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2019
MCM/ICM
Summary Sheet

(Your team's summary should be included as the first page of your electronic submission.)

Type a summary of your results on this page. Do not include the name of your school, advisor, or team members on this page.

We build a mathematical framework to measure the value of ecological services in an area intended for some land use projects. We use a composite coefficient set to indicate the status quo of the land before the project, considering various types of services in different mediums like air, water and land. Then, we use a logistic growth model to predict the impact of project to the value of the land.

The model was applied to three different cases, Kubuqi Desert greening, steel production by China Baowu Steel Group, and panda habitat Wolong National Nature Reserve. The results show that Kubuqi Desert greening increases the initial deficit value of local land to positive, and the model also informs the planners the “tipping point” for creation and maximization of value. The example of China Baowu Steel Group shows that the pollution exacerbates with more factories. Wolong National Nature Reserve does not have a significant impact to the original environment regardless of the area which agrees with the purpose of a nature reserve. This model suits various land types with modification of coefficients. However, the determination of these coefficients could be complicated in order to achieve an accurate number.

What is the Cost of Environmental Degradation?

Abstract

We build a mathematical framework to measure the value of ecological services in an area. We use a composite coefficient set to indicate the status quo of the landform before the project, considering categories of provisioning services, regulating services, cultural services, supporting services in different mediums like air, water and land. Then, we use a logistic growth model to represent the impact from implementing the project on the landform, which is exponential change limited by a carrying capacity.

We then apply the model to three cases, Wolong National Nature Reserve, China Baowu Steel Group, and Kubuqi Desert greening, representing different types of land use project: improvement, pollution and remedy, respectively. Finally we discuss the implication of this model to project planners, and suggest future research directions.

Keywords: ecological services, valuation, logistic growth model

1. Introduction

Ecological services are the various kinds of benefits humans receive from the natural environment and a properly-functioning ecosystem, such as the purification of air and water; nutrient cycling; resources like timber, fuel and fiber. However, natural ecosystems worldwide are under enormous pressure from human activities, especially from many land use projects. Therefore, it is important to remind people that the loss of these services will leave us worse off.(IUCN, 2005)

2. Assumptions

- The valuation model measures ecological services in monetary terms such that it will be efficient for project planners to use this model in the traditional cost-benefit analysis
- We define ecological service as the benefits human receives from the natural environment and a properly-functioning ecosystem freely
- We define valuation as the estimating the current worth of something
- We define land use project as the total of arrangements, activities, and inputs that people undertake in a certain land cover type, which can be categorized as

residential land use, commercial land use, industrial land use, agricultural land use, recreational land use, transport space, public land Use or open space, etc.

3. Defining the economic cost of land use projects

We define the true economic cost of land use projects to include and account for their impacts on ecosystem services. The impacts on environmental segments include but are not limited to:

- Surface water and groundwater pollution caused by detrimental contaminants dumping, water wastage, ineffective water recycling systems, etc.
- Soil pollution caused by industrial activities of the projects, which mainly result in poisonous man-made waste. The waste generated from the nature itself such as rotten plants and dead flora and fauna only increases the fertility of the soil, but the chemical waste poured by industrial land use projects, the mining activities and other land-use activities can be of great harm to the soil and therefore should be taken into account.
- Air pollution caused by industrial sources of emissions and air quality degradation due to human activities of sensitive land use, etc.

4. The model

To quantify the value of a land use project, framed as "value" (V), which is measured in monetary terms, we consider original ecological value (E) and influence from the implementation of this project (I). Also, we assume the value are uniform across the area of the project, therefore all above values are functions of area (A).

$$V(A) = E(A) + I(A) \tag{1}$$

To define the original ecological value E, we use a coefficient set each indicating the monetary value per unit area the chosen land should bring, which can be positive or negative.

$$E(A) = (\alpha_1 + \alpha_2 + ...) \cdot A_0 = \sum_i^n \alpha_i A_0 \tag{2}$$

where

- coefficient α_i is determined by corresponding metric for assessing ecological services (see section 5 for details).
- n is the total amount of coefficients.
- A_0 is the area of land planned to use.

To define the influence of implementation to the project value (I), we consider the phenomenon of accumulation of impact in an ecological system. Since an ecosystem is a complicated, interrelated system, an initial impact will lead to an exponential higher consequential impact. However, since the amount of ecological services cannot be infinitely high or infinitely low, the environment puts a limit on the exponential growth. Drew inspiration from Pierre-Franois Verhulst's population dynamics(Cramer, 2003), we formulate the I as a logistic growth function in the following way,

$$\frac{dI}{dA} = C_0 I(1 - \frac{I}{K}) \tag{3}$$

We can solve the logistic equation by separation of variables,

$$\frac{dI}{I(1 - \frac{I}{K})} = C_0 dA \tag{4}$$

$$(\frac{1}{I} + \frac{1}{K - I})dA = CodA \tag{5}$$

Then, integrate both sides,

$$\int (\frac{1}{I} + \frac{1}{K - I})dA = \int CodA \tag{6}$$

$$\ln I - \ln(K - I) = C_0 A + D \tag{7}$$

$$\frac{K - I}{I} = e^{-C_0 A - D} = De^{-C_0 A} \tag{8}$$

Rearrange to get the analytical solution of the I value,

$$I(A) = \frac{K}{Ke^{-C_0 A} + 1} \tag{9}$$

where

- C_0 represents the impact of the implementation of the project to the ecosystem. The magnitude of C_0 is the maximum per area rate of change to the value, which is a reflection of the extent of the ecological change the project will cause.
- K is the carrying capacity, which is the maximum ecological value change a particular project can cause. A negative K shows the project is polluting the ecosystem; a positive K indicates the project is improving the ecosystem, and when $K = 0$ the project is not affecting the ecological services of the land.

Therefore, we have the entire model: value of the project as a function of area, with coefficient set α and C_0, λ,

$$V(A) = \sum_{i}^{n} \alpha_i A_0 + \frac{K}{Ke^{-C_0 A} + 1} \tag{10}$$

5. Metrics for assessing ecological services value (coefficient set α)

To approximate the coefficients given due to various ecological services, we first define the term "ecological services" in more accurate categories. The categories below are similar to The Millennium Ecosystem Assessment (MA), a major UN-sponsored effort to analyze the impact of human actions on ecosystems and human well-being.(Board, 2005)

- Provisioning Services
  A provisioning service is any type of benefit to people that can be extracted from nature. Along with food, other types of provisioning services include drinking water, timber, wood fuel, natural gas, oils, plants that can be made into clothes and other materials, and medicinal benefits.

- Regulating Services
  A regulating service is the benefit provided by ecosystem processes that moderate natural phenomena. Regulating services include pollination, decomposition, water purification, erosion and flood control, and carbon storage and climate regulation.

- Cultural Services
  A cultural service is a non-material benefit that contributes to the development and cultural advancement of people, e.g. the building of knowledge and the spreading of ideas; creativity born from interactions with nature; and recreation.

- Supporting Services
  The most fundamental natural processes that allow the Earth to sustain basic life forms, such as photosynthesis, nutrient cycling, the creation of soils, and the water cycle. These processes are the basis for provisional, regulating, and cultural services.

6. Categorize types of land use project

With the above model, we are able to distinguish different situations of land use projects based on specifics of the coefficients, each combination of variables represents a type of land use projects.

1. positive coefficient set (+E(A))
   This indicates the original ecosystem of the land provides ecological services to people. This may be direct, like a supply of drinking water or timber; or indirectly like stabilizing the climate in the area.

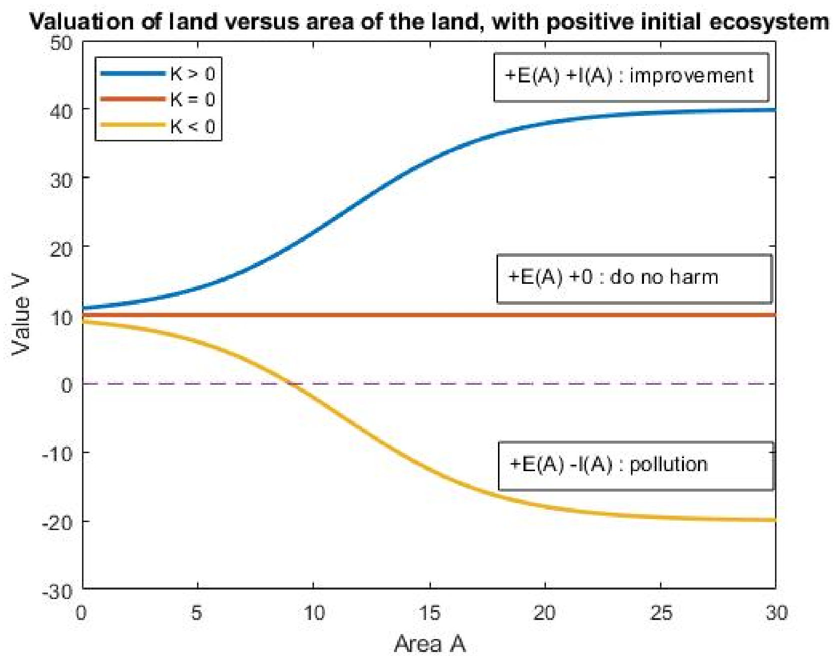

Figure 1: Positive initial system (+E(A))

- with negative K (-I(A))
  This is the most typical type of land use projects for commercial use, as the project is built for profit. The effect of the project will have different consequence for different stakeholders. An example may be a steel production factory near a river, if the investors are only interested in making money, they will probably avoid processing harmful emissions and polluted water, which will greatly jeopardize the original ecological services like drinking water source, clean air, and the biodiversity in the region.
- with neutral K (I(A) = 0)
  This type of land use project usually falls under open space or recreational land use, for example, a national park trying to preserve the natural view.

As the project is not for private use, it may maintain the status quo of the ecosystem, hence the value of the land will not change after implementing the project.

- with positive K (+I(A))
  This type of land use will take place when there is sufficient government funding or donations, as these projects try to enhance the ecosystem which needs a large amount of inputs of personnel and funding for nothing monetary in return. An example may be the establishment of Wolong National Nature Reserve in Sichuan, central China. To protect the endangered giant pandas, China Conservation and Research Center for the Giant Panda was established at Wolong with the efforts of both World Wildlife Fund (WWF) and the Chinese government, with funding primarily granted by the government. This reserve not only protects the giant pandas, but is also home to 4000 different species.(Liu et al., 2001)

2. negative coefficient set (-E(A))
   This indicates the original ecosystem of the land presents ecological deficiencies. For example, this may be an area of soil already polluted and needs cleaning to be reused, or this is a natural landform that can hardly be used. In this case, the value of the land is initially negative.

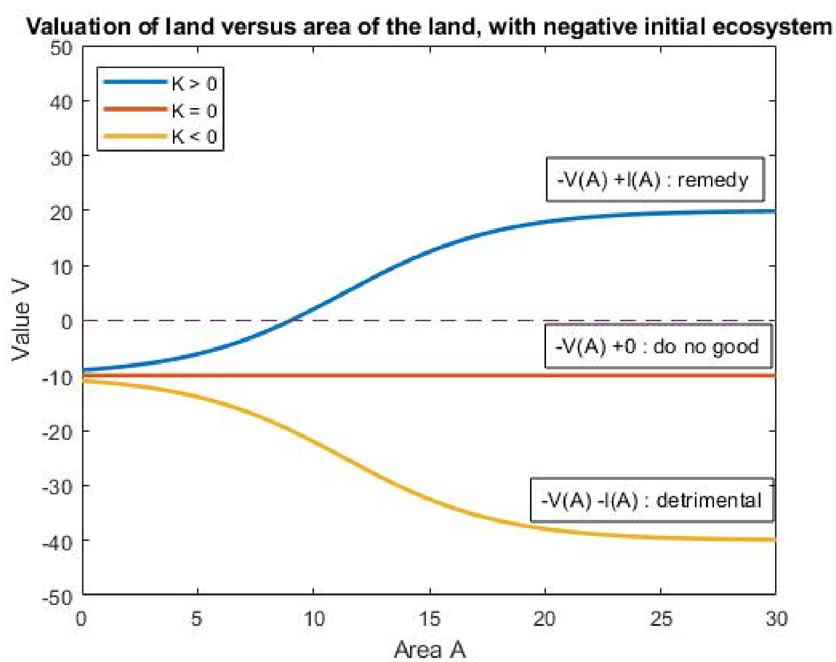

Figure 2: Negative initial system (-E(A))

- with positive K (+I(A))
  This type of land use is generally a kind of remedy or improvement. They are usually performed under the pressure of survival or a great altruism. An example is desert greening, a process of man-made reclamation of deserts for ecological reasons. Thar Desert in India remains dry for much of the year and is prone to soil erosion. High speed winds blow soil from the desert, depositing some on neighboring fertile lands, and causing shifting sand dunes within the desert, which buries fences and blocks roads and railway tracks. A permanent solution to this problem of shifting sand dunes can be provided by planting appropriate species on the dunes to prevent further shifting and planting windbreaks and shelter belts.(Berdell, 2011)
- with neutral K (I(A) = 0)
  Not many projects will be in this category in common sense. Since this project will not have any effect on the already negative ecological situation of the land. One possibility is the building of residential or commercial facilities in the city when the magnitude of the ecological deficiency is low.
- with negative K (-I(A))
  This type of project should be closely monitored by the local authority as they will potentially cause serious events detrimental to the local environment and people. The famous Great Smog of London can be an example of this category. London had suffered since the 13th century from poor air quality, which worsened in the 1600s. However, the energy released from the industrial revolution lures people to establish more and more factories, eventually leading to this notorious event that has the most significant effect of regulations afterwards.(Brimblecombe, 1976)

7. Case studies

In this section, we discuss three cases in detail, which are Kubuqi desert greening; steel production of China Baowu Steel Group; Sichuan Wolong National Nature Reserve.

7.1 case 1: Desert greening in Kubuqi desert, China

> Kubuqi Desert, positions at Inner Mongolias, spans around 18,600 sq km of golden sand. Centuries of grazing had denuded the land of all vegetation, and the regions 740,000 people were wallowing in isolated poverty. In 1988, the Chinese firm Elion Resources Group partnered with local people and the Beijing government to combat desertification. Almost three decades later, one third of Kubuqi has been greened. Special plants have been grown to grip the shifting sands and to prevent the dunes encroaching on farms and villages. (Campbell and BaoTou, 2017)

Figure (a): Satellite image of Kubuqi desert before greening in 2000

Figure (b): Satellite image of Kubuqi desert after greening in 2016

Figure 3: Comparison of kubuqi desert landform between year 2000 and 2016 (yu, 2017)

To evaluate the value of this particular land use project, we have to find the relevant coefficients first in order to apply the model. From the quote we know the area of the desert to be $18600km^2$, and 1/3 of the area will be around $6000km^2$. Before the project starts, we estimate the coefficient sum to be -0.8 for the natural condition of a desert, and the carrying capacity K to be 5000, C_0 value to be 0.002. Therefore, we have the following equation and plot,

$$V(A) = -480 + \frac{5000}{(5000e^{-0.002A} + 1)} \tag{11}$$

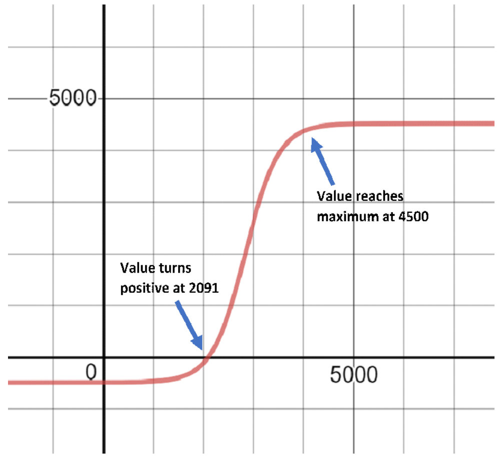

Figure 4: Applying the model to the desert green case

From Figure 4 above we can see that the project turns the value of the land to neutral (V = 0) when the area implemented is 2091 km^2, and brings the value to a steady maximum after area reaches 4500 km^2. As this project actually take around 6000 km^2, which is well above the maximum value amount. This implies this project will greatly improve the local ecosystem and boost the value of the ecological services there.

There is more to consider besides the ecological change itself. Turning a land of quicksand to stable, arable soil with plants covered will first significantly reduce the frequency of sandstorm, while at the same time preventing further desertification, enhancing biodiversity, and bringing some agricultural opportunities. To earn profits from the greening, people in Kubuqi are encouraged to grow licorice, which doesn not require much water and can be sold for large sums for use in Traditional Chinese Medicine (TCM). (Campbell and BaoTou, 2017) However, at the same time, we have to be aware the potential risk lying behind this grand project. Since resources (nutrient element, rainfall, etc.) in desert are extremely limited, trying to profit by growing crops may deplete the ecosystem even more, thereby compromising the effect of the project.

Therefore, to understand the value of the project more comprehensively, we have to also consider the cost of the project, which we assume to be an initial investment plus a fixed cost per unit area,

$$C(A) = -800 - 0.5A \tag{12}$$

Also, the economic income generated from the new arable land is set to be

$$B(A) = 0.2A \tag{13}$$

To put all factors together, we get the following equation and plot,

$$Net(A) = -480 + \frac{5000}{(5000e^{-0.002A} + 1)} - 800 - 0.5A + 0.2A \tag{14}$$

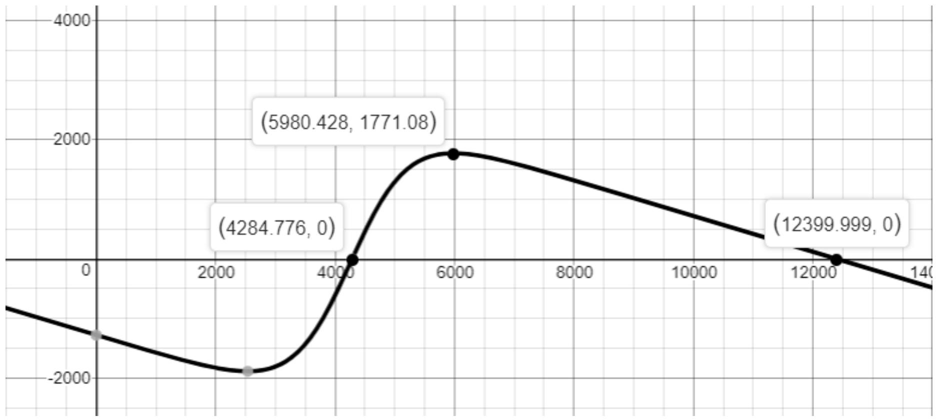

Figure 5: Cost benefit plot of Kubuqi greening project

From Figure 5, we can see that the project is losing money before the area of project expands to 4285 km^2, and it reaches the maximum gains at 5980 km^2, then the project's value starts to slowly slide down because of the limit of water source and nutrient elements. Finally, if the project expands too much, it runs at the danger of depleting resources and would decrease the value of the land.

To visualize the cost-benefit ratio, we can use the following graph to see the clear increase in value of the land, with the much higher ecological value with the creation of indirect economic value from agriculture, solar panel industry, and even tourism.

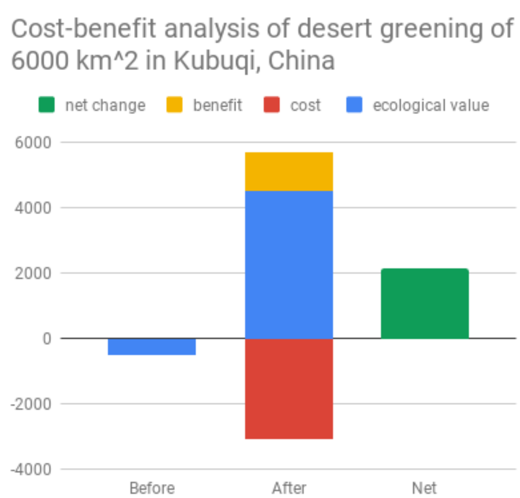

Figure 6: Cost-benefit analysis of desert greening of 6000 km^2 in Kubuqi, China

Based on the cost-benefit stacked column chart above, it is clear that for this particular project of area 6000 km^2 in Kubuqi desert, it should be implemented and it will improve not only the ecological terrain, but more importantly the economic opportunities in the region, thereby raising the residents' standard of living in the process.

7.2 case 2: China Baowu Steel Group

> Steel, as a necessary material in many different area from military use to the structure of buildings, has played an important role since the Worlds Industrial Revolution. Steel industry thus has been seen as the key to economic prosperity. Large steel companies could generate employment, export earnings and tax revenues. However other than these social benefits, steel industry also has a significant impact to environment.

The process of making steel starts from the production of iron. Iron is made from iron ore going through reduction reaction with carbon monoxide under extreme high temperature. The carbon monoxide using here is made from heating carbon with oxygen. The side products of this reaction contribute to major air emission in the process of making iron which are carbon dioxide, sulfide and nitride. Methods for manufacturing steel from iron involve basic oxygen steelmaking(BOS) and electric arc furnace(EAF). Like the process of making iron, both of these two methods require extremely high temperature, thus costing significant amount of energy. To provide this high requirement of energy, burning coal is usually involved to generate heat. Also, significant amount of water is involved in the cooling process.

Thus, due to the huge production of steel and various side product involved and the own characteristics of the production process, steel industry has brought the environmental problems to the table. The costs of ecosystems services must not be ignored.

Figure 7: Air pollution in Shanghui

China Baowu Steel Group is selected as an example for analyzing environment costs using the model mentioned above. China Baowu Steel Group ranked second in

2017 in the production of steel by volume according to The World Steel Association with the production of 65.4 millions of tonnes is the largest steel producer in China. It employs 130,401 employees and has annual revenues of around \$21.5 billion. China Baowu Steel Group located in Shanghai, a port city in the southern China, takes up around 60 square kilometers including various departments in the production process.

As mentioned above, steel factory has a huge impact to the surrounding environment, thus C_0 (measurement of the impact) is chosen to be 0.001. With selected K value, our model for this particular steel factory becomes as following:

$$V(A) = E(A) + I(A) = 5000 - \frac{3000}{1 + 3000e^{-0.001A}} \tag{15}$$

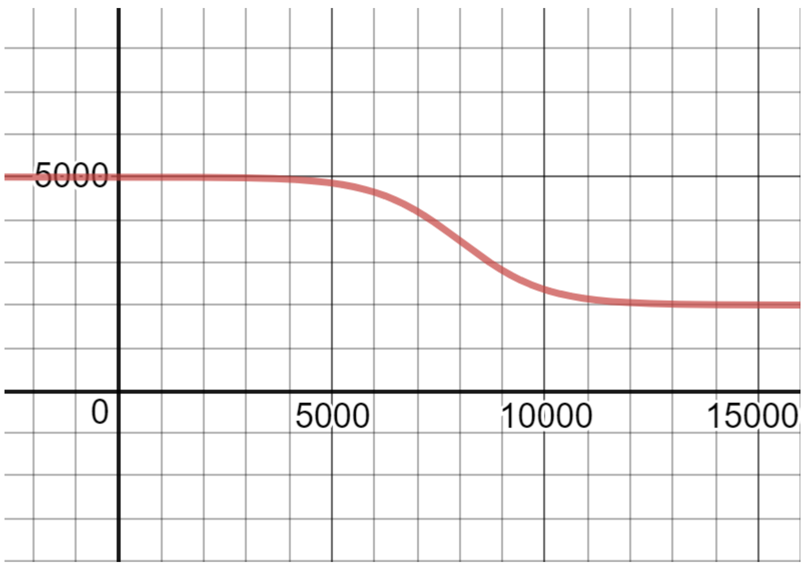

Figure 8: Applying the model to the steel production case

As shown in Figure 8, the total value of this project decreases with increasing land-use area. This agrees with reality. With the significantly increasing steel producing area, Shanghai has become an extremely polluted city with severe air pollution problem. Chinese government thus published many steel production acts to regulate steel producers and one step is to reduce the production area by shutting down many factories.

7.3 case 3: Wolong National Nature Reserve in Sichuan, China

Located in the southwest of Wenchuan County of Sichuan Province, central China, Wolong National Nature Reserve is the third largest nationwide nature reserve in China. As the largest protected area in Sichuan Province with the most complex natural conditions and the largest number of rare animals and plants species, Wolong Nature Reserve covers about an area of over 200,000 hectares, targeting mainly at protecting the natural ecosystem of alpine forest regions and rare animals species such as pandas. The nature reserve experiments the innovative semi-wide stocking mode in order to realize the goal of returning the artificial propagated pandas back into nature. Therefore, the entire nature reserve is constructed based on the local nature principles, following the original fold-and-thrust belt landscape and thus forming a relatively complete alpine forest ecosystem, becoming home to over 4,000 species.

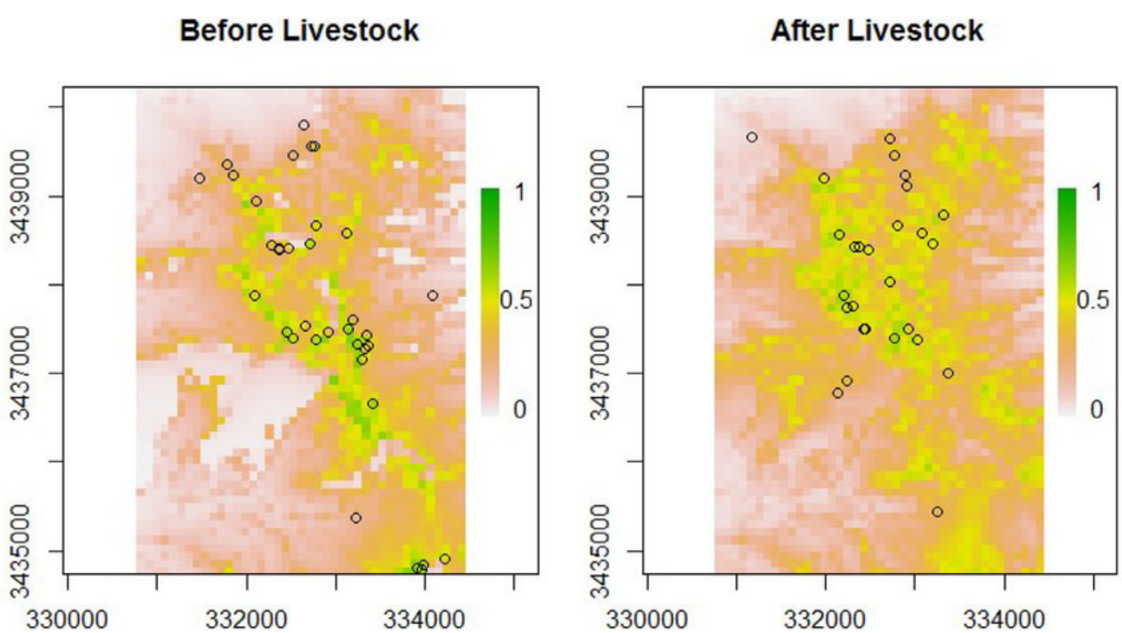

Figure 9: Predictions of giant panda distribution in Wolong Nature Reserve before and after livestock application (Liu, 2017)

It is obvious to confer from the quote that Wolong National Nature Reserve has a positive impact on the surrounding environment and ecosystem services. For example, according to a prediction research of giant panda distribution in Wolong Nature Reserve before and after semi-livestock mode application conducted in 2017, May(Figure 3), the density of giant panda distribution undergoes a significant increase in Wolong's experimental semi-wide stocking mode, which will make a great contribution to maintain the biodiversity of the ecosystem.

In order to evaluate the true economic cost of Wolong National Nature Reserve, it is crucial to consider the impacts on the natural conditions of the surrounding landscape of the protected area. According to Liu Peng and Jiang Shiwei's analysis on the impacts of nature reserves, a strictly regulated nature reserve could provide highly valuable ecosystem services and benefits in terms of carbon stores and recreation. In practice, Wolong Nature Reserve not only protects the balance of ecosystems by keeping and increasing species diversity, but also improve the climate of the surroundings. To numerate the value of this land use project, it is crucial to determine the coefficients in order to apply the above model. According to the quote, the area of Wolong Nature Reserve is estimated to be $2,000km^2$, with a positive K value representing enhancing and implementation of the ecosystem services. We estimate the coefficient sum to be 1 for Wolong Nature Reserve, and the carrying capacity K to be 410. Therefore, we have,

$$V(A) = E(A) + I(A) = 410 + \frac{2000}{1 + 2000e^{1 \cdot A}} \tag{16}$$

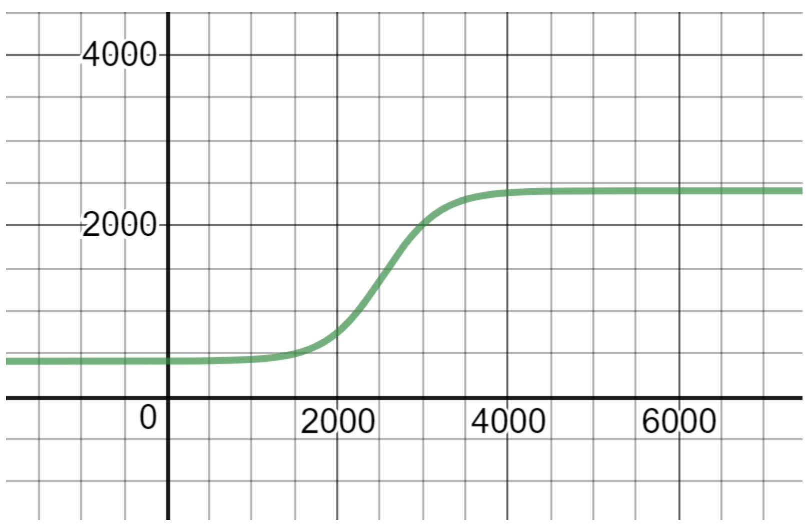

Figure 10: Applying the model to the panda nature reserve case

which depicts a positive appropriate value of the true economic cost of Wolong Nature Reserve.

8. Discussion and Conclusion

From the analysis and results from the case studies, we can conclude that this model can effectively estimate the value of ecological services from different types of land use projects. By analysing the coefficients set and applying this model to various land use projects, the process of understanding the true economic costs of these projects will be more accurate with detailed and appropriate considerations of ecosystem services.

This model provides a way to easily view the threshold of value creation and maximization. Despite the strength of the model shown in the case studies, it also reveals its limitations. To accurately represent the value of the project in specific cases, the coefficients in the model has to be chosen carefully to best illustrate the type and impact brought by the project. Also, this model relies on the assumption that the value and cost generated across the area is uniform, which is not necessarily true in reality. To improve this model, we suggest dividing the area into various sections by various land types and use different coefficients. Thus this model could become a summation of many small sections.

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