Protection and development planning of mud flat: A modelling approach and case study

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Abstract. The aim of this paper was to examine the use of a linear programming model to make protection and development planning of mud flat as good as it can be, on condition that its ecosystem service values are maximized. Such an optimization model for Dafeng County was constructed. This mode represents all the ecosystem service values, which is based on linear programming, subject to the restrictions imposed by the protection and development areas. The result shows that it is possible to obtain an optimization model for planning Dafeng's mud flat by using linear programming method. The result also shows that there is a possibility of improving the performances of ecological restoration of the mud flat by planning uses of the mud flat, in particular maximizing the multiple service benefits of the mud flat simultaneously.

1. Introduction

Protection and sustainable development of mud flat (MF) has obtained much attention in recent years. This is because MF has important ecological and economic benefits. MF can be used as a coastal wetland resource with value of high sustainable development. It has many uses that can be achieved in the agricultural sectors. But, it has also been examined as a vulnerable ecosystem. Thus, it has been found that optimal management function of MF is too weak to make MF to be developed under sustainable development mode [1]. One way to strengthen the management is to join a decision support system. This system is used to improve MF resource management. There has been a lot of research conducted on management decisions to maximize the values of ecosystem services [2] [3]. Barton et al. presented that such decisions could be provided by optimization management models [4]. Otherwise, Wainger et al. provided also such model [5]. However, even though the effect of such optimization management model on taking the benefits of developing MF and restoring the values of its ecosystem services was shown and explained, little interest has been paid to the problem of protection and sustainable development of MF. The present paper presents a flexible linear programming model that can be used to solve such problem. On condition that the ecosystem service values of MF are maximized, subject to other constraint conditions of protection and sustainable development of MF, the model then implements the optimal assignment of MF. Such combination of maximizing the values and holding the conditions formed an effective optimization management system for protection and sustainable development of MF.

2. Material and methods

Our study work was carried out in Dafeng County during 1984-2002. The County is located on Jiangsu Province of China. It is located between latitudes 32°56’-33°36’ N and longitudes 120°13’-120°56’ E. Its average annual precipitation and temperature are 1042 mm 14°C respectively. The

County boosted 77300 hectares of MF. The 11 main types of MF are cultivated-type land, forest-type land, breed aquatics pond-type land, bare seawall-type land, forest seawall-type land, residential-type land, saltern-type land, grass-type land, bare-type land, beach reclamation-type land and water reclamation-type land.

The conflict between the protection and sustainable development of Dafeng's MF was beginning more and more noticeable. The MF-use practices can implement the conversion of terrestrial ecosystems and act an important part in global ecological restoration. The value of ecosystem services of MF also varies significantly with variations of MF-use types. Therefore, subject to the above constraints, how to assign MF-use types and maximize the value of their ecosystem services is really an optimization problem. Further, the problem can be solved by using a linear programming. Thus, such linear programming is an effective way to settle the conflict. To formulate such optimization problem, let V represent the value of ecosystem services based on MF. Thus, the objective of protection and sustainable development of MF is to select the values of X_i (MF-use type *i*) in the following linear programming to make

$$\max V = \sum_{i=1}^{11} X_i \times P_i \tag{1}$$

Subject to:

$$X_2 + X_5 \geq 0.2S_{cf}\ ,\ X_1 + X_8 + X_9 + X_{10} \geq 0.57S_{cf} \tag{2}$$

$$X_3 + X_{11} \geq 0.17S_{cf} \tag{3}$$

$$X_1 + X_2 + X_3 + X_4 + X_5 + X_8 + X_{10} + X_{11} \geq 0.9S_{cf} \tag{4}$$

$$\sum_{i=1}^{7} X_i \times P_i - \sum_{i=8}^{11} X_i \times P_i \leq 0 \tag{5}$$

$$\sum_{i=1}^{7} X_i - \sum_{i=8}^{11} X_i \leq 0\ ,\ X_i \geq 0, i = 1, \ldots, 11 \tag{6}$$

$$\sum_{i=1}^{11} X_i = S_{cf} \tag{7}$$

where:

$P_i =$ X_i's ecosystem service value of MF, $i = 1, \ldots, 11$,

$X_1 =$ cultivated-type land area of MF, $P_1 = 0.92 \times 10^4 \$ km^{-2}$,

$X_2 =$ forest-type land area of MF, $P_2 = 2.61 \times 10^4 \$ km^{-2}$,

$X_3 =$ breed aquatics pond-type land area of MF, $P_3 = 0.04 \times 10^4 \$ km^{-2}$,

$X_4 =$ bare seawall-type land area of MF, $P_4 = 0.20 \times 10^4 \$ km^{-2}$,

$X_5 =$ forest seawall-type land area of MF, $P_5 = 1.31 \times 10^4 \$ km^{-2}$,

$X_6 =$ residential-type land area of MF, $P_6 = 0.00 \times 10^4 \$ km^{-2}$,

$X_7 =$ saltern-type land area of MF, $P_7 = 0.04 \times 10^4 \$ km^{-2}$,

$X_8 =$ grass-type land area of MF, $P_8 = 2.32 \times 10^4 \$ km^{-2}$,

$X_9 =$ bare-type land area of MF, $P_9 = 0.01 \times 10^4 \$ km^{-2}$,

X_{10} = beach reclamation-type land area of MF, $P_{10} = 0.23 \times 10^4 \$ km^{-2}$,

X_{11} = water reclamation-type land area of MF, $P_{11} = 0.04 \times 10^4 \$ km^{-2}$,

S_{cf} = total area of MF ,

$0.2S_{cf} \wedge 0.57S_{cf} \wedge 0.17S_{cf} \wedge 0.9S_{cf}$ = plan developed by the County for its MF .

The following Table 1 gives the solution for the above optimization problem with the help of linear programming software, where "Artificial" and "Nature" represent respectively the development and protection status of MF.

Table 1. Use and optimization of MF of Dafeng County from 1984 to 2002

Use type		1984		1997		2002	
		km^2	%	km^2	%	km^2	%
Artificial	X_1	59.13	18.80	161.4	40.31	173.44	30.73
	X_2	0.76	0.24	0.86	0.21	0.00	0.00
	X_3	22.6	7.18	106.47	26.59	335.31	59.42
	X_4	6.32	2.01	4.15	1.04	8.72	1.55
	X_5	3.77	1.20	10.54	2.63	9.97	1.77
	X_6	0.21	0.07	1.8	0.45	3.46	0.61
	X_7	7.96	2.53	8.37	2.09	8.27	1.47
	Total	100.75	32.03	293.59	73.32	539.17	95.54
Nature	X_8	59.96	19.06	53.95	13.47	1.66	0.29
	X_9	61.57	19.57	31.98	7.99	11.1	1.97
	X_{10}	42.27	13.44	8.53	2.13	1.44	0.26
	X_{11}	50.03	15.90	12.38	3.09	10.97	1.94
	Total	213.83	67.97	106.84	26.68	25.17	4.46
Real Total Area		314.58	100.00	400.43	100.00	564.34	100.00
Artificial	X_1	43.07	13.69	50.11	12.51	63.88	11.32
	X_2	59.16	18.80	69.56	17.37	102.90	18.23
	X_3	3.45	1.10	55.69	13.91	84.97	15.06
	X_4	6.32	2.01	4.15	1.04	8.72	1.55
	X_5	3.77	1.20	10.54	2.63	9.97	1.77
	X_6	0.21	0.07	1.8	0.45	3.46	0.61
	X_7	7.96	2.53	8.37	2.09	8.27	1.47
	Total	123.94	39.40	200.22	50.00	282.17	50.00
Nature	X_8	81.37	25.87	153.59	38.36	233.78	41.43
	X_9	16.97	5.39	25.72	6.42	35.98	6.38
	X_{10}	42.27	13.44	8.53	2.13	1.44	0.26
	X_{11}	50.03	15.90	12.38	3.09	10.97	1.94
	Total	190.64	60.60	200.22	50.00	282.17	50.00
Optimal Total Area		314.58	100.00	400.43	100.00	564.34	100.00

3. Results

Artificial and natural status together with real and optimal areas for all use of MF in 1984, 1997 and 2002 year are shown in Table 1. It is apparent that there is a bias towards excessive and unreasonable exploitation for MF. This is demonstrated in Fig. 1, where the 11 MF-use types for which 3 years of data are available are presented as bar plots. The vertical axle represents the ecosystem service values and horizontal axle represents years. It is apparent that the MF-use types at the optimal bars of the figure have higher ecosystem service values and those at the real bars have lower ecosystem service values. We think that satisfactory decisions for protection and sustainable development of MF will be found by studying these differences of Figure 1.

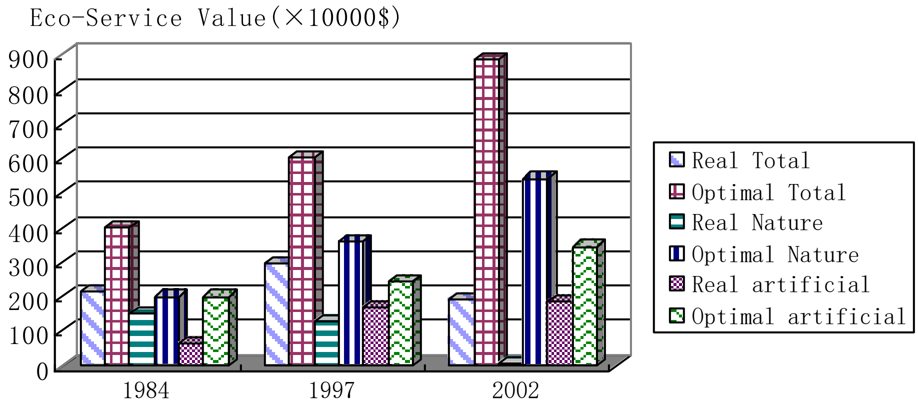

Figure 1. Annual variation of values of the ecosystem service.

4. Conclusion

Most notably, to our knowledge, this may be the first paper to examine the protection and sustainable development of MF with an optimization model based on linear programming. This paper outcome gives strong evidence that this method occurs to be effective in management actions that maximize the value of protection and sustainable development of MF.

Acknowledgments

This study was sponsored by the Major Project of National Science and Technology (Grant 09-Y30B03-9001-13/15-4).

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