water

MDPI

Article

Establishment and Application of Wetlands Ecosystem Services and Sustainable Ecological Evaluation Indicators

Han-Shen Chen [1,2]

[1] School of Health Diet and Industry Management, Chung Shan Medical University, No. 110, Sec. 1, Jianguo N. Rd., Taichung City 40201, Taiwan; allen9750@yahoo.com.tw; Tel.: +886-4-2473-0022

[2] Department of Medical Management, Chung Shan Medical University Hospital, No. 110, Sec. 1, Jianguo N. Rd., Taichung City 40201, Taiwan

Academic Editor: Peter L. M. Goethals

Received: 8 November 2016; Accepted: 7 March 2017; Published: 8 March 2017

Abstract: Gaomei wetlands are national Taiwanese coastal wetlands. Over the past few years, they have grown into an important water bird habitat and popular bird-watching location. However, the rapid growth in tourism has begun to affect the environmental quality in the Gaomei wetlands. This study combined ecosystem services (ES) and ecological footprint (EF) assessments to evaluate the sustainability status according to the features of each ecosystem service for the different Gaomei wetlands land uses. The results found that (a) the total Gaomei wetlands ecosystem service value increased from 59.24 million TWD in 2008 to 98.10 million TWD in 2015, and the ecosystem service function was continuously improving; (b) the EF increased by 56.12% over 8 years; and (c) there was a negative growth rate of 106.54% in the ecological deficit (ED) in the sustainable ecological evaluation indicators (SEEI). The ecological footprint index (EFI) in 2015 was at Level 4 at 1.02, and the environmental sustainability index (ESI) was at Level 3 at 0.49. Results show that Gaomei wetlands have a low sustainability; therefore, the local, regional, and national governments need to implement regulations to strictly control the Gaomei wetlands land use. This study demonstrated that ES and EF theory application can give an objective guidance to decision-makers to ensure that wetlands eco-security can be maintained at safe levels.

Keywords: wetlands; ecological footprint; ecosystem services; ecological security; sustainable ecological evaluation indicators (SEEI)

1. Introduction

As outlined in the Millennium Ecosystem Assessment of the United Nations, wetlands are one of the most threatened ecosystem in the world, with biodiversity loss being the major concern. With the continued loss and degradation of wetlands, ecological services are declining, negatively impacting human life. Factors such as climate change, rural poverty, and increased human population size have resulted in a wetlands loss of ~30%–50% in the last decade [1–3]. As well as providing ecosystem services such as flood control, coastline protection, nutrient recycling, carbon sequestration, and ecotourism, wetlands support many specialized plants and animal species [4–8].

This study was conducted in the Gaomei wetlands, located in Shimizu, Taichung, Taiwan, and designated national Taiwanese wetlands in 2007 (Construction and Planning Agency Ministry of the Interior, 2007). Recently, the Gaomei wetlands have become a major bird destination as a critical winter habitat. However, human activities such as highway construction have led to significant reductions in the sandbars and mangroves with a concurrent loss of biodiversity. Sustainable economic and societal development and reductions in the impact of tourism must be addressed when developing natural resources. This study sought to balance resource and biodiversity conservation with sustainable management and resource development. Because the Gaomei wetlands have similar topography and ecosystems to other Taiwanese wetlands systems, the evaluation model developed in this paper could be used for similar wetlands systems.

Chapin et al. (2000) suggested that ecosystem processes and biological diversity are crucial intermediaries in the overall economic and human systems' global environment [9]. Costanza et al. (1997) defined ecosystem services (ES) as ecosystems that "provide, directly or indirectly, the material and services to promote human welfare" [10]. The UN published the Millennium Ecosystem Assessment (MEA) in 2005, in which ecosystem services are divided into supply services, regulating services, cultural services, and support services [11]. Ecosystem service (ES) assessments have traditionally focused on identifying the individual monetary values for each ecosystem service [12,13]. However, the lack of theoretical frameworks has led to subjective judgments and criticisms [14–16]. The integration of deliberate and non-monetary valuation approaches to ES valuations has increasingly been advocated as a way of revealing the wider value concepts. Such methods, however, have had limited application in practice and have been mostly focused on localized case studies [17–19]. Barbier et al. (2011) evaluated the ecosystem service values in wetlands, mangroves, coral reefs, seagrass beds, and sandy beaches [20]. Bateman et al. (2011) explored the contribution of land use changes on ecosystem services and ecosystems [21]. Su et al. (2012) focused on four ecological zones in Hangzhou, China, to investigate the effect of landscape patterns and ecosystem service changes on urbanization [7]. To examine ecosystem services and biodiversity in Europe, Maes et al. (2012) used four supply function indicators, five adjustment function indicators, and a cultural function indicator to calculate ecosystem service values, and used average species richness and species diversity to measure biodiversity [22].

As previous research on land use and its impact on the environment has tended to focus more on exploring the single highest impact level, there has been less focus on the analysis and evaluation of the impact land-use development and the changes it has had on the natural environment. An econometric model [23,24], a statistical model [25–30] as well as a cellular automata model [31] have to date been the most commonly used evaluation models. Burkhard et al. (2013) believed that, for a more realistic ecosystem service status assessment, ecosystem services at different ecosystems, and the benefits that different ecosystems and land cover types provide, should also be considered [32]. Therefore, some studies have integrated the Millennium Ecosystem Assessment (MEA) and other assessment indicators into comprehensive evaluation indices [33–35]. Nelson et al. (2009) combined land use change ecosystem services with the integrated valuation of ecosystem services and tradeoffs (InVEST) mode to explore the relationship between biodiversity competition with other ecosystem services [36]. Polasky et al. (2011) also used the InVEST mode to quantify changes in ecosystem services, biodiversity, and land use in Minnesota from 1992 to 2001, and to assess the impact of different land use change scenarios on ecosystem services and biodiversity. Using the historical development (1964–2004) in Leipzig, Germany [37], Lautenbach et al. (2011) developed regional scale indicators for different land use structure ecosystem services, such as water purification, pollination, food production, and outdoor recreation, and calculated the systemic functions and analyzed sensitivity tests under different land use types [34]. Geneletti (2012) simulated the impact generated by different land management policies on ecosystem services in the future based on historical land use [38]. In summary, using analysis and prediction modes for land use change along with mode simulations, decomposition, the analysis and synthesis of the complex socio-economic factors, and the interaction processes in natural ecosystems for given land uses to determine land-use change and spatial pattern trends [39–42] have become the focus of current research trends.

Sharp variabilities in the global climate have resulted in desertification, reduced ecosystem resilience, and loss of biodiversity. The 1972 United Nations Declaration on the Human Environment and Eco-Security raised concerns related to the preservation of food and ecosystems and outlined principles for sustainable human development projects, providing a new perspective on environmental resources, human survival and sustainable development reviews. With the development of ecological security theory and as ecological problems became increasingly prominent, researchers began using different indicators and measurement system models or methods to evaluate the ecological security of different regional scales, thus providing early warning models that could serve as vital references [43].

As using quantitative indicators to analyze complex information increases objectivity [44,45], a three-dimensional (economy, ecology, and society) indicator system was developed to study ecological security in Western Nepal [46]. Ecological security has also been measured using the Ecological Footprint Index (EFI) and environmental carrying capacity (ECC) [47].

The Ecological Footprint (EF) Model was proposed by Rees (1992) [48], with the primary feature being its ability to compare human demands on the environment with the biosphere's ability to regenerate resources and provide services. Wackernagel and Rees (2000) proposed that the EF magnitude was directly proportional to the environmental impact (the greater the EF, the greater the environmental impact), and was inversely proportional to the per-capita usable area of biologically productive land (the greater the EF, the smaller the per-capita usable area of biologically productive land) [49]. It is now a widely used measure in the field of ecological economics as it is a quantitative indicator that is easy to understand and calculate. Therefore, this paper uses sustainable ecological evaluation indicators (SEEIs) to measure regional ecological security on a per-unit ecological footprint basis.

In summary, this paper first combines the ecosystem services and ecological footprint models to evaluate the sustainability status based on each of the ecosystem service features for the different Gaomei wetlands land use covers, after which the ecosystem service values are calculated. Subsequently, the SEEI—the ecological remainder (ER), the ecological deficit (ED), the EFI and ESI—is used to analyze the resource utilization efficiency and ecological security in the Gaomei wetlands. The problems identified by the different indicator values are evaluated to develop a systematic measurement apparatus to encourage sustainable development and to review the evolution in sustainable development trends.

2. Materials and Methods

2.1. Study Area

The Gaomei wetlands (24°18′35.07″ N, 120°33′08.21″ E) are located in Shimizu, Taichung, Taiwan. The Gaomei wetlands support diverse bird species and special habitats such as lagoons and sandbars, providing many possible tourist opportunities. As the Gaomei wetlands have been evolving in the past few years from a primarily agriculturally based economy to a primarily tourism based economy, there have been several recent studies focused on tourist behavior and local tourism support initiatives [50–52].

2.2. Methods

This study combines ecosystem services and the EF model to reclassify the EF ecosystem according to the various land-use features for each ecosystem service system at the Gaomei wetlands. The ecological footprint (EF) (demand) and ecological capacity (supply) at the Gaomei wetlands were first evaluated over various periods using an EF model developed from ecosystem services theory, after which an eco-security indicator system was established to estimate the Gaomei wetlands' eco-security, the steps for which were as follows:

2.2.1. Ecosystem Services Value Model

The methods used to estimate the ecosystem service value in the research area were based on the value assessment method models outlined in [10,53,54]. An equivalence factor for the ecosystem service value for the different land uses and land cover at the Gaomei wetlands was calculated using the assessment model, which took the ecosystem service value for the different land use and land covers as the basis for determining the ecosystem service value, as shown in Equation (1):

$$ESV_k = \sum_i^m \sum_j^n A_i \times f_{ij} \times E_a \times S_k \times T_k \tag{1}$$

where ESV is the total ecosystem service value; A_i is the distribution area for the ith type of land use and land cover (gha); f_{ij} is the equivalence factor for the jth ecosystem goods and services item provided by the ith ecosystem; E_a is the production per unit area or the ecosystem service value coefficient; S_k is a K coefficient for regional differences; T_k is a K regional service support coefficient; i is the land use and land covers in the different ecosystems; j is the ecosystem service category.

2.2.2. Accommodation Ecological Footprint

The EF concept [55,56] was used to evaluate the changes in the Gaomei wetlands from 2008 to 2015. To examine the influence of the EF on the environment, the transportation ecological footprint (TREF), the activities ecological footprint (ACTEF), and the food and fiber consumption ecological footprint (FEF) were employed as the evaluation measures. The general formulas for calculating the EF and ECC are shown in Equations (2) and (3):

$$\mathrm{EF} = \mathrm{N} \times \mathrm{ef} = \mathrm{N} \times \sum_{i=1}^{n} (a \times a_i) = \mathrm{N} \times \sum_{j=1}^{6} \left(r_j \sum_{i=1}^{n} \frac{c_i}{p_i} \right) \ (i = 1, 2, 3, \ldots n;\ j = 1, 2, 3, \ldots, 6) \tag{2}$$

$$\mathrm{ECC} = \mathrm{N} \times \sum_{j=1}^{6} ec_{\mathrm{j}} = \mathrm{N} \times \sum_{j=1}^{6} (A_j \times r_j \times y_j),\ (j = 1, 2, 3, \ldots, 6) \tag{3}$$

in which EF is the total EF (gha); N is the total population; ef is the EF per capita (gha); aa_i is the biologically productive area per capita (gha), converted to the ith traded commodity type; c_i is the consumption per capita (kg) of the ith commodity type; p_i is the average global productive capacity (kg/(t/gha)) of the ith consumer goods type; r_j and y_j are the equivalence factor and yield factor (YF) for the jth land type; j is the corresponding land use or land cover type; ECC denotes the total ecological carrying capacity; ec_{j} is the ECC per capita; and A_j is the area per capita of the jth land type in the region.

2.2.3. Ecological Footprint Model

The traditional ecological footprint model converts the EF and ECC of the land ecosystems into biological resource consumption (agricultural land, forest land, grassland, and fisheries) and energy consumption (carbon footprint, completion land) and six other ecological system units. However, as this model includes systems and services ecological functions in the ECC calculation, it assumes that the ecosystem services of the various land ecosystem supply units can be used as fossil fuels. Therefore, the ECC evaluation of the ecosystem service value for the land ecosystems is reclassified in this paper to (1) agricultural ecosystem; (2) forest ecosystem; (3) grassland ecosystem; (4) ecosystem completions; (5) fisheries ecosystems (including lakes, rivers and wetlands); (6) unutilized land; and six other ecosystem units.

Traditional ecological footprint calculations consider only the production of food and raw materials to provide the two ecological functions. However, in the integrated EF model, an appropriate equivalence factor and a yield factor (YF) are used to determine the ecological functions for the biological land productivity and food production raw materials rather than the ecological functions and the ecosystem service value. YF is used mainly to reflect the differences in the different regions per unit area ecosystem services in the Gaomei wetlands, which is calculated as follows:

$$\mathrm{YF}_j = v_j / v_j^- \tag{4}$$

in which YF_j is the yield factor for the *j*th type of ecosystem unit, $j = 1, 2, \ldots, 6$, are the 6 ecosystem units; v_j is the per unit area value of the ecosystem service function for the *j*th type of ecosystem in a region; and v_j^- is the per unit area ecosystem service function value for the *j*th type of ecosystem in Taiwan.

Using Equation (4), the Gaomei wetlands yield factor was calculated from 2008 to 2015, as shown in Table 1.

Table 1. Yield factor (YF) for different land use and land cover ecosystems in the Gaomei wetlands from 2008 to 2015.

Year	Agricultural Ecosystem	Forest Ecosystem	Grassland Ecology System	Fisheries Ecosystems	Ecosystem Completions	Unutilized Land and Six Other Ecosystem Units
2008	1.51	0.92	1.15	1.88	0.62	1.92
2009	1.49	0.91	1.13	1.81	0.58	2.01
2010	1.48	0.88	1.12	1.80	0.54	2.15
2011	1.31	0.77	1.14	1.60	0.40	1.98
2012	1.06	0.60	0.87	1.28	0.15	1.62
2013	1.14	0.63	0.94	1.33	0.15	1.77
2014	1.07	0.57	0.88	1.21	0.11	1.64
2015	1.00	0.52	0.77	1.11	0.08	1.56

2.2.4. Sustainable Ecological Evaluation Indicators (SEEI)

Multiple quantitative indicators (e.g., ED, ER, EFI and ESI) were employed to develop an indicator set to evaluate the Gaomei wetlands ecological sustainability and to establish the standards so as to be able to properly assess the ecological security. The evaluation indicators utilized in this research are outlined in the following subsections.

(a) ED or ER

When the EF is lower than the ECC of a region, there is an ecological remainder (ER), indicating that the corresponding development model is sustainable. When the EF is higher than the ECC of a region, there is an ecological deficit (ED), indicating that the corresponding development model is not sustainable. As the ecological deficit results from excessive human resource demands [57], demand must be reduced to achieve sustainable ecological development. The formulas for ED and ER are shown as Equations (5) and (6).

$$\text{ER} = \text{ECC} - \text{EF} \tag{5}$$

$$\text{ED} = \text{EF} - \text{ECC} \tag{6}$$

in which ER is the ecological remainder, ED is the ecological deficit, ECC is the ecological carrying capacity, and EF is the ecological footprint.

(b) EFI

The EFI compares the resources and energy expenditures to the region's ECC to assess resource utilization and determine development sustainability. The EFI formula is as in Equation (7), and the EFI levels are as shown in Table 2

$$\text{EFI} = \text{EF}/\text{ECC} \tag{7}$$

in which EFI is the ecological footprint index, EF is the ecological footprint, and ECC is the ecological carrying capacity.

Table 2. Ecological Footprint Index (EFI) levels and conditions.

Level	EFI	EFI Conditions
1	<0.5	Safe
2	0.5~0.8	Moderately safe
3	0.8~1.0	Threshold
4	>1.0	Unsafe

Resource: [49].

(c) ESI

The Environmental Sustainability Index (ESI), which was developed by the Center for International Earth Science Information Network (CIESIN), the Yale Center for Environmental Law and Policy (YCELP), and the World Economic Forum, assesses sustainability by measuring the degree to which the ecological systems in a region meet the human ecological demands. The ESI formula is shown in Equation (8) and the ESI levels are given in Table 3

$$ESI = ECC/(ECC + EF) \quad (8)$$

in which ESI is the environmental sustainability index, EF is the ecological footprint; and ECC is the ecological carrying capacity.

Table 3. Environmental Sustainability Index (ESI) levels.

Level	ESI	Regional Ecological Sustainability Extent
1	>0.7	High sustainability
2	0.50~0.70	Low sustainability
3	0.30~0.50	Low unsustainability
4	<0.30	High unsustainability

Resource: [58].

3. Results and Discussion

3.1. Ecosystem Services Value Computation and Analysis Results

Equation (2) was used to calculate the ecological service value of each ecosystem type in the Gaomei wetlands from 2008 to 2015, as shown in Table 4. The total value of the ecosystem services in the Gaomei wetlands increased from 59.24 million TWD to 98.10 million TWD over the 8 years. From 2008 to 2013, the total Gaomei wetlands ecosystem service value increased by 42.27 million TWD due to the increased fisheries (including lakes, rivers, and wetlands) and agricultural land areas, both of which had large ecological service value coefficients. The total Gaomei wetlands ecosystem service value increased from 2013 to 2015; however, during the same period, the Gaomei wetlands total ecosystem service value decreased by 3.41 million TWD because the fisheries area, which had a large ecological service value coefficient decreased rapidly and the increased agricultural land area was not sufficient to compensate for the fisheries reduced ecological service value. Since 2013, therefore, the Gaomei wetlands total ecosystem service value has been decreasing.

From 2008 to 2015, the relative value of each Gaomei wetlands ecosystem type (Table 4) changed variably. The fisheries ecosystem services function value increased then decreased, the forest ecosystem services function value increased, decreased, and then increased, and the grassland ecosystem services function value had an M-shaped pattern: increase–decrease–increase–decrease; the agricultural ecosystem services function value decreased and then increased, with the overall ecosystem services function value increasing. Taken together, the total ecosystem service value in increased by a net of 65.60%, with the fisheries ecosystem service value increasing the most (81.09%), and that of the forest ecosystems decreasing the most (−84.38%) followed by the grassland ecosystems

(−33.39%). The fisheries accounted for 39% of the total utilized land area in the study area; however, the fisheries ecological service value accounted for 75.56% of the total ecosystem service value. Because the fisheries in this area have a high ecosystem service value coefficient, this land use type has a higher total ecosystem service value, highlighting the importance of the fisheries in the Gaomei wetlands ecosystem.

Table 4. Ecosystem service values from 2008 to 2015 for each Gaomei wetlands ecosystem type.

	Year	Fisheries Ecosystems	Grassland Ecology System	Forest Ecosystem	Agricultural Ecosystem	The Completion of Ecosystems	Unutilized land and Six Other Ecosystem Units	Total
Ecosystem Services Values (10^6 TWD)	2008	40.93	6.17	0.32	10.68	0.01	1.13	59.24
	2009	48.85	6.28	0.34	10.74	0.01	1.27	67.49
	2010	53.12	6.35	0.34	10.82	0.01	1.35	71.99
	2011	60.89	6.39	0.36	10.10	0.01	1.44	79.19
	2012	65.11	6.62	0.55	12.08	0.01	1.39	85.76
	2013	83.79	3.34	0.04	12.76	0.01	1.57	101.51
	2014	78.18	4.37	0.05	14.56	0.01	1.44	98.61
	2015	74.12	4.11	0.05	18.49	0.02	1.31	98.10

3.2. EF Computation and Analysis Results

Table 5 details the three Gaomei wetlands activity types and the EF computations. The EF gradually increased from 244.03 global hectares (gha) in 2008 to 380.98 gha in 2015. Of the three EF activity types, the TREF had the largest proportion at an average of 70.18%, followed by the ACTEF at an average of 24.97% and the FEF at an average of 4.85%. Based on these empirical results, the TREF grew from 140.47 gha in 2008 to 267.36 gha in 2015 due to a significant growth in tourist numbers, which caused an increased demand for vehicles, further inflating liquefied fuel demands.

Table 5. Ecological Footprint (EF) for the three activities types and total Ecological Footprint (EF) (unit: gha).

Year	TREF	ACTEF	FEF	EF
2008	140.47	95.14	8.42	244.03
2009	183.70	95.14	13.52	292.36
2010	204.87	95.14	13.37	313.38
2011	184.57	95.14	13.77	293.48
2012	182.99	95.14	12.30	290.43
2013	220.37	95.14	15.54	331.05
2014	267.04	95.14	19.96	382.14
2015	267.36	95.14	18.48	380.98
Average proportion	70.18%	24.97%	4.85%	100.000%

Notes: TREF: transport ecological footprint; ACTEF: activities footprint; FEF: food & fiber consumption ecological footprint; EF: total ecological footprint.

As the Gaomei wetlands gross area did not change substantially between 2008 and 2015, the ACTEF was steady at 95.14 gha; however, the FEF increased from 8.42 gha in 2008 to 18.48 gha in 2015. The FEF indicates the tourist dietary demands inside the Gaomei wetlands and includes grains, coarse cereals, vegetables, fruit, meat, and fish; therefore, the substantial growth in the FEF was linked to the growing tourist numbers. This analysis found that the main tourism ecological resource consumption came from the fossil energy used by the vehicles traveling between residences and destinations and the increase in the land accessible to tourists for leisure activities.

3.3. SEEI Computation and Analysis Results

The *SEEI* indicated that the ED grew by about 106.54% from 2008 to 2015. In 2015, the EFI was rated Level 4 at 1.02, and the ESI was rated Level 3 at 0.49, indicating that the Gaomei wetlands were at an unsafe ecological security level within that time span.

(a) ER/ED

Table 6 gives the computation results for the ER/ED. The ER had a declining trend from 128.54 gha in 2008 to 41.52 gha in 2013. The Gaomei wetlands ecological deficit (ED) decreased from −9.57 gha in 2014 to −8.41 gha in 2015, primarily due to the increased tourist numbers.

(b) EFI

This study utilized the EFI to evaluate the Gaomei wetlands ecological security, the outcomes of which are shown in Table 6. The EFI increased from 0.65 in 2008 to 1.02 in 2015, indicating an unsafe ecological security level, which is predicted to further increase because of the rising tourist demand for resources and services (e.g., bus services, road construction, and waste production).

(c) ESI

Table 6 shows the computational results for the ESI. Between 2008 and 2013, the ESI remained at Level 2, signifying low sustainability. Yet from 2014 onward, the ESI has fallen to Level 3, signifying unsustainability. If this situation is not controlled and improved, the attainment of sustainable ecological development will be impossible.

Table 6. Ecological Footprint (EF), ecological carrying capacity (ECC), ecological remainder (ER)/ecological deficit (ED), ecological footprint index (EFI), and environmental sustainability index (ESI) (unit: gha).

Year	ECC	EF	ES/ED	EFI			ESI		
				Index	Level	Representation Condition	Index	Level	Representational State
2008	372.57	244.03	128.54	0.65	2	Moderately safe	0.60	2	Low sustainability
2009	372.57	292.36	80.18	0.78	2	Moderately safe	0.56	2	Low sustainability
2010	372.57	313.38	59.19	0.84	3	Threshold	0.54	2	Low sustainability
2011	372.57	293.48	79.09	0.79	2	Moderately safe	0.56	2	Low sustainability
2012	372.57	290.43	82.14	0.78	2	Moderately safe	0.56	2	Low sustainability
2013	372.57	331.05	41.52	0.89	3	Threshold	0.53	2	Low sustainability
2014	372.57	382.14	−9.57	1.03	4	Unsafe	0.49	3	Low unsustainability
2015	372.57	380.98	−8.41	1.02	4	Unsafe	0.49	3	Low unsustainability

4. Conclusions

This study employed the ecosystem service value, ecological capacity, EF, and sustainable ecological evaluation indicators (SEEIs) to assess the ecological security and the efficient use of resources in the Gaomei wetlands. We came to the following conclusions:

The total value of the ecosystem services in the Gaomei wetlands increased from 59.24 million TWD in 2008 to 98.10 million TWD in 2015. The EF gradually increased from 244.03 gha in 2008 to 380.98 gha in 2015. Of the three activity EFs, TREF had the biggest proportion (70.18%), with ACTEF (24.97%) and FEF (4.85%) following thereafter. The SEEI indicated that the ED grew by about 106.54% from 2008 to 2015. In 2015, the EFI was rated Level 4 at 1.02, and the ESI was rated Level 3 at 0.49. Therefore, as the Gaomei wetlands are predicted to become ecologically unsustainable over time, local, regional, and national governments need to implement regulations to strictly control the Gaomei wetlands land use.

According to the empirical analysis results, the primary factors influencing various types of activity EFs are presented below.

(a) Tourists had a negative effect on the overall EF from all activities. Therefore, when tourist numbers increased, the EF increased and there was a greater environmental impact. Attempts should be made to increase the environmentally friendly behavior of tourists to decrease the impact of increasing tourist numbers.

(b) The fossil fuels used for transportation had the greatest influence on the TREF. Therefore, strategies aimed at reducing energy use and the commensurate carbon footprints should be developed.

Using public transportation and using environmentally friendly vehicles and services such as electric cars and motorcycles and bicycle rental services should be encouraged. Global positioning systems could be used in rental cars to monitor tourist activity, which can then be used to develop effective transportation systems aimed at decreasing overall fossil fuel use and minimizing the associated carbon footprints.

Acknowledgments: I am thankful to the Ministry of Science and Technology (Republic of China, Taiwan) for financially supporting this research project (grant number MOST 102-2410-H-040-010).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Rahman, M.M.; Islam, M.A. *Better Options for IFM: Uptake Promotion NRSP Project R8306 Final Technical Report: Annex A*; Center for Natural Resource Studies (CNRS): Dhaka, Bangladesh, 2005.
2. Valiela, I.; Fox, S.E. Managing coastal wetlands. *Science* **2008**, *319*, 321–323. [CrossRef] [PubMed]
3. Miththapala, S. *Mangroves. Coastal Ecosystems Series (Volume 2)*; Ecosystems and Livelihoods Group Asia, International Union for Conservation of Nature: Colombo, Sri Lanka, 2008.
4. Fletcher, S.; Kawabe, M.; Rewhorn, S. Wetland conservation and sustainable coastal governance in Japan and England. *Mar. Pollut. Bull.* **2011**, *62*, 956–962. [CrossRef] [PubMed]
5. Feng, M.; Liu, S.; Euliss, N.H., Jr.; Young, C.; Mushet, D.M. Prototyping an online wetland ecosystem services model using open model sharing standards. *Environ. Model. Softw.* **2011**, *26*, 458–468. [CrossRef]
6. Hopkinson, C.; Cai, W.; Hu, X. Carbon sequestration in wetland dominated coastal systems: A global sink of rapidly diminishing magnitude. *Sustainability* **2012**, *4*, 186–194. [CrossRef]
7. Su, S.; Xiao, R.; Jiang, Z.; Zhang, Y. Characterizing landscape pattern and ecosystem service value changes for urbanization impacts at an eco-regional scale. *Appl. Geogr.* **2012**, *34*, 295–305. [CrossRef]
8. Ward, R.D.; Burnside, N.G.; Joyce, C.B.; Sepp, K.; Teasdale, P.A. Improved modelling of the impacts of sea level rise on coastal wetland plant communities. *Hydrobiologia* **2016**, *774*, 203–216. [CrossRef]
9. Chapin, F.S.; Zavaleta, E.S.; Eviner, V.T.; Naylor, R.L.; Vitousek, P.M.; Reynolds, H.L.; Hooper, D.U.; Lavorel, S.O.; Sala, E.; Hobbie, S.E.; et al. Consequences of changing biodiversity. *Nature* **2000**, *405*, 234–242. [CrossRef] [PubMed]
10. Costanza, R.; d'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.V.; Paruelo, J.; et al. The value of the world's ecosystem services and natural capital. *Nature* **1997**, *387*, 253–260. [CrossRef]
11. Millennium Ecosystem Assessment (MEA). *Ecosystems and Human Well-Being: Wetlands and Water Synthesis*; World Resources Institute: Washington, DC, USA, 2005.
12. The Ecological and Economic Foundations. *The Economics of Ecosystems and Biodiversity: The Ecological and Economic Foundations*; Earthscan: London, UK, 2010.
13. UK National Ecosystem Assessment. *UK National Ecosystem Assessment Follow-On Phase: Synthesis Report*; UNEP-WCMC: Cambridge, UK, 2014.
14. Kenter, J.O.; O'Brien, L.; Hockley, N.; Ravenscroft, N.; Fazey, I.; Irvine, K.N.; Reed, M.S.; Christie, M.; Brady, E.; Bryce, R.; et al. What are shared and social values of ecosystems? *Ecol. Econ.* **2015**, *111*, 86–99. [CrossRef]
15. Scholte, S.S.K.; van Teeffelen, A.J.A.; Verburg, P.H. Integrating socio-cultural perspectives into ecosystem service valuation: A review of concepts and methods. *Ecol. Econ.* **2015**, *114*, 67–78. [CrossRef]
16. Fish, R.; Church, A.; Winter, M. Conceptualising cultural ecosystem services: A novel framework for research and critical engagement. *Ecosyst. Serv.* **2016**, *21*, 208–217. [CrossRef]
17. Bunse, L.; Rendon, O.; Luque, S. What can deliberative approaches bring to the monetary valuation of ecosystem services? A literature review. *Ecosyst. Serv.* **2015**, *14*, 88–97. [CrossRef]
18. Hattam, C.; Böhnke-Henrichs, A.; Börger, T.; Burdon, D.; Hadjimichael, M.; Delaney, A.; Atkins, J.P.; Garrard, S.; Austen, M.C. Integrating methods for ecosystem service assessment and valuation: Mixed methods or mixed messages? *Ecol. Econ.* **2015**, *120*, 126–138. [CrossRef]
19. Kenter, J.O. Integrating deliberative monetary valuation, systems modelling and participatory mapping to assess shared values of ecosystem services. *Ecosyst. Serv.* **2016**, *21*, 291–307. [CrossRef]

20. Barbier, E.B.; Hacker, S.D.; Kennedy, C.; Koch, E.W.; Stier, A.C.; Silliman, B.R. The value of estuarine and coastal ecosystem services. *Ecol. Monogr.* **2011**, *81*, 169–193. [CrossRef]
21. Bateman, I.J.; Mace, G.M.; Fezzi, C.; Atkinson, G.; Turner, R.K. Economic Analysis for Ecosystems Assessments. *Environ. Res. Econ.* **2011**, *48*, 177–218. [CrossRef]
22. Maes, J.; Paracchini, M.L.; Zulian, G.; Dunbar, M.B.; Alkemade, R. Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. *Biol. Conserv.* **2012**, *155*, 1–12. [CrossRef]
23. Liu, Y.; Huang, X.; Yang, H.; Zhong, T. Environmental effects of land-use/cover change caused by urbanization and policies in Southwest China Karst area—A case study of Guiyang. *Habitat Int.* **2014**, *44*, 339–348. [CrossRef]
24. Su, S.; Zhou, X.; Wan, C.; Li, Y.; Kong, W. Land use changes to cash crop plantations: Crop types, multilevel determinants and policy implications. *Land Use Policy* **2016**, *50*, 379–389. [CrossRef]
25. Tomaz, C.; Alegria, C.; Monteiro, J.M.; Teixira, M.C. Land cover change and afforestation of marginal and abandoned agricultural land: A 10 year analysis in a Mediterranean region. *For. Ecol. Manag.* **2013**, *308*, 40–49. [CrossRef]
26. Trincsi, K.; Pham, T.H.; Turner, S. Mapping mountain diversity: Ethnic minorities and land use land cover change in Vietnam's borderlands. *Land Use Policy* **2014**, *41*, 484–497. [CrossRef]
27. Du, S.; Wang, Q.; Guo, L. Spatially varying relationships between land-cover change and driving factors at multiple sampling scales. *J. Environ. Manag.* **2014**, *137*, 101–110. [CrossRef] [PubMed]
28. Xiong, X.; Grunwald, S.; Myers, D.B.; Ross, C.W.; Harris, W.G.; Comerford, N.B. Interaction effects of climate and land use/land cover change on soil organic carbon sequestration. *Sci. Total Environ.* **2014**, *493*, 974–982. [CrossRef] [PubMed]
29. Deng, Y.; Srinivasanb, S. Urban land use change and regional access: A case study in Beijing, China. *Habitat Int.* **2016**, *51*, 103–113. [CrossRef]
30. Beyene, F. Land use change and determinants of land management: Experience of pastoral and agro-pastoral herders in eastern Ethiopia. *J. Arid Environ.* **2016**, *125*, 56–63. [CrossRef]
31. Halmy, M.W.A.; Gessler, P.E.; Hicke, J.A.; Salem, B.B. Land use/land cover change detection and prediction in the north-western coastal desert of Egypt using Markov-CA. *Appl. Geogr.* **2015**, *63*, 101–112. [CrossRef]
32. Burkhard, B.; Crossman, N.; Nedkov, S.; Petz, K.; Alkemade, R. Mapping and modelling ecosystem services for science, policy and practice. *Ecosyst. Serv.* **2013**, *4*, 1–3. [CrossRef]
33. Posthumus, H.; Rouquette, J.R.; Morris, J.; Gowing, D.J.G.; Hess, T.M. A framework for the assessment of ecosystem goods and services; a case study on lowland floodplains in England. *Ecol. Econ.* **2010**, *69*, 1510–1523. [CrossRef]
34. Lautenbach, S.; Kugel, C.; Lausch, A.; Seppelt, R. Analysis of historic changes in regional ecosystem service provisioning using land use data. *Ecol. Indic.* **2011**, *11*, 676–687. [CrossRef]
35. Haines-Young, R.; Potschin, M.; Kienast, F. Indicators of ecosystem service potential at European scales: Mapping marginal changes and trade-offs. *Ecol. Indic.* **2012**, *21*, 39–53. [CrossRef]
36. Nelson, E.; Mendoza, G.; Regetz, J.; Polasky, S.; Tallis, H.; Cameron, D.R.; Chan, K.M.; Daily, G.C.; Goldstein, J.; Kareiva, P.M.; et al. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Front. Ecol. Environ.* **2009**, *7*, 4–11. [CrossRef]
37. Polasky, S.; Calderone, G.; Duarte, K.E.; Goldstein, J.; Hannahs, N.; Ricketts, T.H.; Tallis, H. Putting ecosystem services to work: Conservation, management, and trade-offs. In *Natural Capital: Theory and Practice of Mapping Ecosystem Services*; Oxford University Press: Oxford, UK, 2011; pp. 249–263.
38. Geneletti, D. *Integrating Ecosystem Services in Land Use Planning: Concepts and Applications*; CID Research Fellow and Graduate Student Working Paper No. 54; Center for International Development, Harvard University: Cambridge, MA, USA, 2012.
39. Petus, C.; Lewis, M.; White, D. Monitoring temporal dynamics of Great Artesian Basin wetland vegetation, Australia, using MODIS NDVI. *Ecol. Indic.* **2013**, *34*, 41–52. [CrossRef]
40. Julian, J.P.; Wilgruber, N.A.; Beurs, K.M.D.; Mayer, P.M.; Jawarnehd, R.N. Long-term impacts of land cover changes on stream channel loss. *Sci. Total Environ.* **2015**, *537*, 399–410. [CrossRef] [PubMed]
41. Abrantes, P.; Fontes, I.; Gomes, E.; Rocha, J. Compliance of land cover changes with municipal land use planning: Evidence from the Lisbon metropolitan region (1990–2007). *Land Use Policy* **2016**, *51*, 120–134. [CrossRef]

42. Chen, N.; Ma, T.; Zhang, X. Responses of soil erosion processes to land cover changes in the Loess Plateau of China: A case study on the Beiluo River basin. *Catena* **2016**, *136*, 118–127. [CrossRef]
43. Chen, H.S.; Chen, C.Y.; Chang, C.T.; Hsieh, T. The Construction and Application of a Carrying Capacity Evaluation Model in a National Park. *Stoch. Environ. Res. Risk Assess.* **2014**, *28*, 1333–1341. [CrossRef]
44. Warhurst, A. Mining, mineral processing, and extractive metallurgy: An overview of the technologies and their impact on the physical environment. In *Environmental Policy in Mining: Corporate Strategy and Planning for Closure*; Warhurst, A., Raton, L.N.B., Eds.; CRC Press LLC: Boca Raton, FL, USA, 2000.
45. Singh, R.K.; Murty, H.R.; Gupta, S.K.; Dikshit, A.K. An overview of sustainability assessment methodologies. *Ecol. Indic.* **2012**, *15*, 281–299. [CrossRef]
46. Bhandari, B.S.; Grant, M. Analysis of livelihood security: A case study in the Kali-Khola watershed of Nepal. *J. Environ. Manag.* **2007**, *85*, 17–26. [CrossRef] [PubMed]
47. Liu, R.Z.; Borthwick, A.G.L. Measurement and assessment of carrying capacity of the environment in Ningbo, China. *J. Environ. Manag.* **2011**, *92*, 2047–2053. [CrossRef] [PubMed]
48. Rees, W.E. Ecological footprints and appropriated carrying capacity: What urban economics leaves out. *Environ. Urban.* **1992**, *4*, 121–130. [CrossRef]
49. Wackernagel, M.; Rees, W. *Our Ecological Footprint-Reducing Human Impact on the Earth*; New Society Publishers: Gabriola Island, BC, Canada, 2000.
50. Chen, H.S. Establishment and Applied Research on a Wetland Ecosystem Evaluation Model in Taiwan. *Sustainability* **2015**, *7*, 15785–15793. [CrossRef]
51. Chen, T.S.; Lin, H.J.; Huang, S.Y. A framework on habitat connectivity among Taiwan's wetlands for overwintering Black-faced Spoonbill. *Ocean Coast. Manag.* **2015**, *116*, 78–88. [CrossRef]
52. Fang, G.; Huang, C.; Chang, C.; Han, J.; Kuan, H.; Jie, L.; Fu, Z.; Chen, X.; Yang, K.; Tsai, H.H. Atmospheric total arsenic (As), (As^{3+}) and (As^{5+}) pollutants study in central Taiwan. *Environ. Earth Sci.* **2016**, *75*, 124. [CrossRef]
53. Mamattuesun, E.; Hamid, Y.; Anwar, M. Oasis land-use change and its effects on the oasis eco-environment in Keriya Oasia. *China* **2010**, *7*, 244–252.
54. Sawut, M.; Eziz, M.; Tiyip, T. The effects of land-use change on ecosystem service value of desert oasis: A case study in Ugan-Kuqa River Delta Oasis, China. *Can. J. Soil Sci.* **2013**, *93*, 99–108. [CrossRef]
55. Gössling, S.; Hansson, C.B.; Hörstmeier, O.; Saggel, S. Ecological footprint analysis as a tool to assess tourism sustainability. *Ecol. Econ.* **2002**, *43*, 199–211.
56. Martin-Cejas, R.R.; Sanchez, P.P.R. Ecological footprint analysis of road transport related to tourism activity: The case for Lanzarote Island. *Tour. Manag.* **2010**, *31*, 98–103. [CrossRef]
57. Rees, W.E. Getting serious about urban sustainability, eco–footprints and the vulnerability of twenty–first–century cities. In *Canadian Cities in Transition, New Directions in the Twenty-First Century*; Oxford University Press: Toronto, ON, Canada, 2011; pp. 70–86.
58. World Economic Forum, Yale Center for Environmental Law and Policy, Center for International Earth Science Information Network (CIESIN) of Columbia University, and Joint Research Centre of the European Commission. 2005. Environmental Sustainability Index, 2005. Available online: http://www.ciesin.columbia.edu/indicators/ESI/ (accessed on 16 June 2016).