seeks to answer are:

1. How do performance of teams from different regions vary in women's artistic gymnastics competitions? Previous studies suggested wealth as an influential factor in gymnastics training, but they concentrated on relatively small samples of athletes. This study will hopefully fill a gap in the research by investigating regional gymnastics performance differences across the USA.
2. How do the average total score of the top three athletes on each team affect team performance in women's AG? With previous research on gymnastics mostly focusing on athletic skill, sports medicine, or education, it is necessary to examine the relationship between individual strength and team performance using a quantitative approach.

## Data

All data is from the Road To Nationals database, created by two NCAA and club gymnastics coaches. In the database, the six regions in the NCAA are designated as: Central (C), North Central (NC), Northeast (NE), South Central (SC), Southeast (SE), and West (W). The specific teams included in a region varied from year to year. Table 1 below displays the distribution of NCAA gymnastics teams by regions for the three athletic seasons of 2019, 2020, and 2022. Due to the pandemic, only about 80% of the teams competed in 2021, so the 2021 season was not analyzed in the project.

Table 1: Distribution of NCAA Gymnastics Team by Region

Year \ Region	C	NC	NE	SC	SE	W
2019	13	17	19	13	9	11
2020	13	17	19	12	9	11
2022	13	17	20	12	9	10

## Methods

This project consists of two sections; one investigates regional differences in gymnastics team performance, while the other studies the impact of the

top three scoring individuals on each team. In order to include a broader population and eliminate differences between the elite and college scoring systems, only NCAA gymnastics was taken into consideration. Further, team performance was evaluated using the average team score from the targeting season(s) to minimize discrepancies caused by judging bias and athlete conditions.

For the first part of the project, we studied the relationship between the categorical independent variable, regions, and dependent variable, team average score, employing a one-way analysis of variance (ANOVA). Each region's mean team score was compared to every other region's mean team score using the TukeyHSD function in RStudio. We also constructed several plots to compare the range and 95% confidence interval for each region's team average scores. The modeling process was repeated for the 2019, 2020, 2022 seasons.

For the second part of the project, data from the NCAA database was used to model the relationship between the top three scoring individuals from each team and the corresponding team's average score. Multiple linear regression was used in order to take into consideration the variance between the top three scores and number of attendance. ggplots were created to visualize the strength of the linear regression model based on each of the two independent variables. The model only focused on the 2022 season since top individuals' performance fluctuated little from year to year.

## Results

In order to study the performance of gymnastics teams across different regions, we first performed one-way ANOVA to compare the effect of regions on team score for the 2019, 2020, 2022 seasons. Respectively, 82, 81, and 81 teams participated in NCAA gymnastics in 2019, 2020, and 2022. The one-way ANOVA model in RStudio revealed that there was a statistically significant difference between mean team scores between at least two NCAA regions at a 0.01 significance level for all three seasons. Table 2 includes the specific F-value and p-value from all three years.

Table 2: One-way ANOVA Statistics

Year	F-value	p-value
2019	3.944	0.00311
2020	4.607	0.00102
2022	4.459	0.00131

We further conducted Tukey's HSD Test to investigate every single pair of regions. In 2019, Tukey's HSD Test reported significant differences in mean team scores between North Central-Central ( $p=0.0337$ ), South Central-North Central ( $p=0.0388$ ), and West-North Central ( $p=0.0460$ ) at a 0.05 significance level. In 2020, Tukey's HSD Test revealed significant differences in mean team scores between North Central-Central ( $p=0.0361$ ), South Central-North Central ( $p=0.0308$ ), and Southeast-North Central ( $p=0.0432$ ) at a 0.05 significance level. In 2022, Tukey's HSD Test revealed significant differences in mean team scores between Northeast-Central ( $p=0.0498$ ) and South Central-Northeast ( $p=0.0472$ ) at a 0.05 significance level. Table 3 below collects the p-value from all three years' Tukey's HSD Test.

Table 3: Tukey's HSD Test p-value by Year

Regions Compared	2019	2020	2022
NC-C	0.0336535	0.0361226	0.0630993
NE-C	0.2312146	0.0915545	0.0498278
SC-C	1.0000000	0.9999962	0.9999994
SE-C	0.9999998	0.9998784	1.0000000
W-C	1.0000000	0.9999995	1.0000000
NE-NC	0.9246678	0.9968817	1.0000000
SC-NC	0.0388036	0.0307666	0.0592711
SE-NC	0.0649913	0.0432435	0.1257375
W-NC	0.0459586	0.0655222	0.1050475
SC-NE	0.2555576	0.0779405	0.0471544
SE-NE	0.3143723	0.0993613	0.1086421
W-NE	0.2683729	0.1497310	0.0887639
SE-SC	0.9999971	0.9999947	0.9999998
W-SC	0.9999996	0.9999601	0.9999996
W-SE	1.0000000	0.9996174	1.0000000



In order to display the results, box plots of team average scores by region were graphed for the three seasons. For instance, in Fig 1, the x-axis is labeled as “Region”, the y-axis is labeled by “Average Score”, and each of the six regions is color coded. The bolded, center line within each box represents the region’s mean team average score in 2019. The upper and lower boundaries of the box mark the 75th and 25th percentile team score of the region. Since the boxes’ mean values and interquartile ranges differ, it is confirmed visually that team performances differ by region. Fig 2 and Fig 3 confirm similar results for the 2020 and 2022 season.

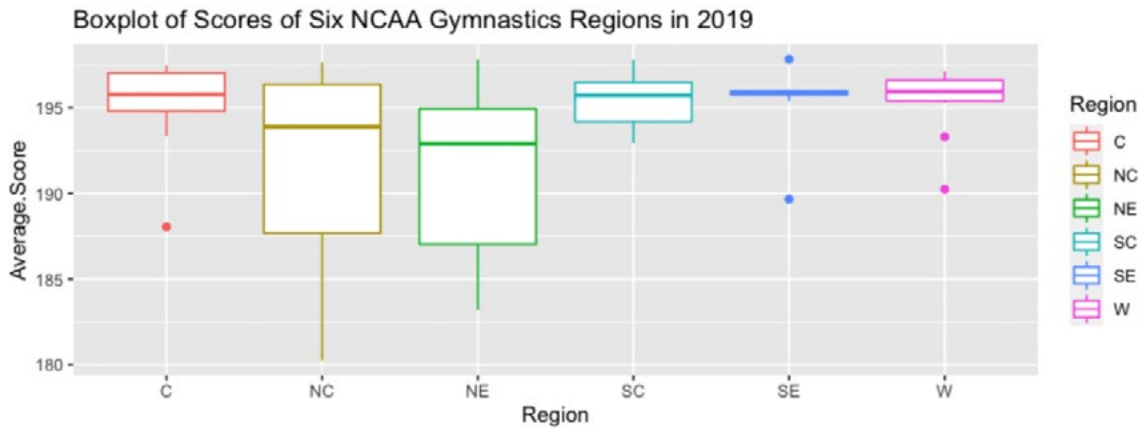


Fig 1. Boxplot of Team Average Scores by Region in 2019

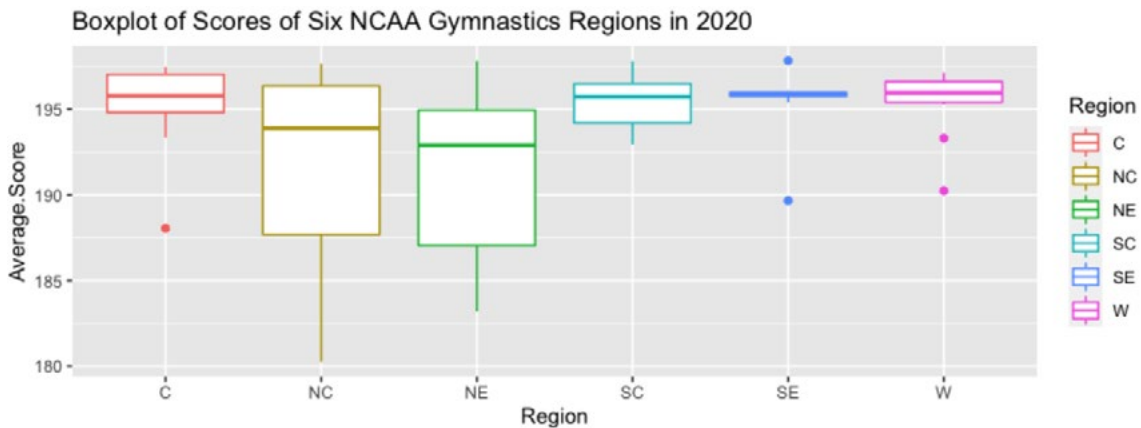


Fig 2. Box Plot of Team Average Scores by Region in 2020

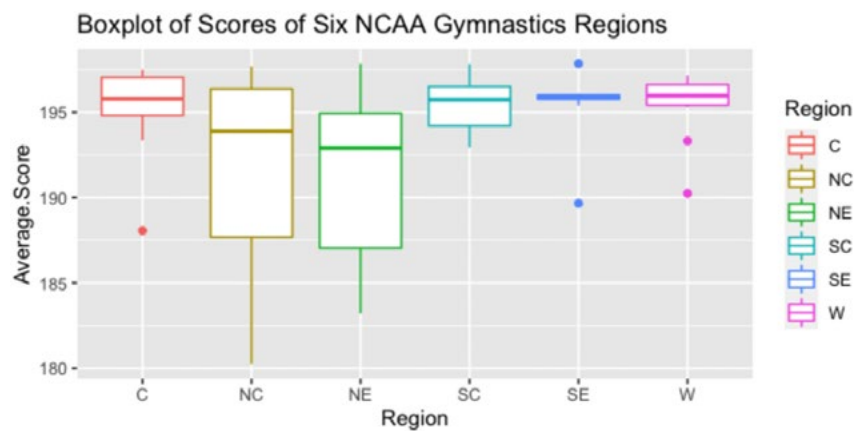


Fig 3. Box Plot of Team Average Scores by Region in 2022

Fig 4, 5, and 6 shown below are 95% family-wise confidence levels of average team scores by region constructed for the 2019, 2020, and 2022 seasons. Each pair of regions being compared is labeled on the y-axis, while x-axis is labeled with values from negative through positive. Each line segment represents the 95% confidence interval of the difference between two regions' mean team score. If the value zero is not within the range of the 95% confidence interval, there is a significant difference between the two regions compared. There are respectively three, three, and two intervals that do not cover zero in Fig 4, Fig 5, and Fig 6, which are consistent with Tukey's HSD Test results.

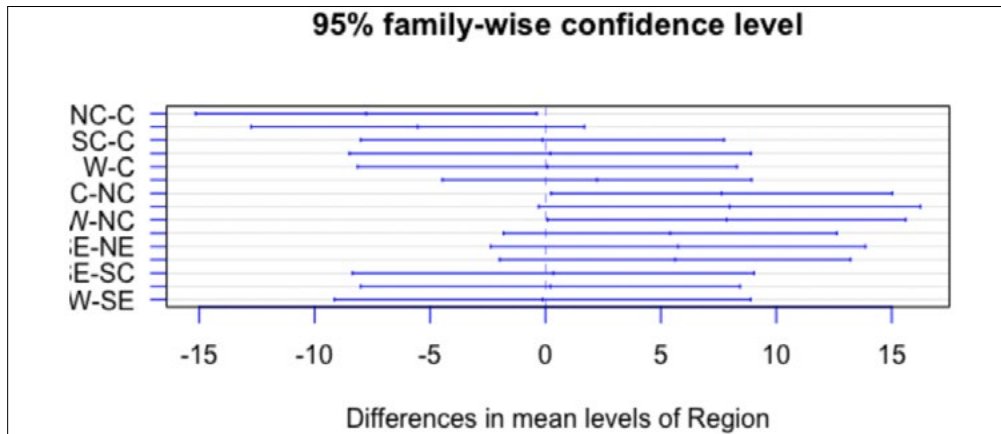


Fig 4. Plot of 95% Family-wise Confidence Level in 2019

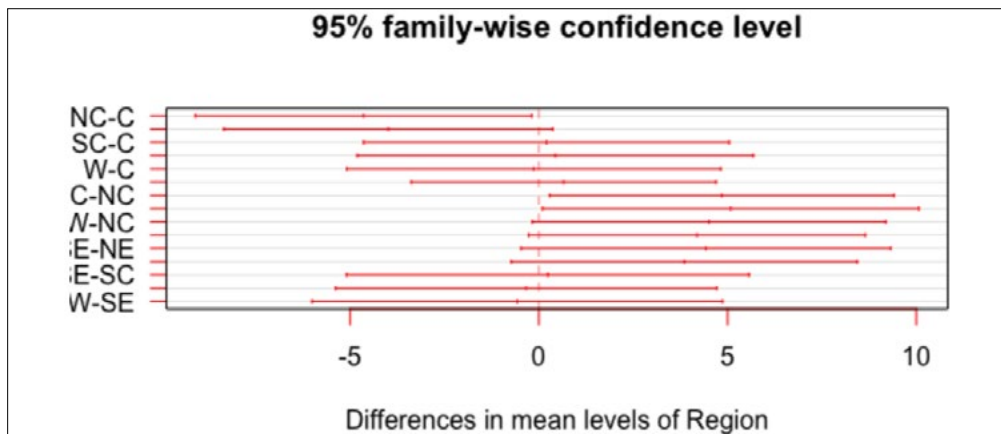


Fig 5. Plot of 95% Family-wise Confidence Level in 2020

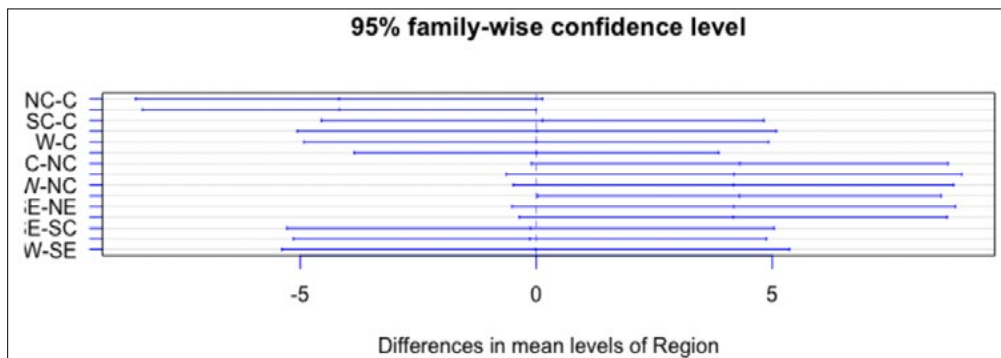


Fig 6. Plot of 95% Family-wise Confidence Level in 2022

To examine whether the top three total scores' average and their variance could predict team performance, a multiple linear regression model was created for the 2022 season. Overall, the fitted regression model was of moderate strength and statistically significant at a 0.01 significance level. The average of top three scores was significantly predictive of the team performance, but the variance did not significantly predict the team score. Table 4 below includes the slope coefficient and p-value for both variables from the multiple linear regression model.

Table 4: Multiple Linear Regression Statistics

	Slope Coefficient	Standard Error	t-statistics	p-value
Intercept	$1.789 \times 10^{-2}$	1.511	118.432	$< 2 \times 10^{-16}$
Average MVP Score	$3.878 \times 10^{-2}$	$3.972 \times 10^{-3}$	9.762	$3.62 \times 10^{-15}$
Variance	$7.966 \times 10^{-5}$	$8.126 \times 10^{-5}$	0.980	0.33

In order to visualize to what degree the actual scores fit into the multiple regression model, two ggplot were constructed for the linear model on each of the two independent variables, displayed in Fig 7 and Fig 8. Both figures' y-axis are labeled with Team Score; Fig 7's x-variable is Average MVP Score, while Fig 8's x-variable is Variance between Top 3 MVP Scores. The blue straight line in each graph is the linear regression model, or linear function, for predicting the team score based on the x-variable. The gray zone is the 95% confidence level for the linear model by default. The black dots represent actual data of participating college teams; the x-coordinate is the team's top three average score (Fig 7) or the variance between top three scores (Fig 8), while the y-coordinate is the team's actual average score during the season. In Fig 7, the black dots are moderately skewed, with about half of the points concentrated around the line, confirming the moderate strength of the model. In contrast, in Fig 8, the black dots are basically randomly scattered, suggesting the model is of weak to no strength and variance between top individual scores do not affect team scores.

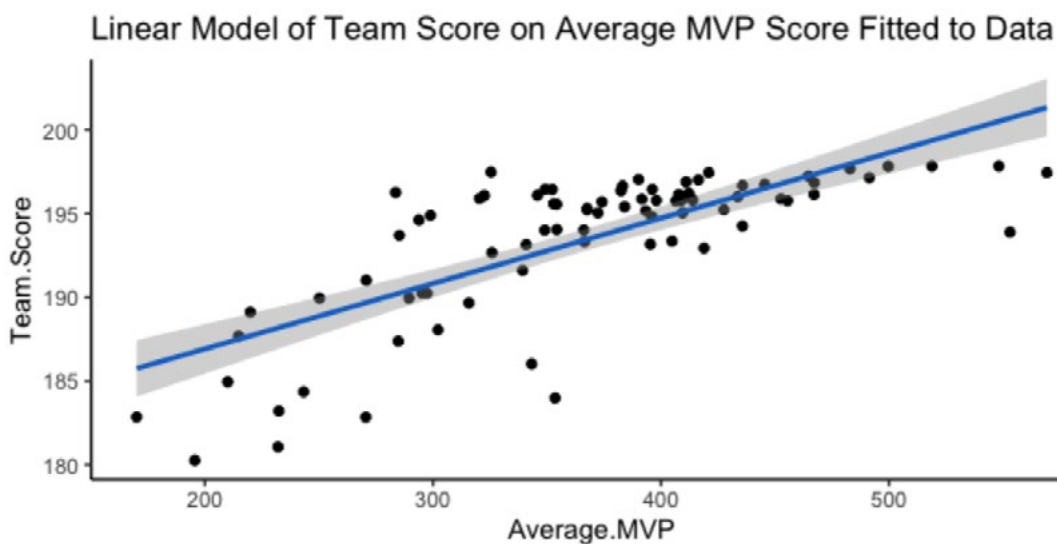


Fig 7. Linear Model of Team Score on Average MVP Score

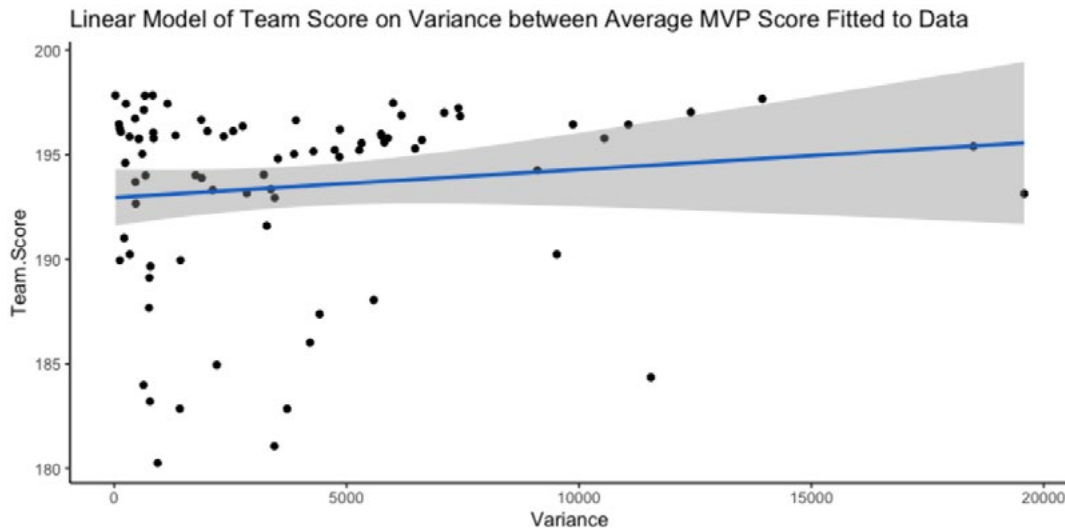


Fig 8. Linear Model of Team Score on Variance between Top 3 Average MVP Score

## Discussion & Conclusion

This study found significant responses to the research questions of how differently teams perform due to their regions and top three scoring athletes. In response to the first research question, for all three seasons (2019, 2020, 2022), the one-way ANOVA model revealed average team scores were significantly different between at least two pairs of regions. In 2019, 2022, and 2022, there were 3 pairs, 3 pairs, and 2 pairs of regions that significantly differed in terms of mean team scores. Speaking of the multiple linear regression model for the second question, the average of top three scores in each team could significantly predict the team score. This suggests that top performing individuals were influential on a team’s performance, especially when Olympians were competing for their schools. In contrast, the variance between the top three individuals did not affect the team performance noticeably.

It is possible that mean team scores of regions in NCAA women’s artistic gymnastics varied from each other due to budget and financial situations. Before the pandemic, the North Central region’s mean team score was significantly different with over half of the other teams. Multiple campuses of the University of Wisconsin (UW), included in the North Central

region, might have caused this scenario. As Division III schools, UW campuses are relatively weak in terms of school budget and size, thereby differentiating the North Central region from the others. After the pandemic, Tukey’s HSD test showed statistically significant differences between only two pairs of schools, the Northeast region included in both. Similar to the North Central region, the Northeast region has several Division III schools, such as Springfield College, that skew the region’s mean team score lower. The finding in this project is thereby important, since it confirms that poorly-funded schools face financial barriers or limitations in recruiting, training, and eventually formal gymnastics competitions.

The research methods still have room for improvement. Specifically, to see the association between MVPs’ and the entire team’s performance, we could have considered each apparatus separately. However, this could not be achieved because not every athlete competed in all four apparatuses. We also could have taken into consideration the conditions of athletes at each game, but there is limited information about every athlete’s injuries or physical fitness.

Overall, however, this study fills the expected gap in gymnastics-related research by taking into consideration a large-sized sample and using statistical

approaches. Current understanding of gymnastics concentrates on the physical aspect of athletes and research projects often study small samples. This project can lead to future looking at socioeconomic and geographical factors in gymnastics, analyzing which regions have limited resources, and considering regional differences in gymnastics through a more humane lens. The association between top individual scores and team performance might also be applicable to other sports, offering a new perspective to research on team sports, team games, and other activities involving teams.

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# Neurobiology of Pathological Gambling: A Literature Review

By Caroline N. Nguyen

## Abstract

Pathological gambling is an impulse-control disorder associated with difficulty managing urges to gamble even at the cost of oneself. This review seeks to investigate existing research on the neurobiological bases of pathological gambling, including abnormal function of brain regions and neurotransmitter systems. Existing research indicates that decreased activity in the prefrontal cortex and ventral striatum is associated with pathological gambling behaviors. Additionally, abnormal production and function of dopamine and serotonin is implicated to be affiliated with pathological gambling. However, the exact abnormalities in these systems are not clearly defined, and further research is required to determine if hyper- or hypo- states are related to pathological gambling. Pharmacological treatments can be investigated based on these neurobiological bases, such as glutamate-related agents and selective serotonin reuptake inhibitors.

## Introduction

“Gambling addiction” exists on a spectrum of severity, and existing research mainly focuses on three types of problematic gambling behaviors. First, pathological gambling (PG) is defined in the DSM-IV as an impulse-control disorder consisting of “persistent and maladaptive gambling behavior” (APA, 1994). It is indicated by five diagnostic criteria, including a) a preoccupation with gambling, b) a need to gamble with increasing amounts of money to achieve excitement, c) repeated failure to cut down or stop gambling behaviors that is associated with irritability or restlessness, d) gambling as a coping mechanism, and e) gambling despite negative financial, legal, or social outcome. In comparison, problem gambling is the common term used for patients who are caused distress by their gambling habits but do not display five of the criteria described in the DSM-IV as defining gambling addiction. Lastly, the DSM-V has replaced the definition of pathological gambling with that of gambling disorder (GD), a substance-related and addictive disorder defined as “persistent and recurrent problematic gambling behavior leading to clinically significant impairment or distress” indicated by similar signs over a 12-month period (APA, 2013). In this paper, I will present research surrounding pathological gambling.

Pathological gambling is a prevalent behavior observed in societies such as the United States. In 2008, lifetime gambling (participation in gambling activity at any point in one’s lifetime) was reported by 78.4% of U.S. respondents; lifetime problem gambling (experiencing problem gambling at any point in one’s lifetime) was reported by 2.3% of respondents, and 0.6% of respondents reported struggling with lifetime PG (Kessler et. al, 2008). While these results demonstrate that most U.S. respondents did not struggle with problem gambling or PG, the facilitation of gambling activities in recent years by video game loot box (items that can be spent inside video games for randomized rewards) systems and monetized gaming activities, is to be noted. Engagement in such activities has been indicated to positively correlate with symptoms of PG (King & Delfabbro, 2020). Additionally, these types of gambling activities are easily accessible by adolescents.

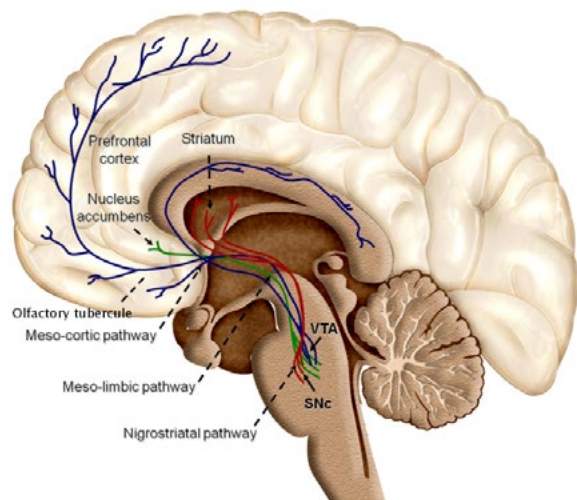
Problem gambling and PG are also associated with financial and social loss. The largest annual gambling losses for respondents averaged \$4,800 USD according to the U.S. National Comorbidity Survey Replication in 2008 (Kessler et. al, 2008). Furthermore, pathological gamblers have reported suffering in their interpersonal relationships. A 2021 study specifically investigated the romantic relationships between PG patients and their partners. The study found that PG was associated with a worse perception of the quality of romantic relationships, as well as an association between PG and insecure attachment (Ponti et. al, 2021). While this study was limited by self-report data and a small sample size, it is clear that PG is associated with negative financial and social consequences and should be treated as the social issue it is. By improving current understanding of PG’s neurobiological bases, PG’s negative social costs can be more effectively avoided.

Many research studies have been conducted to investigate the relationships between neurobiological attributes and PG. By understanding these relationships, clinical interventions can be developed to treat PG and problem gambling to increase the quality of life for patients. Peer reviewed research has revealed that pathological gambling is associated with impaired activation in the prefrontal cortex and mesolimbic system, as well as abnormalities in the production and function of neurotransmitters. It is important to understand the underlying neurological mechanism of pathological gambling, so that more resources can be allocated to the development of clinical and medical interventions to treat pathological gambling.

## Brain Regions linked to Pathological Gambling

The main brain areas demonstrated to be linked to PG are the prefrontal cortex and ventral striatum. Both areas are associated with regulating functions associated with gambling behavior, such as impulse inhibition, reward seeking, and reward anticipation. Hypoactivity of both areas is proposed to be affiliated with PG across several studies.

**Figure 1**  
Reward Structures in the Human Brain



Note. This figure provides an overview of the anatomy of reward structures in the brain. Dopaminergic neurons are located in the substantia nigra (SNc) and ventral tegmental area (VTA) of the midbrain. Their axons project to other parts of the brain including the striatum and PFC. Modified from Overview of reward structures in the human brain, by Arias-Carrión et. al, 2010 ([https://intarchmed.biomedcentral.com/articles/10.1186/1755-7682-3-24/figures/1\\_91](https://intarchmed.biomedcentral.com/articles/10.1186/1755-7682-3-24/figures/1_91)). CC BY 3.0.

## The prefrontal cortex

The prefrontal cortex (PFC) is the area of the cerebral cortex covering the frontal lobe. Dopamine in the PFC serves to regulate cognitive control and is responsible in part for attention, impulse inhibition, prospective memory, and cognitive flexibility functions (Pizzorno & Murray, 2020). In relation to PG, the PFC's role in impulse control is especially of note, as PG patients often struggle to properly manage gambling impulses. Additionally, increased activity in response to reward reception, such as that in gambling behaviors, has been demonstrated in the PFC (Choi et. al, 2012).

Brain imaging studies have been widely used to investigate the relationship between the PFC and PG. Certain cognitive tasks are known to typically trigger cerebral blood flow and metabolic responses in prefrontal cortical areas; however, in PG patients, this activity fails to occur or is diminished, indicating

diminished PFC function (Elman et. al, 2013). For example, decreased ventromedial PFC activity has been demonstrated in response to gambling cue presentation and incongruent stimulus presentation (Stroop task) in PG patients (Potenza et. al, 2003). Potenza et. al selected 13 PG patients and 11 healthy subjects (both groups were similar in age and all were high school graduates). Event-related fMRI imaging was used to analyze ventromedial PFC activity while subjects performed the Stroop task. While both PG and healthy subjects demonstrated activity changes in similar parts of the brain (which includes the right insula, right thalamus, and dorsal anterior cingulate), they differed mainly in activation of the left ventromedial PFC. PG patients demonstrated decreased activity in this region “with a lesser contribution from increased activity in healthy subjects” (Potenza et. al, 2003). The findings of this study indicate PFC hypoactivity may be characteristic of PG.

Gambling addicts have been demonstrated by fMRI scans to experience decreased ventromedial prefrontal activation (associated with impulse control) during inhibition tasks, indicating a lack of inhibition as well as altered reward response (Potenza et. al, 2003). fMRI studies, alongside other imaging and behavioral studies on PG patients, indicate impaired ventromedial PFC activity, executive function, and decision-making – overall, this points to “an alteration in the functional organization of the PFC” (Koehler et. al, 2013).

Fluid intelligence has not been demonstrated to differ between PG patients and controls (Koehler et. al, 2013). This indicates that although activation of the PFC in response to cognitive tasks has been shown to be diminished in PG patients, overall cognitive capacity does not appear to be affected by PG.

Ventral striatum

The ventral striatum (VS) is part of the basal ganglia of the forebrain. The VS itself consists of the nucleus accumbens and the olfactory tubercle. The VS is part of the reward system, and is thus associated with reward-seeking behavior such as that engaged in by gamblers. VS function has also been associated with reward responsiveness and motivational drives, and has been implicated to be associated with habit formations and compulsions (Leeman & Potenza, 2012).



Anticipation of reward is a function highly associated with the ventral striatum. In PG patients, decreased activation in the VS has been demonstrated during reward anticipation (Choi et. al, 2012). Choi et. al selected 15 male PG patients, 15 healthy controls, and 13 OCD patients (group-matched for age, sex, and gender) and analyzed brain activation using fMRI imaging during a monetary incentive task (Choi et. al, 2012). The team chose to focus on regions of interest within the anterior insula and ventromedial caudate nucleus, which is part of the ventral striatum, and found that PG subjects demonstrated decreased neural activity in the ventromedial caudate nucleus compared to OCD and healthy patients. These results indicate that VS hypoactivity may be a feature associated with PG.

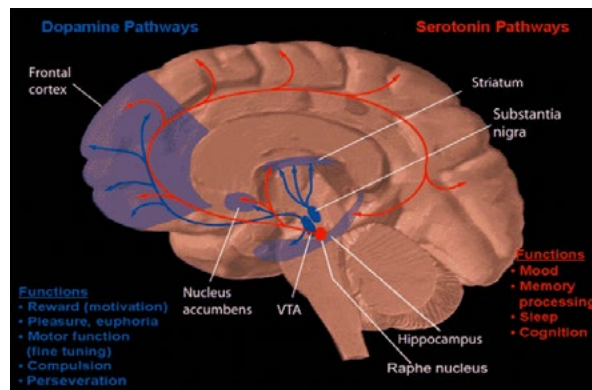
Other fMRI research corroborates the findings of Choi et. al (Reuter et. al, 2005). This same research indicated that reduced ventral striatal activity, along with ventromedial prefrontal activation, was negatively correlated with gambling severity. During simulated gambling tasks, PG patients showed diminished VS activation during anticipation of reward (Reuter et. al, 2005). The hypoactive state of the VS associated with PG indicates “decreased reward sensitivity, suggestive of high risk for addictive behavior” (Choi et. al, 2012). Other fMRI research found no correlation between participants’ scores on the Gambling Symptom Assessment Scale or the Kurzfragebogen zum Glücksspielverhalten questionnaire, which measures DSM-IV diagnosis criteria for PG, and functional connectivity between the PFC and VS (Koaehler et. al, 2013). This poses a contradictory conclusion that the interaction between the PFC and VS affects the probability of developing behaviors rather than the severity of PG symptoms. Thus, no clear conclusion can be drawn regarding whether ventral striatal activity is affiliated with severity of symptoms or merely the presence of symptoms.

## Neurotransmitters linked to Pathological Gambling

Dysfunction of neurotransmitter systems is also evident in patients affected by PG. While links to several neurotransmitters such as norepinephrine have been suggested, dopamine and serotonin are the main two neurotransmitters implicated in PG. Excessive dopamine has been generally asserted to be associated

with PG, while diminished serotonin levels have been proposed in association with PG.

**Figure 2**  
Dopamine and Serotonin Pathways



Note. From Dopamine and serotonin pathways, by National Institutes of Health, 2009 (<https://www.drugabuse.gov/pubs/teaching/largegifs/slide-2.gif>). In the public domain.

## Dopamine

Dopamine (DA) is a neurotransmitter associated with executive function, motivation, arousal, reward, and reinforcement. These cognitive functions are highly associated with PG, which is characterized by reward-seeking behavior through the pursuit of monetary gain, as well as difficulty controlling gambling behaviors. Increased DA function and activity has been proposed to be associated with PG (Boileau et. al, 2014).

Ventral striatal DA synthesis capacity has been demonstrated to “correlate with inter-individual variation in disinhibitory personality traits” (Larence & Brooks, 2014), especially fiscal irresponsibility. The fact that ventral striatal DA synthesis capacity increases with tendencies of fiscal irresponsibility is consistent with the fact that these traits are present and associated with PG.

Additionally, dopaminergic response to oral amphetamines has been demonstrated by PET scan to be greater in PG subjects over control subjects (Boileau et. al, 2014). This again supports the idea that dopaminergic function, being related to the reward-seeking nature of gambling, is altered in

patients with PG.

Increased DA activity has been demonstrated to promote risky gambling behavior such as that seen in PG patients. Researchers who studied loss-chasing – gambling intended to recover losses – administered pramipexole (PPX) to healthy adult subjects in order to test the relationship between DA and loss-chasing behavior. PPX is a dopamine D3/2 agonist; administering it replicates the effect of DA binding to receptors. Administration of PPX in the study “[increased] the value of losses that participants were willing to chase and, at the same time, [reduced] the value of losses that participants were willing to surrender when quitting (Campbell-Meiklejohn et. al, 2010).” While overall, PPX did not increase the proportion of loss-chasing or consecutive loss-chasing decisions, the results of the study indicated that increased DA activity promoted riskier gambling behaviors.

However, conflicting research posits that DA production and function decreases with PG rather than increases. As discussed earlier, VS hypoactivity in PG patients indicates “decreased reward sensitivity, suggestive of high risk for addictive behavior (Choi et. al, 2012).” Choi et. al links VS hypoactivity to a hypodopaminergic state and decreased reward sensitivity. Additionally, a hypodopaminergic state has been previously attributed to substance abuse disorders including cocaine, methamphetamine, heroin, and alcohol dependencies (Boileau et. al, 2014). However, because of the inherent clinical and behavioral differences between substance abuse disorders and PG, it is not clear if these findings are generalizable to PG.

While increased DA production and function has been proposed to be associated with PG, there also exists evidence that contradicts this conclusion. The existence of a relationship between PG and abnormal DA levels is clear, but further research is necessary to define the nature of this relationship.

## Serotonin

Serotonin is a neurotransmitter associated with, among others, the functions of behavioral initiation, inhibition, and aggression. Like dopamine, these functions are highly associated with the act of gambling. Studies surrounding the relationship

between serotonin and PG are less numerous than those surrounding the relationship between DA and PG. However, serotonergic dysfunction has still been demonstrated on multiple occasions to be associated with PG. Existing evidence has suggested both hyposerotonergic and hyperserotonergic states as being associated with PG.

Research into serotonin presence in PG patients has indicated a potential link between a hyposerotonergic state and PG. In male PG patients, hallmarks of a reduced serotonergic function have been demonstrated, namely diminished cerebrospinal fluid levels of 5-hydroxyindoleacetic acid and diminished platelet levels of monoamine oxidase activity (Iancu et. al, 2008). Additionally, research into the serotonin transporter (SERT) protein found decreased maximum binding capacity in PG patients (Marazziti et. al, 2008b). All of these factors indicate that decreased serotonergic production or function are associated with PG.

However, increased serotonin activity has also been proposed to be affiliated with PG behaviors. Research into loss chasing suggested a relationship between loss chasing and serotonin (Campbell-Meiklejohn et. al, 2010). Serotonin is made from the amino acid tryptophan, and the study made use of tryptophan depletion to test the effects of serotonin on loss-chasing behaviors. 34 healthy adult patients of mixed gender were selected by the research team to participate and followed a low-protein diet (<2g) the day before the study and faster overnight. During the study, the team administered drinks containing tryptophan to 17 subjects and administered drinks lacking tryptophan to 17 others before asking subjects to participate in a computerized loss-chasing game. To eliminate confounding variables, subjects were not informed of the probabilities of good or bad outcomes or how much play money they had accumulated during the game, and were told that they could not achieve the best outcome by either exclusively playing or quitting. Prior research referenced by the study indicated that tryptophan depletion, which would reduce serotonin activity, would be “expected to increase gambling to recover losses in [the study’s] healthy adult participants (Campbell-Meiklejohn et. al, 2010).” However, the opposite occurred, and tryptophan depletion actually resulted in a reduced proportion of loss chasing decisions in the study’s subjects. This would indicate that serotonin may play a role in loss

chasing, a noted PG behavior.

Compared to DA, serotonin's role in PG is less clearly defined. While it is clear that serotonin is affiliated with PG, evidence has surfaced that supports both increased and decreased serotonin activity/production in PG patients. More research is needed to define how abnormal serotonin activity contributes to PG and PG behaviors.

## Pharmacological Treatment of Pathological Gambling

By understanding the previously demonstrated neurobiological bases of PG, treatment plans and interventions can be developed to address it in patients. By understanding how PG affects and is affected by the brain, particularly in relation to neurotransmitter systems, drug treatments can be developed to target PG. This section will review existing research on pharmacological interventions and their effectiveness in treating PG patients. However, instead of covering all existing research, this section focuses on interventions that have a firm foundation in existing literature.

### Glutamate

The glutamatergic system is especially notable in how it has been investigated as being potentially of benefit in pharmacological treatment of PG. Glutamate is a principal excitatory neurotransmitter, and it has been proposed that addictions rise out of an impaired ability to inhibit drug seeking behaviors (Pettorruso et. al, 2014). Whether this conclusion is generalizable to PG is unclear, but based on this idea, the glutamatergic system has been proposed to be of use in the exploration of clinical treatments of PG. Furthermore, the nucleus accumbens, which makes up a vital part of the ventral striatum, is associated with reward-seeking behavior. Improving glutamatergic tone in the nucleus accumbens “has been implicated in reducing the reward-seeking behaviour in substance addictions (Grant et. al, 2012).”

Administration of agents associated with glutamate have yielded promising results. The administration of N-acetyl cysteine (NAC), which

modulates glutamate, to 27 PG patients over an 8-week period resulted in 59% of subjects experiencing significant reductions in PG symptoms during the open-label phase (Grant et. al, 2012). After another 6-week double-blind phase, 83% of subjects who received NAC experienced significant reductions compared to 28.6% of subjects who received the placebo. These results indicate that NAC may be of potential benefit as a pharmacological treatment for PG. Other research indicated that memantine, which reduces glutamate excitability, could be of potential benefit to PG patients by reducing cognitive and compulsive symptoms in PG patients (Pettorruso et, al, 2014). In a 10-week open-label trial, 29 PG patients experienced significant decreases in PG-YBOCS (Yale-Brown Obsessive Compulsive Scale modified for PG) scores as well as time spent gambling.

Considering glutamate's relationship to PG behaviors as well as existing clinical research on glutamate-related agents, investigating the glutamatergic system as a means of treating PG holds promise for future research. Glutamate-related agents such as NAC and memantine have already been shown to aid in relief of PG symptoms; further research may also prove successful and more significant if performed on a larger scale.

### SSRIs

Selective serotonin reuptake inhibitors (SSRIs) are medications which function through the inhibition of serotonergic reuptake, increasing serotonin activity (Chu & Wadhwa, 2022). They are commonly used as a treatment for depression and have a limited effect on the function and production of other neurotransmitters like DA. Considering the earlier discussed link between serotonin and PG, SSRIs have been proposed as being of benefit to PG patients.

Paroxetine is one such SSRI that has been investigated as a treatment for PG. Following a 1-week placebo phase, 45 PG patients either received a placebo or paroxetine over 8 weeks (Kim et. al, 2002). Patients who received paroxetine may also have received increasing doses. Statistically significant reductions in scores on the Gambling Symptom Assessment Scale and Clinical Global Impressions were observed in the paroxetine group over the placebo group, indicating that paroxetine may be

beneficial in treating PG.

Fluvoxamine is another SSRI that has been investigated as a treatment for PG. However, research into fluvoxamine has yielded mixed results in double-blind studies. One 16-week crossover study supported its efficacy with an average dose of 207 mg/day, but a longer 6-month parallel-arm study found no significant difference between fluvoxamine recipients and placebo recipients (Grant et. al, 2012). It is important to recognize that the latter study had high drop-out rates. Still, the mixed results mean that fluvoxamine cannot yet be reliably suggested as a treatment for PG symptoms.

Investigation into other SSRIs yielded no significant results at all. Investigation into sertraline, another SSRI, demonstrated no significant difference in improvement between placebo and active-recipient PG subjects over 6 months (Grant et. al, 2012). SSRIs theoretically hold promise as potential treatments for PG symptoms due to the relationship between serotonin and PG. However, just like research into the serotonergic system's role in PG, clinical research into SSRIs have resulted in very mixed results. SSRI treatments as a group are worth investigating, but studies should be conducted on individual treatments to indicate clinical significance.

## Conclusion

Research into the neurobiological bases of PG is best characterized as mixed evidence. While hypoactivity in brain regions such as the prefrontal cortex and ventral striatum has been strongly indicated by existing research, neurotransmitter systems of dopamine and serotonin are less clearly defined. For both of the neurotransmitter systems discussed in this review, findings support both hyperactivity and hypoactivity as being potentially associated with PG, although DA is more strongly implicated to be associated with increased production and function than serotonin is with either increased or decreased levels. Similarly, studies done on pharmacological treatments for PG have not all yielded clear results. While some treatments such as NAC, memantine, and paroxetine have been indicated by clinical research to hold significant promise as treatments for PG symptoms, other treatments such as fluvoxamine and sertraline did not appear to be as strongly supported. While

glutamate-related agents and SSRIs hold promise, it appears that individual treatments should be investigated and these groups of treatments cannot be generalized as beneficial or not.

Overall, existing research is promising in determining the neurobiological bases of PG as well as potential treatments for its symptoms. In the case of particular brain regions, hypoactivity of the PFC and VS are strongly supported by existing research. However, more research is necessary to indicate the exact relationships between neurotransmitter systems and PG as well as determining future pharmacological treatments for PG symptoms.

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# “Not like th’ inhabitants o’ th’ earth”: The Queer “Other” in *Macbeth*

By Thomas P. Catalano

## Author Bio

Thomas Catalano is a senior at Loyola High School of Los Angeles. He is very passionate about the field of economics and plans to study it in college; however, he is also very interested in the study of literature. He is very involved in extracurricular activities at his high school, including Co-Editor-In-Chief of the newspaper, Co-Editor-In-Chief of the yearbook, Co-Captain of the Public Forum Debate Team, Chapter President of Junior State of America, and a member of the Varsity Tennis Team. He is currently engaged in an independent research capstone project on cultural narratives of Latino people found in literature.

## Abstract

This literature review offers a queer theory analysis of William Shakespeare’s *Macbeth*. The following questions drove my research: “How do the heteronormative Christian values in *Macbeth* endorse the traditionalist principles of the English monarchy? How does Christianity place limitations on gender expression in the context of the Renaissance?”

An antithetical reflection of the traditional male-female binary, queerness in *Macbeth* manifests in the weird sisters’ androgynous attributes and *Macbeth*’s invocation of Hecate before murdering King Duncan; furthermore, queerness is otherized and demonized through its association with states of evil and disorder. The witches’ queerness produces their opposition to divine order. Through their esoteric evil practices, they possess *Macbeth* into invoking the mythological queen of witches, Hecate, and assassinating King Duncan, the epitome of patriarchal, heteronormative order. In doing so, *Macbeth* creates a satanic anti-kingdom of which the witches themselves rule through their occult queer evil. Thus, the witches represent the ultimate opposition to the divine monarchy in their state of indeterminate gender expression, which contradicts the Christian cultural norms of the gender dichotomy.

*Keywords:* *Macbeth*, Shakespeare, queer theory, witches, Renaissance, King James I, disorder, unholiness, tragedy

## “Not like th’inhabitants o’ th’ earth”

### The Queer “Other” in *Macbeth*

William Shakespeare commissioned by King James I to write *Macbeth*, the equivocal language used by the Weird Sisters associates queerness with unholy disorder, and the Christian *logos* used by King Duncan and other ordering figures associates heteronormativity with holy order; furthermore, this juxtaposition is informed by the historical context of King James’s mission to legitimize his rule after his succession of Queen Elizabeth I. Stephanie Spoto explains the political tensions regarding the archetypal witch’s queerness as an opposition to the divine right of kings during the Renaissance: “The fear of the witch’s power links directly to a fear of the witch’s sexuality, a fear which James I of Scotland outlines as growing from the anxieties surrounding the possibility of an inversion of the gender hierarchy” (Spoto, 2010, p. 58). At the North Berwick Witch Trials in 1590, King James I was a witness against a group of witches that plotted to murder him. At the will of King James I, Shakespeare used witches to represent gynocentric, queer power because the witch archetype connotes occult, evil layers, as opposed to James’s predecessor Queen Elizabeth, whose virgin Mary archetype would connote layers of order and divinity. The occult unholiness of the witches is primarily revealed through recurring storm imagery and equivocal language. Through their esoteric evil practices, they possess *Macbeth* into invoking the mythological queen of witches, Hecate, and assassinating King Duncan, who is the epitome of patriarchal, heteronormative order. In doing so, *Macbeth* creates a satanic anti-kingdom of which the witches themselves rule through their occult queer evil. Thus, the witches represent the ultimate opposition to the divine monarchy in their state of indeterminate gender expression, which contradicts the Christian cultural norms of the gender dichotomy. The juxtaposition of queer equivocation and heteronormative *logos* affirms King James I’s patriarchal rule and implies that unholy otherness associated with the queerness of the matriarchal witches and the matriarchal rule of Queen Elizabeth is disordering. By hiring Shakespeare to write *Macbeth*, King James I posed himself as a holy restorer of order to a nation ridden by queer, gynocentric disorder. Represented as figures of indeterminate, queer gender expression, the occult, demonic witch

archetype embodies an oppositional force to divine heteronormative order and Christian norms of the Renaissance; furthermore, the linguistic juxtapositions of queer characters—the witches and *Macbeth*—and heteronormative characters—King Duncan and Banquo—underscore Shakespeare’s attempt to otherize queerness through the descent of the heroic defender of androcentric order into a psychological space of gynocentric evil.

Epitomizing divine androcentric power, King Duncan and Banquo embody heteronormativity as an embrace of Christian cultural norms; moreover, their adherence to the gender dichotomy and use of Christian *logos* maintain their characters as symbols of holy order. King Duncan and Banquo provide the standard of archetypal manhood and heroism from which *Macbeth* will begin and ultimately regress: “One of the organizing themes of *Macbeth* is the theme of manliness: the word (with its cognates) echoes and re-echoes through the scenes, and the play is unique for the persistence and subtlety with which Shakespeare dramatizes the paradoxes of self-conscious ‘manhood’” (Ramsey, 1973, p. 286). A historical reflection of King James I, King Duncan embodies the archetypal divine monarch whose divine right to rule places him at the top of the Great Chain of Being, the ordering construct of Romantic society which emphasizes the king as a holy extension of God’s will. King Duncan exemplifies divine transcendence through Christian *logos*: “I have begun to plant thee, and will labour / To make thee full of growing” (Shakespeare 1.4.28-29). His claim of “planting” Banquo parallels God’s biblical creation of Earth; furthermore, the vegetation imagery reifies the natural order and hierarchy of the Great Chain of Being. After *Macbeth* and Banquo first encounter the witches, who prophesize that *Macbeth* will be King and that Banquo’s descendants will be king, Banquo’s reliance on reason juxtaposes *Macbeth*’s descent into insanity: “[H]ave we eaten on this insane root, / That takes reason prisoner” (Shakespeare 1.3.86). Like King Duncan, Banquo uses Christian *logos* through the vegetation imagery of the root, emphasizing Banquo as a defender of the natural order. Banquo’s role as the archetypal expression of heroic manhood allows him to resist the witches’ occult spellcasting. Banquo is aware that “the instruments of darkness tell us truths, / Win us with honest trifles, to betray’s / In deepest consequence” (Shakespeare 1.3.125-128), so he relinquishes possession of his sword to his son,



Fleance, in the case that he becomes overtaken by the esoteric, evil witchcraft: “Here, take my sword. . . . Merciful powers, / Restrain in me the cursed thoughts that nature / Gives way to in repose” (Shakespeare 2.1.4-9). Following his encounter with the witches, Banquo remains the voice of righteous masculinity and reason, and surrenders his sword because he notices that heaven’s “candles are all out” (Shakespeare 2.1.5); thus, during a time of psychological darkness under the influence of the witches’ prophecy, Banquo maintains his moral certainty and ultimately rejects the witches’ equivocal language with clarity: “May they not be my oracles as well / And set me up in hope? But hush, no more” (Shakespeare 3.1.9-10). While divine order is represented by androcentric heteronormativity, the witch archetype alters the consciousness of ordering figures with esoteric evil practices and “spellcasting” in the form of equivocal language.

Representing an inversion of the traditional gender binary, the witches also invert the Great Chain of Being and alter the male consciousness of *Macbeth* to produce a wicked Scottish anti-kingdom that they themselves control through their psychological possession of *Macbeth*. The witch archetype inherently embodies an unholy opposition to the natural, Christian order: “Whether one considers them as human witches in league with the powers of darkness, or as actual demons in the form of witches, or as merely inanimate symbols, the power which they wield or represent or symbolize is ultimately demonic” (Curry, 1933, p. 400). The witches exist “upon the heath” (Shakespeare 1.1.7), which is the untamed country beyond the space of human civilization and constructs; this wild setting reflects the symbolic nature of the witches as antithetical forces of holy order. One witch says, “That will be ere the set of sun” (Shakespeare 1.1.5), which introduces the concept of liminal space, as the sunset represents the transitional state of day to night. Not only are the witches associated with a transitional nature, but they are also associated with darkness, a symbolic representation of the witches as demonic, evil figures. The witches’ state of fluidity illustrates the deconstruction of Christian binaries, which is epitomized by their indeterminate gender expression: “[T]heir gender becomes more difficult to distinguish as they cast aside traditional roles and acquire new masculine, or anti-maternal, positions, and appearances” (Spoto, 2010, p. 66). Upon his interaction with the witches, Banquo is unable to determine their gender identities, for they exist

beyond the absolutes of the Christian world: “You should be women, / And yet your beards forbid me to interpret / That you are so” (Shakespeare 1.3.45-47). Because Banquo is the archetypal embodiment of heteronormativity, he is incapable of comprehending the witches’ androgyny. The witches’ queerness and opposition to heteronormative order allow them to invert social and political constructs: “The fear of the witch’s power links directly to a fear of the witch’s sexuality, a fear which James I of Scotland outlines as growing from the anxieties surrounding the possibility of an inversion of the gender hierarchy” (Spoto, 210, p. 58). Such anxieties about hierarchical inversions were present in the witch hysteria of King James I’s rule, as he expressed in *Daemonologie*, a compendium about witchcraft: “He believed this chaotic rebellion to be satanic forces intent on disrupting his benign, god-sanctioned reign, and to be connected in a biblical precedent as treason: ‘For rebellion is as the sinne of witchcraft,’ a passage that explicitly illustrates the connections between power-inversion and witchcraft” (as cited in Spoto, 2010, p. 55). King James I’s historical view of witchcraft as an existential threat to political order manifests in *Macbeth* because the witches are capable of altering the human psyche through their equivocal language that transforms heteronormative characters into queer characters: “Witches can cast diseases and make men ‘unable for women’ by ‘weakening the nature’ of them. The fear that women could reduce men to impotence demonstrates that many anxieties surrounding gender hierarchy were related to sexual power and sexual surrender” (Spoto, 2010, p. 58). The witches psychologically emasculate *Macbeth* and possess his consciousness to assassinate King Duncan and create a Scottish anti-kingdom. As *Macbeth* embodies a state of queerness in embracing the matriarchy of witchcraft, the holy order of the kingdom is inverted, as “castles topple on their warders’ heads” (Shakespeare 4.1.55). The metaphorical inversion of the castle represents the inversion of Scotland’s political structure under *Macbeth*’s disordering reign controlled by the witches.

While the witch archetype inherently poses an antithetical threat to divine order, Shakespeare supplements the queer associations of witchcraft with storm imagery. Rulers of a dark, satanic anti-kingdom, the witches are solidified as agents of cataclysmic disorder by fog and storm semiotics, which appear each time the witches are present; furthermore, the storm and fog imagery presents an inversion of orderly

nature and contribute to an anti-Christian narrative of witchcraft. The witches' affiliation with such chaotic imagery represents Shakespeare's attempt to otherize and demonize queerness as an antithetical reflection of the traditional male-female binary through its association with states of evil and disorder. When the witches first enter at the beginning of the play, "thunder and lightning" (Shakespeare 1.1.0) appear, immediately establishing their connection to calamitous nature, which is symbolic of political and metaphysical disorder. The witches' association with storm imagery furthers their role as antithetical embodiments of orderly human constructs, for they exist outside the constraints of Christian binaries: "Upon occasion, indeed, they themselves brew storms on land and tempests at sea, thus destroying the products of men's hands at home and distressing or sinking ships abroad" (Curry, 1933, p. 395). The witches are inherently agents of satanic evil in their queer gender expressions; moreover, their ability to shape the weather into chaos symbolizes their unholy, disordering role. Additionally, the sky is traditionally symbolic of the Christian God; therefore, the witches' presence "in thunder, lightning, or in rain" (Shakespeare 1.1.2) further demonizes them as unholy oppositions of divine order, as God's domain, the sky, enters a tumultuous state. This metaphorical relationship represents Shakespeare's conservative, Christian gaze on queer identities. The witches' equivocal language, which is paradoxical and evil by nature, is not only evident in the wicked control of the human subconscious but also in the disordering control of nature: "The entire situation, both the human context and the natural setting, can be totally transformed by the Weird Sisters, and . . . their influence is always of a malignant and perverse kind" (Tomarken, 1984, p. 82). In addition to storms, the witches are also associated with fog imagery, as the witches "hover through the fog and filthy air" (Shakespeare 1.1.10). The fog represents a state of confusion that is reflective of the contradictory language employed by the witches; the filthy air represents the failed vision of the witches, which reinforces the Christian gaze of the Renaissance as superior. Ultimately, the disordering semiotics connected to the witch archetype reflect the societal gaze on queerness as demonic and innately evil; therefore, "Shakespeare's Weird Sisters are intended to symbolize or represent the metaphysical world of evil spirit" (Curry, 1933, p. 400). The semiotics implicit in the storm imagery that surrounds the witches are

indicative of the witches' archetypal representation as agents of Satan.

Like the chaotic nature imagery associated with the witches, their antithetical language indicates the conservative societal gaze on queerness. Reflections of occult queerness, the witches practice esoteric spellcasting through complex, contradictory linguistics known as equivocal language; furthermore, the paradoxical nature of equivocal language juxtaposes the divine truth of Christian *logos*, which further develops the queer witches as oppositional to Christianity. Perpetuating a state of queerness, equivocal language is the method by which the witches are able to alter the male consciousness into one of queerness: "Equivocation leads to treason in that it holds back mentally one-half of a proposition in order to delude the hearer by that half which is spoken" (Huntley, 1964, p. 398). The witches' self-negating speech represents disorder because the language is a sequence of antithetical words, which, when spoken together, are essentially void of meaning. The paradoxical linguistics tied to queerness underscore that the witches are outside the constraints of the ordering male-female binary and embody a disordering, indeterminate state. The witches equivocate their speech countless times throughout the play, such as saying, "When the battle's lost, and won" (Shakespeare 1.1.4). The witches' equivocal language underscores the disordering uncertainty of *Macbeth's* fate, juxtaposing the divine truth of King Duncan and Banquo's Christian *logos*. Seeking to demonize figures of indeterminate gender identities to reify the monarchical rule of King James I, Shakespeare characterizes the witches as equivocators, a sign of satanic evil according to the Renaissance truth candidacies: "Shakespeare begins simply enough with the assumption that equivocation springs from the devil and that, in the Christian view of order, the devil is the archtraitor" (Huntley, 1964, p. 397). The epitome of anti-Christianity, the witches' equivocation, such as "Double, double, toil and trouble" (Shakespeare 4.1.10), is associated with the potion they make prior to prophesizing *Macbeth's* fate for the second time: "Cool it with a baboon's blood, / Then charm is firm and good" (Shakespeare 4.1.37-38). The blood of this potion is a perverse allusion to the sacramental blood; therefore, the witches' potion represents the anti-Sacrament, furthering Shakespeare's conservative narrative of the queer witches as unholy equivocators conspiring with the devil. Equivocation ultimately

becomes a form of occult, unholy spellcasting, as the witches subvert *Macbeth's* male consciousness and make it queer: "Meeting the witches, who . . . are in league with the devil, he [*Macbeth*] is seduced by their technical equivocation, and, through . . . his own moral weakness, ends by becoming its victim" (Huntley, 1964, p. 397). Because the equivocal language of the witches is a form of queer spellcasting, the witches enchant *Macbeth* with their satanic linguistics, and under their metaphysical possession, he embodies queerness by embracing the matriarchy of witchcraft.

Through *Macbeth's* possessed invocation of Hecate, the mythological queen of witches, before murdering King Duncan, *Macbeth* becomes part of the matriarchy that is witchcraft, and the rigid male-female binary dissolves as he embodies the feminine characteristics of witchcraft; additionally, *Macbeth's* queerness in this moment is associated with evil because it precedes his violent killing of the Christian, heteronormative King Duncan and chaotic plot to take over Scotland. The witches' satanic linguistic spell having taken effect, *Macbeth* begins to repeat their equivocation, which signals his descent from a psychological space of androcentric order to gynocentric disorder. The witches say, "Fair is foul, and foul is fair" (Shakespeare 1.1.9); *Macbeth* repeats, "So foul and fair a day I have not seen" (Shakespeare 1.3.38). *Macbeth's* coerced adoption of linguistic disorder represents the unraveling of his heteronormative reason into queer insanity as he encounters androgynous otherness. Furthermore, *Macbeth's* equivocation indicates the witches' domination of his psyche: "The psychological procedure whereby evil makes use of *Macbeth's* conscience is . . . directly related to the enchantment of *Macbeth*" (Tomarken, 1984, p. 85). The witches' psychological control of *Macbeth* leads him to assassinate King Duncan, which represents the symbolic assassination of heteronormative order and the birth of a queer anti-kingdom ruled by the weird sisters. *Macbeth* embodies queerness preceding his murder of King Duncan: "Witchcraft celebrates pale Hecate's offerings" (Shakespeare 2.1.51-52). *Macbeth* offers King Duncan's body as a sacrifice to Hecate, making him a male witch, or warlock; consequently, *Macbeth* embraces the matriarchy of witchcraft as his male consciousness is queered. The male-female binary of the Christian orderly world is dismantled by *Macbeth's* new state of queerness: "At the first of the play, *Macbeth's* 'manly' actions in war are

not contradictory to a general code of humaneness or 'kindness' irrespective of gender: but as the play develops, his moral degeneration is dramatized as a perversion of a code of manly virtue, so that by the end he seems to have forfeited nearly all of his claims on the race itself" (Ramsey, 1973, p. 285). Upon *Macbeth's* assassination of King Duncan, *Macbeth* ascends to the throne of Scotland; however, he inverts the Great Chain of Being of the Scottish hegemony, which would have placed the heteronormative, divine figure at the top of the political hierarchy rather than a queer, demonic figure. Contrary to the natural order commanded by the Christian norms of the Renaissance, *Macbeth*, possessed by the witches, creates a satanic anti-kingdom: "By this time, treasonous equivocation which is not the whole truth has turned the world of value upside down. *Macbeth* is a traitor to the king; but when *Macbeth* becomes king, then all those forces of righteousness against him become 'traitors'" (Huntley, 1964, p. 398). *Macbeth's* queered consciousness leads to a violent, perverted Scottish kingdom, which epitomizes the conservative societal gaze on queerness as a destructive force of unholy evil.

A classic Shakespearian tragedy, *Macbeth* centers on the descent of the Scottish kingdom from a state of divine, heteronormative order to evil, queer disorder under *Macbeth's* chaotic reign as king. *Macbeth's* consciousness is psychologically altered by the witches through their equivocal spellcasting, as he embodies the archetypal queer warlock. *Macbeth's* state of queerness is inherently oppositional to the ordering constructs of Christian society because by "embracing . . . equivocation he communes not with God but with the devil" (Huntley, 1964, p. 399). This unholy anti-Christian narrative of *Macbeth's* queer transformation and the consequential demise of the Scottish kingdom epitomizes Shakespeare's tragedy, which encodes significant queer oppression narratives. Interestingly, the tragedy finds resolution when *Macbeth* faces his death as a reconstituted man, having eradicated his queerness. As he realizes his existential fate—death, *Macbeth*, having been under the witches' wicked spell, finally shatters their satanic, linguistic influence, as Macduff dismantles their flawed prophecy of *Macbeth's* immortal reign: "Despair thy charm, / And let the angel whom thou hast served / Tell thee, Macduff was from his mother's womb / Untimely ripped" (Shakespeare 5.8.13-16). An antithetical representation of equivocal language, Macduff's

Christian *logos* restores *Macbeth*'s heteronormative righteousness, as *Macbeth* realizes the truthlessness of the witches' equivocation: "And be these juggling fiends no more believed, / That palter with us in a double sense, / That keep the word of promise to our ear, / And break it to our hope" (Shakespeare 5.8.19-22). As *Macbeth* overcomes the psychological control of the witches, he returns to a state of valiant manhood, mirroring his condition before first encountering the Weird Sisters. Aware that he is fated to die, *Macbeth* does not surrender to Macduff but rather embodies the archetypal expression of male heroism: "I will try the last. Before my body / I throw my warlike shield" (Shakespeare 5.8.32-33). *Macbeth*'s ultimate rejection of the witches' queer matriarchy of occult witchcraft and return to the heteronormative patriarchy represents the death of the tragedy, for in *Macbeth*, queerness is the tragedy. The conservative gaze of the Renaissance otherizes queerness as an anti-Christian opposition to societal order so that the tragedy of Shakespeare's play becomes intertwined with queerness; therefore, the restoration of patriarchal heteronormativity to Scotland marks the resolution of the Shakespearean tragedy.

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