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MS ENVIRONMENTAL BIOLOGY CAPSTONE PROJECT

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MS ENVIRONMENTAL BIOLOGY
CAPSTONE PROJECT

by

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Masters of Science
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CHAPTER 1. LITERATURE REVIEW: MANAGEMENT OF MOUNTAIN PINE BEETLE OUTBREAKS AND THE IMPACT ON OPEN-CUPPED NESTING BIRD SPECIES

There are many natural disturbances that impact North American pine forests. One disturbance that has increased due to climate change is the death of pine trees through mountain pine beetle outbreaks. Outbreaks are the increase of the size of mountain pine beetle populations, which then amplifies the death of pine trees. Favoring ponderosa, lodgepole, sugar pine, and western white pine, mountain pine beetles kill these trees by eating the phloem, or the live tissue of trees carrying sugars (Safranyik & Wilson, 2006). With increasing temperatures through climate change, mountain pine beetles have become bivoltine, meaning their life cycles have become longer, allowing the beetles to eat through more phloem, in turn killing more pine trees and creating more outbreaks (Mitton & Ferrenberg, 2012).

As mountain pine beetle outbreaks become increasingly frequent, more tree stands die, changing the state of the ecosystem, and in turn, the species richness of pine forests (Johnstone et al., 2016). One way to discover if flora and fauna species richness is decreasing in forests is through indicator species, which can be observed to determine the conditions of the ecosystem. Indicator species are important because they show responses to environmental impacts through decline of fecundity and disappearing from habitat (Carignan & Villard, 2002). Indicator species are sensitive to changes in their ecosystem and we can use them to identify the cause of change, rather than just knowing change occurred in the area (Carignan & Villard, 2002). If indicator species begin to disappear, that may indicate a decrease in species richness in the ecosystem. Birds are important indicator species because they respond to disturbances on a variety of spatial scales and they pollinate plants, spread seeds, and kill invasive species (Sekercioglu, Wenny, & Whelan, 2016; Whelan, Şekercioğlu & Wenny, 2015). Bird species are influenced by their habitat (Carignan & Villard, 2002). If birds disappear from a landscape, that suggests the habitat is not suitable for them, plants are no longer pollinated, and seeds are not spread. Mountain pine beetle outbreaks may inadvertently impact bird species richness, specifically open-cupped nesting bird species which use open nests on tree limbs. However, management that focuses on pre- and post-mountain pine beetle outbreaks may negatively impact open-cupped nesting bird species more than outbreaks themselves. Examining the impact of pre- and post-outbreak forest management compared to no management may determine whether avian species are significantly impacted by mountain pine beetles, and if pre- and post-management plans are better for open-cupped bird nesting species than allowing beetle outbreaks without managing them.

There is little research on open-cupped nesting bird species richness after a mountain pine beetle outbreak. Data on open-cupped nesting birds are important because their habitat is being disrupted more than that of ground-nesting birds and cavity nesting birds, because of the increasing loss of live trees (Mosher, 2011). While studies have focused on the biodiversity of bird species after an outbreak of beetles in a pine forest, they have not specifically focused on open-cupped nesting bird species. As mountain pine beetle outbreaks increase, so does the population of cavity-nesting species (Saab et al., 2013). This influx of cavity-nesting birds is attributed to the fact that mountain pine beetles are a food source for cavity nesters (Drever, Goheen & Martin, 2009). Therefore, species richness of open-cupped nesting bird species may increase if mountain pine beetles are a food source for them. Mountain pine beetles are a reliable food source for birds (Drever, Goheen & Martin, 2009) and many open-cupped nesting birds may rely on these beetles as a food source if they are insectivores.

Mountain pine beetle outbreaks decrease canopy cover (Lehnert, Bässler, Brandl, Burton, & Müller, 2013). Indicator species richness, including that of birds, declined with lower canopy cover. Twice the number of indicator species prefer open forests compared to more closed-canopy ecosystems. Indicator bird species composition was similar in open, transitional and closed canopy forests, suggesting that canopy availability may not be a significant variable for open-cupped nesting bird species (Lehnert, Bässler, Brandl, Burton, & Müller, 2013). This could potentially mean that open-cupped nesting bird species richness neither benefit nor decline in response to mountain pine beetle outbreaks. After a spruce beetle outbreak in Alaska, there was a decline of large basal area, or larger sized white spruce trees in the forest and the beetles avoided black spruce which then altered the ecosystem. Understory vegetation and understory-nesting bird species increased with tree mortality. With avian species, both cavity-nesting woodpecker and tree-nesting bird species density did not differ significantly between high mortality or low mortality stands (Matsuoka, Handel & Ruthrauff, 2001). Although this study was not specifically on mountain pine beetle outbreaks, similarities between post-outbreak forest structures suggest that similar bird species compositions can occur compared to the post-spruce beetle outbreak forests. Mountain pine bark beetle outbreaks may therefore not significantly impact open-cupped nesting bird species richness.

The impact of mountain pine beetle outbreaks to open-cupped nesting avian species is difficult to determine with the existing research, making management suggestions for mountain pine beetle outbreaks challenging. Clarifying how mountain pine beetle outbreaks affect open-cupped nesting bird species would allow for better forest management plans that could help determine what would benefit open-cupped nesting bird species. Management proposals that have been implemented in the past include thinning trees before or after the outbreak, or no management at all. Determining the best forest management plan may help determine whether mountain pine beetle outbreaks impact open-cupped nesting bird species more than the forest management for the outbreaks itself.

With the increase of mountain pine beetle outbreaks, considering the best management options is becoming more important when thinking about the overall flora and fauna community structure of the forest and how management may alter community structure more than the disturbance itself. In lodgepole forests, tree thinning before outbreaks resulted in an increase in tree resilience which decreased mountain pine beetle attacks (Mitchell, Waring & Pitman 1983). As tree resilience increases, other species may benefit. Open-cupped nesting bird species could maintain populations and species richness because living trees could still provide habitat when the forest is thinned. However, in other cases, thinning was unlikely to decrease beetle outbreaks and may be more ecologically detrimental to forests than mountain pine beetle outbreaks themselves (Kulakowski, 2016). If an outbreak were to occur after the thinning of the stand, this would be even more damaging to the ecosystem because more trees would die from the outbreak and the forest would already be thinned. Studies that tested whether forest thinning decreased bird populations found a trend of increasing bird species richness from thinned to old growth forests, but these differences were not significant (Kutt, 1996). Since thinning forest stands decreases forest composition heterogeneity, that then decreases the species richness of other animals that relied on those specific tree species for habitat and food. Birds can be impacted by the thinning of forest stands. A few specific species of birds that were found in old growth forests and non-treated forests compared to thinned forests are the superb lyrebird and the rufous whistler (Kutt, 1996). Thinning forest stands may not be the best management option when considering open-cupped avian nesting species because of the risk of decreasing overall species richness of the entire forest.

One post-outbreak management option is logging dead trees after a pine beetle outbreak. Forest managers want to use deadwood from after outbreaks for logging. However, managers have determined that there is positive nest success of black-backed woodpeckers in post-beetle-outbreak forests and these dead forests provide habitat for black-backed woodpeckers, so it is important that they are not logged (Bonnot, Rumble, & Millspaugh, 2008). Although woodpeckers are not open-cupped nesting bird species, if leaving deadwood benefited woodpeckers, it may also benefit open-cupped nesting bird species. With the small amount of research that has been done on mountain pine beetle outbreaks and their impacts on open-cupped bird species richness, considering other bird species might help determine which management approach will be best.

Management of forests after mountain pine beetle outbreaks can also consist of taking slash, or fallen dead trees, out of the forests or keeping slash on site after logging the trees that died. Average shrub cover was higher when logs remained on site than when logs were removed from sites (Dhar, Parrott & Hawkins, 2016). This suggests that salvage logging, the collection of dead trees, following beetle outbreaks is the most effective method when considering the regrowth of the understory; however, with respect to birds, this may not be the best approach because logging also increased invasive plant species richness, and that may impact the ecosystem later. Invasive species outcompete native foliage, which provides habitat and food sources for open-cupped nesting bird species. Keeping dead trees on site means using fewer resources to remove these trees and this allows dead trees to fall at their own rate which is slightly slower than if the forest is thinned (Mitchell & Preisler, 1998). These dead trees remaining in the forest would still leave habitat and native food sources for open-cupped avian nesting species and cavity-nesting species. Taking slash after a pine beetle outbreak would not be the most effective management option when considering the species richness of avian species, specifically open-cupped nesters.

Avian species richness was higher in post-mountain-pine-beetle-outbreak forests that were not managed before or after the outbreak compared to managed forests. This is due to the increase of niche spaces for different species in unmanaged forests. This may indicate that open-cupped nesting bird species richness would improve in an unmanaged post-outbreak ecosystem (Paillet et al., 2010). Although there is still not enough information to determine if and how open-cupped nesting bird species richness are impacted by mountain pine beetle outbreaks, allowing mountain pine beetle outbreaks to occur may be the best option when considering management, because although mountain pine beetle outbreaks are continuing to increase, there is still habitat and food sources for avian species when these outbreaks occur.

More research is needed on the impact of mountain pine beetle outbreaks on open-cupped nesting bird species. Multiple management techniques have been implemented on pine forests in order to determine whether they improve resilience of trees facing mountain pine beetle disturbances, but little research has considered how other species are affected by management. Forest management techniques may be more detrimental to the species richness of open-cupped nesting birds than no management because of the loss of additional habitat from deadwood. With pre- and post-management options, other bird specie's populations were impacted with loss of habitat, decreasing their populations. If other avian species are negatively impacted by pre- and post-management options, then open-cupped nesting bird species may also be at risk. With more research, we can determine if mountain pine beetle outbreaks have a more negative impact on open-cupped nesting bird species richness than pre- and post-forest management.

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CHAPTER 2. GRANT PROPOSAL: THE IMPACT OF MOUNTAIN PINE BEETLE OUTBREAKS AND THEIR MANAGEMENT ON BIRD SPECIES RICHNESS AT ROCKY MOUNTAIN NATIONAL PARK

Abstract

Warming temperatures have increased the number of mountain pine beetle (MPB) outbreaks in conifer forests. This rise of MPB outbreaks have increased the percentage of pine tree mortality, decreasing biodiversity, and altering the ecosystem. Assessing indicator species, such as birds, and determining the impact MPB outbreaks have had on their species richness can be important in providing information on forests that have been affected by MPB outbreaks and determine if management will improve species richness of birds and overall biodiversity. I will conduct point count surveys of birds in RMNP to determine species richness in areas that have not been impacted by MPB outbreaks, areas that have been impacted but not managed, and areas that have been managed after MPB outbreaks to discover if post-management of outbreaks significantly decrease bird species richness more than MPB outbreaks themselves. These data will provide more information on how MPB outbreaks and their management impact species richness of bird species and will be important for determining if management techniques are necessary for improving the health of pine forests.

Objectives

My objective is to assess the impact of MPB outbreaks and their management on bird species richness. I propose to conduct point count surveys on bird species to determine species richness in forested areas of Rocky Mountain National Park (RMNP) that were unaffected by MPB outbreaks, impacted by MPB outbreaks but not managed, and managed after MBP outbreaks. I will compare bird species richness in areas of RMNP that did not have any MPB outbreaks to areas that were impacted by MPB outbreaks. I will also compare bird species richness of areas affected by MPB outbreaks that were not managed post-outbreak to areas managed after outbreaks. These point counts will provide more information on how MPB outbreaks impact species richness of bird species, as well as how post-management of the forests impact species richness.

Hypothesis

H1: Bird species richness will be higher in areas of RMNP that did not experience MPB outbreaks than those that did.

H2: In areas of RMNP that experienced MPB outbreaks, unmanaged areas will have higher bird species richness than areas that were managed after outbreaks.

Anticipated Value

MPB effects on forests in RMNP have not been extensively studied, and little research exists on the impacts of MPB outbreaks and their management on bird species in RMNP and other conifer forests. Because birds are indicator species, assessing the impact of MPB outbreaks on bird species will provide information on how much these outbreaks are changing the ecosystem. The number of MPB outbreaks are increasing (Carroll et al. 2003), killing more trees, making it important to figure out the best approach to increasing the overall health of forests and the species richness of all species within forests. Determining if managing forests after MPB outbreaks impacts bird species could help improve management techniques in MPB outbreak forests in RMNP and other forests.

Literature Review

Many natural disturbances impact North American pine forests. One disturbance that has increased due to climate change is the death of pine trees from MPB outbreaks. These outbreaks entail the increase in size of MPB populations, which then amplifies the death of pine trees. With increasing temperatures, MPB have become bivoltine, meaning their life cycles have become longer, allowing the beetles to eat through more phloem, in turn killing more pine trees and creating more outbreaks (Mitton & Ferrenberg, 2012). This is important because with increase of MPB outbreaks, the higher percentage of dead trees alters the species richness of pine forests, ultimately changing the composition of the ecosystem (Johnstone et al., 2016). This continual growth of MPB outbreaks could alter forest structures, which could decrease native flora and fauna species richness. Decline of overall biodiversity can alter ecosystems, and lead to the loss of ecosystem services that we need to sustain ourselves (Hooper et al. 2012).

Observing indicator species in forests can help determine if flora and fauna species richness is decreasing. Birds respond to detrimental environmental impacts through decline of fecundity and disappearing from habitat, revealing that the ecosystem is changing (Carignan & Villard, 2002). Bird species are important indicators because they respond to disturbances on a variety of spatial scales and they pollinate plants, spread seeds, and kill invasive species (Sekercioglu, Wenny, & Whelan, 2016; Whelan, Şekercioğlu & Wenny, 2015). If indicator species begin to vanish, that may suggest a decrease in total species richness in the ecosystem.

MPB outbreaks decrease canopy cover (Stone & Wolfe, 1996). This reduces habitat for birds, which may drop the number of bird species. Since MPB outbreaks are also increasing in number, the initial reaction to the outbreak may be positive because of the increase of food source (MPB), but these enhanced conditions may end up being detrimental to bird species richness as time increases because of the continued death of pine trees, altering bird habitat (Martin, Norris & Drever, 2006). However, forest management after MPB outbreaks may negatively impact bird species more than outbreaks themselves. Examining the impact of post-outbreak forest management compared to no management may determine whether avian species are significantly impacted by MPBs, and if post-management plans are better for bird species than allowing beetle outbreaks without managing them.

One post-outbreak management option is logging dead trees after a pine beetle outbreak. In RMNP, certain areas of the park are managed once outbreaks end, however, the optimal number of trees to treat in order to prevent further damage from MPB is unknown ("Frequently asked questions about the mountain pine beetle epidemic: Rocky Mountain Research Station", 2015). In some forests, forest managers want to use deadwood from after outbreaks for logging. However, managers have determined that there is positive nest success of black-backed woodpeckers in post-beetle-outbreak forests and these dead forests provide habitat for these species, so it is important that they are not logged (Bonnot, Rumble, & Millspaugh, 2008). If leaving deadwood benefits woodpeckers, it may also benefit other bird species. Considering bird species as an indicator species might help determine if management or no management will be best for forests.

In studies conducted in Europe, avian species richness was higher in post-mountain-pine-beetle-outbreak forests that were not managed before or after the outbreak compared to managed forests (Paillet et al., 2010). This was due to the increase of niche spaces for different bird species in unmanaged forests. Although there is still not enough information to determine if and how bird species richness is impacted by MPB outbreaks, allowing them to occur without managing for them may be the best option, because although MPB outbreaks continue to increase, there is still habitat and food sources for avian species when these outbreaks occur.

There were continuous MPB outbreaks in RMNP (Figure1) from 2002-2010 due to rising temperatures and fire suppression (Mountain Pine Beetle Epidemic Killing Forests, Colorado, USA: Global Warming Effects, 2011). RMNP has removed hazardous trees as a management technique for MPB outbreaks. They have applied this management method in areas around higher populations of people in order to protect their visitors ("Forest Health: Mountain Pine Beetle", 2018). However, in the backwoods of RMNP, it is harder to apply management practices because of absence of roads for equipment. The presence of sites with no MPB outbreak, sites that were not managed after MPB outbreaks, and sites that were managed for MPB outbreak makes RMNP a useful place for studying how MPB impacts bird species richness. RMNP's last outbreak ended ten years ago, allowing enough time for the recovery of the forest and for me to determine if there were any lasting impacts on bird species.

More research is needed on the impact MPB outbreaks and their management have on bird species to help maintain the health of forests. Thinning of stands after MPB outbreaks has been implemented in pine forests in order to determine whether they improve resilience of trees facing MPB disturbances, but little research has considered how other species are affected by management. Forest management post-MPB outbreaks may be more detrimental to bird species richness than no management because of the loss of additional habitat from deadwood. With research conducted in RMNP we can determine if MPB outbreaks have a more negative impact on bird species richness than post-forest management.

Methods

To conduct my study, I used GIS to determine locations in RMNP where there were no MPB outbreaks, areas where there were MPB outbreaks but no management, and areas where there was management after MPB outbreaks. Regions around Timber Lake were not impacted by

MPB outbreak, Grand Lake was impacted by MPB outbreaks but not managed, and areas around Bear Lake were managed after MPB outbreaks (Figure 2). To test my hypotheses, following Ralph et al (1995), I will conduct point count surveys at each site in late spring/early summer 2020 in order to detect birds that breed in the area. Common birds in RMNP during this time of year include multiple species of warblers (*Setophaga sp.),* the American robin (*Turdus migratorius*), and the red-headed woodpecker (*Melanerpes erythrocephalus*) (Birds of Rocky Mountain National Park – full list, 2012). For each day of data collection, point count surveys will only occur at one of the sites (Timber Lake, Bear Lake, or Grand Lake). In each study site, a 50-hectare (ha) grid will be placed, and thirty 50x50 meter plots will be located throughout the grid with at least 0.1 ha in between each plot so as not to measure species richness in the same areas. For each day I collect data, I will randomize the order of the 30 plots in order to control for the time of day each point survey is conducted. I will conduct 15-minute point count surveys using fixed radius point counts by standing still in the middle of the plot and recording every species of bird I see and hear (Petit, Petit, Saab, & Martin, 1995). In order to reduce the probability of overcounting birds, individual birds of the same species will only be recorded when I observe distinct differences between birds, or multiple birds are in the same location at the same time (Buskirk & McDonald, 1995). I will survey each site location three times in each month.

To test my hypotheses, I will conduct two paired t-tests, one comparing the bird species richness of forest that was not impacted by MBP outbreaks to forest affected by MBP outbreaks but were not managed, and the other comparing the bird species richness of forests that had MPB outbreaks but were not managed and forests that were managed after MBP outbreaks. These data analyses will be conducted in R version 3.6.1 (R Core Team, 2019).

Negative Impacts

There are minimum negative impacts for this study. The biggest negative impact is that the birds may be scared away during data collection. This can be avoided by being quiet during data collection, not drawing any attention to myself.

Schedule

May 5 – June 18, 2020	Conduct bird point-count surveys at Grand Lake, Bear Lake, and Timber Lake. Each week I will spend one day collecting data at each site for three weeks in a month.
June 19 – August 1, 2020	Data Analysis and Report Draft
September 1, 2020	Finalized Report

Budget

Item	Cost, unit (source)	Quantity	Total Cost
Binoculars	$170 (Cabelas)	1	$170
Gas	$0.52 per mile (OSC)	2160 miles total (120 miles round trip, 18 trips)	$1,123
Field Notebooks	$25	2	$50
Stipend	$2500	1	$2500
RMNP Pass	$70 (National Park Service	1	$70
Total			**$3,913**

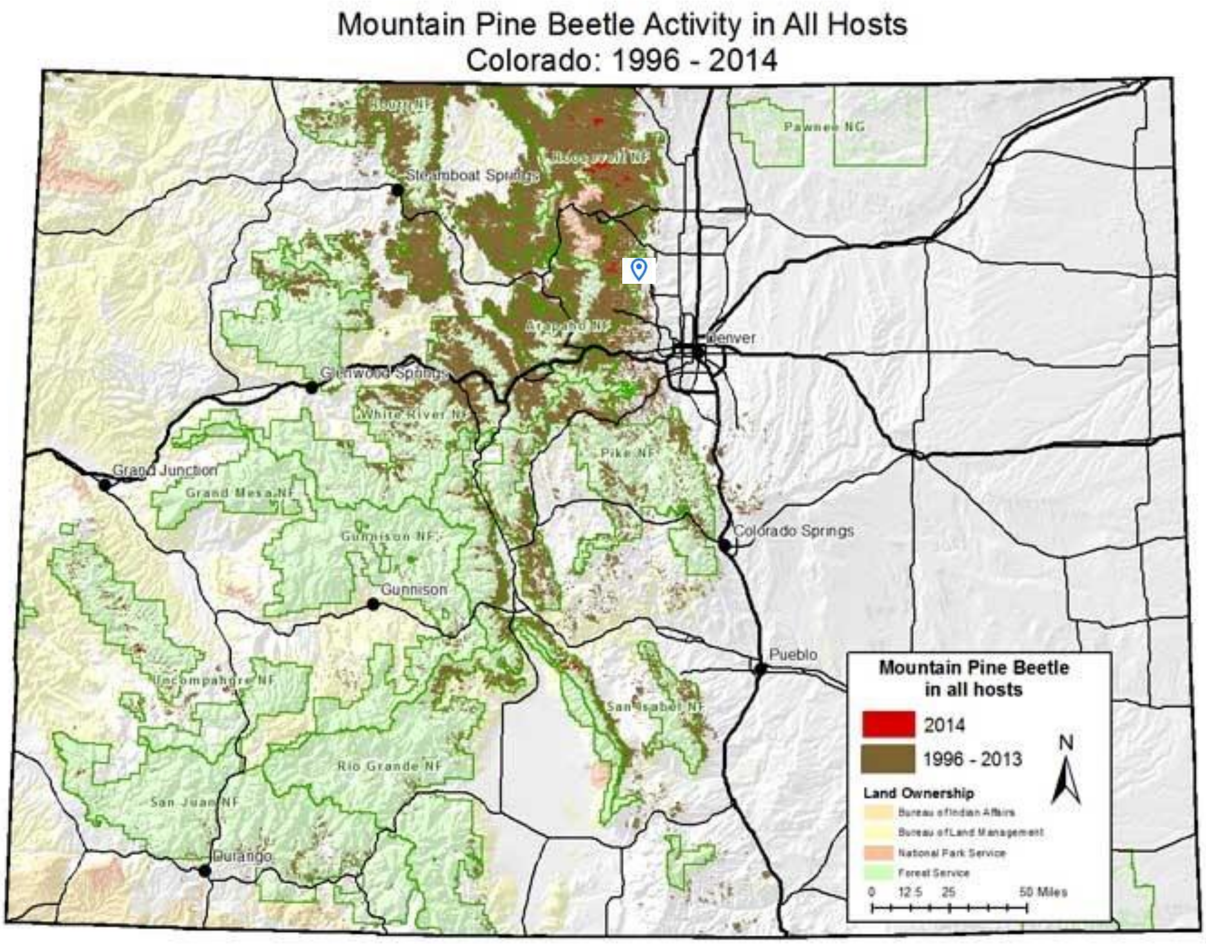

Figure 1: Mountain Pine Beetle outbreaks that have occurred in Colorado since 1996. Point is RMNP.

https://www.nps.gov/romo/learn/nature/mtn_pine_beetle_background.htm

Figure 2: Locations of study sites are Grand Lake, Bear Lake, and Timber Lake.

https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.pinterest.com%2Fpin%2F552113235568575796%2F&psig=AOvVaw3853TJOWe9niBRpb74EW_i&ust=1573600321753000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCOiX65Ok4-UCFQAAAAAdAAAAABAW

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CHAPTER 3. JOURNAL MANUSCRIPT: DETERMINING IF MIXED-SPECIES PAIRINGS CONTRIBUTE TO PRIMATE WELFARE: OBSERVING AFFILIATIVE AND AGGRESSIVE BEHAVIORS BETWEEN TWO MIXED-SPECIES PAIRS OF GIBBONS AT DENVER ZOO

Abstract

Gibbons are one of the few socially monogamous primate species. Because of their need to socialize, pairing gibbons in zoo enclosures helps ensure their welfare and decrease stress levels. When a gibbon loses a mate, the individual might have no socialization opportunities if the zoo does not have another individual of the same species for pairing. At Denver Zoo, managers paired mixed-species gibbons instead of having them live alone. I collected focal samples on all four individuals to observe their aggressive and affiliative behaviors as well as proximity to one another. I predicted that these two mixed-species pairings would express 10% or more affiliative behaviors and less than 1% aggressive behaviors, similar to the activity budget of same-species pairings. I also predicted they would have the same or higher percentage of affiliative behavior to same-species pairs at the Oakland and Sacramento Zoos. Pair 1 spent 23.4% of their time engaged in affiliative behaviors and Pair 2 spent 1.67% of their time engaged in affiliative behavior. Only Pair 1 showed any aggression towards one another. Compared to the same-species pairs at the Oakland and Sacramento Zoos, Pair 1 expressed a higher percentage of affiliative behaviors than both pairs, while Pair 2 expressed a lower percent of affiliative behaviors. These results suggest that socializing across gibbon species may benefit gibbons, so managers should consider pairing lone primates with another closely related species in order to improve their welfare.

Introduction

Living alone can negatively impact primates' well-being. Social deprivation can change the behaviors of captive animals and can increase stress as well as abnormal behaviors (Mallapur & Choudhury, 2003; Mallapur, Waran & Sinha, 2005). Behaviors that are signs of stress and boredom include human-directed masturbation, posterior presenting to humans, pacing, and self-mutilation behaviors such as biting the skin and banging limbs on the enclosure (Hosey & Skyner, 2007; Mallapur & Choudhury, 2003). In order to decrease abnormal behaviors, zoos have started to mix primates of different species for socialization when no other member of the same species is available. Many of these mixed pairings have been species of monkeys who are known to associate in the wild (Leonardi et al., 2010; Wojciechowski, 2004). While researchers worried about interspecific aggression, another cause of stress, they found that although there were aggressive behaviors between the different species, these pairings could co-exist (Leonardi et al., 2010; Wojciechowski, 2004). Since naturally associated monkeys were found to be able to live with one another, other primates may also be able to benefit from mixed-species pairing.

Gibbons, lesser apes, belong to the family Hylobatidae and are closely related to humans. Gibbons are the most diverse of all surviving apes with nineteen separate species recognized within four groups (Cunningham & Mootnick, 2009; Fan et al., 2017; Koehler, Bigoni, Wienberg & Stanyon, 1995).The four gibbons genera—*Hylobates*, *Hoolock*, *Symphalangus*, and *Nomascus* –are as genetically similar to each other as chimpanzees are to humans; each species of gibbon branched off from a common ancestor over a short evolutionary time period, explaining the minimal distinguishing characteristics for every species (Müller, Hollatz & Wienberg, 2003). Typically, gibbons live in a group of 2-6 individuals containing one pair of breeding adults and their offspring (Sommer & Reichard, 1997). In the wild, gibbon's behaviors consist of grooming, playing, travelling for food, vocalization, and protecting one another from predators (Brockelman, 2009).

Gibbons, like most primates, are very social animals and they live within pairs or groups (Honess & Marin, 2006). Gibbons are one of few socially monogamous primates, meaning they live with one mate for their whole adult life and groups consist of a mating pair and their offspring (Cunningham & Mootnick, 2009). Therefore, in zoos, adult gibbons are typically housed with an opposite-sex gibbon of the same species, which provides the gibbons with the social opportunity crucial to their well-being (Honess & Marin, 2006). Gibbons that live in zoos together can be as social in enclosures as their counterparts living in the wild (Warren, 2010). Many primates living with others of the same species devote an average of 10% or less of their activity budget to social behaviors, with aggressive behaviors occupying less than 1% of their activity budget (Sussman, Garber & Cheverud, 2005). A pair of white-cheeked gibbons that live and interact together in captivity in Lincoln Park Zoo in Chicago were shown to exhibit more affiliative behaviors, such as social grooming, to one another more than aggressiveness (Lukas et al., 2002). More affiliative interactions also take place when the female-white cheeked gibbon was in estrous (Lukas et al., 2002). Paired primates, such as squirrel monkeys and baboons have exhibited lower stress compared to isolated individuals (Visalberghi & Anderson, 1993). Expressing affiliative behavior is a sign that a set of gibbons paired are socially benefitting from one another.

Maintaining close proximity is another sign that members of a gibbon pair are benefitting from one another. It has been argued that spatial proximity in the wild advertises a female's paired status and impedes males from mating with paired females (Reichard, 2003), but there has been very little research done on spatial proximity in gibbons in captivity (Zhen-Hua, Huang, Wen-He, Qing-Yong & Jiang, 2013). At the Lincoln Park Zoo, a same-species pair of white-cheeked gibbons displayed 3.8% of their time in proximity, or within an arm's reach to one another and 5.4% of the time in physical contact (Lukas et al., 2002). Close spatial proximity could be related to less stress between gibbons living with one another and could be correlated with less aggressive behaviors being displayed because in order to avoid aggression, gibbons stay farther away from each other (Fan & Jiang, 2010). However, if a gibbon loses a mate, and no other gibbon of the same species lives in that zoo, they may end up living alone for a period of time (Leonardi et al., 2010). In order to benefit gibbons' well-being and decrease stress levels, mixing species may be a better alternative than housing a gibbon alone. Zoo managers need to know the activity budgets of mixed-species pairings and how they interact with one another in order to make informed management decisions.

Studying the affiliative and aggressive behaviors of gibbons allows us to ensure their welfare and their levels of stress and establish if certain aspects of their environment cause stress. If pairing mixed-species is beneficial, the activity patterns and social behavior of mixed-species pairs should be similar to same-species pairs and exhibit less abnormal behaviors. Learning the behaviors of mixed-species pairs will help us determine if socializing them with different species is more beneficial than social isolation (Hosey, 2005). At Denver Zoo, animal care managers created two mixed-species pairs of gibbons so that none of them are housed alone, with the goal of providing social opportunities to reduce stress levels. One pair includes a female white-cheeked gibbon *(Nomascus leucogenys)* and a male golden-cheeked gibbon (*Hylobates gabriellae),* and the other pair consists of a male golden-cheeked gibbon and a female siamang (*Symphalangus syndactylus*).

In order to determine if the two mixed-species pairs at Denver Zoo exhibit affiliative behaviors as frequently as same-species pairs, the results of this study will be compared to same-species gibbon pairs at the Oakland and Sacramento Zoos. The Oakland same-paired species exhibited affiliative behavior 12% of the time, and the Sacramento Zoo pair displayed affiliative behavior 7% of the time (Warren, 2010). The pair at the Oakland Zoo were housed at an island enclosure, while the male and female gibbon at the Sacramento Zoo lived in a large cage structure. Comparing the behaviors of these two same-species pairs to Denver Zoo's mFixed-species pairs can help care managers determine the welfare of their gibbons (Warren, 2010).

There is a scarcity of research about mixed-species gibbons interacting with one another; therefore, it is important to study whether or not housing mixed-species gibbons at Denver Zoo together may be more beneficial to their well-being compared to housing them alone. This will help managers establish if socializing gibbons from different species improves their overall welfare. If mixed-species pairings are considered a healthy pairing, they should display similar percentages of affiliative and aggressive behaviors to same-species pairs. I predict that the mixed-species pairs of gibbons will spend at least 10% of their time engaged in affiliative behavior (mating, grooming, being-groomed, and food-sharing) and 1% or less of their time in aggressive behaviors similar to the percentage of behaviors exhibited by same-species pairs compiled from multiple studies (Sussman, Garber & Cheverud, 2005). Similarly, conspecific pairs in multiple primate species spend a majority of their day in close proximity to one another (Sussman, Garber & Cheverud, 2005). Therefore, I also predict that the two mixed-species pairs at Denver Zoo will remain in proximity more frequently than apart. Finally, I predict that the two mixed-species pairs will engage in equal or greater percentages of affiliative behaviors compared to same-species pairs at the Sacramento and Oakland Zoos.

Methods

Study Species

The two mixed-species pairs of gibbons studied at Denver Zoo included the golden-cheeked gibbon and the white-cheeked gibbon pair (Pair 1, Figure 1) and the golden-cheeked gibbon and siamang pair (Pair 2, Figure 2). The female white-cheeked gibbon and the male golden-cheeked gibbon were introduced to one another in 2017 when the female's mate died. The siamang and golden-cheeked gibbon were introduced to each other in 2018. At Denver Zoo, the adult members of the two mixed-species pairs only interact with one another as they are the only members of the group, similar to if they were in the wild.

A comparison of percentage of behaviors that are deemed affiliative within an activity budget to gibbons in other zoos will be conducted. Therefore, I compared the mixed-species pairs at Denver Zoo with two same-species of white-handed gibbons (*Hylobates lar*) at the Oakland and Sacramento Zoos. Instantaneous scan sampling was used to collect data on these two pairs and affiliative behavior was called social in this study, with no aggressive behaviors mentioned.

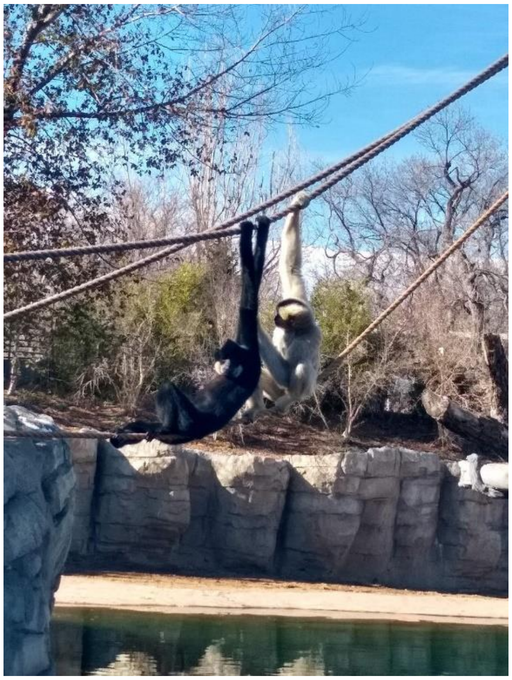

Figure 1: The male golden-cheeked gibbon (left) being groomed by the female white-cheeked gibbon (right) in their enclosure.

Figure 2: The female siamang (left) and the male golden-cheeked gibbon (right) sitting in close proximity to one another in their enclosure.

Study Site

I conducted this study at Denver Zoo in Colorado in the Toyota Elephant Passage (39 ° 74’96.88” N, -104°95’05.38” W) and the Primate Panorama (39 ° 45’03” N, -104°57’34” W). The enclosure for Pair 1 has three islands connected by rope with enrichment activities and trees on each island (Figure 3). The gibbons in this enclosure are able to view the one-horned rhino (*Rhinoceros unicornis*) in the enclosure adjacent to theirs, as well as the Asian elephants (*Elephas maximus*). Pair 2 live in the Primate Panorama on the far western side of the zoo. Their enclosure consisted of trees and vegetation and is surrounded by mesh (Figure 4).

Figure 3: Pair 1 enclosure in the Toyota Elephant Passage.

Figure 4: Pair 2 enclosure in Primate Panorama.

Data Collection

Another researcher and I collected data on these mixed pairs of gibbons from November 2018 to December 2019, for a total of 36.7 hours on Pair 1 and 33.7 hours on Pair 2. We observed each individual gibbon for thirty-minute focal samples, collecting data on aggressive and affiliative behavior, as well as proximity, at each minute mark (Table 1). Aggressive behavior included kicking, biting, and scratching towards their counterpart or a zoo visitor or researcher. Affiliative behavior included playing, grooming, being groomed, mating, food share, and approaching behaviors (Table 1). We also used all-occurrences sampling to collect data on aggressive behaviors and mating because of the rarity of these behaviors. Proximity was defined as 0-1 meters apart, while 1+ meters was considered not within proximity. When the focal subject was out of view (OOV), proximity was not recorded.

Table 1: Ethogram of gibbon behavior.

Behaviors for Scan Sampling	**Definition**
Play (Affiliative)	Includes chasing, wrestling, interacting with object with conspecific without obvious intent to do harm or display dominance
Groom (Affiliative)	Picks through partner's hair or skin with hands or mouth.
Being groomed (Affiliative)	Partner picks through focal subject's hair or skin with hands or mouth
Mate (Affiliative)	Includes mounting, intercourse, sexual presentation
Approach (Affiliative)	Moves within 1m of other individual conspecific who does not turn away or yield ground
Food Share (Affiliative)	Feeds simultaneously on same food item; hands or receives food item to/from other individual
Aggressive	Includes fighting, hitting, kicking, biting, lunging, attacking, supplanting, etc.
Other	Any behavior not otherwise specified in ethogram
Out of View	Focal animal cannot be seen or cannot be distinguished from other individuals

Data Analysis

I compared the proportion of the total amount of affiliative behavior between the two gibbons with the total amount of aggressive behavior using a proportion test in R (R Core Team, 2019) and a paired t-test to determine whether the difference between the percentage of time spent in affiliative and aggressive activities was significant. I also conducted a proportion test to determine whether the gibbons spent significantly more time in proximity (0 meters, 0-1 meters) compared to time spent greater than one meter apart. I then compared the percentage of affiliative behaviors with the pair of white-handed species of gibbons at the Oakland and Sacramento Zoos described above (Warren, 2010).

Results

Pair 1 spent 23.4% (95% CI: 21.64-25.21) of their time engaged in affiliative behavior (Figure 5). Pair 1 engaged in only 1 aggressive behavior, or 0.04% (95% CI: 0.002-0.2) of the time, showing that the gibbons engaged in affiliative behaviors significantly more than aggressive behaviors (p value < 0.0001, 95% CI: 0.215-0.251). The male and female gibbon spent 50.7 % (95% CI: 48.06-53.5) of the time in close proximity.

Pair 2 spent 1.67% (95% CI: 1.18 – 2.36) of their time engaged in affiliative behavior and was 3.45% of the time (95% CI: 2.72-4.36, Figure 6) engaged in aggressive behavior, all of which was displayed by the male; this difference, however, was not statistically significant (p-value = 0.9, 95% CI: -0.008 – 0.007). The male gibbon and female siamang spent 13.79% of the time in close proximity (p value < 0.0001, 95% CI: 0.122-0.154).

Comparing these two mixed-paired species pairs to same-species pairings at other zoos, Pair 1 spent 11.4% more time in affiliative behavior than the white-handed gibbons at the Oakland Zoo, who only displayed affiliative behavior 12% of the time, and 16.4% more than the gibbons at the Sacramento Zoo who displayed affiliative behavior 7% of the time. However, Pair 2 spent 5.33% less time in affiliative behaviors than the same-species pair at the Sacramento Zoo and 14.73% less than the gibbons at the Oakland Zoo.

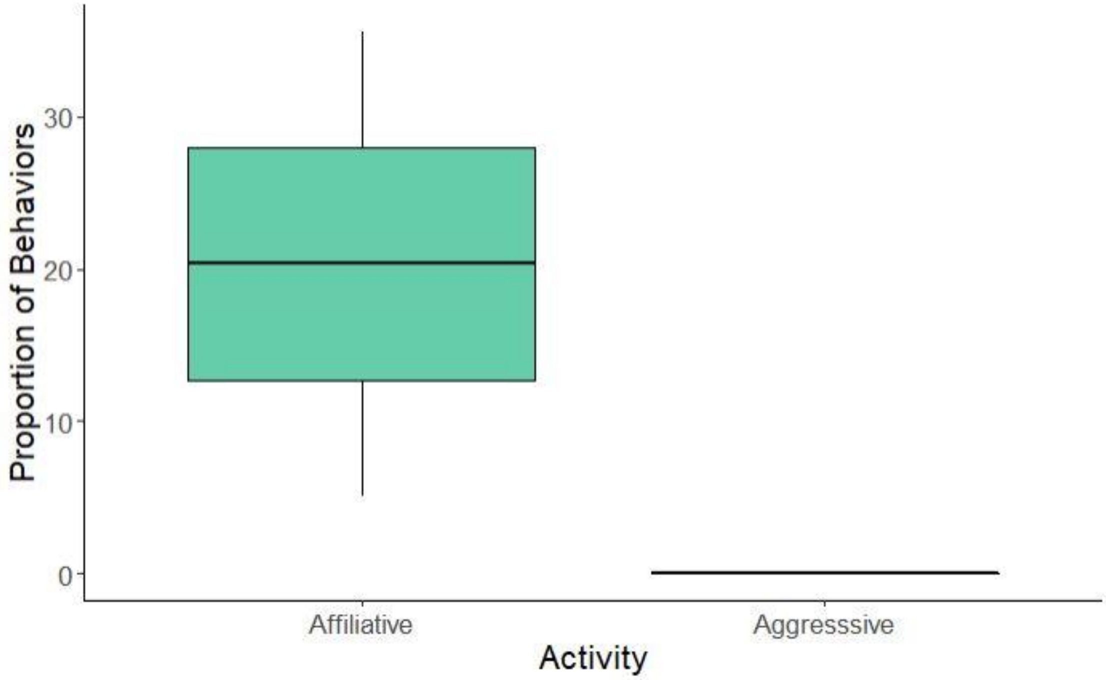

Figure 5: Proportion of affiliative and aggressive behavior conducted by Pair 1

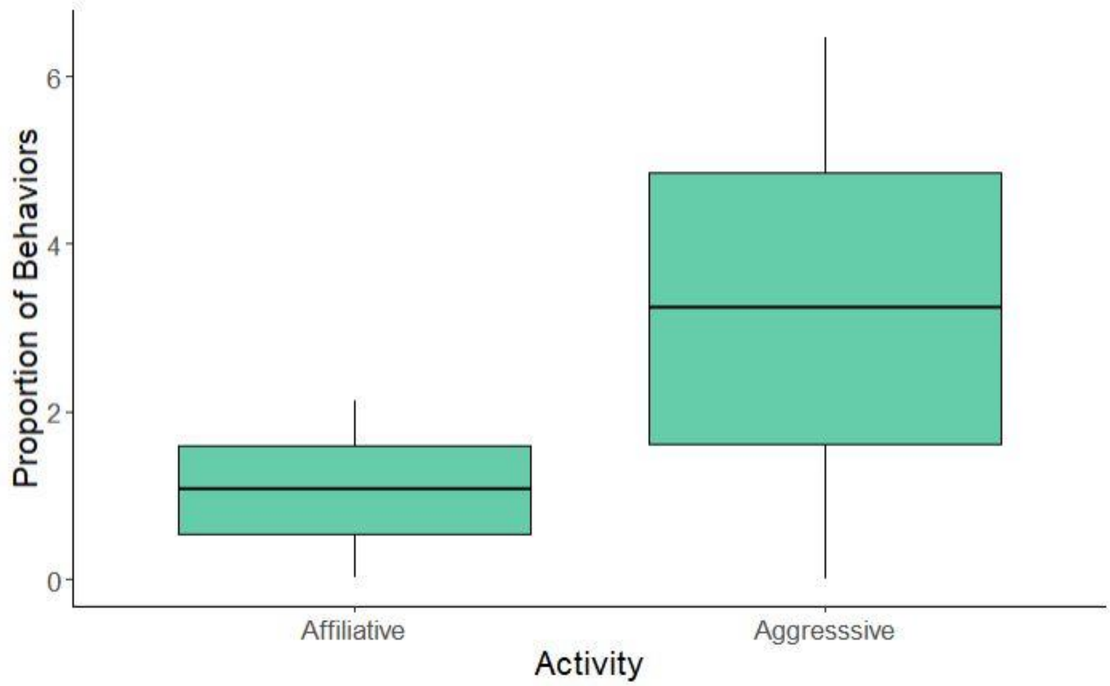

Figure 6: Proportion of affiliative and aggressive behavior conducted by Pair 2

Discussion

Pair 1 spent more time engaged in affiliative behaviors than aggressive behaviors. As predicted, they spent more than 10% of their activity budget in affiliative behaviors and less than 1% of the time in aggressive behavior. Furthermore, Pair 1 remained in proximity more frequently than being more than one meter apart, supporting my second prediction. Pair 2, however, spent less than 10% of time being affiliative with one another and more than 1 % of the time engaged in aggressive behavior. Additionally, Pair 2 did not spend more time in close proximity than time spent more than one meter apart. Therefore, my two predictions were not supported for Pair 2. Finally, when comparing the affiliative behaviors of the same-species pairings at the Oakland and Sacramento Zoos to the two mixed-species pairs at Denver Zoo, only Pair 1 had a higher percentage of affiliative activity compared to the two same-species pairs at the Oakland and Sacramento Zoos. Pair 1 supported my hypothesis while Pair 2's percentage of affiliative behavior was lower than both the pairs at the Oakland and Sacramento Zoos.

One reason affiliative behaviors were observed more in Pair 1 than Pair 2 could be because of the differences in rearing between the two pairs. Both the male and female in Pair 1 were reared by gibbon parents, while the male golden-cheeked gibbon in Pair 2 was human reared. Parental rearing is important for the development of the immune, endocrine, and nervous systems, but can also form the foundation of later development for social affiliation and communication (Simpson et al., 2019). So, depending on the gibbon and their rearing history, social behaviors may differ and explain the aggressive behaviors from the male gibbon in Pair 2.

Pair 1 had a high percentage of affiliative behaviors compared to Pair 2 and same-species pairs in other zoos. The higher percentage of affiliative behavior could be caused by the group size of visitors to the gibbons' enclosure. Pairs of white-handed gibbons at the Metro Toronto

Zoo and Bowmanville Zoo were found to increase grooming behaviors when visitor group size increased (Cooke & Schillaci, 2007). Pair 1's enclosure allows for a large group of people to view the gibbons, and this large group of people could increase grooming behaviors. Noise level and viewing group size can significantly impact behavioral responses such as communicative behaviors and may suggest a need for social bonding when large groups accumulate (Cooke & Schillaci, 2007). So, increased affiliative behavior may be a sign of increased stress from zoo visitors and more research could be done to determine if higher group numbers impact the levels of grooming on Pair 1's behaviors.

Although Pair 2 engaged in more aggressive than affiliative behaviors, the acts of aggression were never towards one another. The majority of aggressive actions were by the male gibbon towards one of the data collectors. This skewed the data, making it seem like there were frequent signs of aggression, when they only occurred when that data collector was present. This may have occurred because the data collector was female and the male gibbon became very focused on females he saw regularly, such as the female zookeepers. This also affected the proximity data because the male gibbon followed around the data collector. Given all of the aggressive behavior was aimed at the data collector and not the female siamang, the gibbon and siamang displayed no behavioral stress because of one another.

The two same-species pairs of gibbons at the Oakland and Sacramento Zoos had similar enclosures to each mixed-species pair, which removes enclosure environment as a confounding factor. The Oakland Zoo gibbons live on an island enclosure similar to Pair 1, and the Sacramento Zoo gibbons inhabit a large caged enclosure similar to Pair 2 but with less vegetation. The Oakland Zoo gibbons exhibited 5% more social activities compared to the Sacramento Zoo gibbons, while Pair 1 also had higher affiliative behaviors compared to Pair 2.

This shows that with different environments, the mixed-species pairs will alter their behaviors (Cooke & Schillaci, 2007; Warren, 2010). Smaller enclosures create more abnormal behaviors (Mallapur & Choudhury, 2003), and environments that have more terrestrial space allows gibbons to exhibit more species-appropriate behaviors, allowing them to interact with their enclosure and decrease aggressive behaviors (Anderson, 2014).

My results are also similar to studies of same-species gibbons at other zoos. At the Lincoln Park Zoo on the white-cheeked gibbons found that they spent only 2.9% of the time socializing (Lukas et al., 2002), far less socialization than Pair 1 and similar to Pair 2. This shows that there can be a wide range of social behaviors depending on the pair studied. Another study on black-crested gibbons in a nature reserve of 129 ha was found to express 1.2 % of their time playing, however these gibbons had a wider range of habitat, so they were able to locomote and forage more than gibbons in zoos (Fan et al., 2008). These studies further suggest that habitat and habitat size need to be considered that may impact affiliative and aggressive behaviors.

Same-species gibbon pairs have exhibited a higher percentage of aggressive behaviors in other zoo studies compared to the aggressive behavior conducted by the mixed-species pairings. The Perth Zoo held two groups of gibbons—one of silvery gibbons (*Hylobates moloch*) and one of white-cheeked gibbons, but these acts of aggression took place in larger groups housed together (Burns, Dooley & Judge, 2011). The two groups contained four gibbons and with both the highest percentages of aggression occurred between the adult male and subadult male. The higher percentage of aggression suggests that the adult male had to continuously display dominance to the sub-adult (Burns, Dooley & Judge, 2011). The Lincoln Park Zoo white-cheeked gibbons pair showed lower percentage of proximity than Pair 1 and similar percentages as Pair 2, with only 3.8% of their time in proximity to one another and 5.4% of the time in physical contact (Lukas et al., 2002). Pair 1 spent 50.7% of their time in proximity

Pair 1 also spent more time engaged in affiliative behavior than the average wild gibbon. All species of gibbons in the wild spend an average of 4-6% of their energy budget grooming (Brockelman, 2009). Pair 1 had a higher percentage of affiliative behavior compared to gibbons in the wild, while Pair 2 percentage of affiliative behavior was slightly lower; however, gibbons in the wild need to focus on searching for food more than gibbons in captivity. Their need to spend more time foraging for food, compared to gibbons that are fed in enclosures, creates less time for gibbons in the wild to socialize (Anderson, 2014).

This study was limited to the two mixed-species pairs of gibbons' outdoor enclosures. Behaviors that the mixed-species pairs conducted indoors may have altered the results because of the closer quarters compared to their outdoor enclosure. Because the mixed-species pairs indoor area is a smaller area, gibbons would have had to spend more time in closer proximity with one another. This also restricted data collection because gibbons were only in their outdoor enclosures when the temperature was above 40 degrees Fahrenheit. Colder temperatures may have altered behaviors, increasing resting time and spatial proximity to one another in order to stay warm (Fan, Fei & Ma, 2012). It was more difficult to observe Pair 2 because the focal subjects were out of view from certain angles, so a greater proportion of scans were "out of view" compared to Pair 1. The behavior of the gibbons during these out of view data points are unknown; it is possible that they engaged in affiliative behaviors during many of these times because these areas can be quieter and are away from the public (Lukas et al., 2002).

Such results suggest that socializing across gibbon species benefits gibbons; therefore, mixed-species pairing should be considered as a management technique. This will decrease their levels of stress from lack of social interactions compared to if they lived alone and may be as beneficial socially as same-species pairings because they need social interactions, so, mixed-species pairs living together is a viable alternative to gibbons living alone. Although the cohabitations mixed-species pairs at Denver Zoo were a success, the pairings of mixed-species should be attempted on a case by case basis. Enclosures with more space and trees will create a less hostile environment, and mental health caused by rearing of the primates, should be considered before action takes place. Overall, mixed-species pairing of gibbons should be considered as a care management technique.

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CHAPTER 4. STAKEHOLDER ANALYSIS: STATE CONTROL OF GRAY WOLF (*CANIS LUPUS*) MANAGEMENT PLANS- A CONCERN FOR THE FUTURE GRAY WOLF POPULATION

Gray wolves (*Canis lupus*) were reintroduced into Yellowstone National Park in 1995 (National Park Service, 2020a). After fourteen wolves were brought into Yellowstone National Park from Canada (Sanders, 2020), wildlife enthusiasts were thrilled to see and hear this iconic species in its native environment, and biologists were afforded an opportunity to test what happens when predators are reintroduced into an ecosystem (BBC, 2014). The wolf population grew to include 94 wolves and expanded into Idaho, Montana, and Wyoming thereby making the reintroduction of wolves a success (National Park Service, 2020b). However, the reintroduction of wolves was a matter of great dispute because of the polarizing views of different stakeholders towards wolves. Naturalists felt wolves symbolized the beauty of the untouched West, but ranchers believed wolves threatened their livelihoods because wolves were violent and aggressive predators of livestock (Mission:Wolf, 2018). Now that the wolf population has rebounded, plans to manage the wolf population must be crafted. Wolves do not care about state lines and can travel thirty miles in a day (National Park Service, 2017). Wolves need a single biologically-based management plan rather than a politically-driven plan subject to competing stakeholder ideologies within each state. The gray wolf population needs to be managed under one plan. Having one management plan for the entire ecosystem will ensure that the wolf population in Greater Yellowstone will remain stable.

Temporary patterns in gray wolf abundance in the Yellowstone area reflect shifting wolf management policies during the last century. In the early 1900s, Yellowstone managers allowed hunters to hunt gray wolves without limit thereby diminishing the wolf population. By 1926 the last wolf pack was killed and only a few wolves remained in Yellowstone (National Park Service, 2020a). Since that time, the gray wolf population had declined throughout the United States to such a degree that gray wolves were listed as endangered under the Endangered Species Act (ESA). By placing the gray wolf on the endangered species list, the federal government took control of its management. A population managed under the ESA remains under federal control until the population stabilizes and is deemed recovered. Once an endangered species is delisted, states control its management once more and craft their own specific recovery plans (U.S. Fish and Wildlife Service/Endangered Species Program, 2020). The management of gray wolf populations shifted between federal and state control multiple times in the areas surrounding Yellowstone National Park. From 2005-2009 the gray wolf was delisted and relisted numerous times because environmental groups fought to reinstate wolves under the ESA on account of wolf population declines (Alderman, 2009; National Park Service, 2020a). Environmental groups argued that these declines threatened genetic diversity in wolf populations because Yellowstone wolves were effectively disconnected from surrounding populations (Alderman, 2009; National Park Service, 2020b). In 2011, Congress delisted gray wolves as an endangered species in Idaho and Montana, removing wolves from federal protection under the ESA (Idaho Department of Fish and Game, 2019). Wyoming followed shortly after and removed wolves from the endangered species list in 2017. Although the number of gray wolves has stabilized in these states, the history of the gray wolf going on and off the endangered species list means that the wolf populations in these states are not being consistently managed (National Park Service, 2020a).

Inconsistent management strategies caused by this continuous back-and-forth between jurisdictions has resulted in an unstable and fluctuating wolf population (National Park Service, 2020). Removing the wolf from the endangered species list and federal management allows states to issue hunting licenses for wolves, but these laws are becoming more lenient as states control wolf management for longer periods of time. Each state gradually changes its wolf management plan, making it more challenging to manage the wolf population consistently across multiple state plans that differ in management approach. Therefore, state management plans should be reassessed with the goal of instituting a common plan for all states surrounding Yellowstone. If the state plans prove to be inadequate to protect the wolf population from substantial declines, federal regulation should be reimplemented, or all states' plans should manage gray wolf populations throughout its range in Greater Yellowstone.

Key groups disagree about how to manage the gray wolf population because of their diametrically opposed viewpoints on wolves. Trying to find a solution that pleases everyone is difficult. Because their income relies on prey hunted by wolves, stakeholders such as hunters and ranchers strongly support management policies that lower wolf abundance. Hunter advocacy groups have lobbied that wolves should remain off the endangered species list and be taken under more permissible hunting regulations. Hunters have argued that wolves decrease wildlife, including elk, that hunters prize around the Yellowstone area (Bohrer, 2005). Although hunters argue that elk populations have fluctuated and declined since the reintroduction of wolves (National Park Service, 2020c), studies in Yellowstone have found that elk populations may have declined more so from hunting than wolf predation (Staff, 2007). Hunters fear that re-assessing management plans may reduce the number of licenses that are given out each year for hunting wolves.

Ranchers also argue for a smaller, highly controlled gray wolf population because wolves prey upon cattle, resulting in a loss of income. The ranchers would like to keep wolves off the endangered species list and increase the flexibility of hunting laws because wolf predation results in annual losses of $6,679 in profits (Chaney, 2014). In states around Yellowstone, flexibility would allow ranchers to protect their livestock by hunting wolves without a hunting license if cattle deaths could be definitively linked to wolf predation. Although ranchers receive compensation from state funds or the federal government for dead cattle (Missoulian, 2015), proof that wolves killed cattle can be difficult to ascertain because cattle deaths by wolves may be indistinguishable from other causes such as exhaustion and internal bruising (Thomas, 2018). Idaho, Montana, and Wyoming combined have six million heads of cattle, a high source of income for the area; therefore, an increase of wolves would potentially mean more cattle deaths for ranchers, thereby decreasing their income (Living with Wolves, 2020).

Not only do state legislatures need to listen to ranchers to develop Fish and Wildlife laws, but they must also solicit other public input, often disproportionately from their most vocal constituents. Montana and Wyoming have among the highest rates of hunting participation compared to other states, and hunters are one of the constituents legislatures are trying to appease by changing hunting laws (U.S. Fish and Wildlife Service, 2007). When wolves were delisted in Idaho, Montana, and Wyoming, these states had similar management plans to each other. Now, as time has progressed, each state's management plan has diverged, taking different approaches to easing hunting regulations. Enacted legislation in these states have relaxed restrictions on wolf hunting, thereby impeding wolf recovery. A bill in Montana recently passed to decrease the price of hunting licenses (Missoula Current, 2019), while in Idaho a bill has been proposed to make wolf hunting season year-round (Russell, 2020). In Wyoming, increased hunting of wolves resulted in the lowest wolf population size since management was taken over by the state in 2011 (Associated Press, 2019). Eighty-five percent of the state is considered a “predator zone,” where wolves can be hunted without limits (Koshmrl, 2017). In Idaho, each hunter can kill up to 20 wolves in a year (Preacher, 2019). There are no recent updated management plans for Idaho and Montana, and Idaho has not counted its wolf population since 2015, suggesting that these new management regulations are untested. As time has progressed since federal control of wolf populations in Idaho, Montana, and Wyoming ended, growing inconsistencies among state management policies increase the likelihood of gray wolf population declines.

The most obvious agency that wants to implement a consistent management plan across state lines is the National Park Service (NPS). The NPS supports a thriving wolf population because wolves benefit the ecosystem in indirect ways. Yellowstone National Park favors management goals that include a robust wolf population maintained by increased hunting restrictions. Since the reintroduction of wolves in Yellowstone, elk populations have stabilized from unsustainable levels and other species such as willows, aspen, and grizzly bears have benefited significantly from reinstituting top-down control in the system (Farquhar, 2019). Yellowstone managers cannot easily recreate the degree of top-down control maintained by a strong wolf population, therefore declines in the wolf population may threaten the beneficial changes brought about by their reintroduction (Fortin et al., 2005; National Park Service, 2020c).

The delisting of gray wolves can take a toll on the stability of the wolf population and top-down trophic cascades. Delisting wolves decreases the growth of the wolf population by fragmenting robust populations into smaller populations which cannot sustain themselves without outside help (Donovan, 2019). Decline of the wolf population also leads to a decrease in community biodiversity via trophic cascades, which cannot be easily restored by managerial actions (Ripple & Beschta, 2012). To mimic the ecosystem level effects of a natural predator requires a heavier and more costly hand in management by humans (Peterson & Douglas, 2003). In order to manage gray wolves to maintain their ecosystem services as a keystone predator, we must focus on one management plan for all the states around Yellowstone. A common management approach will likely have a longer lasting impact on Yellowstone wolves and will prevent declines both within the wolf metapopulation and the larger community to which the wolf belongs.

Yellowstone biologists and tourists alike similarly favor keeping wolves protected. By relaxing hunting restrictions, states in Greater Yellowstone ultimately altered wolf behaviors (Robbins, 2017). Increased wolf hunting in these states has prompted wolves to recognize and avoid people, making research on wolves more difficult for biologists within Yellowstone. When collared wolves are killed by hunters, research results can be significantly skewed due to the small sample sizes employed in radio collaring studies. For instance, humans were responsible for over half of the collared wolves killed in 2012, resulting in pack disbandment, making observing pack behavior difficult for researchers (Povilitis, 2015).

Local economies have benefitted from increased tourism since the reintroduction of wolves into Yellowstone (Staff, 2011). Educating tourists about wolves can not only indulge visitors' curiosities about wolves, but also helps visitors see wolves in a positive light (Staff, 2011). More education about the role of wolves in ecosystems will convince tourists that wolves are an integral part of keeping populations of elk, bison, and other populations stable. While campers, hikers, and bird watchers who come to Yellowstone National Park may differ in their reasons for visits, all groups of tourists benefit from a stable wolf population. The re-introduction of the wolf led campers and hikers to Yellowstone, and many people go to Yellowstone to create memories of a unique experience that involves wildlife, including wolves. However, wolf sightings dropped 45% after hunting in the states surrounding Yellowstone commenced, diminishing the overall experience of tourists who come to view wildlife (Robbins, 2017). Since the reintroduction of wolves, bird watchers in Yellowstone should encounter more birds because overbrowsing of vegetation by elk has decreased. As a result, vegetation quantity and quality has improved nesting resources and food for birds (Ripple & Beschta, 2012). Therefore, a variety of tourists—from campers to bird watchers—can have a positive experience because of the presence of robust wolf populations.

Another primary stakeholder in maintaining a strong wolf population are the Native American people who have inhabited the Yellowstone region for centuries. Gray wolves are sacred to Native American cultures (Koshmrl, 2017). Many Native American tribes believe that humans are closely related to wolves and that wolves symbolize courage and good hunting (Native Languages of the Americas, 2015). This suggests that the tribes around Yellowstone find hunting wolves disrespectful. Yellowstone National Park is associated with a coalition of 26 Native American tribes that has suggested a "no-kill buffer" zone around the park to protect the wolves when they move in and out of Yellowstone (Koshmrl, 2017). Having a buffer around Yellowstone would allow wolves to roam around freely, but overall, Native American tribes around Yellowstone are against management plans that kill wolves.

The stakeholders involved in the Yellowstone ecosystem are many and their input is equally important. Input from Native Americans, lovers of National parks such as campers and bird watchers, hunters, and ranchers is equally critical in building a plan that is endorsed by the public and therefore sustainable. I believe the best course of action is to reassess management plans of Idaho, Montana, and Wyoming and create one management plan that all states follow, whether it is under state or federal control. If management is not synchronized for all the states near Yellowstone, this may destabilize wolf packs in the future. The resulting fluctuations of the wolf population will disrupt the top-down control reinstated by wolf reintroduction, influencing all stakeholders who are focused on the management of gray wolves. Gray wolves benefit Yellowstone National Park's economy and enhance the experience of everyone within the National Park system. Hunting of wolves under a universal management plan would still be allowed but would be more consistently controlled, resulting in stable wolf populations that would benefit stakeholders who value an ecosystem that benefits from these predators. However, even with more stringent wolf hunting regulations, it is possible for stakeholders like hunters and ranchers to coexist without conflict because wolves can be managed in non-lethal ways. Hunters and ranchers alike are important in this management decision because of their heavy influence on legislatures that craft policies to protect or exploit natural resources. Despite the current differences in management approach among the states that comprise the Greater Yellowstone area, a common management plan is possible. As long as the population of gray wolves in the Yellowstone area is strong and unlikely to collapse, reassessing management plans and monitoring the wolf population in each state will allow Idaho, Wyoming, and Montana to create management plans that balance the needs of all stakeholders. Wolves need a consistent management plan that is based on biology, rather than one that focuses on politics which is subject to competing stakeholder ideologies within each state.

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