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ORIGINAL PAPER

Food security and ecological footprint of coastal zone of Bangladesh

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Abstract This paper presents the present status of food security and ecological footprint, an indicator of environmental sustainability of the coastal zones of Bangladesh. To estimate the present status of the food security and ecological footprint of the coastal zone of Bangladesh, primary and secondary data were collected, and the present status of food security and environmental degradation (in terms of ecological footprint) were calculated. To estimate the household food security, primary data were also collected from all the households in a representative selected village. A quantitative method for computation of food security in grain equivalent based on economic returns (price) is developed, and a method of measuring sustainable development in terms of ecological footprint developed by Wackernagel is used to estimate the environmental sustainability (Wackernagel and Rees in Our ecological footprint: reducing human impact on the earth. New Society, Gabrioala, BC, 1996; Chambers et al. in Sharing nature's interest-ecological footprint as an indicator of sustainability. Earthscan, London, 2000). Overall status of food security at upazila levels is good for all the upazilas except Shoronkhola, Shyamnager and Morrelgonj, and the best is the Kalapara upazila. But the status of food security at household levels is poor. Environmental status in the coastal zones is poor for all the upazilas except Kalapara and Galachipa. The worst is in the Mongla upazila. Environmental status has degraded mainly due to shrimp culture. This study suggests that control measures are needed for affected upazilas and any further expansion of the shrimp aquaculture to enhance the food security must take into account the environmental aspects of the locality under consideration.

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1 Introduction

Costal Zone is most frequently defined as land affected by its proximity to the sea and that part of the sea affected by its proximity to the land or, in other words, the areas where the processes which depend on the sea–land interactions are the most intensive. The total area of Bangladesh is 147,570 km^2. Of which coastal zone is 47,203 km^2, and it is roughly 32% of the whole country. According to 2001 population census, total population of Bangladesh is 123.15 millions. Of which 35.1 millions live in coastal area, and it is approximately 28% of the total population of Bangladesh.

The coastal zone of Bangladesh is rich in natural resources offering many tangible and intangible benefits to the nation. Excessive fishing and over exploitation of coastal resources, water quality deterioration, mangrove destruction for aquaculture, and conversion of agricultural land into aquaculture pond are the major problems which need to be managed on a priority basis.

Cultivable land in the coastal zone of Bangladesh is 2.85 million ha, and about 1.0 million ha of arable land are affected by varying degrees of salinity and most of these lands remain fallow in dry season (Karim et al. 1990). It is estimated that about 0.25 million ha of land has a good potential for coastal aquaculture (Ahmed 1995). Out of that, about 0.18 million ha of land area is suitable for shrimp culture (Khan and Hossain 1996). Shrimp aquaculture in the coastal zones is expanding rapidly, and agricultural lands are converted into aquaculture ponds. The rapid expansion of shrimp farm development during the last decade along with the adoption of extensive and improved extensive culture techniques has caused growing concern as to its adverse effect on the coastal environment and damage to the traditional agricultural systems. The socioeconomic scenarios have changed rapidly.

The other special features of the coastal zone is its multiple vulnerabilities out of periodic cyclone and storm surges, salinity intrusion, erosion, pollution, and overall lack of physical infrastructure. Coastal natural-resource uses reflect primarily subsistence agriculture with an emphasis on food production, e. g. paddy rice along with some cash crops and coastal fisheries, which provide a major food and income source. Also important, in some areas, is aquaculture with an emphasis on shrimp production for the export market, and some salt production for domestic needs.

Food security is a worldwide problem that has called the attention to governments and the scientific community. It particularly affects developing countries. The scientific community has had increasing concerns for strategic understanding and implementation of food security policies in developing countries, especially since the food crisis in the 1970s. The process of decision making is becoming increasingly complex due to the interaction of multiple dimensions related to food security (Giraldo et al. 2008).

In most analysis in food security conditions in developing countries, multiple indicators are used to reflect the various dimensions of the problems. Some of the most commonly used types of indicators in the assessment of food security conditions are food production, income, total expenditure, food expenditure, share of expenditure of food, calorie consumption, and nutritional status etc. (Riely et al. 1999).

There are several definitions of food security available but the most cited definition is the one of FAO (1996), and it defines the objective of food security as assuring to all human beings the physical and economic access to the basic food they need. This implies three different aspects: availability, stability, and access.

Several studies have been reported around food security in Bangladesh in terms of per capita food availability (Begum 2002), pattern of household food consumption and causes of food insecurity (RDRS 2005) and access and utilization of food, and causes of food and nutritional food security (Mishra and Hossain 2005). These studies give a descriptive statistics of the food security.

The theory and the method of measuring sustainable development with the ecological footprint were developed during the past decade (Wackernagel and Rees 1996; Chambers, et al. 2000). The Ecological Footprint is a synthetic indicator used to estimate a population's impact on the environment due to its consumption; it quantifies total terrestrial and aquatic area necessary to supply all resources utilized in sustainable way and to absorb all emissions produced always in a sustainable way.

Several studies have been reported on applications of ecological footprint to address the environmental sustainability (Wackernagel et al. 1999; Monfreda et al. 2004; Zhao et al. 2005; Medved 2006; Chen and Chen 2006; Bagliani et al. 2008; Niccolicci et al. 2008). This technique has been applied to wine production (Niccolicci et al. 2008), regional level (Zhao et al. 2005), national level (Medved 2006; Chen and Chen 2006; Bagliani et al. 2008), and national and global accounting (Wackernagel et al. 1999). The ecological footprint has been jointly used combining emergy analysis to evaluate ecological footprint for regional level (Zhao et al. 2005) and national level (Chen and Chen 2006) as well as to assess ecological footprint and biocapacity (Monfreda et al. 2004; Medved 2006; Bagliani et al. 2008).

The purpose of this study is to estimate the present status of the contribution of expanding population, decreasing agriculture, expanding aquaculture for shrimp farming and forests to food security and ecological factor.

2 Materials and methods

2.1 Site selection

The coastal zone of Bangladesh covers 147 upazilas (subdistricts) within 19 districts. Further, a distinction has been made between upazilas facing the coast or the estuary and the upazilas located behind them. A total of 48 upazilas in 12 districts that are exposed to the sea and or lower estuaries are defined as the *exposed coast*, and the remaining 99 upazilas of the coastal districts are termed *interior coast.* Exposed and interior coastal zones of Bangladesh are indicated in the map of Bangladesh as shown in Fig. 1. Five districts from the exposed coast and nine upazilas from the five districts having exposure to sea and or lower estuaries were randomly selected. The purpose of this random selection was also to include penaeid shrimp culture as well as rice cultivation in the upazilas under study. The selected upazilas are given in Table 1, and the selected upazilas are the representatives of the exposed coast of Bangladesh.

2.2 Data collection and analysis

The analysis presented here is based on survey data. To estimate the present status of the food security and ecological footprint of the coastal zone management systems of Bangladesh, primary and secondary data were collected. Two sets of questionnaire were prepared to collect data on population, crop production, aquaculture, livestock, and

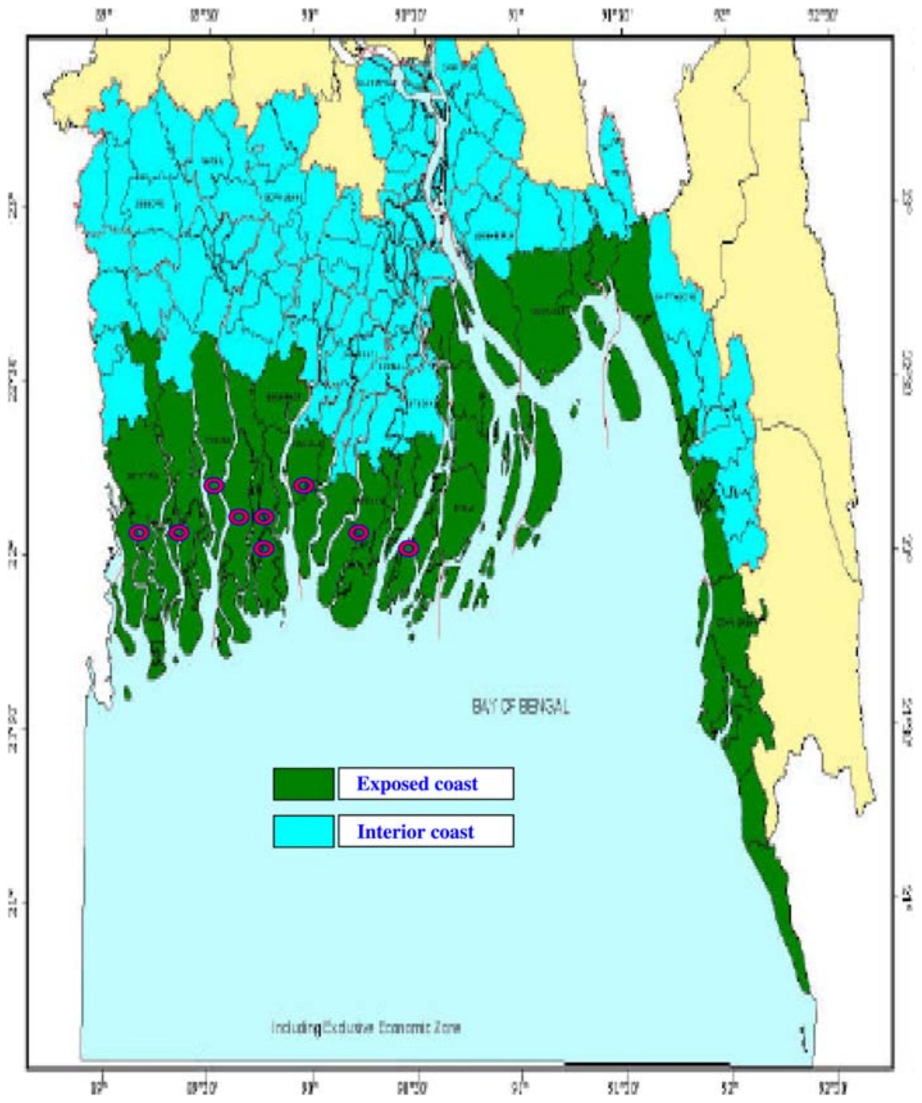


Fig. 1 Map of the coastal zone of Bangladesh

Table 1 Selected upazilas from exposed coastal zone of Bangladesh

District	Upazila
Patuakhali	Kalapara, Galachipa
Borguna	Pathargata
Satkhira	Shyamnagar
Khulna	Dacop, Koyra
Bagerhat	Mongla, Morrelgonj, Sharonkhola

forestry, and the questionnaire were structured into three parts: (1) general information, (2) information for computation of food security, and (3) information for computation of ecological footprint. To estimate the present status of the food security and ecological footprint at upazila level, secondary data were collected on population, crop production, aquaculture, livestock, and forestry from the upazila office, department of agricultural extension and department of statistics at upazila levels. Primary data were collected from the household/farm levels from randomly selected villages of the already selected upazilas to cross check the secondary data and meeting the gaps realized during the collection of secondary data. The collected data and information were compiled, edited, summarized, and analyzed, and the present status of food security and environmental degradation (in terms of ecological footprint) were determined.

A typical village named Baraikhali was selected from Dacop upazila of Khulna district to find out the individual household food security status, and also data were collected from all the households in this village using predesigned questionnaire. This village is in the exposed coast and includes shrimp culture and rice cultivation. Total number of households in the village was 182.

2.3 Computation of food security

USDA evaluated food security based on the gap between projected domestic food consumption and a consumption requirement (USDA 2007). All food aid commodities were converted into grain equivalent based on calorie content. Based on USDA concept, the food security is defined as

$$\begin{aligned}\text{Food security} = \big(&\text{food available from different sources and also equivalence}\\ &\text{food from different sources} - \text{food requirement}\big)/\text{food requirement}\end{aligned} \tag{1}$$

Yusuf and Islam (2005) reported that the daily food requirement data of BBS (Bangladesh Bureau of Statistics) and INFS (Institute of Nutrition and Food Science) are not adequate, and consumption of such a diet would produce physiological deficiencies of both energy and protein leading to protein–energy malnutrition as well as micronutrient malnutrition, and they proposed a dietary composition for balanced nutrition in Bangladesh. The total food intake proposed is 2,345 kcal/cap, and it is midway between the values suggested by WHO (2,310 kcal) and FAO (2,400 kcal). The proposed 2,345 kcal is equivalent to 1.357 kg of rice based on price. All food aid commodities were converted into grain equivalent based on economic returns (price) to compute the food security. Based on this concept, the food security is computed as

$$\begin{aligned}\text{Food security} = \big[\big(&\text{food available from crops} + \text{food available from aquaculture}\\ &\text{and equivalent food from income of aquaculture} + \text{food available from livestock and}\\ &\text{equivalent food from income of livestock} + \text{food available from forestry and equivalent}\\ &\text{food from income of forestry}\big) - \text{total food requirement}\big]/\text{total food requirement}\end{aligned} \tag{2}$$

Positive food security means surplus food, and negative food security means shortage in food supply to lead healthy life. The structure of food security computation is shown in Fig. 2.

This indicator of food security gives a quantitative measure of food security that can be achieved from the available foods and incomes derived from different sources. The major drawback of this indicator is that it does not give the nutritional status that actually prevails.

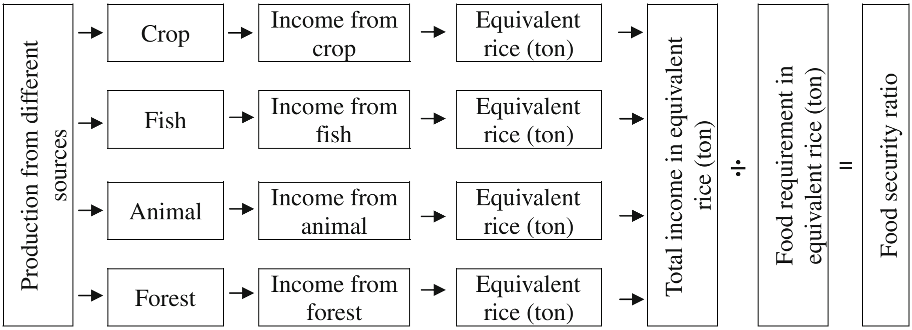


Fig. 2 Structure of food security computation

2.4 Computation of ecological footprint and biological capacity

The ecological footprint calculation is based on the average consumptions data and converted into uses of productive lands. The bioproductive land is divided into 6 categories according to the classification of the World Conservation Union: (1) cropland; (2) grazing land; (3) forest; (4) fishing ground; (5) build-up land; (6) energy land.

Total ecological footprint is the sum of the ecological footprints of all categories of land areas which provide for mutually exclusive demands on the biosphere. Each of these categories represents an area in hectares, which is then multiplied by its equivalence factor to obtain the footprint in global hectares. Thus, ecological footprint can be expressed as (Monfreda et al. 2004):

$$\text{Ecological footprint (gha)} = \text{area (ha)} \times \text{equivalence factor (gha/ha)} \tag{3}$$

where, Area (ha) = all categories of land areas, in ha

$$\text{Equivalence factor} = \text{the world average productivity of a given bio productive area/} \\ \text{the world average potential productivity of all bioproductive areas.}$$

Specifically, an equivalence factor is the quantity of global hectares contained within an average hectare of cropland, build up land, forest, pasture, or fishery. The structure of the computation of ecological footprint is shown in Fig. 3.

An important part of the ecological footprint analysis of a region or zone is represented by the calculation of its biological capacity (Biocapacity) that takes into account the surfaces of ecologically productive land located within the area under study. Biological capacity represents the ecologically productive area that is locally available, and it indicates the local ecosystems potential capacity to provide natural resources and services. Biological capacity is the total annual biological production capacity of a given biologically productive area.

Biological capacity can be expressed as (Monfreda et al. 2004):

$$\text{Biocapacity (gha)} = \text{area (ha)} \times \text{equivalence factor (gha/ha)} \times \text{yield factor} \tag{4}$$

where

$$\text{Yield factor} = \text{local yield/global yield}$$

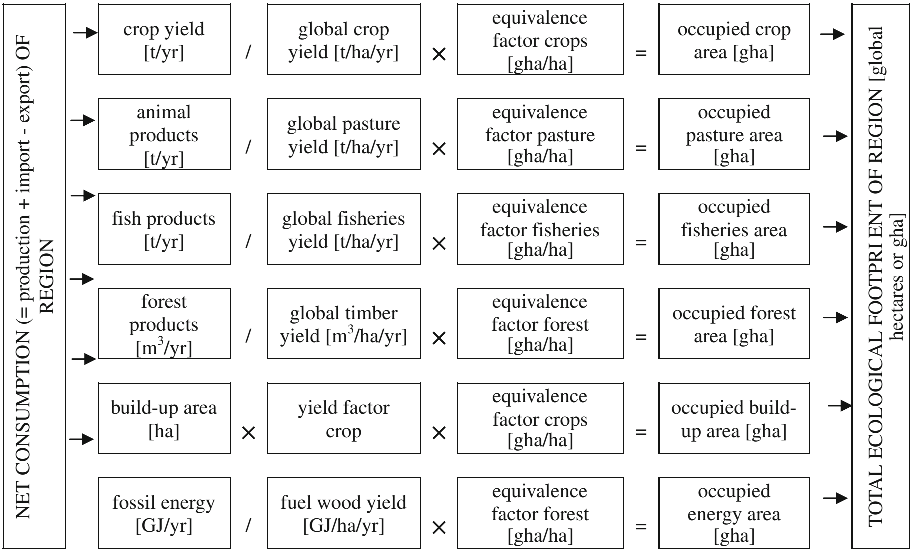


Fig. 3 Structure of ecological footprint computation

Total biocapacity is the sum of all bioproductive areas expressed in global hectares by multiplying its area by the appropriate equivalence factor and the yield factor specific to that country/locality. The structure of the computation of biocapacity is shown in Fig. 4. Biological capacity can be compared with the ecological footprint, which provides an estimation of the ecological resources required by the local population. The ecological status is expressed as the difference between biocapacity and ecological footprint. A negative ecological status (BC $<$ EF) indicates that the rate of consumption of natural resources is greater than the rate of production (regeneration) by local ecosystems (Rees 1996). Thus, an ecological deficit (BC $<$ EF) or surplus (BC $>$ EF) provides an estimation of a local territory's level of environmental sustainability or unsustainability. This also indicates how close to sustainable development the specific area is.

3 Results and discussion

Figure 5 shows the food security status in the nine upazilas of Shyamnagar, Dacop, Koyra, Shoronkhola, Mongla, Morrelgonj, Patharghata, Kalapara, and Galachipa. Kalapara (+164.19%), Galachipa (+128.42%), Dacop (+77.24%), Koyra (+34.42%), Mongla (+36.87%), and Patharghata (+8.53%) have positive food security status and Shyamnagar (−6.08%), Shoronkhola (−23.65%), and Morrelgonj (−30.29) have negative food security status. This implies that Kalapara, Galachipa, Dacop, Koyra, Mongla, and Patharghata are food surplus and Shyamnagar, Shoronkhola, and Morrelgonj are food deficit upazilas in terms of available foods and incomes derived from different sources.

Figure 6 shows the contributions of crop and fish to food security in the nine upazilas of Shyamnagar, Dacop, Koyra, Shoronkhola, Mongla, Morrelgonj, Patharghata, Kalapara, and Galachipa. Galachipa (69%) has the largest contribution to food security from crop

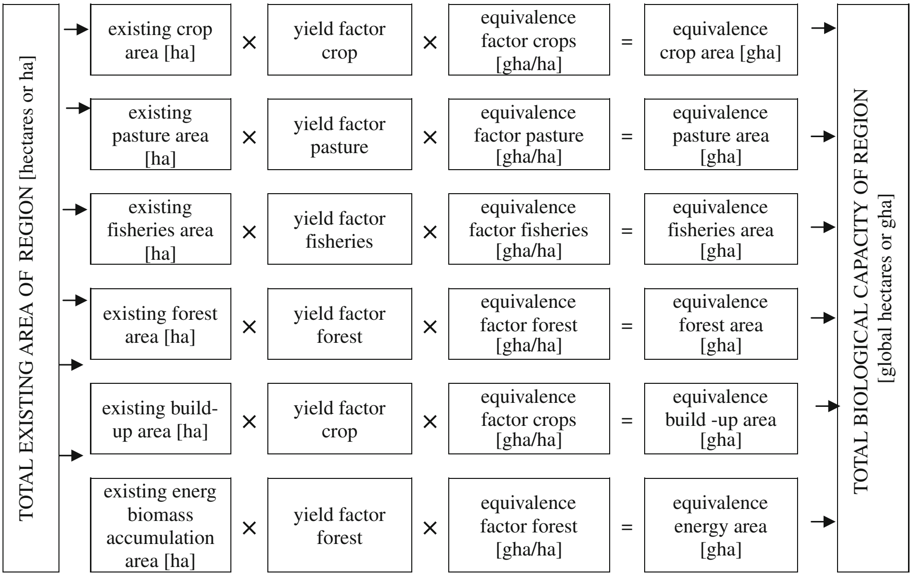


Fig. 4 Structure of biological capacity computation

Fig. 5 Food security status of different upazilas

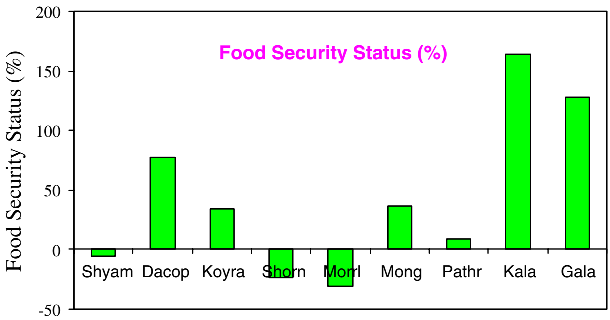
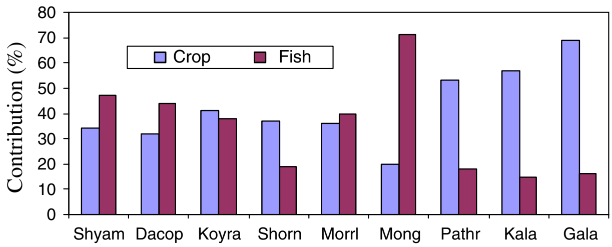


Fig. 6 Contributions of crop and fish to food security



followed by Kalapara (57%) and Patharghata (53%), and these upazilas are crop dominated, while Mongla (71%) has the largest contribution to food security from fish followed by Shyamnagar (47%) and Dacop (44%), and these upazilas are aquaculture dominated.

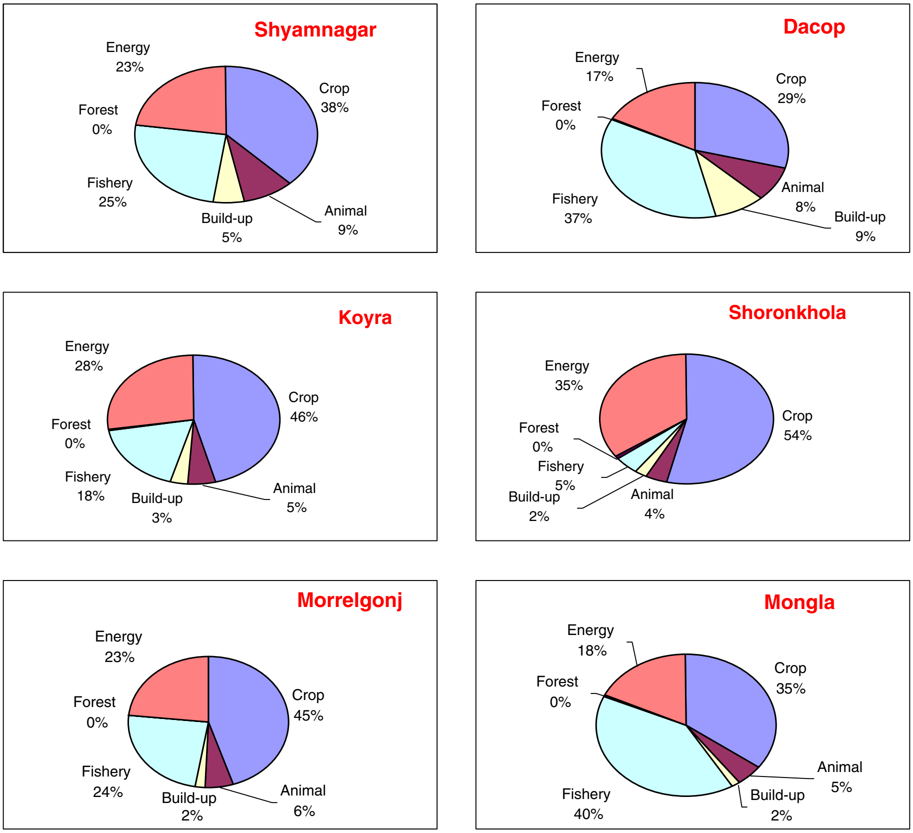


Fig. 7 Percentage ecological distribution of six upazilas of Khulna region

Koyra and Morrelgonj have almost equal contributions from crop and fish. This implies that aquaculture plays vital role to ensure food security at upazila levels.

Figure 7 shows the contributions to ecological footprint from different resources in the Khulna region (Shyamnagar, Dacop, Koyra, Shoronkhola, Mongla, and Morrelgonj). For all these upazilas, the contributions to ecological footprint from crop is 29–54%, from energy is 17–35%, and from fishery is 5–40%. But the contribution from fishery is the largest in Mongla and it is 40%. Thus, in this region, shrimp culture is popular, and its contribution to environmental degradation is large.

Figure 8 shows percentages of contributions to ecological footprint from different resources in the Barisal region (Patharghata, Kalapara and Galachipa). For all these upazilas, the major contribution comes from crop (49–56%) followed by energy (24–26%). But the contribution from fishery is 4–9%. Thus, in this region, shrimp culture is still not popular, and its contribution to environmental degradation is very small.

Figure 9 shows the ecological footprint in the nine upazilas of Shyamnagar, Dacop, Koyra, Shoronkhola, Mongla, Patharghata, Kalapara, and Galachipa. The largest ecological footprint is at Dacop (0.74 gha/cap) followed by Mongla (0.664 gha/cap), and the lowest ecological footprint is at Shoronkhola (0.389 gha/cap). This implies that Dacop and

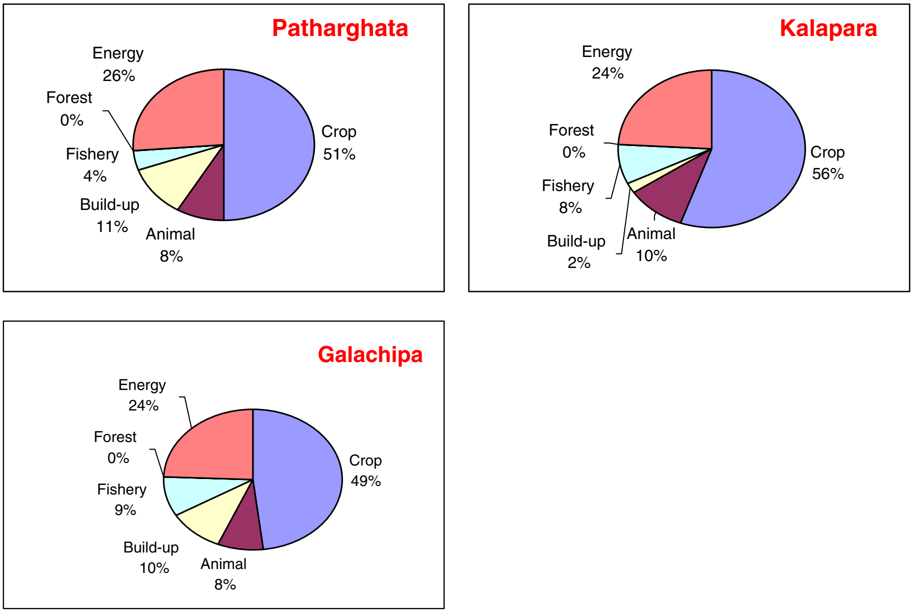


Fig. 8 Percentage ecological distribution of three upazilas of Barisal region

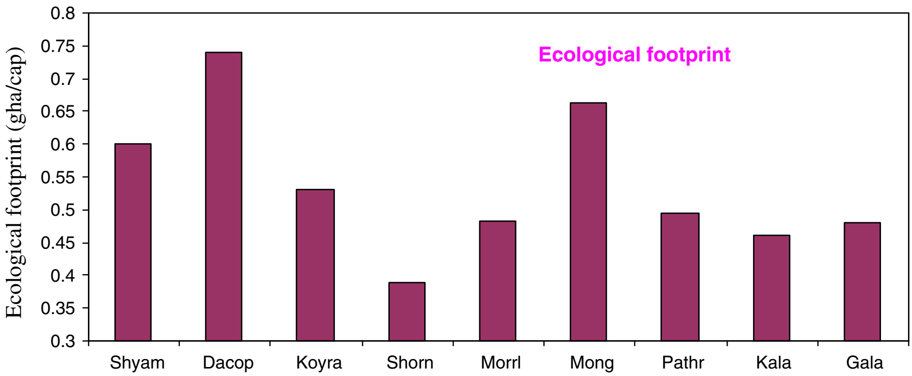


Fig. 9 Ecological footprint of different upazilas

Mongla have suffered serious environmental degradation, and Shoronkhola is the least suffered upazila.

Figure 10 shows the biocapacity in the nine upazilas of Shyamnagar, Dacop, Koyra, Shoronkhola, Mongla, Morrelgonj, Patharghata, Kalapara, and Galachipa. Kalapara and Galachipa have the largest biocapacity (+0.802 gha/cap) and the lowest is at Mongla (+0.157 gha/cap).

Figure 11 shows the ecological status of the nine upazilas of Shyamnagar, Dacop, Koyra Shoronkhola, Mongla, Morrelgonj, Patharghata, Kalapara, and Galachipa. The ecological status of Kalapara and Galachipa is surplus (+0.306, +0.322 gha/cap), and this implies that these upazilas are not facing any environmental degradation. These two

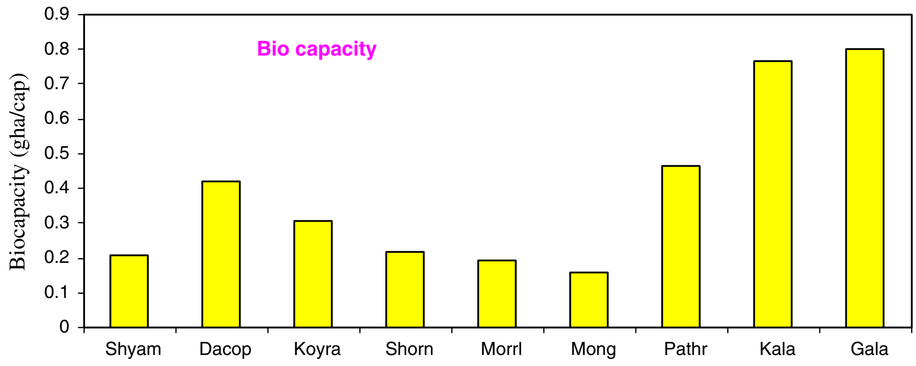


Fig. 10 Biological capacity of different Upazilas

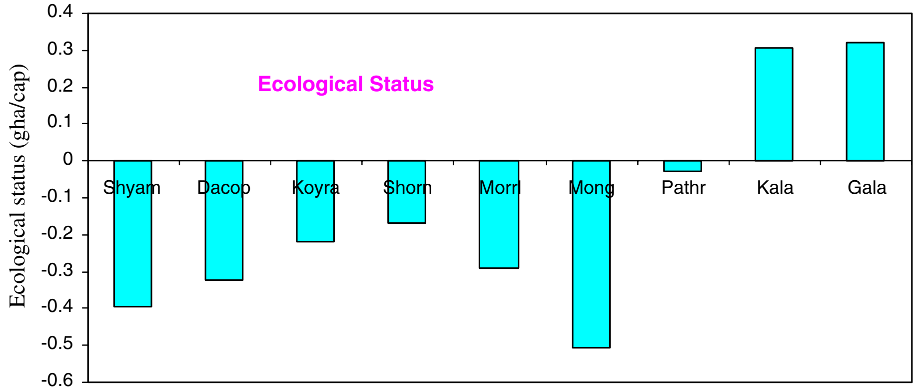


Fig. 11 Ecological status of different Upazilas

upazilas are crop dominated. The upazilas that have suffered the most are Mongla, Shyamnagar, Dacop, and Morrelgonj where shrimp culture is at commercial level for export market. The highest and the least suffered upazilas are Mongla (−0.5076 gha/cap) and Patharghata (−0.027 gha/cap), respectively. Wackernagel et al. (1999) also reported that the ecological status for Bangladesh as a whole is −0.20 gha/cap.

Figure 12 shows the contributions of crop and fish to ecological status in the nine upazilas of Shyamnagar, Dacop, Koyra, Shoronkhola, Morrelgonj, Mongla, Patharghata, Kalapara, and Galachipa. The contributions of both crop and fish to ecological status of Shyamnagar, Morrelgonj, and Mongla are negative resulting ecologically deficit upazilas while the rest of the upazilas have surplus ecological status from crop production. However, fish production (shrimp) creates deficit ecological footprint, and Dacop and Mongla are mainly affected (ecological deficit) by the shrimp production. This implies that the increase in shrimp culture moves the coastal zone toward unsustainable development.

The present status of food security, food self-sufficiency ratio, contributions of crop production and aquaculture to food security and environmental degradation in terms of ecological footprint in the nine upazilas of the coastal zones of Bangladesh at a glance are shown in Table 2.

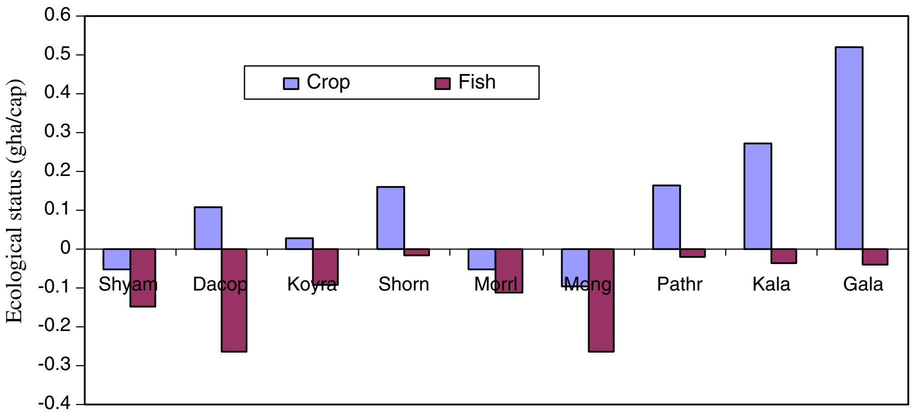


Fig. 12 Ecological status from crop and fish of different Upazilas

Table 2 The present status of food security and ecological status of nine upazilas of the coastal zones of Bangladesh at a glance

Name of Upazila	Contribution to food security (%)		Food self-sufficiency ratio	Food security status (%)	Ecological footprint (gha/cap)	Biocapacity (gha/cap)	Ecological status (gha/cap)
	Crop	Fish					
Shyamnagar	34	47	0.86	−6.08	0.601	0.207	−0.394
Dacop	32	44	1.72	77.24	0.741	0.418	−0.322
Koyra	41	38	1.24	40.06	0.530	0.309	−0.22
Shoronkhola	37	19	0.92	−23.65	0.389	0.220	−0.169
Morrelgonj	36	40	0.70	−30.29	0.482	0.192	−0.2896
Mongla	20	71	0.85	36.87	0.664	0.157	−0.5076
Patharghata	53	18	1.10	8.53	0.495	0.467	−0.027
Kalapara	57	15	3.06	164.19	0.461	0.768	+0.306
Galachipa	69	16	2.12	128.42	0.480	0.802	+0.322

This research shows that the overall status of food security at upazila levels is good for all the upazilas (8.53–164.19%) except Shoronkhola (−23.65%), Shyamnager (−6.08%) and Morrelgonj (−30.29%), and the best is the Kalapara upazila (164.19%). The environmental status in the coastal zones is poor for all the upazilas (−0.5076 to −0.027) except Kalapara (+0.306) and Galachipa (+0.322), and the worst is the Mongla upazila (−0.5076). The environmental status in the coastal zones has degraded mainly due to shrimp culture. This suggests that the control of shrimp production and increasing the yield factor of the crops without additional load on the environment can lead toward sustainable development.

3.1 Household food security

Figure 13 shows the household level food security of a typical village Baraikhali. Only about 37.4% of the population of the village Baraikhali has access to food for round the

Fig. 13 Household food security status in the village Baraikhali

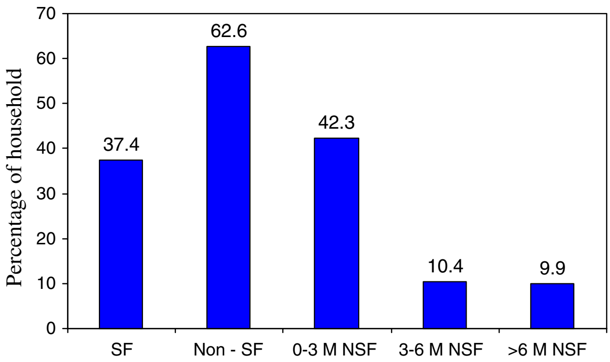
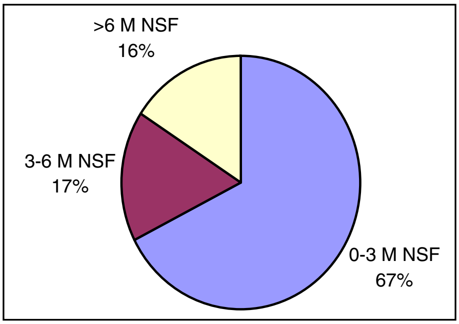


Fig. 14 Percentage distribution of food security



year, and the picture of food security at village level is different from that of upazila level where the overall status of food security is good. This happens mainly due to the fact that shrimp production in the village is dominated by local/nonlocal private enterprises who care mainly for profit maximization rather than poverty alleviation of the local poor and also who care little to protect the local environment.

Figure 14 shows the percentage distribution of food security in the village Baraikhali. Almost 42.3% of the households in the village Baraikhali have suffered from food insecurity for 0–3 months followed by 10.4% of the households for 3–6 months and 9.9% for more than 6 months.

4 Conclusions

A quantitative method for computation of food security in grain equivalent based on economic returns (price) is developed, and the food security and ecological footprint of the coastal zone of Bangladesh are estimated.

Overall status of food security at upazila levels is good for all the upazilas except Shoronkhola, Shyamnager, and Morrelgonj, and the best is the Kalapara upazila. But the status of food security at household levels is poor.

Environmental status in the coastal zones is poor for all the upazilas except Kalapara and Galachipa. The worst is the Mongla upazila. Environmental status has degraded mainly due to shrimp culture. This study suggests that control measures are needed for affected upazilas and any further expansion of the shrimp aquaculture to enhance the food security must take into account the environmental aspects of the locality under consideration.

Most of the upazilas operate in an ecological deficit by exerting more load on the environment than that can be replenished. This indicates that the load imposed on the environment has substantially exceeded its carrying capacity. The path of decreasing ecological footprint should be followed if the development is to be sustainable in the long run by controlling the shrimp production and increasing the yield factor of the crops without additional load on the environment.

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