Benefit Assessment of Forest Function in Reducing Soil Erosion and Nutrient Loss in Anji County of Taihu Lake Basin

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Abstract The non-point source pollution arising from soil erosion is one of the main reasons for the deterioration of the water quality of the Taihu Lake Basin. Forest plays an important role in controlling soil erosion and reducing nutrient loss. Based on the survey data on forest resources in Anji County, we estimate the amount of soil erosion and nutrient loss of nitrogen and phosphorus reduced by forest, using soil erosion modulus method and soil nutrient content. In accordance with the degradation coefficient of pollutant and regional compensation standards of environmental resources, we assess the ecological benefits of forest function in reducing nutrient loss of nitrogen and phosphorus in Anji County. The results show that the forest in Anji County can reduce the soil erosion amount at 1.51 million t annually on the average, so as to control the nutrient loss of 1 409 t of total nitrogen and 577 t of total phosphorus in soil, equivalent to annually avoiding the flow of 824 t of total nitrogen and 410 t of total phosphorus into river water; this ecological service function can make forests in Anji County get 92.55 million yuan of ecological compensation funds (about 688 yuan/hm^2 · a), equivalent to 15 times of the current ecological compensation standard (47 yuan/hm^2). The study reveals the importance of forest function in controlling soil erosion and nutrient loss in the upper reaches of Taihu Lake Basin to water environment protection in the basin, conducive to carrying out pollution control and protection work of the water environment in the basin.

Key words Forest, Soil erosion. Nutrient control, Benefit assessment, Taihu Lake Basin, Anji County

In recent years, the water eutrophication and aggravated quality of water environment in Taihu Lake Basin have become increasingly prominent[1], and the substance migration arising from soil erosion is one of the main carriers of non-point source nutrient element input in Taihu Lake Basin[2]. Soil erosion is the process by which soil and rock are removed from the Earth's surface by natural processes such as wind or water flow, and then transported and deposited in other locations[3]. Soil erosion not only reduces the content of organic matter and nutrients in soil, but also damages the land structure, and pollutes water with the loss of soil[4].

Anji County of Zhejiang Province, is located in Xitiaoxi basin, upper reaches of Taihu Lake Basin. Abundant precipitation and mountainous and hilly topography create the conditions for the occurrence of soil erosion. Especially in recent years, the land use degree is continuously improved and a lot of chemical fertilizer is applied in this region. The output of nitrogen and phosphorus nutrient by different land use types has attracted close attention[5-7]. However, good forest vegetation plays a significant role in controlling soil erosion[8], thereby helping to reduce the nitrogen and phosphorus nutrient loss brought by soil erosion. But for the nonce, people seem to pay more attention to the impact of the socio-economic activities on the water environment of river basin, lacking understanding of the role of natural vegetation in controlling the non-point source pollution in the river basin.

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Based on the survey data on forest resources in Anji County, in accordance with the existing research results, we assess the role of forest in controlling soil erosion and nutrient loss, reducing the pressure of the water pollution in this region, in order to provide a reference for the water pollution control and water environment protection in Taihu Lake Basin.

1 Overview of the study area

Anji County (30°53′ - 30°23′N, 119°35′ - 119°14′E) is a county in the prefecture - level city of Huzhou in Zhejiang, with a population of 450 000. Anji county is well known for its bamboo, containing as it does 60 000 hectares of bamboo groves, with over 40 different species of bamboo. It has been designated a pilot county for ecological and green building construction. Anji is 65 kilometers from Hangzhou. It administers 15 townships, such as Dipu, Meixi, Xiaofeng, Baofu and Xilong. The topography of the county includes four types (mountain, hill, hillock, plain). Hills and mountains account for 49.84% of the total area. Anji County has a subtropical monsoon climate, with an average annual temperature of 12.2 - 15.6 ℃, and annual precipitation of 1 100 - 1 900 mm.

The soil type in Anji County mainly includes red soil, yellow soil, endodynamorphic soil, damp soil, and paddy soil. There are great differences in the fertility of the mountains. The natural vegetation in Anji County includes *Cyclobalanopsis glauca*, *Castanopsis sclerophylla*, evergreen broadleaf forest, *Pinus massoniana*, mixed forest, *Phyllostachys heterocyla Pubescens* and shrub vegetation. According to the survey data on forest resources in 2007, the forest resources in Anji County mainly include coniferous forest

(20 383.49 hm^2), broadleaf forest (19 497.64 hm^2), mixed forest (8 401.4 hm^2), bamboo forest (69 698.47 hm^2), economic forest (5 495.67 hm^2) and shrubbery (10 952.67 hm^2).

The tree species of coniferous forest mainly includes *Cunninghamia lanceolata*, *Pinus massoniana*, *Pinus elliottii*; the tree species of deciduous broadleaf forest is *Quercus acutissima*, *Quercus variabilis*, *Dalbergia balansae* and other secondary forests; the tree species of evergreen broadleaf forest mainly include *Fagaceae*, *Lauraceae*, *Theaceae*, and *Magnoliaceae*; the broad-leaved tree species in the mixed forest mainly include *Angiospermae* and *Cyclobalanopsis glauca* (*Thunberg*) *Oersted*; coniferous tree species mainly include *Pinus massoniana* and *Cunninghamialanceolata*(*Lamb.*)*Hook*. In addition, the bamboo forest is widely distributed in Anji County and the species include *Phyllestachys pubescens*, *Phyllostachys iridescins*, *Dianthus chinensis* Linn, and *Phyllostachys glauca*. The economic forest mainly includes *Castanea mollissima*, *Carya cathayensis*, *Myrica rubra*, *Pyrus sorotina*, *Prunus persica*. The shrubbery mainly includes Koilodepas hainanense and *Morus alba*. The forest distribution of Anji County is shown in Fig. 1.

2 Calculation method

2.1 The amount of soil erosion controlled by forest Based on the research results of forest soil erosion in the Anji area[2, 9-11], through analysis we get the amount of soil erosion in various types of forest land in Anji County, as is shown in Table 1. If taking the annual amount of soil erosion in non-forest land as a control, the amount of soil erosion controlled by forest can be calculated by equation (1).

$$S = (S_{non} - S_f) \times A \quad (1)$$

where S is the amount of soil erosion controlled by forest (t/a); S_{non} is the amount of soil erosion in non-forest land [t/(hm^2 · a)]; S_f is the annual amount of soil erosion in different types of woodland; A is the area of woodland (hm^2).

2.2 The nutrient loss amount reduced by forest According to the measuring of soil nutrient content in the woodland in Anji County[12], we can get the average nitrogen and phosphorus nutrient content in the soil with depth of 0 – 40 cm in six kinds of woodland (Table 2), so the nutrient loss and soil erosion controlled by forest in Anji County can be calculated by the formula (2).

$$N = S \times \beta_i \quad (2)$$

where N is the controlled total nitrogen or total phosphorus nutrient loss reduced by soil erosion (t/a); β_i is the total nitrogen or total phosphorus nutrient content in the woodland soil (mg/g).

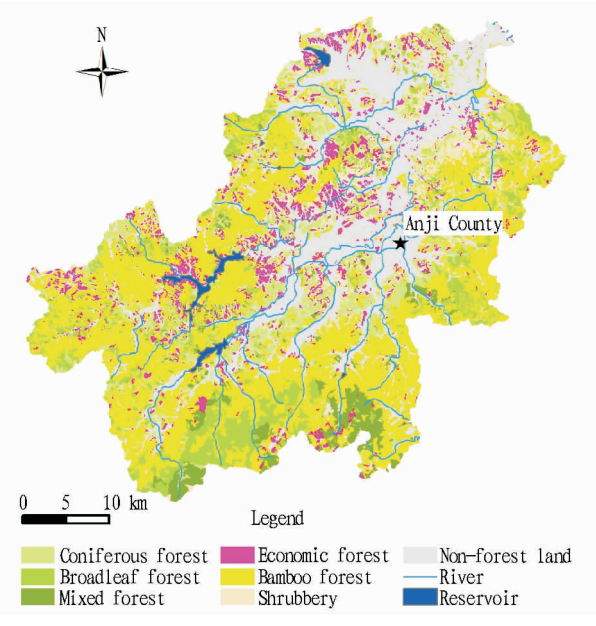

Fig. 1 Distribution of forest resources in Anji County

Table 1 The amount of soil erosion in various types of forest land in Anji County Unit: t/hm^2 · a

Coniferous forest	Broadleaf forest	Mixed forest	Bamboo forest	Economic forest	Shrubbery	Non-forest land
352.15[9]	294.5[9]	186.6[10]	722.78[9]	1 469.13[2]	200[11]	1 681.2[2]

Table 2 The soil nutrient content in different woodland in Anji County Unit: mg/g

Item	Coniferous forest	Broadleaf forest	Mixed forest	Bamboo forest	Economic forest	Shrubbery
Total nitrogen	0.617	1.176	0.964	0.859	0.838	1.355
Total phosphorus	0.267	0.534	0.416	0.361	0.325	0.388

2.3 The ecological benefits of forest function in reducing nutrient loss Through the ecological process of canopy intercepting rainfall, litter interception and soil layer infiltration, forest controls the occurrence of soil erosion, reducing the nutrient loss of nitrogen and phosphorus in woodland soil arising from soil erosion, equivalent to the reduction of total nitrogen, total phosphorus and other non-point source pollutants flowing into the river water. With the gradual improvement and maturing of the point source pollution control technology, the researches on the non-point source pollution increasingly attract attention[13-16]. River load ratio is an important parameter describing non-point source pollutants flowing into river[17]. At the same time, river water also plays a role in diluting and degrading the nutrients of nitrogen and phosphorus, so using the river load ratio and dilution and degradation proportion of non-point source pollutants, we can calculate the amount of pollutants discharged into rivers reduced due to the forest's control over nutrient loss of nitrogen and phosphorus.

The forest is able to control the occurrence of soil erosion, and reduce the input of nitrogen and phosphorus nutrients in soil to the water of river basin, thereby reducing the economic input into

the water pollution control and water environment protection in the river basin, bringing direct economic benefits to mankind. According to the regional compensation standards of environmental resources in the Taihu Lake area, we can estimate the economic value brought by this ecological services function. The calculation formula is as follows:

$$V = N \times \lambda \times (1 - \eta) \times P \quad (3)$$

where V is the economic value generated from the forest function in controlling soil nutrient loss (yuan/a); λ is the river load ratio of total nitrogen or total phosphorus; η is the degradation coefficient of pollutants; P is the reduced compensation value of unit total nitrogen or total phosphorus (yuan/t).

3 Results analysis

3.1 The soil erosion amount controlled by forest Within the forest ecosystem, the role of different types of forest in controlling soil erosion (Fig. 2). The bamboo forest controls 0.668 million t of soil from soil erosion, accounting for 44% of the total forest soil conservation in Anji County, followed by coniferous forest and broadleaf forest, both conserving 0.27 million t of woodland soil; shrubbery and mixed forest conserve 0.16 million t and 0.13 million t of soil, respectively; the economic forest makes the minimum contribution to conserving soil.

However, in terms of the ability of per unit area of forest to conserve soil, the mixed forest and shrubbery are the best, close to 15 t/hm^2 · a, followed by broad-leaved forest and coniferous forest; the ability of per unit area of bamboo forest to conserve soil is 9.58 t/ (hm^2 · a); the ability of per unit area of economic forest to conserve soil is the worst.

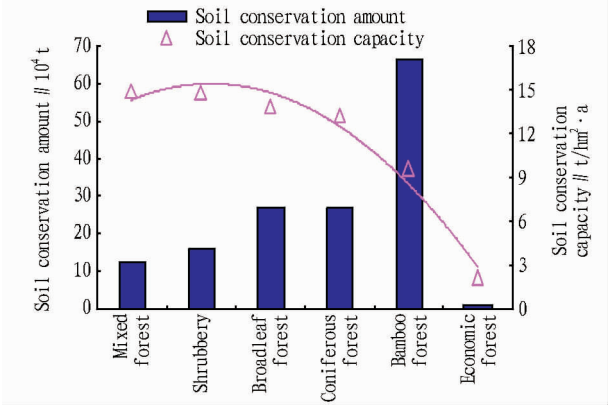

Fig. 2 The soil erosion amount controlled by forest in Anji County and the forest's capacity

3.2 The nutrient loss amount reduced by forest The forest in Anji County controls the occurrence of soil erosion, and reduces the loss of nutrient nitrogen and phosphorus in soil. According to equation (2), we conduct estimation and find that due to the soil conservation function, the forest in Anji County can avoid the loss of 1 409 t of total nitrogen (TN) and 577 t of total phosphorus (TP). Bamboo forest can control 574 t of total nitrogen and 241 t of total phosphorus to avoid loss, accounting for 41% and 42% of total amount of nutrient loss reduced by forest, respectively, followed by broad-leaved forest and shrubbery; the economic forest makes the least contribution to reducing nutrient loss. The contribution of forest to reducing the soil nutrient loss is related to the soil conservation, and also related to soil nutrient content.

In terms of the ability of different types of forest to control nutrient loss, the ability of shrubbery to control the loss of total nitrogen is the greatest, followed by broadleaf forest and mixed forest; the ability of bamboo forest to reduce the loss of total nitrogen is slightly different from the ability of coniferous forest to reduce the loss of total nitrogen; the ability of economic forest to control the loss of total nitrogen is the poorest. The ability of broadleaf forest to control the nutrient loss of total phosphorus is very prominent, followed by mixed forest and shrubbery; the ability of bamboo forest to control the nutrient loss of total phosphorus is close to the ability of coniferous forest to control the nutrient loss of total phosphorus; the ability of economic forest to the nutrient loss of total phosphorus is the smallest (Fig. 3).

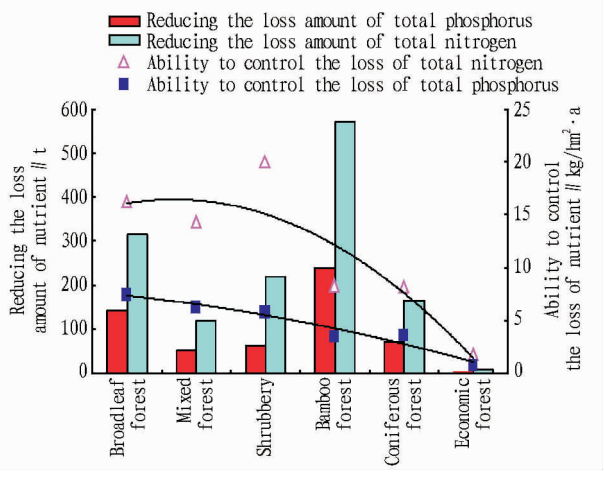

Fig. 3 The nutrient loss amount of nitrogen and phosphorus in soil reduced by forest in Anji County

3.3 The ecological benefits of forest function in reducing nutrient loss If there is no presence of forest ecosystem in Anji County, due to the existence of the phenomenon of soil erosion, there will be 1 409 t of total nitrogen (TN) and 577 t of total phosphorus (TP) suffering losses. If calculating in accordance with the river load ratio of non-point source pollution at 0.9[21], in the process of nitrogen and phosphorus nutrients moving in the river, affected by the physical, chemical and biological processes, the degradation coefficient is 35% and 21%, respectively[22]; there will be about 824 t of total nitrogen and 410 t of total phosphorus flowing into river water, further increasing the pressure of water environment pollution in the Taihu Lake Basin. The functions of forest in conserving soil reduce soil erosion and the nutrient loss of nitrogen and phosphorus in the soil, thereby reducing these non-point source pollutants flowing into the river water, saving the economic input into water environment governance and protection in the river basin, so it has the service value of ecosystem.

If according to the compensation standards of environmental resources in Taihu Lake Basin in Jiangsu Province (namely ammo-

nia nitrogen 100 000 yuan/t and total phosphorus 10 000 yuan/t), and the ratio between ammonia nitrogen and total nitrogen in conventional sewage (1:1.6), we can estimate the ecological value from the function of forest in Anji County in controlling soil erosion, reducing the nutrient loss of nitrogen and phosphorus at 92.55 million yuan/a. The ecological value of function in controlling total nitrogen nutrient is 51.45 million yuan, and the ecological value of function in controlling total phosphorus nutrient is 41.01 million yuan.

If carrying out ecological compensation in accordance with this ecological service function, the compensation for per unit area of woodland is about 688 yuan/hm^2, while the current ecological compensation standard of ecological forest in Anji County is 47 yuan/hm^2, only equivalent to one fifteenth of the value of forest function in reducing the nutrient loss. In the light of different types of forest, the ecological compensation value per unit area of broadleaf forest and shrubbery is the highest, followed by mixed forest, coniferous forest and bamboo forest; the ecological compensation value per unit area of economic forest is the lowest (Fig.4).

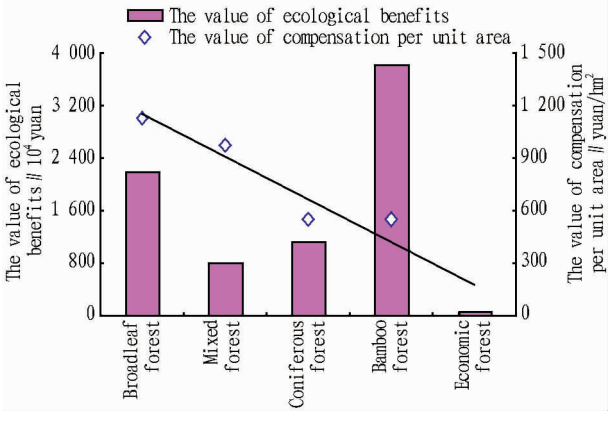

Fig.4 The ecological benefits of forest function in reducing the nutrient loss of nitrogen and phosphorus in Anji County

4 Discussions

Vegetation is the most important factor affecting soil erosion[18]. Different forest types have different ability to control soil erosion: the arbor forest's ability to conserve soil and water is higher than that of shrubbery[19]; due to mosaic distribution of above-ground and underground parts, mixed forest can form a good structure, and thus have the greater soil and water conservation function than the pure forest[20]; in general, the soil's ability to resist erosion in broadleaf forest is greater than that in coniferous forest, barren hills and wasteland[21].

In the Taihu Lake Basin, the characteristics of soil erosion are different in different types of woodland[2, 4, 9-10]; at the same time, the soil nutrient loss is closely related to the soil nature[4]. The content of total nitrogen, total phosphorus and total potassium in the soil, is mainly determined by the cycling process of the plant nutrient and soil parent rock type, also vulnerable to the artificial fertilization measures. In mountainous areas of Anji County, the soil nutrient content in the pine forest, fir forest, broadleaf forest, bamboo forest, mixed forest, economic forest and shrubbery is different[12]. In the Taihu Lake Basin, highly intensive human activities and river basin characteristics of plain cause about 34.467 million t of soil erosion annually[10], and the annual soil erosion modulus of agricultural land is 1681.2 t/hm^2 · a[2].

However, relative to other land use types, the forest has good function in retaining soil[8]. Taking the soil erosion of farmland in Taihu Lake Basin as the control, we calculate the amount of soil erosion reduced by forest in Anji County annually at 1.51 million t, an average of 11 t/hm^2 · a, lower than the national forest's ability to retain soil per unit area (4.04 - 48.64 t/hm^2 · a)[23], indicating that forest's ability to retain soil in Anji County has large room for improvement.

Soil erosion is a natural process, and there is soil erosion in any land use type. The quantitative evaluation of regional soil erosion and nutrient loss is a complex task, involving a number of factors, such as climate, hydrology, soil, topography and vegetation. In the process of evaluating and analyzing the forest function in controlling soil erosion and nutrient loss in Anji County, this study does not consider the impact of precipitation characteristics, terrain slope and other factors in different geographical locations, and does not involve the differences in the content of soil nutrient in the same woodland, which is the problem to be researched and solved in the future.

Although the parameters cited in this study are from the fixed-point experimental data, they can not accurately reflect the real situation of soil erosion and nutrient loss in woodland in Anji County; due to the limitations of the data resources and research methods, the amount of soil erosion and nutrient loss in woodland can only be roughly estimated, but this does not hamper people's understanding of the importance of forest function in controlling soil erosion and nutrient loss in Anji County.

5 Conclusions

The forest in Anji County can reduce the soil erosion amount at 1.51 million t annually on the average, so as to control the nutrient loss of 1 409 t of total nitrogen and 577 t of total phosphorus in soil, equivalent to annually avoiding the flow of 824 t of total nitrogen and 410 t of total phosphorus into river water; this ecological service function can make forests in Anji County get 92.55 million yuan of ecological compensation funds (about 688 yuan/hm^2 · a), equivalent to 15 times of the current ecological compensation standard (47 yuan/hm^2). The study reveals the importance of forest function in controlling soil erosion and nutrient loss in the upper reaches of Taihu Lake Basin to water environment protection in the basin, conducive to smoothly carrying out pollution control and protection work of the water environment in the basin.

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poor vegetation and weak soil foundation, soil erosion is liable to occur due to its weak resistance for rainfall despite of the low rainfall in total. Climatic variation is caused by heat budget changes of the entire planet, which will exert an influence on the general atmospheric circulation and ocean current, even leading to changes of heat and moisture region distribution in the atmosphere. In a certain region, when the distribution is significantly greater or less than the annual average, abnormal climate will take place. Most of the heat obtained by the earth comes from solar energy (sunshine amount). The natural phenomena such as solar activities and volcanic eruption may lead to climatic variation, and global warming, acid rain as well as ozone depletion etc caused by synthesis compound emissions will also bring about direct or indirect influences.

4.2 Human factors The occurrence and development of desertification have close links with social economy. Unreasonable economic activities of human beings constitute the primary cause for desertification. And in turn, human beings are direct victims of desertification. The socio-economic factors relating to desertification include overpopulation, over cultivation, over grazing, deforestation and low irrigation levels. Over cultivation and over grazing have a direct causal relationship with population growth. With the increase in population, the demand for agricultural products and animal products will increase, which gives rise to over cultivation and over grazing.

5 Conclusions

In combination with data from diverse sources, the primary cause for desertification in western Jilin Province is the shortage of water resources. As the precipitation keeps decreasing year by year irregularly and the rivers are seasonal rivers, the production and domestic water supply is not enough, especially the agricultural water. As a result, in the respect of desertification control and land conservation, water conservancy shall prevail. The solution of water problems is fundamental to the control of land desertification in western Jilin Province.

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