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Carlson, Craig M. ***A Literature Review of Golden Eagle Populations and Reproductive Response to Diet in the Uintah Basin.***

Abstract

The golden eagle (*Aquila chrysaetos*) is a large raptor with resident and migrant populations in many western states. It is a monogamous species that will typically only initiate a clutch once per year. Habitat, prey species population, and dietary breadth influence reproductive success of the eagle. Here, an examination of the cold desert habitat, specifically the Uintah Basin, Utah and the surrounding mountains of the Western Cordillera were considered. Populations of prey population decline explained by a bottom-up trophic scale species may determine fecundity rates in some populations, with resulting decline correlating to prey species abundance. This association of specific prey population decline and eagle reproductive rate decline was not witnessed in all studies reviewed. Volume of prey drives reproductive success beyond impacts of dietary breadth, which is beneficial during prey population down-cycles. This is especially true for paired eagles with direct correlation between reproductive success and prey abundance. High nest fidelity, regardless of prey population, encourages nesting pairs to return to established nests but impairs the eagles due to climate change, specifically increased temperatures that affect nesting success. Suggestions are provided for future research to ensure survival of these populations.

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Chapter I: Introduction

The golden eagle (*Aquila chrysaetos*) is a large raptor with protections under the Bald and Golden Eagle Protection Act and the Migratory Bird Treaty Act. The raptor has a wide range that covers most of North America during some part of the year. Populations occur in parts of Europe and Asia and is ranked by the IUCN Red List as least concern for extinction. This evaluation showing stability does not consider regional or habitat specific populations that are changing. Recourse from loss of local populations may not impact global populations, but a loss of a national symbol in cultures accustomed to the proud eagle will be impacted. Extirpation has the capacity to harm the animal as well as the community. As habitats change due to resource extraction, human disturbance, and invasive species introduction the golden eagle is challenged and could face local extinction.

This literature review is based on knowledge gained during the co-op experience. This occurred at the Vernal field office of the Bureau of Land Management where experience was gained working with the wildlife biologists of the Vernal field office as well as working with the Utah Department of Wildlife Resources' biologists and graduate students of Utah State University. While working with these groups a concern for golden eagle populations was often discussed. Some beliefs discussed were the impact of invasive cheatgrass to the prey species, the effect of climate change on the populations and resulting migration patterns and how a change in prey population could cause resident eagles to eventually relocate. Further challenges are faced from habitat loss and changes in wildfire frequency and increased temperature from cheatgrass (Stewart & Hull, 1949). The permanent loss of the species in this area would be detrimental to the Uintah Basin.

In this literature review, a case is made for further research to ascertain specific causes for possible decline of *A. chrysaetos* in the Uintah Basin. Ultimately, the goal is to provide for long-term stability of the local population and the species as a whole.

Statement of the Problem

The loss of a local population of golden eagles will harm the environment from a top-down food web consideration. These animals maintain a balance of various primary consumer populations and also remove carrion from the environment. Further harm will be done to local cultures with the removal of this species. The research questions for this review are: Is dietary breadth as important as volume to continue successful reproductive rates? Is there potential for climate change to harm both resident and migrant populations of the golden eagle?

Purpose of the Study

The purpose of this study is investigation of current knowledge regarding the golden eagle's diet and reproductive requirements. This high motility species can act as an indicator species for the impact of climate change if it is determined that climate change has altered the habitat or migration patterns substantially. Dietary needs may be the driving force behind reproductive success and this review examines the impact of volume versus quality and if one is more fundamental. Further, there will be a review of habitat needs and how climate change may be influencing the reproductive success of the species. Consideration will be given to potential differences between the resident and migrant eagle populations.

Assumptions of the Study

With this study, the following assumptions exist:

1. Golden eagle migrants may also leave the area if resident eagles leave.

2. Invasive cheatgrass will change the landscape and harm the environment further than has already occurred.
3. High nest fidelity will overcome dietary challenges, but may cause local extinction of resident species.

Definition of Terms

Terms and their definitions pertinent to the review:

Carrion. Deceased animal carcasses frequently termed "roadkill" although they may occur at any location of an environment.

Extirpation. Local extinction of a species with populations still occurring outside the immediate ecosystem or region.

Fecundity rates. A term for reproductive rate that explains the number of offspring produced.

High nest fidelity. The high probability that a species will return to a nesting site or area even if unproductive the previous year(s).

Invasive species. A species that is not native to the environment but is aggressive in reproduction and/or growth which may outcompete native species.

Lagomorphs. Taxonomic identification consisting of Leporidae (Leporids) and Ochotonidae.

Leporidae. Taxonomic family for rabbits and hares, also called leporids.

Lotka-Voltera Equations. A set of equations that explain how populations cycles of prey influence the population cycles of predators.

Mesopredators. A predator that preys upon other species and can also be preyed upon; not the top predator of an environment.

Ochotonidae. Taxonomic family for pikas.

Prey availability hypothesis. A hypothesis that considers the prey population (volume) to be directly linked with the population size of the predators consuming the prey.

Resource extraction. The taking of resources such as oil, natural gas and/or coal through mining or similar techniques.

Limitations of the Study

A large limitation of the study is the difficulty to quantify the impact of each challenge to the species. While it is known diet composition and quantity are of the utmost importance it is not yet known if a high volume of a lesser diet composition will sustain a species in a specific habitat. It is also known that invasive cheatgrass has increased the likelihood of high intensity wildfires which challenge the eagle, but it is not known if the challenge is long-term or if the eagle will return to a burnt nesting area the current or following year.

Methodology

Analysis of correlations between dietary breadth, reproduction and nesting. Sources explaining the challenges of diet volume to diet composition are reviewed. This allows for consideration of management styles to best maintain reproductive rates of the golden eagle. Further, there was a review of known heat-based fatalities to nestlings and the impact of climate change to migration and nesting.

Chapter II: Literature Review

In the Uintah Basin of Utah there is concern for potential future decline of golden eagles and successful nests. Speculation of causes varies, but the natural resources extraction and invasive cheat grass have caused a change in habitat. Further potential for temporary declines could be due to down-cycling of prey species, such as Lagomorphs. Lagomorphs consist of the families Leporidae (leporids) which are rabbits and hares and the family Ochotonidae which consists of pikas. Since lagomorphs are the preferred diet of golden eagles this can be detrimental to the eagle population. Prey size structure and availability can influence raptor populations. As optimum prey volume decreases, it increases necessary energy expenditure for hunting to acquire necessary nutrients to sustain optimal health. This increased cost likely also impacts reproductive rates of the eagles (Bedrosian et al., 2017). If the cost is too high for a specific prey species it should either adapt to alternate prey, thus increasing dietary breadth, or adjust hunting techniques to limit energy expenditure. In the case of *A. chrysaetos*, there is high nest fidelity, increasing the likelihood of annual nesting region returns even in the event of prey species decline.

Habitat Selection

Utah's golden eagle population prefers high cliffs with varied surrounding vegetation and mountainous terrain with pinyon-juniper forests. Some nests may be near stands of pinyon pine, juniper and sagebrush while others may have little to no ground cover and surrounded by other cliff bands. Since a nesting territory may be large, it is likely that pairs have multiple nests (Millsap, Grubb, Murphy, Swem, & Watson, 2015). The monogamous species has been known to move between initial and alternative nests (Millsap et al., 2015) but are believed to remain within a nesting territory due to overall nest fidelity. Preferred habitat in Utah has moderate to little ground cover required by prey in the cold desert, but can include forested mountainous terrain of the Western Cordillera (Bedrosian et al., 2017). Eagles will avoid non-sagebrush-steppe habitats in some studies (Domenech, Bedrosian, Crandall, & Slabe, 2015), but this may be population specific as exemplified in the Western Cordillera populations.

Vegetation plays a key role in determining distribution of raptors because it correlates to the requirements of prey species for food and/or shelter (Preston, 1990). When a nesting territory is established with most or all requirements for nesting and diet the eagles will maintain these nests and revisit alternative nests over thirty years later (Kochert & Steenhof, 2012).

Preferred habitat for eagles is likely also preferred by competitors relying on the same prey. Lyly et al. (2015) stated that ideal habitat will be shared between multiple predators (competitors), and smaller mesopredators may even become part of the eagle's diet. The home range, however, may be expanded as evidenced by Braham et al. (2015). After chicks fledge, each eagle pair may stray in various directions, branching from their primary area of occupation and possibly moving to different territory types such as aspen-conifer and away from pinyon-juniper.

Diet Composition

Primary eagle diet in the Uintah Basin consists of small mammals such as lagomorphs and rodents. This can include hares, rabbits, marmots, ground squirrels, and prairie dogs. Carrion is another food source as well as larger mammals such as antelope, but this is a smaller portion of the eagle's diet. Composition of sampled eagle diet is >50% lagomorphs and >20% rodents (Olendorff, 1976, p. 235); therefore, the vast majority comes from small mammals. Preference of diet has been established as jackrabbits in some studies, and this does not change regardless of prey density (Steenhof & Kochert, 1988, p. 37).

The prey availability hypothesis relating to prey abundance and/or ability to capture prey applies to this situation. As lagomorph 10-year population cycles occur, it will influence the eagles' ability to sustain the population. As the cycle declines on the lagomorphs down-cycle, eagles must be more efficient at capturing their prey. This could also mean expansion of diet to other species. Having an expanded diet should not drastically impact breeding productivity (Whitfield et al., 2009). With this consideration, prey density is the driving factor of breeding productivity and a sufficient volume of any prey will provide a positive result. Note that this does not mean the optimum or 'best' reproductive rates will occur with alternative prey. Bedrosian et al. (2017) determined that reproductive rates may suffer if primary prey population (leporids) is not maintained and the eagles resort to alternative diets.

Carrion consumption is supplementary to live prey but carries potential harms with consumption. One problem plaguing carrion consumption is the potential for lead poisoning from unclaimed game (Cochrane, Lonsdorf, Allison, & Sanders-Reed, 2015). In the Uintah Basin there is opportunity for carrion from small and large mammals. While most carrion is from natural causes or traffic fatalities, some is in the form of unclaimed game or gut piles potentially containing lead ammunition fragments. Golden eagles are susceptible to lead toxicity which can prove to be fatal at certain concentrations. Accumulation of lead can occur and causes additional challenges as the bird ages (Kelly et al., 2011, p. 5). This indicates potential for lead toxicity and potentially fatal concentrations as low as 5 $\mu g * g^{-1}$ for renal lead concentration (Wayland, Neugebauer, & Bollinger, 1999).

Impacts of Prey Density

Abundance of prey is a factor to the predator's population size, but the ability to capture the prey in the environment may also be a significant factor. According to Watson and Davies

(2015) who compared current diet analysis with historic data, there are successful populations with little to no leporid or sciurid (squirrel) inclusion in the eagle's diet. Opposing these claims, Steenhof, Kochert, and Mcdonald (1997) stated that leporid abundance may be a significant factor that influences successful nesting from the time of laying eggs until they are fledged eagles. Supporting Steenhof is information provided by Bates and Moretti (1994), albeit they found weak correlation between the rabbit population and eagle productivity. Prey populations driving reproductive success through bottom-up processes were also indicated from Schmidt, McIntryre, Roland, MacCluskie, and Flamme (2018) where direct association between fecundity and prey populations were discovered. These can be explained by Lotka-Volterra equations where prey populations have a correlation to reproductive eagle rates (Vlastimil, 2007).

Further, there is a difference between live prey and carrion and how it impacts the total population dynamic. Watson, Rae, and Stillman (1992) found that carrion impacts nesting density while live prey affects breeding success. Understandably, this may be linked to a preference for ideal sized prey and when extra energy expenditure is required for prey it may cause a decline in reproductive progress. Schweiger, Funfstuck, and Beierkuhnlein (2014) determined that if prey is too small the energy expenditure may be too great and the same with prey that is too large. This would impose a challenge for nesting with excessive energy usage to hunt and/or deliver the food to the nest.

Breeding and Nesting Response

Nesting can occur within a wide range of the raptor's territory and can include many nests. These nests are maintained even if they are not used each year, which indicates that pairs stay in the nesting territory for multiple years (Millsap et al., 2015). This is also concordant with the overall principle of high nest fidelity. Paired eagles may protect a nest for up to seven years but may frequently switch between nests in the pair's nesting territory quite frequently (Slater, Keller, & Knight, 2017). This migration consistency and nesting territory fidelity has caused genetic distinctiveness between populations that interweave during migration. Doyle et al. (2016) found that Alaskan eagles are distinct from other eagles that share the same territory, further reinforcing the concept of nest return.

Bates and Moretti (1994) described a correlation between rabbits in the area and fecundity rates. However, does not mean it is exclusive to lagomorphs, or specifically, leporids. Sciurids are also known to comprise a small portion of breeding eagle diets, but the overwhelming diet is provided by leporids (Bedrosian et al., 2017). Without mammals this size it may be a challenge for paired eagles to create a successful nest.

Migrant eagles play a key role in breeding and territory establishment. If an abundance of migrant eagles populate an area, it could force out resident eagles if dietary needs for successful breeding are already at risk. Further problems occur if there is insufficient preferred prey for the migrant eagles which will then cause them to also relocate. Millsap et al. (2013) determined that population size in the four studied regions were mostly stable, but that migrant eagles may be expanding their range to new areas. This can be explained as relocating when prey populations decline without range changes due explicitly to reproduction.

Migrant Eagles and Climate Change

Climate change has created additional challenges to the migrant eagle population by changing the ideal timing for nesting. Golden eagle migration is triggered by photoperiod activation (Lapoint et al., 2017) meaning that daytime length initiates time for migration. This unchanging factor is problematic when the temperature plays a key role in nesting. The study performed by Lapoint et al. (2017) shows that older birds are coupled more tightly to photoperiod activation and will maintain migration timing of previous years irrespective of other factors, such as changing temperature regimes. If the nesting time is not correct it could mean failure of the nest. Heat is a major contributing factor of nestling mortality as discovered by Beecham and Kochert (1975), “Possible heat prostration accounted for the largest number (17) of dead nestlings (41% of the mortality)” (p. 510). Indication of heat caused nestling fatality signals difficulty for the species, which migrate at the same time of year, but arrive to increased temperatures in the region. It is likely that resident eagles are also affected, but it is unclear if the nesting time is photoperiod-triggered similar to migration patterns.

Chapter III: Summary, Critical Analysis, Recommendations

The following chapter will summarize information found in the five sections of the literature review: habitat selection, diet composition, impacts of prey density, breeding and nesting response, and migrant eagles and climate change. Following the summary will be discussion of the author's critical analysis and recommendations for future research.

Summary

The research questions considered in this review were: Is dietary breadth as important as volume to continue successful reproductive rates? Is there potential for climate change to harm both resident and migrant populations of the golden eagle?

Following the review of literature regarding dietary breadth and volume, it is clear there is potential for successful reproduction with a diverse or limited scope of prey and that terrain may determine this factor (Bedrosian et al., 2017). With sufficient volume of prey even opportunistic and generalist style hunting behavior will result in survival. Some studies documented a correlation between lagomorph population and reproductive rates (Steenhof et al. 1997) and (Bates & Moretti, 1994), but this may be selective based on the population and habitat.

The habitat in the Uintah Basin is pinyon-juniper with stands of sagebrush and surrounding cliffs. There is much variation in the habitat between forested mountainous terrain of the Western Cordillera and sagebrush laden cold desert which joins to the cordillera. The differences in the terrain seemed to have direct influence over dietary staple where cold desert regions presented highest take of black-tailed jackrabbits with limited diversity and mountainous populations focused on rock squirrels (Bedrosian et al., 2017). The cold desert habitat potentially supports theories provided by Steenhof et al. (1997) that leporid abundance controls eagle populations but is refuted through the frequent prey of rock squirrels in mountainous terrain (Bedrosian et al., 2017, p. 351). Potentially there is a link for some habitats between leporid populations and the eagle population while other habitats with fewer leporids have eagle populations not controlled though leporid abundance. A study by Preston, Jones, and Horton (2017) identified their studied population as being prey abundance-dependent. This signals that in all populations, prey volume directly controls reproductive rates. However, some populations also yield correlations between specific prey abundance and reproductive rates. Topography is a further consideration as discovered by Crandall, Bedrosian, and Craighead (2015), “territories with higher ruggedness may not be as productive”. Although selected by the breeding pair for nesting, it may behoove habitat managers to consider other nesting areas that are less rugged to focus their efforts.

Diet volume, composition, and competition appear to be the greatest challenges for these eagles. With some form of prey, the eagles should remain productive although not at optimal levels. Since there is no control of migrant populations and prey cycles will continue to vary so will the reproductive success and population of the golden eagle in Utah.

After reviewing the literature on impact of climate change to both resident and migrant populations, it is clear there is potential effect to both resident and migrant populations. Exceptional challenges can be imposed on migrant eagles due to photoperiod trigger and the necessary journey to a nesting territory. This does not mean resident eagles are not challenged as both will suffer the increased temperatures that cause nestling mortality (Beecham & Kochert, 1975). Special consideration for nesting pairs must be given to afternoon direct sun exposure for the nests. This is believed to be the contributing factor (Beecham & Kochert, 1975). Further, as temperatures increase earlier in the year it will cause nesting to occur in already increased temperatures and thermoregulation problems may be exacerbated by direct sunlight exposure in some instances.

Critical Analysis

Reproductive rates are determined by prey species, but a large dietary breadth will not impose significant challenges to breeding productivity according to Whitfield et al. (2009). It seems that some studies oppose this. For instance, the work performed by Bedrosian et al. (2017) explained that reproductive rates may suffer if leporid populations decline. Other considerations are supplementary diet such as carrion. Watson et al. (1992) discovered a link between carrion and nesting density, but live prey impacts breeding success. The study performed by Watson may have a correlation between carrion and nesting density, but it is unlikely this is the primary cause. Prey population variance will occur and even during down-cycling of prey population the eagles remain in the established nesting territories.

High nest fidelity may cause nesting eagles to remain in the same nesting territory each year and continue to fail. Lapoint et al. (2017) explained the danger in that the species typically will not produce a second clutch if the first fails. This means the pairs nesting in an area may go one or more years without a successful clutch. Consequently, successful nesting is dependent on prey, but especially when thermoregulation of nestlings may be compromised by climate change.

Considerable impact is due to climate change affecting migration patterns, (possibly) nesting behavior of resident eagles, and likely to prey species as well. Encroachment of habitat from resource extraction and human disturbance will play a factor in the future of the species, but climate change may be the bane of Uintah Basin's eagle population.

Recommendations

Future research regarding diet composition and volume for the golden eagle in the Uintah Basin is critical to predict survival of resident and migrant populations of this area. Population cycles of prey species will occur and may differ based on territory such as the Western Cordillera compared to the cold desert. Examination of prey groups could be performed during down-cycle of mountainous prey species and if expansion of hunting territory occurs during these cycles. Does the prey population's down-cycle in the Uintah Basin result in reproductive distress or further expansion of dietary breadth? Determination of impact would include the effect of climate change as well as how invasive species such as cheatgrass are changing the environment. The indication of climate change stressing migrant eagles is now known (Lapoint et al., 2017), but further studies of resident eagle nest timing should be performed. Do resident eagles depend on photoperiod trigger for nesting or is there a different indicator to illicit a nesting response? Thorough answers to this question and others posed will provide managers with critical tools to ensure survival of this national symbol.

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