THE ROLE OF BEAVERS IN ECOSYSTEM RESTORATION AND THE ENVIRONMENT

by

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Dr. Jian Wang	Dr. Brian McLaren
Major Advisor	Second Reader

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ABSTRACT

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Key Words: wetlands, fragmentation of habitat, beaver dam, degeneration, aquatic organisms, beaver restoration project.

This thesis analyzes the role of beavers in ecological restoration and the environment. At the same time, it discusses controversies related to beavers and gives final recommendations. This paper analyzes the impact of North American and Eurasian beavers on wetland habitats and some species populations by consulting and integrating a large amount of literature data, and summarizes the importance of beavers to ecological restoration and their negative effects on the ecological environment. At the same time, this paper makes a further comparative analysis of these two influences. The results show that from the current situation of the fragmentation of biological habitats and the continued increase in the number of endangered species, beavers have the ability to build dams and carry out other actions to protect biological habitats from damage to a certain extent; however, considering the aggravation of forest land degradation, the beaver restoration project is not conducive to the improvement of the forest land environment, and it will also affect the growth of some aquatic organisms. Therefore, in order to promote the restoration of ecosystems by beavers and reduce the harm of beavers to related species, it is necessary to manage the population of beavers reasonably. This article provides a comprehensive literature on the role of beavers in ecological restoration and the environment, and at the same time it gives reasonable suggestions for the management and development of subsequent beaver restoration projects and lays the foundation for future ecological restoration programs.

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Many thanks to Dr. Jian Wang and Dr. Brian McLaren for being my advisor and second reader to guide me through this graduation thesis. With their help, I gained a higher level of knowledge about this research topic.

1.0. INTRODUCTION

As ecosystem engineers, beavers have been recognized by more and more ecologists. Moreover, people have a strong interest in their ability and methods to restore ecological habitats, especially wetland ecosystems. At present, with the degradation of forest land and the intensification of desertification and other factors, wetland, as a region with very rich biodiversity, is declining globally (Nummi 2020). Therefore, in recent years, people have begun to protect beavers and greatly reduce their trapping, while reintroducing them into the relevant ecological environment to restore the ecosystem (Malison 2016). In fact, the history between humans and beavers can be traced back to the 18th to 19th centuries (Small 2016). At that time, people hunted and killed beavers aggressively and used fur to make coats, which led to a significant reduction in the number of beavers. In the past few decades, people have gradually realized the importance of beavers for ecological restoration and begun to take corresponding measures to protect them (Small 2016). However, due to previous overhunting, the number of beavers has been severely reduced or eliminated. Although efforts have been made to reintroduce beavers into some areas, they are still scarce or absent in many river sections.

Beavers have significant impact on ecological restoration and the surrounding ecological environment. Beavers often build dams in streams, which provide important ecological services for aquatic and riparian ecosystems and enhance biodiversity, especially for some species such as water birds (Nummi 2014). Research has found that in wetland ecosystems containing beavers, the abundance and diversity

of waterfowl species are on the rise. For example, *common teal Anas crecca* and *green sandpiper Tringa ochropus* have the fastest increase in their numbers (Nummi 2020). Therefore, the beaver, as an ecosystem engineer, can lay the foundation for the development of the wetland waterfowl community. After beavers were introduced into agriculturally degraded swamps, the species richness of vegetation increased by an average of 46%, and the cumulative number of related species increased by about 148% (Law 2017).

These results are very meaningful for the restoration and development of the ecosystem. On the other hand, beavers have shown a negative effect on the ecological environment in some cases. Researchers surveyed the river ecosystem containing salmon and showed that beavers seriously affected the population of salmon in Kwethluk, and they led to a significant decrease in the number of young salmon (Malison 2016). In addition, through research, Malison found that the biomass of salmon in Kwethluk without the influence of beaver is three times that of salmon under the influence of beaver (Malison 2016). Moreover, beavers interfere with the growth and development of forest vegetation to a great extent (Nummi 2014). Therefore, beavers have different effects in different situations.

Because beaver populations are still scarce in some areas and they are an integral part of river ecosystems, some ecologists have begun to implement beaver restoration projects to increase the population of beavers. In this case, the choice of regions and environment to be implemented is very important. Before selecting the implementation area, researchers will observe the living places of some beavers.

Beavers tend to live in areas where streams are small and shallow enough, whether in the National Forest or Yellowstone National Park, and these areas are rich in willow trees (Figure 1; Ritter 2020). Therefore, through the investigation of relevant data, the researchers gave some conditions for the implementation of beaver ecological restoration. First of all, the project needs to be carried out in degraded river areas where beaver populations are sparse (Ritter 2020). At the same time, people need to evaluate the gradient of the river section, the width of the river and other environmental conditions to find the most suitable area for the project (Ritter 2020). Moreover, these areas must be far away from grazing areas, because the surrounding vegetation variables have a great relationship with the survival and development of beavers, and directly affect the progress and results of the project (Small 2016).

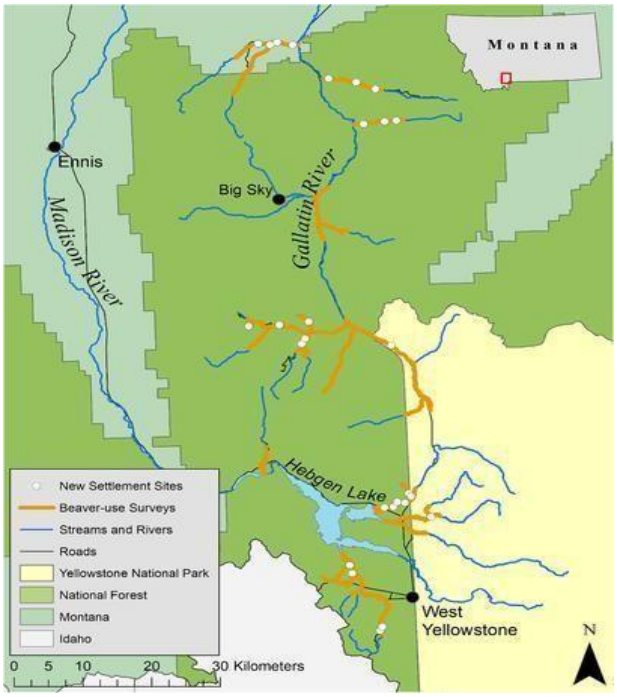

Figure 1. Streams with beavers in the upper Gallatin River and Madison River basin in the United States (Ritter 2020).

This thesis mainly conducts research from two aspects of positive and negative impacts, and analyzes the disputes arising from different viewpoints to help people have a deeper understanding of the role of beavers in ecological restoration and the environment, and manage the implementation of beaver restoration projects rationally.

1.1. Objective:

The objective of this thesis is to integrate and analyze the role of beavers in ecological restoration and their influence on the environment, to analyze and judge related arguments, and to further rationally manage the development of beavers and beaver restoration projects.

1.2. Hypothesis:

There is a debate here. Should the beaver restoration project be widely implemented to promote ecological restoration, or should we consider the current ecological environment and the population of some endangered species to slow down the development of the beaver? Based on the current impact and contribution of beavers on ecological restoration, I guess that the importance of beavers to ecological restoration is higher than its negative impact on the environment, and the beaver restoration project should be promoted.

2.0. LITERATURE REVIEW

2.1. Beaver and ecosystem engineer:

Ecosystem engineers are mainly organisms that can create, modify, destroy or maintain the habitats in which they live, and these organisms will have a significant impact on the species richness and heterogeneity of an area (WorldAtlas 2017). According to the introduction of the WorldAtlas website, ecosystem engineers are generally divided into two categories, allogeneic engineers and autologous engineers. Beaver is an allogeneic engineer, because it can change the environment by transforming biological or non-biological materials (WorldAtlas 2017). Due to these particularities of ecosystem engineers, they have become an indispensable part of the ecosystem and can help people improve habitat conditions and the ecological environment. On the other hand, the beaver, also known as *Castor canadensis*, is a herbivorous mammal, and it is the largest rodent in Canada and the second largest rodent in the world (Boonstra 2021). Moreover, beavers are one of the only mammals other than humans that can create their own environment and change environmental conditions through their own activities. Because it can change and create the environment, it has become an ecosystem engineer and it is a very important organism for the improvement of the wetland ecosystem. Usually, they build dams in streams and provide important ecological services for aquatic and riparian ecosystems and enhance biodiversity (Law 2017).

Because beavers and other ecosystem engineers have the characteristics of improving the ecological environment, people pay more and more attention to these

creatures, and begin to restore and protect some creatures, especially beavers. At the same time, people introduce these organisms into some ecologically damaged environments to repair and improve related environments and habitats.

2.1.1. The role of Ecosystem engineer:

Ecosystem engineers exist in various environments, and they strongly influence ecological processes, thereby affecting the distribution of species and resources (Baubin 2021). The role of ecosystem engineers in the ecosystem is very large. According to related studies, ecosystem engineers, perennial shrubs and ant nests can enhance the abundance of phototrophic, nitrogen cycle and stress-related genes in soil drought conditions (Baubin 2021). Moreover, for wetland habitat conditions, beavers, as ecosystem engineers, can increase the abundance and diversity of aquatic birds, and at the same time help restore the ecological environment and conditions of wetland habitats (Nummi 2020). What's more, ecosystem engineers can promote further species greatness by increasing the complexity of ecosystem processes (WorldAtlas 2017). In addition, ensuring that ecosystem engineers can also help stabilize the overall diversity of the landscape, which is also one of the importance of ecosystem engineers.

2.1.2. The hazard of beavers to the environment:

The destruction of forest tree species by beavers is also something that people need to pay attention to. According to Härkönen's research, the continuous expansion of beaver populations has caused severe forest damage in Finland, and the average

damaged area has reached 2.2 hectares. Especially some tree species with commercial value, such as Pinus sylvestris, Picea abies, were more severely damaged (Härkönen 1999). Therefore, the destruction of forest tree species by beavers and how to protect the safety of tree species when beavers are introduced need to be paid attention to. Moreover, beavers are not friendly to the development of some aquatic fish. Researchers conducted a lot of research on salmon in the Kol River in Kamchatka without beavers and the Kwethluk River in Alaska with beaver activities. They found that the presence of beavers seriously affected the development of salmon populations, especially threatening the survival of young salmon (Malison 2016). According to the results of the study, compared with the number of salmon in Kwethluk, the Kol River produces more salmon biomass and 40 times more individuals than the original number; while, due to the large number of beaver dams in the Kwethluk River, the salmon density is very low (Malison 2016). In addition, Eurasian beavers are very easy to carry viruses and parasites, and they are potential hosts for a series of infectious diseases and parasites (Girling 2019). At the same time, many infectious viruses are zoonotic, which is very detrimental to the growth and development of humans and other organisms (Girling 2019). In particular, they carry some of the highest risk pathogens, such as Cryptosporidium parvum, Eimeria and so on. These pathogens are very threatening to the health of humans and other animals, and can even cause death.

Therefore, before the introduction of beavers, a large number of safety inspections and health screenings are required to reduce the hazards of beavers to

humans and other organisms.

2.1.3. Intraspecific aggression:

Aggressive behavior is a very common phenomenon in animals. Usually aggressive behavior involves the behavior of an animal causing harm to another animal, and this kind of harm may be actual harm or potential harm (Huntingford 2019). Moreover, the purpose and method of aggressive behavior in males and females are also different. The aggressive behavior of males is mainly to compete for or protect territory, resources, etc., and achieve their goals through some threatening displays, fights, etc.; while, for most female animals, their purpose is simple, just to protect themselves and their children by carrying out threatening attacks (Campagna 2018). Therefore, biologists also divide the aggressive behavior between animals into two categories, predatory or antipredatory aggression, and intraspecific aggression is also included (Huntingford 2019). Based on the explanation of aggressive behavior, intraspecific aggression refers to an animal attacking another member of its own species. In addition, intraspecific aggression usually occurs in two or a few members, and generally does not involve larger animal groups.

2.1.3.1. Intraspecific aggression of beavers:

Beavers are monogamous territorial mammals, and they have a very strong sense of territory, which has a great influence on the number of beavers introduced (Boonstra 2021). Therefore, the researchers conducted investigations on Eurasian beavers and North American beavers on the phenomenon of intraspecies attack respectively to understand the aggression behavior within the beaver populations and the relationship between the population density of beavers and intraspecies

aggression. Through a large number of investigations, it has been found that nearly 50% of the beaver species in the beaver population have scars on their tails, which is a relatively high percentage for intraspecies aggression (Mayer 2020). At the same time, the relationship between intraspecific aggression and population density of Eurasian beavers and North American beavers is different. In Eurasian beavers, most intraspecific competition and aggression decreased with the increase of population density; while for North American beavers, intraspecific aggression and population density showed a positive correlation trend (Mayer 2020).

2.1.3.2. Cause of intraspecific aggression in beaver populations:

Beavers have a strong awareness of territorial resources, and the driving factors of intraspecific competition and attack are the acquisition and possession of territorial resources, which leads to a stronger reaction of beavers to intraspecific aggression (Mayer 2020). At the same time, this aggressive behavior is very important and can have a great impact on individual fitness and the growth and development of the species (Mayer 2020). Therefore, for these reasons, the frequency of intraspecific aggression in beaver populations is relatively high.

2.1.3.3. The harm of intraspecific aggression of beavers:

O'Brien et al. (2018) found in their investigations that the aggression and aggressive behaviors in the beaver population caused great harm to some individual beavers. They found multiple wounds caused by intraspecific attacks on an 8- to 10-week-old beaver, and because these wounds were not treated in time after being attacked, they developed multiple abscesses, and the two hind limbs have developed severe sensory loss (O'Brien 2018). In addition, according to the

study of Mayer et al. (2020), the intraspecific attack of beavers has an impact on the population and the surrounding environment. A large number of intraspecific attacks have caused mate changes, population declines, and unstable territorial possession patterns, which are unfriendly to the environment in which beaver populations live due to frequent changes (Mayer 2020). Therefore, the aggression within the beaver population has serious harm to the individual beaver, the population and the surrounding environment.

2.2. Ecological restoration:

There are plant, animal, and microbial communities in the ecosystem, and the ecosystem in which these communities are located may be destroyed or degraded by man-made or nature at a certain period of time (OMCAR Foundation 2021). In order to restore these damaged or degraded ecosystems to a sound state, ecological restoration has emerged. Ecological restoration is mainly to assist in the restoration of degraded or destroyed ecosystems while protecting the ecosystems that are still intact (UN Environment Programme 2021). Moreover, ecological restoration can promote richer biodiversity in the ecosystem and make the ecosystem healthier (UN Environment Programme 2021). Although ecological restoration can help restore the biodiversity, structure and function of degraded ecosystems, it cannot replace protection (OMCAR Foundation 2021).

2.2.1. Purpose of ecological restoration:

The main purpose of ecological restoration is to restore the damaged ecosystem to an intact state, and to enrich the biodiversity and species richness of related areas

(UN Environment Programme 2021). Moreover, ecological restoration work can well reduce the human impact caused by dam construction, and restore the natural state of the wetland and related biological communities as much as possible (Funk 2013). In addition, the secondary goals of implementing ecological restoration are biodiversity offset, water quality improvement, and social reasons, and the researchers found that the secondary reasons vary according to different stakeholders and regions (Hagger 2017). Hagger found through statistical data that the increase or offset of biodiversity is currently the biggest motivation for people to implement ecological restoration projects; while the driving factors provided by ecosystem services such as water quality improvement and social reasons are only the motivation for a small number of stakeholders to carry out ecological restoration projects.

2.2.2. Ecological restoration in wetlands:

The wetland ecosystem is the best natural environment for long-term storage or emission of greenhouse gases such as carbon dioxide, and it is also a source of methane emissions (Mitsch 2012). Moreover, the wetland ecosystem is rich in biodiversity, such as water birds, fish, and so on (Nummi 2014). Therefore, wetland is a very important ecosystem to ensure biodiversity and provide ecosystem services such as carbon sequestration. However, the current wetland area is decreasing globally due to the progress of desertification, forest degradation, and habitat fragmentation (Nummi 2020). In order to protect the wetland ecosystem and prevent the area from continuing to decline, ecologists have begun to conduct ecological restoration studies on wetlands, and people have also begun to implement a series of ecological restoration projects on wetlands. In this process, people discovered that

beavers can help restore wetland habitats by building dams and other actions (Small 2016). Therefore, the introduction of beavers as ecosystem engineers in wetland ecosystem restoration projects is very conducive to the process of ecological restoration.

All in all, the role of wetland ecosystems on the environment and biological communities is very important, and in order to protect biodiversity and endangered species, it is very necessary to implement ecological restoration projects on wetland ecosystems.

2.2.3. The importance of beavers in ecological restoration:

As the area of wetlands is declining on a global scale, beavers, as natural agents of wetland ecological restoration projects, are gradually being introduced by more and more land managers to restore hydrological functions, increase biodiversity, restore the integrity of habitats, and reduce the impact of extreme weather on water balance and ecosystems (Romansic 2021). Therefore, the beaver is very important for ecological restoration, especially for the wetland ecosystem. The researchers studied the biological richness and diversity of seven species of waders and ducks in Southern Finland ponds containing beavers. The results show that whether it is waterfowl or duck, the number and abundance of species in each pond each year will be much higher than the number and abundance before beaver activities (Nummi 2014). At the same time, in subsequent investigations, Nummi found that the *common teal Anas crecca* and *green sandpiper Tringa ochropus* were the most responsive species. Moreover, due to the restoration of ponds by beavers, the biodiversity of

waterbirds in this area is also increasing (Nummi 2020). In addition, beavers can build dams to create large and deep pools with long water cycles, which is conducive to the survival, development and reproduction of aquatic and semi-aquatic species (Romansic 2021). Romansic and other researchers have studied the relationship between beaver dams and pond amphibians in the southern part of the Washington Cascade Range of the north-west USA, and concluded that Rana aurora and Ambystoma gracile are abundant in areas with beaver dams, and they reproduce in large numbers; while, it is difficult to find these two creatures in areas without beaver dams.

Therefore, beavers are very important to the progress of ecological restoration projects by increasing biodiversity and providing ecological services.

2.3. Beaver restoration project:

The beaver restoration project mainly refers to trapping and relocating beavers or introducing them into areas where they can repair and protect related ecosystems (USU Restoration Consortium 2021). Usually beaver restoration projects are implemented in degraded river systems with little or no beaver activity (Ritter 2020). The main purpose is to use beavers to restore the ecology of the relevant areas and provide corresponding ecological services for the ecosystem, while increasing biodiversity (Small 2016). At present, the beaver restoration project is being implemented by more and more researchers and land managers, especially in some native areas of North America or Eurasia where the climate is dry (Romansic 2021). Furthermore, research has shown that both Eurasian and North American beavers can contribute to the conduct and realization of beaver restoration projects, although they live in different conditions (Mayer 2020). Therefore, in order to promote the

restoration and development of global wetland ecosystems, researchers will reintroduce North American and Eurasian beavers during the implementation of beaver ecological restoration projects, and treat their restoration capabilities and results equally.

2.3.1. Location selection of the beaver restoration project:

The selection of the site of the beaver restoration project is very important, because it will not only affect the progress of ecological restoration, but also affect the development of the beaver population. Usually the site selection of beaver restoration projects will be researched and screened based on the suitability of the habitat (Ritter 2020). Ritter and others conducted a survey of beaver activities in streams in the upper reaches of the Missouri River in southwestern Montana, USA, to assess the habitat conditions required for beaver restoration projects (Ritter 2020). They showed that the river section of the new habitat selected in the implementation of the beaver restoration project needs to have a relatively low gradient ($\beta \pm SE = -0.72 \pm 0.27$), a narrow channel ($\beta = -1.31 \pm 0.46$), and high channel complexity ($\beta = 0.76 \pm 0.42$), high canopy cover of woody riparian vegetation ($\beta = 0.56 \pm 0.21$), and low-lying areas directly adjacent to the river ($\beta = 0.36 \pm 0.24$), where β represents the size of the covariate effect (Ritter 2020). In addition, beaver restoration projects should be implemented in some areas without grazing or some areas with grazing management (Small 2016). Small explained that grazing affects the relationship between vegetation variables and the existence of beavers, especially willows (Small 2016). Willow is a necessary vegetation for beavers when building dams, so its availability is a very important variable for the existence and development of beaver dams (Small 2016).

However, grazing will destroy the symbiotic relationship between beavers and willows, which will seriously affect the development of ecological restoration projects (Small 2016).

3.0. MATERIALS AND METHODS

3.1. Literature and data:

The main research objects of this thesis are two kinds of beavers, the North American beaver (*Castor canadensis*) and the Eurasian beaver (*C. fiber*), and in-depth exploration of their impact on the surrounding environment and ecological restoration. In Figure 2, I find that these two beavers are in completely different states. Figure (a) shows the population density of Eurasian beavers in different river regions, and Figures (b) and (c) show the population density of North American beavers in lakes and ponds. Through the analysis of the line chart, although the population density of Eurasian beavers increased during a certain period between 2010 and 2015, the density was rapidly declining after 2015; while for North American beavers, although the population density from 2013 to 2014 was very low due to unreasonable hunting, the population density was on the rise after 2015. Additionally, although the density declined in 2018, the trend thereafter is still rising. Moreover, the population density of North American beavers greatly exceeds that of Eurasian beavers. Genarally, from these three pictures, it can be found that although the density of beavers in North America is increasing, in order to better introduce beavers for ecological restoration, the beaver population still needs to be managed reasonably and the hunting needs to be greatly reduced, especially for Eurasian beavers.

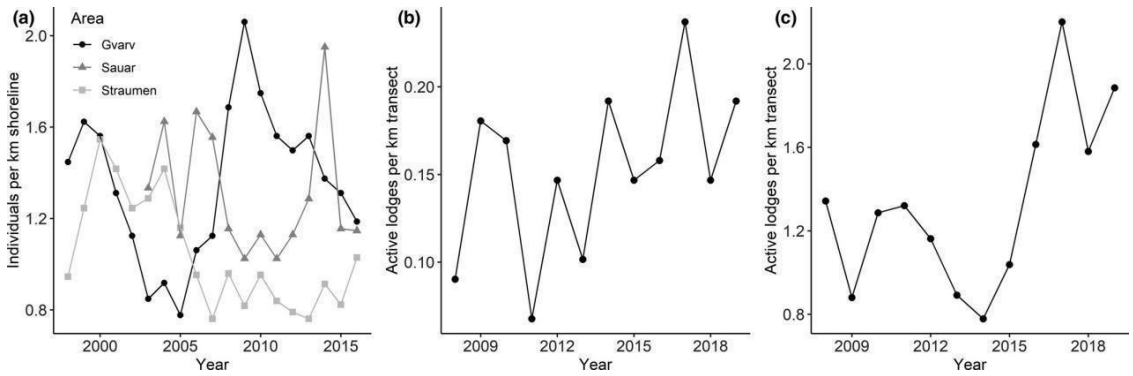

Figure 2. Line graph of population density of Eurasian beaver and North American beaver over time (Mayer 2020).

What's more, through reading a wide range of relevant literature and website information to understand the role of beavers in the environment and restoration. In the relevant information, the author has defined the beaver and ecological restoration, and also analyzed the negative impact of the beaver on the environment and the positive effect on ecological restoration. Figure 3 shows a conceptual model of the effect of patch productivity on the species richness of waterfowl communities. It can be clearly found that too low or too high patch productivity is not conducive to the development of species richness. According to Nummi's survey of beavers in wetland ecosystems, in ponds without beavers, the invertebrate abundance index averages around 40 (Nummi 2008). By observing Figure 3, this value is relatively low and is not conducive to the development of waterfowl communities and biodiversity. However, the invertebrate abundance index reached 280 in the pond in the Evo research area where beavers live, which is a very large improvement (Nummi 2008). For the index of 1250, it makes the richness reach the highest point, but this result only exists in the eutrophic lakes of eastern Finland (Nummi 2008). Therefore, it is not difficult to see from this picture that the positive effect of beavers on ecological

restoration is very huge. In addition, the authors have clarified the location of the beaver ecological restoration project in order to better realize ecological restoration. In order to fully explain the influence of beavers, I provide a comparative case of salmon development in the Kol River in Kamchatka, Russia without the influence of beavers and the Kwethluk River in Alaska under the influence of beavers, and another example of the positive effects of beavers on amphibian development in Washington Cascade Range of the north‐west US. Moreover, I have conducted different literature readings and integrations for the different situations of North American beavers and Eurasian beavers for the universality and accuracy of the conclusions.

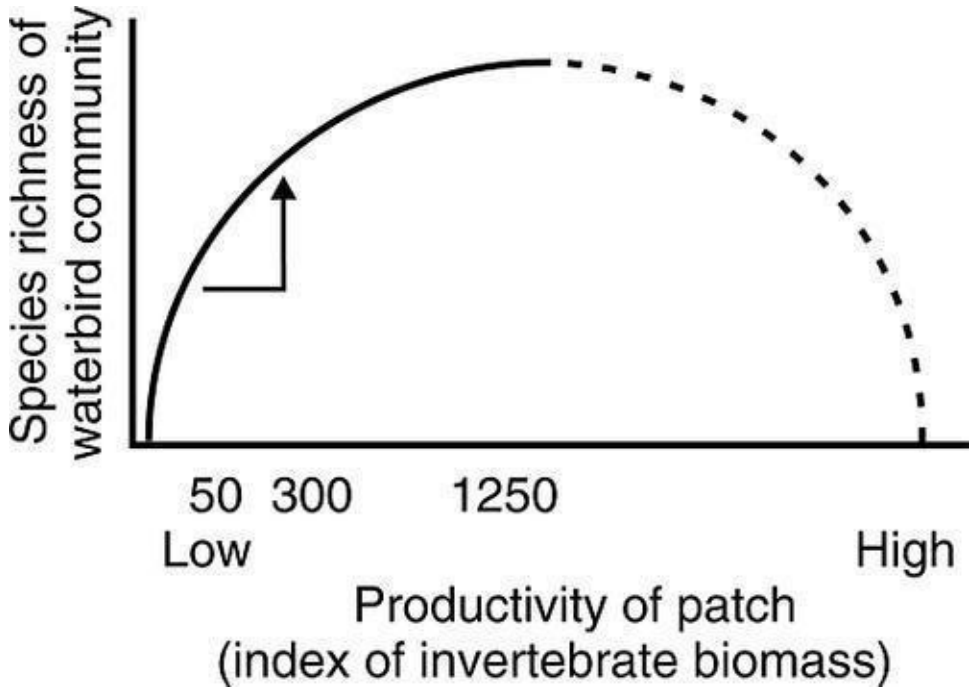

Figure 3. The relationship between species richness of waterbird community and index of invertebrate biomass (Wright 2004).

3.2. Literature search and analysis:

I mainly searched and reviewed the relationship between beavers and ecological restoration projects and the importance of ecological restoration under the influence of current environmental problems to further understand the role of beavers. Moreover, by reading relevant literature and integrating and categorizing the data on the impact of beavers, I conducted a comparative analysis of the positive impacts of beavers on the abundance of waterfowl populations and the biodiversity of aquatic organisms in the restoration of wetland ecosystems, and the negative effects of beavers on some special creatures such as salmon and trees to measure the pros and cons of introducing beavers into the ecosystem. Finally, the relevant conclusions are drawn to prove the previous conjecture, the importance of beavers to ecological restoration is higher than its negative impact on the environment.

4.0. RESULTS

4.1. Debate about beaver:

Based on the information reviewed and related reports, it is easy to draw a conclusion that people have different opinions on whether or not to carry out a beaver restoration project, which has led to the emergence of a debate. Some researchers, such as Romansic, Nummi, etc. believe that the introduction of beavers is very beneficial to ecological restoration and development, and they strongly encourage beaver restoration projects; however, for Malison and some public opinion, beavers have adverse effects on some ecological factors, such as some fish and tree species, so they do not agree with the reintroduction of beavers into related ecosystems.

4.1.1. Supporter's point of view:

According to the content shown in a large number of data, most researchers are more inclined to encourage the reintroduction of beavers, and through a large number of experimental research results, the role of beavers in promoting ecological restoration is explained from various aspects such as ecosystems, biodiversity and biological richness. Based on relevant experimental results, the introduction of beavers has a great effect on the development and restoration of aquatic and riparian ecosystems, especially wetland ecosystems, such as providing important ecological services, increasing biodiversity and richness, and so on. These advantages play a key role in solving or mitigating current environmental problems and climate change. Moreover, Mayer indicated that both the Eurasian and North American beavers can greatly aid in the restoration of ecosystems such as wetlands (Mayer 2020).

First, the positive impact of beavers in various ecosystems is most evident in the increase in biodiversity and species richness. According to Law's research on beaver reintroduction experiments, after ecosystem destruction, reintroduction of beavers and continued investigation of various environmental factors led them to find that vegetation richness increased by 46% over the 12 years, and the accumulation of all investigated species increased by 148%, which has extremely important implications for ecosystem restoration and subsequent development. At the same time, the frequency of natural disasters, such as floods and droughts, has also decreased significantly due to a significant increase in plant cover and a decrease in species indicative of high nitrogen (Law 2017). Moreover, beavers can not only improve vegetation richness but also promote the development of other organisms in ecosystem restoration, especially for waterfowl and amphibians (Nummi 2014).

Nummi has found in more than ten years of research that beavers can well affect the biodiversity and richness of waterfowl in wetland ecosystems, and even after the introduction of beavers, two waterfowl species have been added to related research plots, *Mallard Anas platyrhynchos* and *wigeon Anas penelope*. Therefore, the reintroduction of beavers not only lays the foundation for the cyclic management of waterbird communities, but also becomes an extremely critical measure for the creation and restoration of wetland ecosystems. In addition, the establishment of beaver dams can maximize ecological benefits in the corresponding ecosystem, which can help people to minimize ecological and management costs for ecosystem restoration projects (Romansic 2021). Furthermore, beavers can facilitate the reproduction and development of amphibians by building dams. Romansic's findings

showed that amphibians were more likely to live in areas with beaver dams and were 2.7 times more abundant in species richness than undamped areas. Especially for Rana aurora and Ambystoma gracile, their occupancy greatly increased under the influence of beavers.

According to Figure 4, the figure mainly shows the richness of species at different growth rates in two areas with and without beaver dams. It is obvious to find that whether it is slow-growing species, variably developing species or the fast-growing species, areas with beaver dams have greater species richness, especially for slow-growing species and variably developing species. Moreover, the slow-growing species have the highest richness in the areas with dams; while, in the areas without dams, the fast-growing species are more abundant than the other two species. Therefore, the presence of beavers is even more important for these slower-growing species. In summary, beavers can well promote the improvement of various biodiversity and biological richness in the ecosystem, and then help ecosystem restoration to solve some environmental problems, which is one of the key reasons for researchers to support beaver restoration projects.

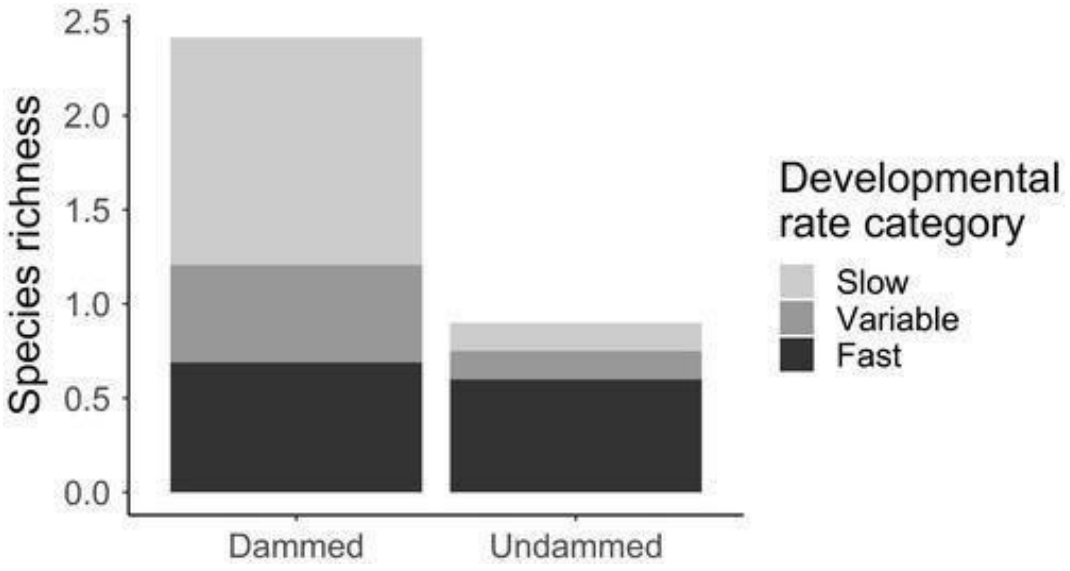

Figure 4. Species richness for dammed and undamped sites, and average number of species for each developmental rate category. The slow-growing species are northern red legged frogs etc., the variably developing species are long-toed salamanders etc., and the fast-growing species are Cascades frogs etc. (Romansic, 2021)

In addition, beavers can contribute to future ecosystem development and protect the state of associated ecosystems in ecosystem restoration. First, they can transform abandoned ecosystems into more species-rich, diverse and heterogeneous wetland ecosystems over time, which is important to address the current crisis of wetland loss (Law 2017). Furthermore, based on Law's findings, beavers play a critical role in water resources as well as in sediment storage and flow decay, a key approach to helping address wetland issues. Secondly, although beavers can destroy some vegetation and affect the growth and development of some trees, according to Small's content, they are in fact a symbiotic relationship with some tree species, such as willows, which shows that the two species can mutually benefit and develop (Small 2016). Therefore, it is not entirely correct to think that beavers continue to destroy and threaten trees and vegetation. In addition, beavers are extremely important for

aquatic ecosystem restoration and development because they can affect the depth of water in aquatic ecosystems and prolong water cycles (Romansic 2021).

Table 1. Statistical analysis of water depth in areas with and without beaver dams at different times in 2017 (Romansic 2021).

Time	Habitat variable	Undammed mean ± SE	n	Dammed mean ± SE	n	Test statistic	p
Early summer	Water depth (cm)	50 ± 11	20	187 ± 18	29	$F_{1,45} = 41.727$	<0.001
Midsummer	Water depth (cm)	14 ± 3	9	76 ± 12	11	NA	<0.001
Late summer	Water depth (cm)	11 ± 3	6 (9)	32 ± 7	8 (13)	$F_{1,8.6} = 6.78$	0.030

The content shown in Table 1 is simplified and integrated according to Romansic's research, and it mainly shows whether the presence or absence of beaver dams has an impact on water depth at different times. In this table, the times are mainly early summer, midsummer, and late summer, and the habitat variable is the depth of water in the aquatic ecosystem. SE is the standard error, and Mean ± SE is mainly used to express the distribution of the population mean. Moreover, n is the sample size, that is, the number of locations, and the values in parentheses are the total number of pools. Finally, the p-value is a parameter used to determine the results of hypothesis testing, and it is one of the most important factors in determining whether there is a relationship between dams and water depth. In addition, in this experiment, the α value was 0.05. According to Table 1, we can

clearly find that the Mean ± SE of the presence of beaver dams increases significantly, and the p value is less than 0.001 in early summer and midsummer, indicating that the presence of dams will closely affect water depth in these two periods. On the other hand, in late summer, although the p-value was 0.030, it was still less than 0.05, so there was still a relationship between beaver dams and water depth during this period. To sum up, beaver dams can indeed promote the increase of water depth, which is of great significance for the restoration and development of ecosystems, especially alleviating the threat and negative effects of drought on aquatic ecosystems. At the same time, the increase in water depth is extremely beneficial to the reproduction and development of most fish and amphibian species.

Therefore, based on the above viewpoints, beavers can not only promote biodiversity and richness, but also contribute to the protection and development of ecosystems, which are the main reasons why most researchers support the reintroduction of beavers to help people carry out ecological restoration projects.

4.1.2. Opponents' view:

However, not all researchers are very supportive of the reintroduction of beavers, and there are even some who still strongly hope that beavers can be driven out of parks and other ecological environments, due to their negative impact on trees and other wildlife. At a recreational park in southern California's Riverside County, near Lake Skinner, managers believed that beavers were constantly destroying trees and making the park's vegetation messy, according to related reports, so they announced that they would use the relevant license to trap these beavers, and in order to justify

the behavior and deter protesting tourists, they also claimed that the beavers have seriously affected the survival and development of a large number of characteristic birds (WORTH A DAM 2018). Proponents of the beaver restoration project disagree with these reasons, but opponents say it is entirely possible. Moreover, in the view of opponents, the development of beavers not only affects birds and vegetation, but also harms fish and their own populations, and even human health. Based on Malison's research, the impact of beaver introductions on salmon population densities is dramatic. Researchers compared the Kol River in Kamchatka, Russia, which is less affected by beavers, with the Kwethluk River in Alaska, which has a large number of beavers (Malison 2016). They surveyed each important habitat, like ponds, rivers, shoals of channels, etc., and found that in the salmon-dominated habitats, salmon densities were similar for all habitat types in the Kol; while for the Kwethluk River, salmon densities in ponds with high beaver densities were 3 to 12 times lower than in other habitats, which was very influential and severely hindered salmon development (Malison 2016). In addition, salmon densities in the Kwethluk River were consistently lower than those in the Kol River in any habitat (Malison 2016). Furthermore, according to Malison estimated, the Kol River produced 40 times more salmon than Kwethluk. It can be seen that the existence of beavers has a serious negative impact on the survival and development of salmon.

In addition, the population density of beavers not only affects other species, but even has a detrimental effect on their own development, especially intraspecific competition. Mayer conducted extensive surveys of the habitats of Eurasian beavers

and North American beavers, and conducted related research on intraspecific competition for factors such as beaver population density, age, and sex (Mayer 2020). He found that in large and concentrated habitats, such as lakes, the number of beaver tail scars is affected by population density (Mayer 2020). Moreover, in some habitats, intraspecific aggression continued to increase with increasing population density. These results are detrimental to beaver population development, and may even affect local beaver species richness, mate changes, and territorial occupation (Mayer 2020). Figure 5. is a good example of the effect of changes in beaver population density and age category on the number of scars on their tails. It is clear that higher population densities increase the frequency of intraspecific competition among beavers, leading to an increasing number of tail scars. In addition, intraspecific competition is more frequent with age, which is one reason for the increase in the number of scars on beavers' tails. According to O'Brien's research, intraspecific competition among beavers not only leads to an increase in the number of tail scars, but also leads to bacterial infection of many wounds, which can lead to secondary complications. This can cause them to develop symptoms such as sensory disturbances, and even some bacteria can be life-threatening (O'Brien 2018). Therefore, the researchers do not recommend introducing large numbers of beavers into ecosystem restoration projects.

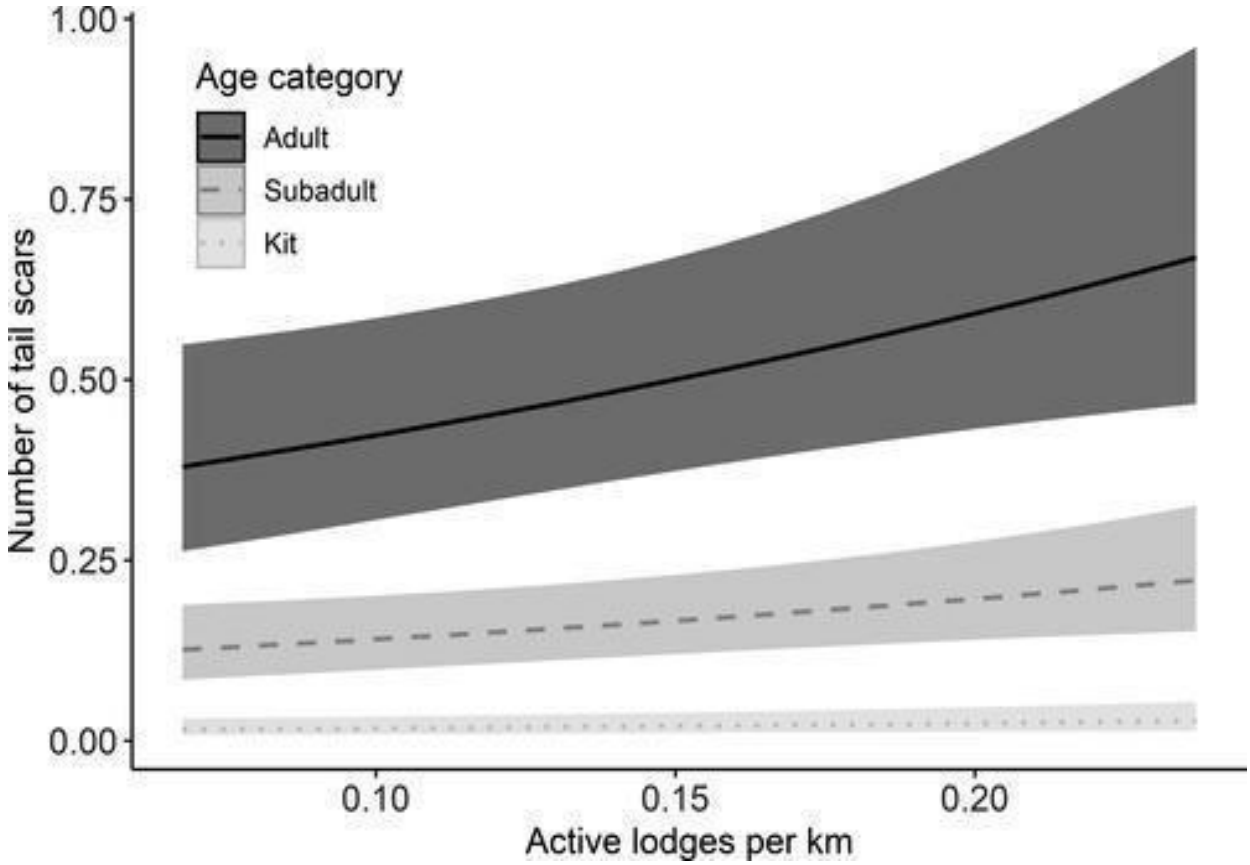

Figure 5. Effects of population density and age categories on the number of tail scars in North American beavers (Mayer 2020).

Additionally, the reintroduction of wild animals has adverse effects on social order and ecological norms while threatening the development of related species, especially human health and safety (Crowley 2017). Girling studied a large number of wild Eurasian beavers and found that wild beavers have a lot of infectious diseases and parasites, in other words, they are hosts of some viruses, bacteria and parasites (Girling 2019). Moreover, some of these infectious organisms are zoonotic, which means that these infectious diseases can threaten human health and safety through the introduction of wild beavers (Girling 2019). Although in European countries such as the United Kingdom, relevant personnel will conduct health checks on beavers before

reintroducing them and strictly prohibit the introduction of individuals containing high-risk pathogens, such as Cryptosporidium parvum, Salmonella spp. or terrestrial rabies virus, etc. (Girling 2019), there are still some low-risk wild beavers entering the corresponding ecosystem, which is also dangerous for human and ecological development. Therefore, the UK will strictly regulate the reintroduction of beavers in order to maintain ecological and political order.

In this case, some researchers oppose the implementation of beaver ecological restoration projects due to the adverse effects beavers have on other species, their own development, and human health and social stability.

5.0. DISCUSSION

According to the results described above and the views of the researchers, the implementation of the beaver restoration project is highly controversial. Considering environmental, ecological and species development factors, most researchers still support the reintroduction of beavers and more natural restoration of the ecosystem; however, there are still some opponents who believe that too much natural restoration will lead to a rapid increase in the number of beavers and affect ecological development. In this case, how well to measure and determine the positive and negative impacts of beavers is very important for the development of subsequent Beaver Restoration Project. It is critical to measure the relevant impacts especially from the perspective of nature as well as wildlife, since human's own views and interests are short-term.

As we all know, wetland ecosystems, as the best natural environment for storing and emitting greenhouse gases, continue to decrease in area around the world. Moreover, Mitsch stated in 2012 that the global wetland area only accounts for between 5% and 8% of the terrestrial landscape, which is very small and extremely detrimental to biodiversity development. However, these 5% to 8% wetlands still have a net carbon sink of about 830 Tg/yr carbon, averaging 118 gC m-2 yr-1 net carbon (Mitsch 2012). This shows that the wetland ecosystem is one of the key factors for the solution of global warming and climate change, so the restoration of wetland ecosystems is urgent, and beavers are one of the best ecosystem engineers to restore

wetland ecosystems. Therefore, in the interest of mankind, beaver restoration projects are very meaningful, because they can really help people change the status quo of the development of the earth's wetlands and bring benefits to climate change mitigation. However, for the wildlife perspective, there are both negative and positive effects here. Based on Malison's research, beavers have detrimental effects on salmon survival and development, and have been able to greatly reduce associated fish populations (Malison 2016). On the other hand, their presence also contributes to species richness and diversity in waterfowl communities and positively impacts amphibians and other fish species through the construction of beaver dams.

Based on measurement and analysis from both perspectives, and by integrating most sources and relevant information, I prefer to support the Beaver Restoration Project, and I think the presence of beavers is positive when they are good for more and bad for few. As mentioned by Law, beavers increase habitat heterogeneity and biological richness while converting abandoned agricultural land into species-rich wetland habitat (Law 2017). So reintroducing beavers into ecosystems has a huge capacity to help ecosystems recover, not destroy them. Moreover, it has been suggested that after the reintroduction of beavers, their biomass will continue to rise, leading to extensive destruction of vegetation and frequent interspecific competition. This is indeed an issue to consider, but in the natural state, in addition to the presence of beavers in the ecosystem, there are also their predators, such as wolves. As the keystone species in the ecosystem, wolves can well balance the number of beavers and some other species to protect the stability of the ecosystem (Garibaldi 2004).

Therefore, based on the presence of keystone species, beaver populations can be controlled in nature. In addition, human control and selection of introduction locations can also avoid explosive population growth in beavers. According to the Ritter report, the introduction of beavers into uninhabited or abandoned habitats not only allows beavers to promote ecological restoration in the area, but also effectively slows down the rate of beaver development. At the same time, researchers can calculate the complexity of the river channel, the canopy coverage of woody vegetation on the river bank, etc. to control the adaptation of beavers, which in turn affects the reproduction and development of beavers. On the other hand, Small's research showed that proper grazing can reasonably impede the symbiotic relationship between beavers and willows, thereby affecting beaver development. Therefore, beaver restoration project still requires effective human disturbance to achieve faster ecosystem restoration. In addition, for the parasites, bacteria and fungi carried by beavers, the United Kingdom has taken reasonable and effective measures, that is, strict health screening of introduced beavers and control of individuals containing high-risk pathogens. Although this does not guarantee entry of pathogens from low-risk individuals into human society, the measure has so far been very effective and has not caused serious human health problems.

All in all, for these reasons, I think the beaver restoration project is very meaningful for wetland ecosystem restoration and the solution of global climate problems.

6.0. CONCLUSION

In conclusion, by integrating the relevant information collected, beavers do have adverse effects on the development of some organisms and vegetation, but we still do not ignore the more benefits they bring in the process of ecosystem restoration. Moreover, as an ecosystem engineer, it can more beneficially help the destroyed ecosystem to restore, and even convert other abandoned ecosystems into wetland ecosystems and restore them. These roles are currently very important for solving or mitigating environmental problems and climate change problems.

In addition, although beavers can reproduce in large numbers and cause great harm to their own populations and vegetation after they are reintroduced into the ecosystem, researchers have the ability to understand the degree of adaptation of beavers by calculating corresponding environmental indices and other values, and then manage the beavers rationally to reduce intraspecific competition and protect most of the vegetation. Therefore, after the negative effects of beavers are properly addressed, their positive effects are critical to amphibian development and habitat restoration.

To sum up, based on the relevant information I have learned, I am more supportive that the positive impact of beavers on ecosystem restoration is greater than their negative impact on organisms and vegetation under certain human management.

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