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A Study on the Optimal Planning of Forest Ecosystems on Hainan Island in the Context of the Integrated Development of Lakes, Wetlands and Forests

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Abstract: Hainan Island has rich water resources and unique lake ecosystems. Organically connecting lakes and wetlands with forest ecosystems should be considered in order to strengthen biodiversity protection, form a continuous green corridor to promote species migration and gene exchange, and enhance the stability and resilience of the overall ecological system and maximize its benefits. The method of linear programming was used in this study to analyze the forest ecosystem on Hainan Island in China in order to provide a scientific basis for the integration, protection and management of lakes, wetlands and forests. This study points out that the ratio of the area of timber forest, protection forest, special-purpose forest and bamboo forest should be adjusted from the current 68:22.9:7.1:1.8 to 24:72.8:2.5:0.6. The average shadow price of the reasonable use of different forest lands on Hainan Island is 2512.46 CNY/ha and the optimal value of special-purpose forest is 4376.04 CNY/ha, rather than the current 6888.50 CNY/ha. This study also shows that the timber forest, special-purpose forest and bamboo forest on Hainan Island are short-term products, while protection forest, wood-fuel forest, economic forest, open forest land, shrub land, young afforested land and non-forest land are long-term products, for which it is not easy to obtain benefits in the short-term. A combination of long- and short-term forest ecological planning should be considered to maintain the various long-term benefits. This study finally proposes that Hainan Island should reduce its proportion of timber forest area; increase its proportion of protection forest area; focus on the integrated development of lakes, wetlands and forests and biodiversity conservation goals; and pay close attention to the adjustment of forest type structure in order to meet the needs of ecological province construction and sustainable development.

Keywords: integrated development of lakes, wetlands and forests; biodiversity protection; forest ecological planning; optimum structural adjustments; Hainan Island; China

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1. Introduction

Hainan Island is a tropical island that has rich water resources and a unique lake ecosystem. In order to strengthen biodiversity protection, it is vital to consider organically connecting lake, wetlands and forest ecosystems to form a coherent green corridor, promote species migration and gene exchange, enhance the stability and resilience of the overall ecosystem and maximize the benefits of the forest ecosystem [1]. According to statistics, the number of lakes on Hainan Island is relatively small, and the lakes are mainly artificial. The total area of lakes on Hainan Island comprises dozens of square kilometers [2]. While the volume of water stored in the lakes of Hainan Island is relatively small, these lakes play important roles, mainly for urban water supply and agricultural irrigation needs. In addition to its function in urban water supply and agricultural irrigation, the lake ecosystem on Hainan Island has high biodiversity and provides habitats for a variety of birds, fish and other aquatic life. Abundant vegetation around the lakes on Hainan Island, such as mangroves and reeds, plays an important role in protecting these ecosystems [3]. Therefore, the lakes in Hainan have an important function in improving ecosystem service functions, protecting biodiversity, enhancing carbon sink functions, facilitating scientific research and monitoring systems, and enabling social and economic development. How-ever, for many years, Hainan Island has lacked a plan for the integrated development of lakes, wetlands and forest ecosystems, resulting in these ecosystems being threatened or degraded, which has a certain impact on the strategic goal of constructing an "ecological province" and interferes with the coordinated development of these different ecosystems [4]. Therefore, the optimal linear programming method was adopted in this study to analyze the forest ecosystem in Hainan, providing a scientific basis for the integrated development, protection and management of lakes, wetlands and forests.

The theory of ecological planning originated with Howard's 1898 book *To-morrow: A Peaceful Path to Real Reform*, in which he proposed the "Garden City Movement" which, for the first time, combined urban planning with urban economy and environmental greening, laying the foundation for the development of ecological planning theory.

In 1960, Professor McHarg, director of the Department of Environmental Planning at the University of Pennsylvania, introduced the concept of territorial ecological planning; that is, the planning of a possible use of land without any harmful conditions or with mostly harmless conditions. In other words, ecological land use planning that is based on ecological principles is called ecological planning [5]. McHarg established a framework for ecological planning, which became the basic paradigm for ecological planning research.

In 1984, the United Nations defined ecological planning in the MAB 57th report as follows: "ecological planning is the creation of an optimal environment for human activities that fully integrates technology and nature, induces human creativity and productivity, and provides high material and cultural standards, both in terms of natural ecology and social psychology." The term "ecology" is therefore no longer a narrowly defined biological concept, but has the meaning of social, economic and environmental integration and sustainable development. At present, ecological planning is generally considered to be "the use of biological and socio-cultural information to present possible opportunities and constraints on decisions about landscape use" or, as McHarg defines it, "the way in which an area can be interpreted as a biophysical and social process in the operation of regulation and time." It can also be reinterpreted as "an explicit presentation of the opportunities and constraints faced in relation to any given human use, and an investigation can reveal the most appropriate location and process" [5]. Ecological planning is now a popular field in planning research around the world and a new direction for planning practice and achieving sustainable development.

In recent years, the integrated development and planning of lakes, wetlands and forests have gradually developed [6] and have also become hot research topics for the modernization of island and marine eco-environmental governance [7,8], island ecological security and so on [9]. Particularly in the construction of marine ecological civilizations [10], the application of frontier technology for marine mapping and island ecological protection and restoration [11], island ecological restoration planning [12], island ecological protection and restoration policy research [13] and island ecological management and restoration research, among other fields, ecological planning plays an important role in the study of the integrated development of lakes, wetlands and forests in island and marine environments [14,15].

2. Methods and Data

2.1. Methods

An ecological planning approach was adopted in this study to carry out research on optimal forest ecological planning based on the ecological management of lakes, wetlands and forests on Hainan Island. Specifically, a linear programming model was used to allocate and optimally solve for the relevant scarce resources [16]. The general form of the linear programming model is as follows:

$$Max(Min)\ z = \sum_{j=1}^{n} c_j x_j \tag{1}$$

$$\text{s.t.} \sum_{j=1}^{n} a_{ij} x_j \leq b_i i = 1, 2, \cdots, m \tag{2}$$

$$x_1, x_2, \cdots, x_n \geq 0$$

In the above equation, x_j is the variable; c_j is the coefficient of the objective function; a_{ij} is the coefficient of the constraint variable; b_i is the upper limit of the constraint; and m, n are the number of constraints and the number of variables, respectively [17].

The theory and methods of ecological planning have been further developed since their proposal; ecological planning methods especially have become increasingly standardized.

In Professor Steiner's *The Living Landscape*, the contents related to ecological planning include how to carry out ecological planning; steps, methods and principles for defining planning problems and planning objectives; landscape analysis at the regional scale; landscape analysis at the local scale, detailed analysis; planning area concepts and schemes; landscape planning; community participation and citizen education; design schemes and planning and design. These considered the basic elements of ecological planning. Therefore, it is necessary to use these aspects to carry out the integrated development of lakes, wetlands and forests on Hainan Island [3].

Hainan Island, as the earliest approved pilot eco-province in China, carries out forest ecological planning. In accordance with the theory of sustainable development and ecological economics, it is building a highly developed socio-economic system with a reasonable forestry industry structure, a good ecological environment, full and rational use and protection of forest resources, effective management of the island ecological environment and the realization of both economic and ecological virtuous cycles within the provincial administrative area. The ecological and economic system is an important guarantee for achieving a high degree of unity and sustainable development between economic take-off and environmental protection, material and spiritual civilization and natural and human ecology.

2.2. Data

The data for this study were mainly obtained from the Hainan Statistical Yearbook 2022 [18], the China Forestry and Grassland Yearbook (2021) [19] and relevant studies [20–22].

Hainan Island is located at the southern tip of China, with a geographical position between 18°09′–20°10′ N and 108°03′–111°03′ E. It is the second largest island in China. According to 2022 statistics, the length of Hainan Island's coastline is 1910 km. The northern part of the island is across the sea from Guangdong's Leizhou Peninsula, with the whole island surrounded by sea on all sides, comprising a total area of 34,400 km^2. Hainan Island's topography is high in the middle and low in all directions, with the Wuzhi

Mountain (1867.1 m above sea level) in the middle of the island as the center, forming an asymmetrical ring of mountains, hills, terraces and plains. In the land area of the island, plains, terraces and hills below 200 m above sea level account for 70% of the total area and are mainly distributed in the north, northeast and coastal areas; low mountains and high hills from 200 m to 500 m above sea level account for 20.2%; and mountains above 500 m above sea level account for 9.8% of the total area of the island [20].

Hainan Island is an independent tropical landscape unit with a land area of only 0.35% of the total land area of China and a high concentration of species diversity. According to statistics, the island has a total of 242 families, 1210 genera and 3146 species of wild vascular plants, accounting for 68.6%, 38.0% and 11.6% of the total in China, respectively. The densities of these families, genera and species per 10,000 ha are 71.34, 356.72 and 927.48, respectively, higher than the national average of 0.368, 3.317 and 28.281 in China. Hainan Island has a total of 344 species from 60 families of birds and 76 species from 24 families of animals and is also exceptionally rich in amphibians, reptiles, insects and macrofungi [23].

Hainan Island also has abundant forest resources. Here, forest mainly refers to plant communities that comply with the Regulations on the Implementation of the Forest Law of the People's Republic of China. Specifically, it includes arbor forest, bamboo forest and shrub land specially stipulated by the state. These areas can be divided into protective forests, special-purpose forests, timber forests, economic forests and energy forests (original fuelwood forests) according to their use [19]. According to the data of the eighth national forest resources inventory from 2009 to 2013, Hainan Island has a forestry land area of 1,699,600 ha, of which 1,349,300 ha is forested, 15,600 ha is open forest, 205,100 ha is shrub land, 0.084 million ha is young afforested land, 0.012 million ha is nursery land, 120,000 ha is non-forested land and 33,600 ha is bamboo forest. The forest coverage rate of the whole island is 49.80%, with a total standing forest stock of 72,814,900 m^3 (excluding rubber forests), of which 66,130,300 m^3 (90.82%) is forest stock volume, accounting for the majority, and 6,684,600 m^3 (9.18%) is other stock.

The data of the latest ninth national forest resources inventory from 2014 to 2018 show that the area of forestry land on Hainan Island has increased to 1,944,700 ha, of which 1,666,600 ha is forested, 0.72 million ha is open forest land, 47,900 ha is shrub land, 25,200 ha is young afforested land, 0.036 million ha is nursery land, 0.01894 million ha is non-forest land and 45,060 ha is bamboo forest. The results of the inventory show that Hainan Island has a forest cover of 48.87%, which is the fourth highest forest cover in China, and a total standing forest stock of 78,636,100 m^3, with a forest stock of 71,951,600 m^3, of which the forest stock is all standing stock [19].

As for the lakes and wetlands of Hainan Island, the total area of wetlands on Hainan Island is 320,000 ha [15]. The survey results show that there are 21 types of wetland in Hainan, including coastal; river; lake; swamp and constructed wetlands; mangroves; ponds; and artificial farms. The spatial distribution of the natural wetland area has not changed significantly in the past 10 years. Coastal wetlands have the largest area of all wetland types, accounting for 54%. Constructed wetlands have the second largest area, accounting for 36%. Lake and marsh wetlands are less distributed, while mangrove, coral reef and seagrass beds are widely distributed. The natural wetland area of Hainan Island has not changed significantly in the past 10 years, and the area of constructed wetlands has increased significantly [15]. In Hainan, tectonic, river, sea and karst lakes are common types of lakes, but there are not many natural lakes with a large area that are in their original state. According to data released by the water resources department, there are more than 1100 reservoirs in Hainan, which are the main forms of lakes on the island. Among them, Ledong Jianfengling Tianchi, at an altitude of about 800 m, is the highest and largest alpine lake [24]. Compared to the lakes and wetlands, the forest resources of Hainan Island play an important role in social and economic development, maintaining the ecological balance and protecting biodiversity, as well as having an irreplaceable function in the maintenance and stability of Hainan's ecological environment, in particular, in the integrated development of lakes, wetlands and forests. Therefore, it is particularly important to carry out forest ecological planning on Hainan Island [24].

In order to estimate the price of forest resources in the data collection, 4 counties (cities) were selected out of the 19 counties (cities) in the three types of topographic zones (mountainous, low mountain terraces and terraced plains) on Hainan Island according to a stratified sampling method. The prices of local market transactions of forest land, forest trees and forest environmental services in 2021 were collected, and finally, the average price of forest land and forest trees was calculated via the comprehensive processing and value of forest environmental services. The specific methods were as follows.

The proportional allocation method in stratified sampling was adopted to determine the sample size for each stratum:

The overall sample size N = 19 counties (cities).

The overall division into 3 topographic zones, K = 3.

The number of counties (cities) in the ith topographic zone is N_i (i = 1, 2, . . ., K).

One county (city) in each topographic area was pre-sampled as a sample point for determining the price of forest resources. That is, n = 3.

The number of sample units n_i from each topographic zone N_i; then, $n = n_1 + n_2 + \cdots + n_k$.

$$n_1/N_1 = n_2/N_2 = \cdots = n_k/N_k = n_k/N \quad (3)$$

$$n_i = n \cdot N_i/N (\mathrm{i} = 1, 2, \cdots, k) \quad (4)$$

At least 4 cities and counties must be selected as sample points in each stratum to determine unbiased estimates of forest resource prices on Hainan Island (19 cities and counties in 3 topographic regions). The number of sample points in each stratum is shown in Table 1.

Table 1. Distribution of samples by stratum for forest resource price calculation on Hainan Island.

Terrain Type	Mountains	Low Mountain Platform	Terraces, Plains
Number of counties and cities in the stratum	5	6	8
Number of samples in the stratum	1	1	2

In the specific calculations, the city of Tongzha was selected as a sample for the mountains type; Changjiang County was selected as a sample for the low mountain platform type; and the cities of Haikou and Sanya were selected as samples for the terrace and plain types, respectively.

3. Forest Ecological Planning in Hainan

Hainan is an island-type province with a central uplift and high mountainous undulations to the south of the center. Topographically, the whole island is divided into mountainous areas, mainly concentrated in the central and southern part, accounting for about 25.4% of the island's area; low mountainous terraces are mainly concentrated in the north and east, accounting for about 13.3% of the island's area; and plain terraces are scattered in the coastal areas, accounting for about 61.3% of the island's area. In addition, there are not many natural lakes with a large area that are in their original state. The natural wetland area has not changed substantially in the past 10 years, and the area of constructed wetlands has recently increased significantly [15]. In this case, forest ecological planning is mainly carried out considering the integrated management of lakes and wetlands. Therefore, using the sample point setting method and formula of data collection, forest land, forest price and forest environmental service price were calculated, and the ecological planning of Hainan forest was subsequently carried out.

3.1. Woodland and Forest Prices

The most important aspect of carrying out forest ecological planning is the determination of the price of forest resources. The determination of forest resource prices mainly includes the price of forest land and trees and forest environmental services. The price of forest land and trees is calculated using the replacement cost method for young and middle-aged forests, and the net present value method is used for near-mature, mature and over-mature forests, with a discount rate of 6%. Based on the information provided in the report "Study on the valuation of forest resources in Hainan Province and their inclusion in the Green GDP" [25] and based on the price index of production materials from 1987 to 2022 in the Hainan Statistical Yearbook 2022 [18], the prices of forest trees in Hainan Province in 2021 were calculated using the above method and are shown in Tables 2 and 3. The calculated prices of forest land are shown in Table 4.

Table 2. Calculated forest prices for dominant tree species in Hainan Province in 2021.

Dominant Species	Chinese Fir	Conifer	Eucalyptus	Natural Broadleaf Forest	Soft Broadleaf Tree	Casuarina
Prices (CNY/m^3)	280	350	273	522	174–290	232

Source: Jin Y., Ouyang Z.Y., Lin S.K., 2008 [25].

Table 3. Combined forestry prices by species in Hainan Province.

Forest Type	Timber Forest	Protective Forest	Special-Purpose Forest	Fuelwood Forest	Economic Forest	Bamboo Forest	Sparse Forest	Scattered Woods
Price per cubic meter of forest (CNY/m^3)	271.5	271.5	271.5	268.42			271.5	271.5
Price per hectare of forest (CNY/ha)	28,844.16	25,124.61	68,884.98	6120	23,314.8	33,000	11,810.25	

Source: Jin Y., Ouyang Z.Y., Lin S.k., 2008 [25].

Table 4. Calculation of forest land prices in Hainan Province in 2021.

Forest Type	Woodland Price (CNY/ha)
Timber Forest	2884.42
Protection Forest	2512.46
Special-Purpose Forest	6888.50
Fuelwood Forest	612.0
Barren Hills and Wasteland	535.5

Table 4. *Cont.*

Forest Type	Woodland Price (CNY/ha)
Bamboo Forest	3300
Nursery Land	2331.48
Shrub Land	612.0
Unforested Silvicultural Land	535.5
Economic Forest	2331.48
Non-Forest Land	535.5

Note: (1) Taking into account Chapter 2, Article 23, Item 4 of the Regulations on the Transfer of Land Use Rights of the Hainan Special Economic Zone for a Reimbursement, the value of barren land, young afforested land and non-forest land is lower than the value of fuelwood forest land. (2) Nursery land is mainly used for economic purposes, and its forest land price is the same as that of economic forest land. (3) Shrub lands may also provide fuelwood, and their woodland prices are the same as those for fuelwood.

3.2. Prices of Forest Environmental Services

Forest environmental services include a very broad range of activities, mainly including carbon sequestration and oxygen production, water conservation, soil protection, the provision of habitats for plants and animals, atmosphere purification, forest recreation and biodiversity protection. Therefore, the price of forest environmental services in Hainan is mainly calculated for these seven aspects.

The calculation of the price of forest environmental services is based on the study by Zeng Qingbo and Li Yide et al. [21] The extent of the benefits of forest environmental services is calculated using the substitution method and the Contingent Value Method (CVM) based on actual surveys [21]. The CVM method is used to calculate the extent of environmental service benefits [21], which is then converted into 2021 prices based on the production index of Hainan from 1987 to 2022. The forest water supply benefits are mainly calculated as the benefits of forest flood regulation and replenishment using the substitution method. The calculation is based on an average price of CNY 0.2 per cubic meter of industrial, agricultural and domestic water production on Hainan Island in 2021, and the benefit of water conservation is mainly calculated according to the current price of tap water in the island. The soil conservation benefits are mainly calculated as fixed soil and fertilizer maintenance benefits based on an average price of CNY 10 for one tonne of excavated soil; in addition, the nutrient content of the topsoil layer of 30 cm is used in the calculation. The forest soil conservation benefits are mainly calculated as soil improvement benefits from forest litter as 9.177 t/ha.a for primary forests and 9.323 t/ha.a for natural secondary forest [4]. The benefit of forest carbon sequestration and oxygen production is calculated as the benefit of carbon sequestration and the benefit of O_2 release. The cost of carbon sequestration is calculated according to the average cost of 1 t of CO_2 treated by industrial enterprises at CNY 250 (treatment rate of 80%) [4], and the price of O_2 is calculated according to 16% of the current market price of medical O_2 in Hainan [5]. The benefits of forest providing habitat for plants and animals is calculated according to the actual cost of establishing forest nature reserves on Hainan Island. The benefits of atmosphere purification are mainly calculated based on the average cost of removing one cubic meter of atmospheric dust in the national industry [5]. The benefits of forest recreation are mainly calculated for forest ecotourism, and the benefits of tourism in primary and natural secondary forests are calculated as 1248 CNY/ha.a and 133 CNY/ha.a, respectively [23]. The benefits of biodiversity protection are calculated using the CVM method [26], the minimum annual benefit per hectare for biodiversity conservation is 710.99 CNY/ha.a and the maximum annual benefit is 29,625.07 CNY/ha.a [27]. The prices derived for forest environmental services are shown in Table 5.

Table 5. Calculation of environmental service benefits of forest resources in Hainan in 2021.

No.	Environmental Benefit	Calculated Value of Environmental Benefits per Hectare per Year (CNY/ha.a)	Notes
(1)	Water conservation	2330.04	(1) According to the Ninth Forest Resources Inventory in China, Hainan has 347,700 ha of primary forest, accounting for 10.20%, and 3,062,700 ha of natural secondary forest, accounting for 89.80%. Therefore, (1), (2), (3), (4) and (6) are derived as a weighted average of the annual environmental benefits per hectare based on primary and natural secondary forest. (2) Standard deviation σ_{n-1} = 2572.74.
(2)	Atmosphere purification	296.87	
(3)	Soil protection	432.86	
(4)	Carbon sequestration and oxygen release	3269.19	
(5)	Habitat for plants and animals	\	
(6)	Forest recreation	246.73	
(7)	Biodiversity protection	710.99–29,625.07	
Total		7286.68	

Note: Biodiversity protection benefits are taken as a lower bound in the totals.

The results of the test are shown in Table 6. The results of the test show that the different estimates of environmental service benefits are derived from the same general population and follow a normal distribution, indicating that the estimates have statistical significance and a certain scientificity [7].

Table 6. The normality test of the unit price of environmental services.

Item	Kolmogorov–Smirnov [a]			Shapiro–Wilk		
	Statistic	df.	Sig.	Statistic	df.	Sig.
Estimated unit price of environmental services	0.274	7	0.12	0.777	7	0.024

[a] Lilliefors significance correction.

Therefore, the estimated values of forest environmental service benefits on Hainan Island are as follows:

(1) The estimated value of water conservation is 2330.04 CNY/ha.a per hectare per year.
(2) Atmosphere purification is estimated at 296.87 CNY/ha.a per hectare per year.
(3) The estimated benefit of forest soil protection is 432.86 CNY/ha.a per hectare per year.
(4) The estimated value of carbon sequestration and oxygen release per hectare per year is 3269.19 CNY/ha.a.
(5) The benefits of forest providing habitat for plants and animals are already included in biodiversity conservation and are not considered here.
(6) The estimated value of forest recreation per hectare per year is 246.73 CNY/ha.a.
(7) The estimated value of forest biodiversity conservation per hectare per year is 710.99–29,625.07 CNY/ha.a.

As a result, the estimated value of the environmental service benefits of forest resources on Hainan Island is 7286.68 CNY/ha.a, with an estimated standard deviation σ_{n-1} = 2572.74. The normality test of the unit price of environmental services is shown in Table 6.

It can be seen, from Table 6, that Kolmogorov–Smirnov's Sig. = 0.12 > 0.05 for the unit price of environmental services. Therefore, the null hypothesis is accepted, which indicates that the unit price of environmental services follows the normal distribution and is independent, and the linear programming study on the environmental benefits of forest resources on Hainan Island could proceed [27].

3.3. Forest Ecological Planning

According to the above calculated price per unit of forest land, forest price and forest environmental benefits in Hainan, let the planning area of timber forest be x_1 hundred ha, the area of protection forest such as water conservation and soil protection be x_2, the area of fuelwood forest be x_3, the area of special-purpose forest be x_4, the area of economic forest be x_5, the area of bamboo forest be x_6, the area of open forest land be x_7, the area of shrub land be x_8, the area of unforested silvicultural land be x_9 and the barren hills and wasteland as well as non-forest land be x_{10}. According to the ninth national forest inventory in China, the area of forestry land in Hainan Province is 1,725,900 ha. In order to maintain consistency with forest resource inventory data in China, the starting unit of all data measurements is 100 [18]. Therefore, according to the linear planning, the forest ecological planning equation is written as follows:

$$Max: 2884.42x_1 + 2512.46x_2 + 612.0x_3 + 6888.50x_4 + 2331.48x_5 + 3300x_6 + 1181.03x_7 + 612.0x_8 + 535.5x_9 + 535.5x_{10}$$

$$S.T: \begin{cases} x_1 < 4150 \\ x_2 > 1391 \\ x_3 < 84 \\ x_4 < 432 \\ x_5 < 4498 \\ x_6 < 108 \\ x_7 < 624 \\ x_8 < 1210 \\ x_9 < 168 \\ x_{10} < 4594 \\ x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} = 17,259 \\ x_i \geq 0; (i = 1, 2, \cdots, 10) \end{cases}$$

Using LINGO 18.0 software, the above linear programming was further solved as shown in Table 7.

Table 7. Objective function values.

1>	**46,881,680.0**	
Variable	Value	Reduced Cost
x_1	4150.000000	0.000000
x_2	12,569.000000	0.000000
x_3	0.000000	1900.460000
x_4	432.000000	0.000000
x_5	0.000000	180.980000
x_6	108.000000	0.000000
x_7	0.000000	1331.430000
x_8	0.000000	1900.460000
x_9	0.000000	1976.960000
x_{10}	0.000000	1976.960000
Row	Slack or Surplus	Dual Prices
2>	0.000000	371.960000
3>	11,178.000000	0.000000
4>	84.000000	0.000000
5>	0.000000	4376.040000
6>	4498.000000	0.000000
7>	0.000000	787.540000
8>	624.000000	0.000000

Table 7. *Cont.*

1>	**46,881,680.0**	
9>	1210.000000	0.000000
10>	168.000000	0.000000
11>	4594.000000	0.000000
12>	0.000000	2512.460000

Therefore, from the above calculation results, it can be seen that the optimal solution of linear programming is x_1 = 4150, x_2 = 12,569, x_4 = 432 and x_6 = 108, i.e., 415,000 ha of timber forest, 1,256,900 ha of protection forest, 43,200 ha of special-purpose forest and 10,800 ha of bamboo forest should be developed in order to maximize the benefits of forest land, forest value and forest environmental services on Hainan Island. At this point, the maximum annual benefit would be CNY 4.688 billion. In this way, the value of forest ecosystem services on Hainan Island is the highest in the context of the integrated development of forests, lakes and wetlands [17].

Further sensitivity analysis of the above calculations is presented in Table 8.

Table 8. Obj. coefficient ranges.

Variable	Current Coef.	Allowable Increase	Allowable Decrease
x_1	2884.420000	INFINITY	371.960000
x_2	2512.460000	371.960000	180.980000
x_3	612.000000	1900.460000	INFINITY
x_4	6888.500000	INFINITY	4376.040000
x_5	2331.480000	180.980000	INFINITY
x_6	3300.000000	INFINITY	787.540000
x_7	1181.030000	1331.430000	INFINITY
x_8	612.000000	1900.460000	INFINITY
x_9	535.500000	1976.960000	INFINITY
x_{10}	535.500000	1976.960000	INFINITY

The sensitivity analysis also shows that it is necessary to increase the prices of protection forest x_2, shrub land x_8, unforested silvicultural land x_9 and the barren hills and wasteland and non-forest land x_{10} so that their prices are capped at 1900.46 CNY/ha, 1900.46 CNY/ha, 1976.96 CNY/ha and 1976.96 CNY/ha, respectively (Table 9).

Table 9. Righthand side ranges.

Row	Current RHS	Allowable Increase	Allowable Decrease
2	4150.000000	11,178.000000	4150.00000
3	1391.000000	11,178.000000	INFINITY
4	84.000000	INFINITY	84.00000
5	432.000000	11,178.000000	432.00000
6	4498.000000	INFINITY	4498.00000
7	108.000000	11,178.000000	108.00000
8	624.000000	INFINITY	624.00000
9	1210.000000	INFINITY	1210.00000
10	168.000000	INFINITY	168.00000
11	4594.000000	INFINITY	4594.00000
12	17,259.000000	INFINITY	11,178.00000

4. Results and Discussion

Forest ecological planning has played an important role in the integrated development of lakes, wetlands and forests on Hainan Island. Therefore, according to the above calculation, we obtained some basic results, and related problems should be discussed.

(1) From the results of the forest ecological planning of Hainan Island, it can be seen that the benefits of forest land, forest trees and forest environmental services should be maximized so that the areas of timber forest, protection forest, special-purpose forest and bamboo forest are maintained at 415,000, 1,256,900, 43,200 ha and 10,800 ha; namely, at a ratio of 24:72.8:2.5:0.6. At present, the areas of the four forest types on Hainan Island are 415,000, 139,100, 43,200 ha and 10,800 ha, respectively, with a ratio of 68:22.9:7.1:1.8. Therefore, reducing the proportion of timber forest area and increasing the proportion of protection forest area is an urgent requirement for ecological construction but also circular economy development in Hainan Province [28]. In particular, it is conducive to the integrated development of forests, lakes and wetlands and the maximization of the value of forest ecosystem services.

(2) It can be seen, from the optimal solution of the dual problem of forest ecological planning on Hainan Island, that the average economic valuation of reasonable use of different forest types (i.e., the average shadow price) is 2512.46 CNY/ha. Economically, this is the valuation of the marginal revenue obtained per unit of forest land with the optimal allocation of specific production conditions. Mathematically, it is equal to the optimal solution of the dual variable corresponding to woodland in the dual problem. Therefore, the optimal valuation of Hainan special-purpose forest should also be 4376.04 CNY/ha, rather than the current 6888.50 CNY/ha, to promote the optimal development of integrated lakes, wetlands and forests.

(3) The shadow price truly reflects the influence and contribution of resources to income for the optimal decision in the economic structure. The higher the shadow price of a resource, the greater the contribution of the resource to the total income. The shadow price is positive, indicating that the resource is a short-term product. A shadow price of 0 indicates that the resource is a long-term product. Therefore, shadow price is a reasonable price that reflects the scarcity of resources [29], market supply and demand relations and other factors. It guides people to make reasonable use of resources and obtain maximum benefits. The planning results show that the timber forest (x_1), protection forest (x_2), special-purpose forest (x_4) and bamboo forest (x_6) on Hainan Island are short-term products (Figure 1). The figure below displays primal solution values of a non-zero ratio, indicating that profits can be gained easily in a short time. The fuelwood forest (x_3), economic forest (x_5), open forest land (x_7), shrub land (x_8), unforested silvicultural land (x_9), barren hills and wasteland as well as non-forest land (x_{10}) are long-term products. The pie chart shows dual solution values of a non-zero ratio, demonstrating the difficulty of obtaining benefits in the short term (Figure 2) [30]. Therefore, in the forest, ecological planning should be carried out in the short term and long term to maintain the various benefits.

(4) From the results of the dual solution in the planning process (Figure 2), it can be seen that benefits can easily be derived from timber forest (x_1), protection forest (x_2), special-purpose forest (x_4) and bamboo forest (x_6). Therefore, attention should be paid to their development, and the development area should be planned well. At the same time, it is necessary to properly promote the development of other forest types, especially for the ecological governance of Hainan Island, which involves long-term stability, and more attention should be paid to the appropriate development ratio of other forest types.

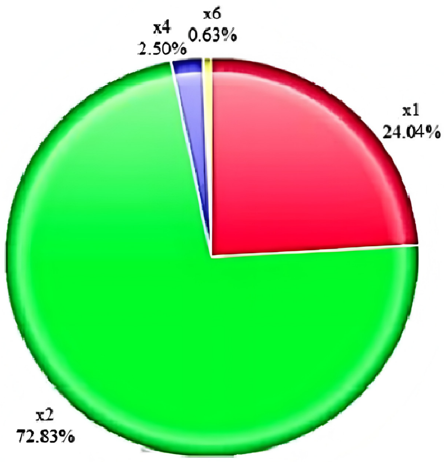

Figure 1. Chart reporting primal solution values.

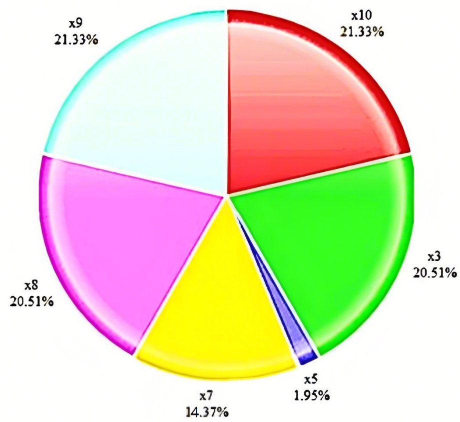

Figure 2. Chart reporting dual solution values.

5. Conclusions and Suggestions

It can be seen, through the research on the optimal forest ecological planning of Hainan Island in the context of the integrated development of lakes, wetlands and forests, that one of the important aspects of integrated development is effective forest ecological planning; that is, forestry land planning should be formulated conforming to ecological requirements according to ecological principles in order to maximize the overall benefit of forestry land and give full play to the best protection benefit of forests. For the construction of Hainan ecological province especially, it is very important to realize a highly developed social economy, a reasonable industrial structure, the full utilization and protection of forest resources, and an ecological system of economic and ecological virtuous cycles, as well as the integrated development of lakes, wetlands and forests. Therefore, the following conclusions were drawn, and suggestions are put forward related to the problems discussed.

(1) The ratio of timber forest, protection forest, special-purpose forest and bamboo forest must be adjusted from the current 68:22.9:7.1:1.8 to 24:72.8:2.5:0.6 in order to promote the integrated development of lakes, wetlands and forests and maximize the benefits of woodlands, trees and forest environmental services on Hainan Island. The average shadow price of the reasonable use of different forest types on Hainan Island is 2512.46 CNY/ha, and the optimal valuation of special-purpose forest is 4376.04 CNY/ha, rather than the current 6888.50 CNY/ha. This will not only contribute to the long-term stability of Hainan's ecological environment, but also to the long-term development of Hainan Island's social economy and environment.

(2) In the management of Hainan's lakes, wetlands and forest ecological environment, we should pay close attention to the restructuring of forest types such that the proportional structure of different forest types is suitable for the needs of the construction of the ecological province and high-quality development. Regarding the ecological province construction and high-quality development goals, Hainan has carried out a 1 million mu (about 66,700 ha) coconut forest project and natural forest protection project, implemented a sea defense forest project and strengthened forest protection, among other measures. It has also increased the area of afforestation, completing an average of 16,000 ha per year, raising the forest cover to 62.1% [18,31]. These activities have given a strong impetus to the restructuring of forest types and high-quality development, but efforts should continue to be stepped up to further increase the proportion of protection forest to around 73% to meet the needs of ecological construction and high-quality development.

(3) The structure of the forestry industry should be adjusted and the growth of trees promoted to ensure long-term benefits. In the management of the lakes, wetlands and forest ecological environment, attention should also be paid to the adjustment of the forestry industry structure such that forestry production is mainly shifted from the production of a single tropical crop to the production of a variety of forest products and services. The added value of Tropical High-Efficiency Agriculture (THA) in Hainan Province in 2020 was CNY 84.289 billion, accounting for 15.20% of the GDP in that year; in 2021, the added value of THA was CNY 96.204 billion, accounting for 14.90% of the GDP of Hainan as a whole in that year, representing a decrease [18,32]. The value added from forestry output accounts for a certain proportion of this. Therefore, in order to promote the increase in the proportion of added value of high-efficiency agriculture with tropical characteristics, it is necessary to adjust the structure of the forestry industry by transitioning from the production of single tropical crops to the production and service of various forest products, promote the growth and benefits of forest trees, and give full play to the best effects of lakes, wetlands and forest ecological environment governance.

(4) The development of forestry industries and the ecological environment management of lakes, wetlands and forest should be priorities. Hainan's four leading industries are tourism and related industries, modern service industries, high-tech industries and highly efficient agricultural industries with tropical characteristics, among which forestry's advantageous industries play an important role. The dominant forestry industry is tropical crop cultivation, mainly consisting of rubber, coconut, coffee, pepper, betel nut, sisal, cashew nuts and eucalyptus. The long-term cultivation of these crops will have a certain environmental impact on the soil; in particular, the extensive cultivation of eucalyptus trees will cause soil degradation and affect biodiversity conservation. However, if management is strengthened and appropriate technical measures are taken, not only can these advantageous industries be promoted, but the environment can also be protected, and ecological management especially is very important for lakes, wetlands and forest. According to research, the oil of eucalyptus in Australia has been an inconvenience for local farmers for many years, as the tree has a high growth capacity and, yet, is of little use. However, researchers have found that, using certain techniques, the oil of the eucalyptus tree can not only be used as a safe alternative fuel but can also reduce the salt content of the soil. This oil can be heated at high temperatures to extract an oil concentrate, which is then refined to produce diesel fuel to power engines. In addition, the roots of the eucalyptus tree can reach the water-bearing layers of the soil and help to reduce its salt content [33–35]. Therefore, strengthening technical research and forestry management to promote the

development of forestry's advantageous industries and environmental protection is not only necessary for the sustainable development of Hainan's forestry industry, but is also an inevitable choice to strengthen the environmental protection and integrated development of lakes, wetlands and forests.

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References

1. Zhang, Y.X.; Chen, Z.H. Study on the relationship between wetland and surrounding land use change: A case study of Hainan Province. *Geogr. Res.* **2007**, *26*, 1132–1133.
2. Cui, H.; Wang, L.X.; Ou, Y.; Yan, B.; Han, L.; Li, Y. Research progress on phosphorus migration and transformation in wetland ecosystem. *J. Water Ecol.* **2020**, *41*, 105–112.
3. Mekonnen, S. Review on the role of forest landscapes in watershed hydrologic processes. *Environ. Earth Sci.* **2017**, *7*, 97–104.
4. Chen, Z.-Z.; Lei, J.-R.; Wu, T.-T.; Chen, D.-X.; Zhou, Z.; Li, Y.-L.; Hong, X.-J.; Yang, Z.-Y.; Li, Y.-D. Accounting of gross ecosystem production of national parks: A case study of Hainan Tropical Rainforest National Park. *Chin. J. Appl. Ecol.* **2021**, *32*, 3883–3892.
5. Ye, X.D.; Zhou, Q. *Blue Ecology*; China Economic Press: Beijing, China, 2005; pp. 42–50, 249–257. (In Chinese)
6. Zhang, J.; Zhou, W.; Wang, Y. Spatial optimization of ecological security pattern in Hainan Province based on landscape ecology theory. *J. Landsc. Archit.* **2019**, *3*, 68–74.
7. Chen, W.H. Industrial development and spatial layout optimization in Hainan. *Open News* **2019**, *3*, 69–73. [CrossRef]
8. Yang, Z.J.; Yan, H.N.; Wang, B. International experience and inspiration of modernizing China's marine ecological environment governance. *Pac. J.* **2017**, *25*, 81–93.
9. Huang, J.C.; Lin, H.X.; Qi, X.X. A literature review on optimization of spatial development pattern based on ecological-production-living space. *Prog. Geogr.* **2017**, *36*, 378–391. [CrossRef]
10. Cao, J. Expecting more beautiful bays. *China Ecol. Civiliz.* **2022**, *50*, 3.
11. Chen, H.C.; Lou, Y.; Liu, C. Reflections on the ecological protection and restoration of China's coastal zone. *For. Surv. Plan.* **2022**, *47*, 96–99.
12. Lei, Z.J.; Wang, J.; Huang, L.J. Planning and engineering practice of river ecological restoration in coastal zone of Zhenhai District. *Water Resour. Dev. Manag.* **2022**, *8*, 32–38+52. (In Chinese)
13. Zhang, J.; Lu, W.H.; Song, W.T. Research on ecological protection and restoration policies of China's coastal zone. *Land Resour. Inf.* **2021**, *244*, 18–25.
14. Lou, X.F.; Yang, S.; Xu, X.C. Coastal zone restoration in the Guangdong-Hong Kong-Macao Greater Bay Area based on the concept of ecological civilization construction. *Water Resour. Hydropower Technol.* **2021**, *52*, 332–334, (In Chinese and English).
15. Li, Y.Z.; Sun, T.; Chen, S.K. Study on wetland protection in Small and medium-sized lakes (reservoirs) in Hainan Province: A case study of Dagangba Reservoir. *Rural. Sci. Technol.* **2018**, *33*, 116–118. (In Chinese) [CrossRef]
16. Luo, M.; Yang, C.Y.; Sun, Y.Q. The NbS pathway of ecological protection and restoration practices in China's coastal zone. *China Land* **2022**, *434*, 4–7.
17. Xiong, Q.G. Research on the processing of multi-objective planning models based on linear programming models. *Sci. Technol. Innov.* **2020**, *28*, 42–43.
18. Hainan Provincial Bureau of Statistics, Survey Office of National Bureau of Statistics in Hainan. *Hainan Statistical Yearbook (2022)*; China Statistics Press: Beijing, China, 2022; pp. 138–141. (In Chinese)
19. State Forestry and Grassland Administration. *China Forestry and Grassland Yearbook (2021)*; China Forestry Press: Beijing, China, 2022; pp. 22–44. (In Chinese)
20. Forestry Zoning Office, Ministry of Forestry, People's Republic of China. *Forestry Zoning in China*; China Forestry Press: Beijing, China, 1987; pp. 266–270. (In Chinese)
21. Zeng, Q.B.; Li, Y.D. *Tropical Forest Ecosystem Research and Management*; China Forestry Press: Beijing, China, 1997; pp. 127–129. (In Chinese)
22. Zhang, Y. Study on optimal forest ecological planning in Hainan Province. *For. Econ.* **2007**, *176*, 47–50.

23. Li, Y.D. Tropical forest resources and their ecological and environmental protection functions. *Trop. For.* **2002**, *30*, 16.
24. Zhang, L.; Lei, J.R.; He, R.X.; Zhou, P. Evaluation of Ecosystem Services in Hainan Island Wetlands Based on Meta-Analysis. *J. Hydroecology* **2024**, *45*, 70–77. (In Chinese)
25. Jin, Y.; Ouyang, Z.Y.; Lin, S.K. A preliminary study on the framework of green GDP accounting in Hainan Province. *Ecol. Econ.* **2008**, *3*, 48–53+64.
26. Bao, W.K.; Lin, Q. A study on ecological restoration zoning of coastal zone from the perspective of land and sea integration: The case of Xiangshan Port watershed. *Mar. Dev. Manag.* **2022**, *39*, 3–10.
27. Luo, Y.Z.; Zong, S.L. A comparative study of solving linear programming models using Excel and other software. *Electron. Technol. Softw. Eng.* **2022**, *225*, 80–84.
28. Sui, Y.Z.; Sun, D.P.; Li, S.J. Conservation and restoration of coastal zone ecosystems in Dongying City in the context of carbon storage change. *J. Ecol.* **2021**, *41*, 8112–8123.
29. Gerlagh, R.; Dellink, R.; Hofkes, M.; Verbruggen, H. A Measure of Sustainable National Income for the Netherlands. *Ecol. Econ.* **2002**, *41*, 157–174. [CrossRef]
30. Yu, X.Q.; Yu, J. A textual analysis of ecological restoration policies in China's coastal zone based on NVivo. *China Fish. Econ.* **2021**, *39*, 20–30.
31. Fan, H.X.; Wang, J.Z.; Zhu, L.J. Experimental study on the physical model of marine ecological environment restoration engineering in Xihu Port, Xiangshan County. *Mar. Dev. Manag.* **2015**, *32*, 86–90.
32. Gong, Q.; Zhang, R.B.; Wang, L.X. Research on frontier technology and application of marine mapping. *Mapp. Spat. Geogr. Inf.* **2022**, *45*, 1–5+9+12.
33. Du, X.H. Formerly useless oil eucalyptus trees are now treasures. In *Reference News*, 5th ed.; Journey of discovery; Xinhua News Agency: Beijing, China, 2006.
34. Su, Q.M. More Than 1900 km of Coastline on Hainan Island with Diverse Forms and Rich Resources. 2021. Available online: http://hi.people.com.cn/n2/2021/0830/c231190-34890017.html (accessed on 19 January 2021).
35. Yang, B.; Li, M.H.; Huang, C.S. Ian McHarg's ecological planning in the woodlands, Texas: Lessons learned after four decades. *Landsc. Res.* **2015**, *40*, 773–794. [CrossRef]