

# Valuing mangrove ecosystem services: linking nutrient retention function of mangrove forests to enhanced agroecosystem production

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Received: 8 April 2007 / Accepted: 8 January 2008 / Published online: 19 February 2008  
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**Abstract** Mangroves are highly productive wetland ecosystems strategically located at the interface between land and sea. They play an important role in the biogeochemical cycles of the coastal environment, acting as sources of nutrients to adjacent marine and terrestrial ecosystems through active and passive transport. We examined the nutrient contents in mangrove and nonmangrove soils in and around the Bhitarkanika National Park, India and assessed whether the local agricultural producers were aware of and placed a value on this contribution of mangrove forests in enhancing agroecosystem productivity. Soil samples from both mangrove and nonmangrove areas were analysed and quantity of organic carbon, total nitrogen, available phosphorus and potassium were derived. The replacement cost method was used to derive the value of nutrients in mangrove soils. We estimated that each hectare of mangrove contains additional nutrients worth US\$232.49 in comparison to nonmangrove areas. The difference in nutrient content in mangrove versus nonmangrove areas gave the value of US\$3.37 million for the nutrients in 145 km<sup>2</sup> of mangrove forests. The agricultural producers were aware that mangrove

forests act as a source of nutrients and were willing to pay a higher price for the land adjoining mangrove forests. Around 92% of the producers ranked nutrient retention as a secondary function of mangrove forests. Despite crop depredation from wild ungulates and conflict with salt water crocodiles the agriculturist finds the benefit to cost ratio of mangrove forests high and more than 76% were in favour of mangrove restoration. This study provides an opportunity to highlight the importance of mangrove ecosystems to the livelihoods of the local people and the urgent need to sustain these through proper policy and market interventions.

**Keywords** Mangrove ecosystem · Nutrient export · Agricultural productivity · Ecosystem services · Economic valuation · Local people

## Introduction

Mangroves are highly productive wetland ecosystems strategically located at the interface between land and sea which play an important role in the biogeochemical cycles of the coastal environment (Jennerjahn and Ittekkot 2002; Feller et al. 2003). Mangrove litter fall and root biomass have been implicated as the ultimate source of organic matter that is regenerated and a source of carbon and nutrients (Kristensen et al.

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1995). In comparative studies on nutrient cycling on Dutch heathlands it was concluded that as nutrient availability increases, nutrient cycling occurs at a higher speed (Artes 1989). When ecosystem nutrient pools increase in size through nutrient addition, process rates increase as nutrients cycle at a higher speed (Van Oorschot 1994). The nutrients such as inorganic phosphorus, nitrogen, potassium, and organic carbon are provided to adjacent coastal and marine, as well as terrestrial ecosystems through active and passive transport (Twilley 1988; Odum 2000; Gonnee et al. 2004). Mangroves in estuaries receive sediment from a variety of sources including marine and fluvial inputs as well as detritus from fringing vegetation, mainly organic material generated within the estuary itself, aeolin sediment inputs, and human-induced inputs. Sediment moving landward from the sea into estuaries and mangroves is a common phenomenon and is driven by the tidal asymmetry that exists in constricted inlets. These inlets have shorter duration and hence faster current regime during flood tides than ebb tides and thus sediment accumulates preferentially in the estuary in the form of a flood–tidal delta. In many instances, these flood–tidal deltas gradually extend up-stream (Day 1981). In South Asia such deltas are extensively cultivated with paddy varieties that withstand higher levels of salinity and water logged conditions. It is commonly believed by the local communities that cultivated lands nearer to mangrove forests in such areas support higher levels of productivity.

Over the last few decades extensive information has been published on the biogeochemical role of estuaries and mangrove ecosystems (Tam and Wong 1999; Corredor and Morell 1994), but there is little information which links the role of these ecosystems in enhancing production functions of the adjacent agroecosystems through nutrient export. Our objectives were: to examine the soil characteristics of tropical mangrove forests in the Bhitarkanika Conservation Area (BCA) on the east coast of India; quantify and value the nutrient contents in mangrove and nonmangrove soils in terms of inorganic phosphorus, nitrogen, and potassium in order to link these to enhanced fertility of the adjacent agroecosystems; and to find out if the local agriculturalists recognize this contribution of mangrove forests. If the efficiency of production function of the local agroecosystem is linked with the mangrove ecosystem functions,

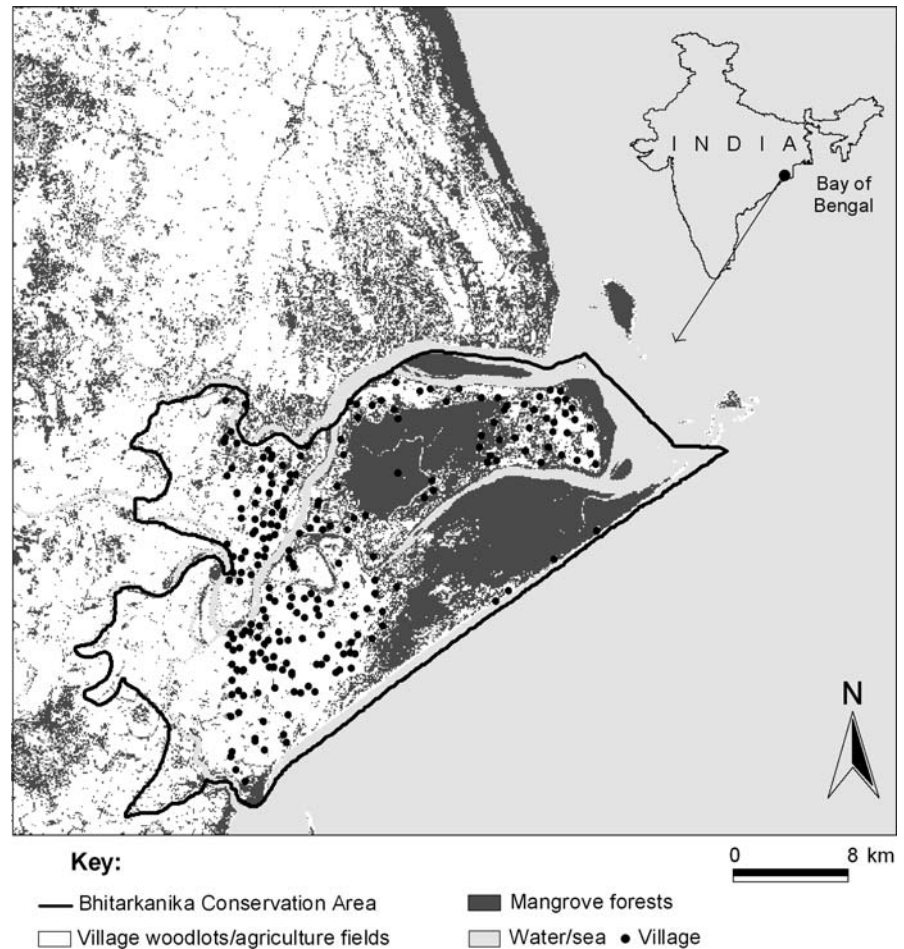
people will be more proactive in conserving mangroves. Further, quantifying and evaluating the conservation benefits in a way that makes them comparable with the returns derived from alternative uses can facilitate improved social decision making in wetland protection versus development conflict situations (Turner et al. 2000).

### Study area

This study was conducted in the Bhitarkanika Conservation Area (BCA) located between 86°45' E to 87°50' E longitude and 20°40' to 20° 48' N latitude (Patnaik et al. 1995) on the east coast of Orissa, India (Fig. 1). It is formed by the estuary of the Brahmani, Baitarani, and Dhamra rivers. The delta is a large estuarine system with a depositional and prograding environment with fluvial, aeolian, and coastal landforms (Mahapatra 2000). The main feature of the Orissa coast is micro-mesotidal, monsoonal wave dominated to mixed energy wave-tide dominated (Davis 1987). The gross littoral drift is 1.5–2.0 million m<sup>3</sup>/year (Mohanty 1990). The terrain is formed by the alluvial filling up of the littoral zone of the Bay of Bengal. It is composed of sandy and muddy beaches along the coast and a network of creeks (Choudhury et al. 1999). The general elevation of the area above mean tide level is between 1.5 and 2 m (Dani and Kar 1999). Most of the area, including the adjoining cultivated areas, gets submerged during fair monsoons. Surface soils close to the rivers vary from 2 m to 4 m in depth that decrease gradually from shore to the mainland (Patnaik et al. 1995).

This mangrove ecosystem and the associated coast harbour the highest diversity of Indian mangrove flora (Naskar and Mandal 1999) and its obligate faunal species. The mangrove forests of Bhitarkanika differ considerably from other Indian mangroves because of their dominant tree species *Heritiera fomes*, *H. littoralis*, and *Sonneratia apetala*. Badola and Hussain (2003) reported a total of 64 species of plants from BCA, which include 28 true mangroves, four mangrove associates, and 32 other species. The mangrove formations in the BCA, once wide spread, are now restricted to 145 km<sup>2</sup> of the National Park, where as the Sanctuary has few degraded mangroves and palm swamps. Considering its ecological and social value the area has been identified as a Ramsar site.

**Fig. 1** Location of Bhitarkanika Conservation Area, India. Land use pattern and distribution of villages in the region



### The agroecosystem of Bhitarkanika Conservation Area

The agroecosystem of BCA consists of 247.9 km<sup>2</sup> of human habitation in 336 villages, village woodlots, and agricultural fields. Subsistence based, nonmechanized agriculture is the main occupation of the people, characterized by small land holdings and dependent on the monsoon. In addition to a single crop of paddy, small quantities of vegetables, coconut, and fish are the only output of the agroecosystem. The local people have low per capita income as few opportunities for small-scale industries exist due to the lack of infrastructure facilities. About 13.5% of the people in the working age category of 20–60 years are unemployed. Many people are working as skilled and unskilled labourers in other states. The average family income is US\$488.9 per annum (Table 1).

### Methods

#### Estimation of nutrient contents in mangrove and nonmangrove soils

The mangrove forests in the Bhitarkanika National Park were stratified into forest blocks with fairly good mangroves of different species and period of inundation during high flood. Sixty soil samples each were collected from relatively pure stands of different mangrove species as well as from the sanctuary area which lacks mangrove forests. At each sampling station a 50 m transect was laid perpendicular to the creeks. Assuming that a high degree of spatial variability may exist over quite small areas, the soil samples were collected from five points at an interval of 10 m on each transect. History of farming in the area was also examined to eliminate samples from areas where chemical fertilizers were used. The soil

**Table 1** Characteristics of the agroecosystem of Bhitarkanika Conservation Area, India ( $\pm$  standard error of mean)

Parameters	Total
Average village size (ha)	113.27 $\pm$ 3.98
Cultivated area irrigated (%)	8.7
Mean family size	7.59 $\pm$ 0.11
Average size of paddy fields (ha)	1.32 $\pm$ 0.12
Overall paddy yield (kg/ha)	948.83 $\pm$ 0.56
No. of coconut trees/household	9.44 $\pm$ 1.05
No. of months of employment	6.25 $\pm$ 0.22
People engaged in agriculture (%)	60.30
People engaged in allied activities (fishing, animal husbandry) (%)	1.96
People engaged in labour (%)	25.47
Income of the family (US\$/annum)	488.86 $\pm$ 10.40
Unemployment rate (%)	13.58 $\pm$ 0.61
Literacy rate (%)	48 $\pm$ 0.01

samples were collected from 10–15 cm depth, labeled on site, air-dried, and brought to the laboratory; pebbles and detritus were removed from each sample. All five samples from each transect were mixed together to form a composite sample. Thus 60 samples each were obtained from both mangrove and nonmangrove areas. The following physical and chemical parameters of soil samples were analyzed using standard techniques as specified for each parameter:

Physical and chemical characteristics of soil:

- Soil texture: texture was evaluated in the laboratory by Bouyoucos hydrometer method (Allen 1989).
- Soil pH: pH value was determined using the electrometric method (Jackson 1967).
- Organic carbon: the organic carbon was determined by the Walkley and Black rapid titration method (Jackson 1967).
- Total nitrogen: the micro Kjeldahl method (Jackson 1967) was used for estimating total nitrogen.
- Available phosphorus: the available phosphorus was estimated by using a photoelectric colorimeter (Allen 1989).
- Available potassium: the available potassium was estimated by N-Ammonium Acetate method using a digital flame photometer (Jackson 1967).

## Valuation of major nutrients

For valuation of soil nutrients the replacement cost approach was used (Bann 1997). This method places a value on the environmental service by estimating the cost of replacing the environmental benefit with alternatives (Dixon and Sherman 1991). It focuses on the costs of providing man-made substitutes for ecosystem services and regards the value of an ecosystem service as the price of the cheapest alternative (Woodward and Wui 2001). Since society would not have to pay such costs if the ecosystem service is available, the idea is that such cost savings indicate the economic value of the service. A fundamental prerequisite is however that the substitute provides exactly the same service as the natural resource which is to be valued. Furthermore, the functional relationships between the ecosystem considered, the ecological functions, and the service that leads to a societal value must be capable of being identified (Dehnhardt 2002). The replacement cost method, which is reliable, has been used extensively for valuing ecosystem services provided by wetlands (Bockstael et al. 2000; Freeman 2003; Sundberg 2004). Most studies that focus on nutrient retention function of wetlands are based on the replacement cost approach (e.g. Byström 2000; Gren et al. 1995; Gren 1995; Breaux et al. 1995; Farber 1996; Thibodeau and Ostro 1981). In this study, the soil nutrients present were related to the cost of equivalent amount of fertilizer to be added. The cost of increasing the soil nutrients in the nonmangrove areas to the level of mangrove areas was calculated by valuing the fertilizers that if added to the soil in nonmangrove areas would bring their nutrient level to that of mangrove areas. The value of the nutrients present in mangrove and nonmangrove soil was derived by multiplying the amount of available nutrient (kg/ha) by the prevailing market price (US\$/kg) of the fertilizer with similar chemical compositions.

## Perceptions of local people about the nutrient retention and export function

To find out whether the local people were aware of and placed a value on the contribution of mangrove forests in increasing the fertility of their agricultural fields, two categories of villages were selected:

villages adjoining mangrove forests (i.e. villages having mangrove forests within 1 km from their boundary) and villages away from the mangrove forests (i.e. mangrove forests at 1–3 km from village boundary). Six villages each from the two categories were selected for intensive sampling and 140 households (74 and 66 from the former and latter categories, respectively) were interviewed to gather information on the types of crops grown, their production per unit area, the problems faced by them as well as their suggestions to improve the productivity of their land. The agricultural land in these villages was further classified into the following categories: (a) land adjoining the mangrove forests, (b) riverside land, (c) land near a forest as well as a river, and (d) land-locked land. All the households interviewed were not using fertilizers in their crop fields.

To examine the perceptions of the people towards the benefits provided by the mangrove forests and their attitudes towards conservation and development issues, thirty-five villages were selected by hierarchical cluster analysis using Ward's method (Jongman et al. 1995) based on 28 parameters. In the selected villages 10% of the households were randomly sampled using a semistructured questionnaire (Badola and Hussain 2003). During the interview, the respondents were explained about the major functions of the mangrove forests and were asked to rank these into three categories (primary, secondary, and tertiary) in order of their significance to their life and livelihoods.

## Results

### Physical and chemical properties of soil from mangrove and nonmangrove areas

The soil from mangrove forests had more clay content as compared to nonmangrove soils. The soil from the nonmangrove area was relatively silty loam (Table 2). The chemical properties of soil such as pH, organic carbon, total nitrogen, available phosphorus, and potassium of mangrove forests were significantly different from soil of nonmangrove areas. Higher quantity of organic carbon (25,326.67 kg/ha), total nitrogen (2,907.00 kg/ha), phosphates (28.11 kg/ha), and potassium (1,564.55 kg/ha) were found in soil

**Table 2** Distribution of soil in different texture class (%) in mangrove and nonmangrove areas of Bhitarkanika Conservation Area, India

Textural class	Mangrove (%)	Nonmangrove (%)
Clay	76.67	36.67
Silty clay	11.67	15.00
Loamy sand	1.67	0.00
Clayey loam	10.00	15.00
Silty loam	0.00	23.33
Loam	0.00	10.00

collected from mangrove forests. However, no significant difference was found in electrical conductivity of mangrove and nonmangrove soils (Table 3).

### Economic valuation of soil nutrients

The estimated value of available nitrogen, phosphorus, and potassium in soil from mangrove areas was higher as compared to nonmangrove areas (Table 4). Each hectare of mangrove forests contained additional nutrients worth US\$232.49 in comparison to nonmangrove areas. This was the cost of increasing the soil nutrients in the nonmangrove areas to the level of mangrove areas per hectare at the prevailing market price of fertilizers. The difference in nutrient contents in mangrove and nonmangrove area gave the value of US\$3.37 million for the nutrients provided by the 145 km<sup>2</sup> of mangrove forests of the Bhitarkanika National Park (Table 4).

### Productivity of the local agroecosystem

The productivity of various crops was much higher in villages adjoining the mangrove forests (0–1 km) as compared to those that were far away from the mangroves (1–3 km), particularly for the major crops such as coconut, vegetables, and paddy (Table 5). The agricultural producers were aware that the mangrove forests act as a source of nutrients which enhanced agricultural productivity. Higher land prices prevailed for agricultural lands in areas near mangrove forests. The highest price (US\$1,770.02 ± 102.43) was for landlocked agricultural land near mangrove forests (Table 6). This is logical as such lands are safe from wildlife damage and saline water

**Table 3** Chemical characteristics and major nutrients in the soil collected from mangrove and nonmangrove areas of Bhitarkanika Conservation Area, India

Parameters	Mangrove (mean)	Nonmangrove (mean)	<i>t</i> value	<i>P</i> value (2 tailed)
pH	7.58 ± 0.06	7.03 ± 0.09	4.797	<0.001
EC (mho)	2.64 ± 0.18	2.30 ± 0.23	1.130	ns
Organic carbon (C, kg/ha)	25,326.67 ± 1,429.81	18,323.33 ± 982.18	4.547	<0.001
Total nitrogen (N, kg/ha)	2,907.00 ± 177.46	2,057.67 ± 112.13	4.514	<0.001
Phosphates (P <sub>2</sub> O <sub>5</sub> , kg/ha)	28.11 ± 3.23	20.08 ± 1.92	4.797	<0.001
Potassium (K <sub>2</sub> O, kg/ha)	1,564.55 ± 100.89	1,222.46 ± 67.24	2.660	<0.05

± = standard error of mean; *ns* not significant

intrusion during storm surge. However, the productivity of the land is not the only determinant of the land price; it is the net economic output that is greater here in spite of crop damage by wildlife, occasional saline water intrusion, and relative inaccessibility. These were explicitly expressed by the agriculturalists as they were aware that the agricultural lands adjoining mangrove forests are significantly enriched due to the nutrients from the mangrove areas and were willing to pay a higher price for this land.

#### Perceptions of local people

When asked to rank the ecological services performed by mangrove forests, respondents ranked protection from storms and cyclones and erosion prevention as the primary functions of mangrove forests. Around 92% of the agriculturalists ranked nutrient retention as a secondary ecological function of mangrove forests; however, they ranked fish production higher than the nutrient retention function. Provision of non-wood forest produce such as honey and medicinal plants from the mangrove forests was also considered as an important function (Table 7). Despite crop depredation from wild ungulates and conflict with salt water crocodiles, the agriculturists find the benefit to cost ratio of mangrove forests high and more than 76% were in favor of mangrove restoration. Very few people feel that forests should be cut and the land used for agricultural purposes.

#### Discussion

Ecological systems form the life support systems within which all economic development takes place

(Costanza et al. 1997). To ensure the sustainability of the services provided by natural ecosystems, it is important to ensure the sustainability of the local agroecosystem, as well as the livelihoods of dependant populations (Badola and Hussain 2003). In a recent paper we presented the role of the storm protection function of the mangrove forests in securing lives and livelihoods of the coastal communities (Badola and Hussain 2005a). Preliminary observations of the Asian tsunami of 2004 further highlight and provide a stark reminder that environmental sustainability and human security are inseparable (Badola and Hussain 2005b; Walters 2005). In this paper we examine the interrelationships of the mangrove forests with the adjoining agroecosystem and emphasize their role in enhancing productivity. Studies that link functions performed by natural ecosystems to human well-being and security can help put conservation on the 'livelihoods' agenda of the local communities and help in resolving the classic battle of conservation vs. development. Studies quantifying ecosystem services have a crucial role to play in the decision making process for resource allocation and use. The most important role that economic valuation can play is to value the ecosystem services and to link them with the tangible benefits that are derived by people (e.g. Daily et al. 1997). Nutrient retention function of the mangrove forests is one such function whose benefits can easily be understood and felt by the people.

In all estuaries an interface exists between fluvial and marine processes, although the nature and intensity of processes operating at this interface may vary. In some systems sea water may extend many kilometers up stream or it may be restricted to inputs from barrier overwash and be confined to areas adjacent to the barrier or mouth of the estuary (Day

**Table 4** Value of available nutrients in soil from the Bhitarkanika Conservation Area, India

Nutrients	Nutrients in mangrove forests (kg/ha)	Nutrients in nonmangrove area (kg/ha)	Estimated value of nutrients in mangrove forests/ha (US\$/kg)	Estimated value of nutrients in nonmangrove area/ha (US\$/kg)	Quantity of extra nutrients in mangrove forests (kg/ha)	Estimated value for extra nutrients in mangrove forests (US\$/ha)	Quantity of extra nutrients in 14,500 ha of mangrove forests (kg)	Estimated value for extra nutrients in 14,500 ha mangrove forests (US\$)
Available nitrogen (N)	2,907.00	2,057.67	610.47	431.97	849.33	178.50	12,315,285	2,588,250
Available phosphates (P <sub>2</sub> O <sub>5</sub> )	28.11	20.08	9.28	6.63	8.03	2.65	116,435	38,425
Available potassium (K <sub>2</sub> O)	1,564.55	1,222.46	234.68	183.34	342.09	51.34	4,960,305	744,430
Total value of N + P <sub>2</sub> O <sub>5</sub> + K <sub>2</sub> O			854.43	621.94		232.49		3,371,105

Market value of fertilizer (US\$/kg\*): nitrogen (N) = 0.21, phosphates (P<sub>2</sub>O<sub>5</sub>) = 0.33, potassium (K<sub>2</sub>O) = 0.15

Source: Fertilizer Association of India, Statistics 2000

1981). In low-lying coastal plains during the high floods, e.g. during monsoon in South Asia, the nutrients from the estuaries may get exported to surrounding uplands due to inundation and wind-generated waves resulting in landward flux of sediments (Swift 1976; Kjerfve 1989). When these nutrients get deposited in near shore agricultural fields, it enhances their productivity. It may be argued that the tidal flooding may increase the salinity of land making it less productive. However, this is not the case in BCA. The net precipitation in the Brahmani–Baitarani River Basin is 53,011 million m<sup>3</sup>/year and the out-flow to the sea is 21,902 million m<sup>3</sup>/year, the maximum occurring during monsoon (ICID 2003). This inundates a large area at the Brahmani–Baitarani–Dhamra estuary. Flooding of the entire area by rain water is the principal vehicle for transportation of nutrients in the estuary and the surrounding areas. The surface water in the Bay of Bengal has low salinity, there are no upwelling areas, and it is richer in terms of nutrients (Pereira and Vannucci 1991). A large quantity of freshwater in the estuary maintains predominantly the *Heritiera fomes*, *H. littoralis*, and *Sonneratia apetala* species landward (Badola and Hussain 2003). Traditionally, people are aware that mangrove forests are nutrient rich, as in the upper reaches of Sunderbans, it is common to see vegetables planted in between pneumatophores of *Heritiera* during low waters of the inter-monsoon period (Vannucci 2001). In our study we found that the adjoining agricultural areas have higher productivity of paddy, which is up to 70 kg/ha, equal to about US\$10/ha. In such a situation where the family income is US\$/488.9 per annum, this function of mangrove forests becomes important for sustaining the livelihoods of the local people, although this may not have the same significance in developed countries with high incomes (Millennium Ecosystem Assessment 2005).

Despite crop damage by wild animals in the lands adjacent to the mangrove forests in the BCA people are willing to pay a higher price for such land, reflecting the recognition of higher productivity. Although local communities recognize the historical and aesthetic value of the BCA, they have placed higher premium on those functions that they perceive as directly benefiting them in terms of security or livelihood. Many studies have emphasized that the attitude of local people is one of the ultimate factors determining the improved management and conservation effectiveness of the

**Table 5** Comparison of agricultural production in Bhitarkanika Conservation Area, India

Agriculture production	Village categories	<i>N</i>	Mean ± standard error of mean
No. of coconut trees	1	5	4.00 ± 0.55
	2	75	10.43 ± 1.23
Coconuts produced/tree	1	5	30.00 ± 6.89
	2	75	40.67 ± 4.51
Yield of vegetables (kg/ha)	1	9	4,974.75 ± 1,064.87
	2	39	7,118.25 ± 1,107.75
Yield of paddy (kg/ha)	1	32	1,125.9 ± 69.70
	2	5	1,196.30 ± 228.95

1 land far from mangrove forests (1–3 km), 2 land close to mangrove forests (0–1 km), *N* number of families

**Table 6** Comparison of price of land in Bhitarkanika Conservation Area, India

Price of land (US\$/ha)	Village categories	<i>N</i>	Mean ± standard error of mean
Land close to river	1	32	914.15 ± 117.99
	2	5	2,111.10 ± 586.63
Land-locked land	1	34	1,436.81 ± 144.48
	2	69	1,770.02 ± 102.43

1 land far from mangrove forests (1–3 km), 2 land close to mangrove forests (0–1 km), *N* number of families

**Table 7** Ecological services and use values provided by the Bhitarkanika Mangrove ecosystem—perception of the agricultural producers (*n* = 268)

Ecological services	Rank 1 (%) Primary function	Rank 2 (%) Secondary function	Rank 3 (%) Tertiary function
Protection from storms and cyclones	88.6	11.0	0.4
Nutrient retention	8.0	92.0	0.0
Land erosion prevention	50.0	50.0	0.0
Fish production	1.9	96.2	1.9
Non-wood forests produce	20.6	73.5	5.9
Tourism	17.2	81.8	1.0
Aesthetic	38.0	61.2	0.8
Historical	8.8	88.9	2.3
Others (biodiversity, ground water recharge, and regional climate control)	18.9	70.3	10.8

protected areas (e.g. Struhsaker et al. 2005). There is a need to improve strategies so that human attitudes, value systems, and behavior can be influenced to the benefit of mangrove ecosystems, in addition to developing policy alternatives that are more acceptable to the local people. Adequate representation of the stakeholders in the decision making process (Hearth 2004; Grimble and Chan 1995) has to be ensured to avoid a ‘tragedy of commons’ outcome in the absence of property rights (Schlager and Ostrom 1992; Udaya Sekhar 2004). At the surface it may appear that the

mangroves of BCA are facing threat of extinction due to high human pressures; however, at a deeper level these are being destroyed because of fundamental economic forces, i.e. information, market, and policy failures as a result of which the products, attributes, and functions of these are not adequately recognized by the policy. This study provides information about the contribution of such ecosystems as well as about people’s impressions and opinions that might be useful in targeting education and public awareness programs and in shaping policy (e.g. Streever et al. 1998).



Although a better understanding of the economic value of the natural resources does not necessarily favor their conservation and sustainable use, it at least permits them to be considered as economically productive systems alongside other land uses (IUCN 2003) and provides an opportunity to highlight the importance of these ecosystems on the livelihoods of the local people, the urgent need to sustain this through diversification and strengthening the resource base, and through appropriate policy and market interventions.

**Acknowledgements** The India Environment Management Capacity Building (EMCaB) Project, Indira Gandhi Institute of Development Research (IGIDR), Mumbai provided funding support for this study. We thank Chief Wildlife Warden, Government of Orissa and Mr. Anup Nayak, Divisional Forest Officer, Mangrove Forest Division, Rajanagar, Orissa for permitting us to carry out this research in the Bhitarkanika Wildlife Sanctuary. We thank Dr. Hemant Kumar Sahu, Ms. Poonam Semwal, Ms. Kalpana Ambastha, Ms. Shivani Chandola, and Mr. Anoop K.R. for helping us in field data collection and analysis.

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