Using Ecological Footprint Model for Port Ecosystem Sustainability Assessment

Z.J. Guo [a], Q. Zhang [b], W.Y. Wang [c]& C. Wang [d]

[a,b,c,d] *Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian, 116024 China*

[a] *E-mail: zjguo@dlut.edu.cn*

[b] *E-mail: zhangqidlut@163.com*

[c] *E-mail: wangwenyuan@dlut.edu.cn*

[d] *E-mail: wangcandlut@hotmail.com*

Abstract: Construction of coastal ports makes port area and nearby sea area become high risk region of ecological emergency and environmental pollution. It is helpful for providing references to protect ecological environment of port by quantifying port ecological carrying capacity. This paper will transfer resources and energy consumed in port production and operation to four ecological productive lands, including arable land, woodland, lawn and water area. Based on them, build port ecological footprint model, considering biological resource, energy and construction land ecological footprint. Furthermore, research resource demand of port ecological system. By comparing the demand and supply of ecological resource, evaluate ecological carrying capacity of port.

Keywords: Port; Ecological Footprint; Ecological Carrying Capacity Model; Ecological Deficit; Ecological Surplus.

1. INTRODUCTION

The port ecological carrying capacity is the basis to solve the sustainable development issue of the port and the premise to determine regional economic development. It is an issue to be addressed facing numerous ports in our country to ensure that the port ecosystem can support its healthy development instead of exceeding its carrying capacity and promote sustainable economic development.

Currently, the research aspects of carrying capacity are mostly focused on land resources, water resources, tourism environment and ecological city, etc., and the research on the port ecological carrying capacity is less. Research on port environmental carrying capacity still adopt the method of evaluation index system (Dai *et al*, 2008). Research on port resources carrying capacity, such as Jiao etc. (2012). Based on channel traffic capacity and anchorage scale calculation methods, establish a channel and anchorage resources carrying capacity model.

Existing researches mostly aim at specific evaluation indexes, and with the change of the evaluation index system, the research conclusion will change. Since the notion of ecological footprint has been proposed by Canadian ecologist Rees (William E. Rees, 2002), the theory of ecological footprint and its calculation methods have been fully developed to be indexes on sustainable development, and have been widely accepted by governments and academic field. It makes the hidden ecological costs clear by measuring the ecological costs of goods and services which humans consumed (Li, 2006). It establish clear measurable indicators to track progress and define the sustainability. It have a common standard so that we can add and compare the ecological productive land in different region. Likewise, we can use this method in port area. Therefore, the resources and energy consumed in the production of port are converted into arable land, woodland, lawn and waters, etc. which could stand for the ecological productive resource in this study. And a model of port ecological carrying capacity is built up based on port ecological deficit and ecological surplus. Finally, it is applied to a port in northern China to study its ecological footprint and ecological carrying capacity.

2. MODEL OF PORT ECOLOGICAL FOOTPRINT AND ECOLOGICAL CARRYING CAPACITY

According to the concept of ecological footprint and the study of Pablo Coto -Millán etc. (2010) on port ecological footprint, the port ecological footprint can be defined as: the required ecological productive land area that support a certain amount of production and operating activities of a port. The ecological productive land on the surface of Earth is divided into six categories: fossil energy land, arable land, lawn, woodland, construction land and waters (Yang *et al*, 2000). The port consists of land and waters, and the backfill land can be attributed to consumption of waters, and the non-backfill land can be attributed to consumption of arable land. The resources and energy consumed in port production and operation are converted into four ecological productive land: arable land, woodland, lawn and waters. The port ecological footprint includes the ecological footprint of biological resources, the ecological footprint of energy and the ecological footprint of construction land.

2.1 Ecological Footprint of Biological Resources

The biological resources refer to the consumption of plant products and animal products consumed by port workers. The biological resources consumed by port workers all the time are discounted by urban per capita consumption. The ecological footprint of biological resources includes arable land, lawn and waters.

$$F_{bi,j} = \sum \frac{C_i}{Y_i} \tag{1}$$

Where $F_{bi,j}$ is the corresponding class j land area of biological resources consumption made by port workers(hm^2); C_i is the consumption of class j biological resource made by port workers (kg); Y_i is the global average yield of class j biological resource (kg/hm^2); $j=1,2,3,4$ stands for arable land, woodland, lawn and waters respectively, $F_{bi,2}=0$; i represents biological resources such as grains, beans and soy products.

2.2 Ecological Footprint of Energy

The ecological footprint of energy refers to the area of the woodland and lawn required to absorb CO_2 produced by the production and consumption of energy (Xie *et al*, 2008). The energy consumed in port is divided into two categories: fossil energy and power.

The ecological footprint of fossil energy is calculated based on the net ecosystem production of woodland and lawn [8]:

$$F_{fo,j} = \frac{\sum C_k \cdot S_k \cdot E_k}{NEP_j} R_j (1 - R_o) \tag{2}$$

where $F_{fo,j}$ is the corresponding class j land area of the port fossil energy consumption(hm^2); C_k is the consumption of class k fossil energy (kg); S_k is the unit mass burn calories of class k fossil energy (MJ/Kg); E_k is the carbon emission factor of class k fossil energy (Kg/GJ); NEP_j is the global annual net ecosystem yield of the class j land (t/hm^2); R_j is the proportion of CO_2 absorbed by the class j land; R_o is the proportion of CO_2 absorbed by the ocean (Borucke *et al*, 2013); $j=1,2,3,4$ stands for arable land, woodland, lawn and waters respectively, $F_{fo,1}=F_{fo,4}=0$; $k=1,2,3$ represents gasoline, diesel and coal.

The ecological footprint of power is calculated according to the ecological footprint of thermal power:

$$F_{el,j} = \frac{C_{el} \cdot S_{co} \cdot E_{co}}{NEP_j} R_j (1 - R_o) \cdot 1.4 \cdot SC \tag{3}$$

Where $F_{el,j}$ is the corresponding class j land area of power consumption(hm^2); C_{el} is the power consumption of thermal power (KW·h); S_{co} is the unit mass burn calories of coal (MJ/Kg); E_{co} is the carbon emission factor of coal (Kg/GJ); SC is the standard coal consumption of unit thermal power (t); R_j, R_o and NEP_j have the same meaning as above; $j=1,2,3,4$ stands for arable land, woodland, lawn and waters respectively, $F_{fo,1}=F_{fo,4}=0$.

2.3 Construction Land Ecological Footprint

Port construction land includes backfill soil and non-backfill soil. The backfill soil comes down to consumption of waters, and the non-backfill soil comes down to consumption of arable land. Construction land ecological footprint:

$$F_{bu,j} = yf_j \cdot A_{bu,j} = \frac{EP_j}{\overline{EP_j}} \cdot A_{bu,j} \tag{4}$$

Where $F_{bu,j}$ is the corresponding class j land area of consumption of port construction land (hm^2); yf_j is the local class j land yield factor; EP_j is the local class j average land ecological productivity (t/hm^2); $\overline{EP_j}$ is the global class j average land ecological productivity (t/hm^2); $A_{fi,1}$, $A_{fi,2}$ is the backfill and non-backfill land area respectively (hm^2); $j=1,2,3,4$ stands for arable land, woodland, lawn and waters respectively, $F_{fo,2}=F_{fo,3}=0$.

2.4 Port Total Ecological Footprint

There are differences in productivity of different ecological productive land. When calculating the total ecological footprint, it is required to be multiplied by the equivalence factor.

$$F_{port} = \sum ef_j \cdot F_j \tag{5}$$

Where F_{port} is the port total ecological footprint (hm^2); ef_j is the equivalence factor of the class j ecological productive land; F_j is the area of the class j ecological productive land (hm^2); $j=1,2,3,4$ stands for arable land, woodland, lawn and waters respectively.

2.5 Port Total Ecological Carrying Capacity

Port total ecological carrying capacity is the area of the ecological productive land provided for the port production and operating activities in the port area. There are differences in productivity of similar ecological productive land in different regions, which can be expressed by yield factor. The yield factor of certain types of land is the ratio of its average productivity and the average productivity of the same land in the world. Multiply the productivity of different ecological productive land of port by the corresponding equivalence factor and local yield factor and you can get the port ecological carrying capacity.

$$C = \sum A_j \cdot ef_j \cdot yf_j \tag{6}$$

Where C is the port total ecological carrying capacity (hm^2); A_j is the area of the class j ecological productive land (hm^2); ef_j and yf_j have the same meaning as above; $j=1,2,3,4$ stands for arable land, woodland, lawn and waters respectively.

2.6 Port Ecological Deficit and Ecological Surplus

To measure the port ecological deficit and ecological surplus, this paper introduces the concept of port ecological carrying capacity level. Port ecological carrying capacity level refers to the extent to which port ecological resource capacity meets the ecological resources demand within a certain stage of development. Port ecological carrying capacity level can be measured by the ratio of port total ecological footprint and port total ecological carrying capacity, i.e., carrying capacity index.

$$I = \frac{F_{port}}{C} \tag{7}$$

Where I is port ecological carrying capacity index, F_{port} and C have the same meaning as above.

When port ecological carrying capacity index is less than 1, it means port ecological surplus; when port ecological carrying capacity index is equal to 1, it means port ecological balance; when port ecological carrying capacity index is greater than 1, it means port ecological deficit.

3. CASE STUDY

A port in northern China has four container berths arranged along the shore, with a water area of 546 hm^2 and a land area of 200 hm^2, which is obtained from reclamation. The annual fuel oil consumption is 7600t, and the annual energy consumption is 37850MW•h in the port in 2012.

The ecological footprint and ecological carrying capacity of the port are calculated based on the model, and the results are shown in Table 1 and Table 2. The results indicate that port ecological carrying capacity index is 6.5 in 2012, which means there is ecological deficit and the port is ecologically unsustainable. According to the data from the literature (Carballo *et al*, 2012), the ecological carrying capacity index in a port in the northern coast of Spain is 4.7 in 2006 by calculating, and the ecological carrying capacity index in the port of Gijon in Spain is 6.2 in 2006 according to the data from the literature (Carballo *et al*, 2012), both of which are ecological deficit.

The ecological carrying capacity index of the city where the port locates calculated by some scholars is 12~15, and the ecological carrying capacity index of the port is less than that of the city. On the one hand, as the traditional high energy consumption enterprise, port consumes a lot of fossil energy, the ecological footprint of which accounts for 90.98% of the total ecological footprint of the port. On the other hand, port includes anchorage, channel, basin and other waters, which are main sources of port ecological carrying capacity, and the ecological carrying capacity of the port totally comes from waters. The waters in port effectively improves its carrying capacity, offsets the ecological footprint of fossil energy and reduces the ecological carrying capacity index.

Table 1. The results of ecological footprint demand.

Items	Land types	Land area/hm^2	Equivalence factor[12]	Equivalence area/hm^2
Ecological footprint of biological resources	Arable land	88.60	2.51	222.40
	Woodland	0.00	1.26	0.00
	Lawn	5.65	0.46	2.60
	Waters	55.54	0.37	20.55
Ecological footprint of fossil energy	Arable land	0.00	2.51	0.00
	Woodland	2774.60	1.26	3496.00
	Lawn	2328.78	0.46	1071.24
	Waters	0.00	0.37	0.00
Ecological footprint of construction land	Arable land	0.00	2.51	0.00
	Woodland	0.00	1.26	0.00
	Lawn	0.00	0.46	0.00
	Waters	560.00	0.37	207.20
Total				5019.98

Table 2. The results of ecological carrying capacity.

Land types	Actual land area/hm^2	Yield factor	Corrected area/hm^2
Energy land	0	1.0	0.00
Construction land	200	2.8	207.20
Arable land	0	1.7	0.00
Woodland	0	1.2	0.00
Lawn	0	0.8	0.00
Waters	546	2.8	565.66
Total			772.86

4. CONCLUSIONS

Based on the ecological footprint theory, a model of port ecological footprint and ecological carrying capacity is built up, and it is applied to a port in northern China to calculate the ecological footprint and ecological carrying capacity. The results show that the model of port ecological footprint and ecological carrying capacity can accurately depict port ecological carrying capacity and provide a basis for evaluating the ecologically sustainable development of port. Furthermore, since waters are the main sources of port ecological carrying capacity, we should strengthen the protection of waters to improve port ecological carrying capacity and promote the healthy, sustainable development of port.

5. ACKNOWLEDGMENTS

The authors would like to thank for the National Natural Science Foundation of China (No.51279026 & No.51309049) for its financial support.

REFERENCES

Dai, M.X., Hu, Y.D., Peng, S.D., et al. (2008). The application of AHP-Fuzzy approach to the sea-port environmental carrying capacity evaluation. *Journal of Safety and Environment* (05): 109-112.

Jiao, Y., Kang Y.T., Yin X.B., et al. (2012). Forecasting an early-warning model of port traffic resource carrying capacity. *Journal of Traffic and Transportation Engineering* (02): 84-92.

William E. Rees. (2002). An Ecological Economics Perspective on Sustainability and Prospects for Ending Poverty. *Population and Environment* (24): 15-46.

Li H., (2006). The Study of Ecological Footprint Theory and Application. Lanzhou University.

Coto-Millán P., Mateo-Mantecón I., Quesada J.L.D., et al. (2010). Evaluation of port externalities: the ecological footprint of Port Authorities, *Essays on port economics*: 323-340.

Yang K.Z., Yang Y., Chen J. (2000). Ecological footprint analysis: concept, method and cases. *Advance in Earth Science* (06): 630-636.

Xie H.Y., Chen X.S., Lin K.R., et al. (2008). The ecological footprint analysis of fossil energy and electricity. *Acta Ecologica Sinica* (04): 1729-1735.

Borucke M., Moore D., Cranston G., et al. (2013). Accounting for demand and supply of the biosphere's regenerative capacity: The National Footprint Accounts' underlying methodology and framework. *Ecological Indicators* 24: 518-533.
Carballo-Penela A., Mateo-Mantecón I., Doménech J.L., et al. (2012). From the motorways of the sea to the green corridors' carbon footprint: the case of a port in Spain. *Journal of Environmental Planning and Management* 55(6): 765-782.