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Environment development linkages: modelling a wetland system for ecological and economic value

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ABSTRACT. Modeling the factors determining ecological and economic value gives rise to conceptual and methodological problems. Economic valuation typically focuses on use value in the short run, whether within or outside the market. Ecologists, however, are more concerned with ecological values, which provide an underlying long-run notion of value interpreted in a more general sense. This paper investigates the nature of the link between these two aspects of value in the context of a wetland in Northern India, which is also designated as a Ramsar site and a national park. A dynamic simulation model in a 'STELLA' environment is set up to understand the linkages between underlying ecological relationships and economic value emerging from them. The simulations point towards a critical dependence of economic value (direct and indirect income derived from the park) on ecological health indices. A non-linearity is to be seen in the impact of an increase in ecological health indices on tourist traffic. This responsive or elasticity with respect to ecological health is more at higher values of the indices, indicating thereby that once efforts at conservation increase the attractiveness of the park above a certain level, the impact may be cumulative and returns in terms of income may rise more than proportionately.

1. Introduction

The nature of human well-being derived from eco-system services depends on their availability as determined by the natural environment and demands for these services created by human populations. While the former is determined by physical and ecological factors, a series of behavioural and institutional factors determine the demands that humans make on eco-systems. Bringing the two sets of factors into a common analytical framework is important in order to:

(i) understand better the linkages between ecological systems and economic value obtained from them;
(ii) devise appropriate policies for managing eco-systems.

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However, such an undertaking raises methodological and conceptual problems. One instance of the emergence of such problems is in the context of interpreting values attached to such services. The literature on economic valuation typically focuses on use value in the short run,[1] whether within or outside the market. Ecologists, however, are more concerned with ecological values, which provide an underlying long-run notion of value in a more general sense. This paper investigates the nature of the link between these two aspects of value in the context of a wetland in Northern India, which has also been designated as a Ramsar site and a national park.

Section 2 places the issue in the context of the literature on economic valuation of wetlands and sets up a schematic representation of economic activity and ecological structure of the Keoladeo National Park. Section 3 gives a brief overview of the national park being studied and its ecological characteristics. Sections 4 and 5 set up a dynamic simulation model to study alternative long-run scenarios with respect to ecological health and resulting economic value derived from the park under alternative scenarios. These scenarios are extrapolated on the basis of a model structure linking aspects of the park's ecology through equations derived from past data and observations. In the latter section, we also report results from an alternative approach used to estimate economic value through the setting up of travel cost-based demand functions for tourism-related services. Section 6 derives conclusions obtained from a study of the scenarios and the linkages between economic and ecological value.

2. Valuation of eco-system services from wetlands

Wetlands are 'areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed 6m'. This definition, adopted by the Ramsar Convention conveys much of the essential characteristics of wetlands. It also suggests that they could give rise to a variety of values. However, assigning a value to an eco-system good or service implies that we define its role in increasing human welfare, whether or not it can be marketed. In order to do this we need to:

(i) identify the physical or environmental linkages which result in the provision of the service;
(ii) identify the economic linkages which help realize the value of the service.

The first helps us to understand what economic functions are being performed by the eco-system, in this case the wetland. It could be production of agricultural commodities, provision of waste assimilation services or of amenity values. Each such good or service again may or may not be marketed. This implies that the economic linkages differ.

[1] Concepts such as total economic value have been introduced in the literature (Pearce *et al.*, 1989). However, in economists' value estimates the concept of trade-offs between different notions of value and opportunity cost are primary since they are relevant in economic decision making (see, for instance, Starett, 1998).

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Accordingly, alternative methods of valuation have been suggested.[2] While household production function approaches[3] are based on the revealed preference approach, stated preference approaches have also spawned a large literature in the context of non-marketed goods and services.[4]

Economic benefits derived from wetlands have also been estimated using alternative approaches (see Söderquist, Mitsch and Turner, 2000). As explained by Acharya (2000), the production function approach measures the welfare change accruing to a household as the sum of the producers' and consumers' surplus accruing to the household out of the use of an environmental good or an eco-system service in production or in consumption. Wetlands may also act as pollution assimilation agents for nitrate pollution created by up-stream agriculture. In this context, they provide a positive externality benefit (Bystorm *et al*., 2000). Alternatively, contingent valuation studies may be used to value wetland amenities (Turner *et al*., 2000).

Each of these approaches integrates into utility theory in different ways[5] and is an extension of the cost–benefit methodology. The latter was used in a large number of early studies as an empirical counterpart of Fisher, Krutilla, and Ciccheti's (1972) evaluation of the development versus conservation argument. They argued that if the development option implies some irreversible transformation of an area, it is always optimal to develop less of the area. Hanley and Craig (1991) used the same framework to determine the relative value of preservation and afforestation of a peat-land in the 'flow country' of Northern Scotland. However, while the returns from forestry were expressed on the basis of an infinite series of rotations, preservation benefits were evaluated using the results of a contingent valuation. Questions could be raised about the validity of comparing the two and hence of the conclusion that the net present value of development turns out to be negative.

Other studies of this genre ignore the ecological benefits. Kosz (1996) argues for instance that in the context of a stretch of wetland area along the River Danube, 'it would be highly efficient for the Austrian economy to build a hydro-electric power station, if there were no ecological benefits at all'. The assumption implicit in the statement 'if there were no ecological benefits' would not now be defensible. To sum up, we have come a long way since those studies and ecological processes are being studied to determine linkages with economic value.

Approaches to economic value obtained from wetlands can be divided into static and dynamic ones. Approaches that estimate consumers' or producers' surplus assuming constancy of stocks of natural capital

[2] See Freeman (1993) for a discussion of alternative approaches to valuation.

[3] See Mäler (1992) for a discussion in the context of environmental goods and services.

[4] Hanneman (1992 and 2001) develops this approach referred to in the literature as the contingent valuation method. For applications in India, see Markandaya and Murty (2000), Murty and Menkhaus (1998), and Hadker *et al*. (1997).

[5] See Freeman (1993) on the linkages between alternative approaches to valuation and consumer theory.

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ignore inter-temporal processes that determine ecological functioning. Alternatively, the production function approach can be incorporated into inter-temporal models of renewable resource use. In such integration exercises, the ecological function affects the rate at which a renewable resource increases and thereby impacts off-take from it. As explained by Barbier (2000), such models depict long-run equilibrium of the resource in terms of steady values for effort put into extraction and resource stocks. However, most models set up for valuation treat wetland areas as being a proxy variable for stocks. This variable is then treated as having a similar impact on harvest rates as the amount of effort put in for resource extraction.[6] We shall argue that a distinction needs to be made between short-run factors (such as effort) impacting on the accrual of value or utility from wetlands or other eco-systems and the longer-run slowly changing factors (such as area) that impact on the functioning of eco-systems and the well-being accruing from them. The latter are studied better by modelling ecological aspects of the system and using scenario analysis. In this paper, we illustrate the application of such an approach to amenity values accruing from wetland eco-systems.

The link between conventional approaches and the methodology adopted in this paper is illustrated as follows. The travel cost method has been used extensively to set up demand functions and estimate the consumer surplus accruing as a welfare gain to tourists from amenity values derived from wetlands. In such a methodology, it is assumed that household i has the following utility function

$$U_i = f(x_1, x_2, \ldots, x_n, L_i)$$

where $x_1, \ldots, x_n$ are ordinary goods. L_i is leisure, the demand function of which is given by

$$D(L_i) = V_i = F(TC_i, HC_{ij})$$

where demand for leisure translates into visits to the wetland park, V, and the number of such tourist visits is a function of travel cost incurred and other household characteristics HC_{ij} such as income, education, opportunity cost of time etc. This formulation yields the demand for tourism and can be used to estimate the incremental welfare gain accruing to a typical household and thereby to all households by a visit to the wetland park.[7] However, this is only a short-run relationship and does not account for changes in the probability of viewing multiple species of avi-fauna or of viewing an important flagship or keystone species.[8] The probability of such viewing is critically dependent on the 'ecological health index' of the park. And it is just possible that, while the short-run economic factors remain constant, a long-term erosion of ecological health caused by a combination of factors operating on the eco-system leads to a declining demand for its

[6] See Ellis and Fisher (1987) and Barbier and Strand (1998).

[7] For an exposition of welfare calculation for a wetland in the production function context, see Acharya and Barbier (2000).

[8] We have estimated such a function in the current case for Keoladeo National Park (see Chopra, forthcoming).

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services and consequently a declining economic value. In other words, the underlying tourism demand function in the long run is as follows

$$D(L_i) = V_i = F(TC_i, HC_{ij}, ECH_p) \quad (1)$$

where ECH_p is the ecological health of the park, which can be parameterized only on the basis of medium-run or long-run time series data and modelling of the wetland eco-system. Ignoring such indicators of ecological health in determining demand for its tourism-related services results in an over estimation of the short-run economic value.

Further, upland economic activity, such as intensified agriculture, may impact the ecology of the wetland adversely by reducing water flows into it or polluting water entering it. In turn this impacts the amenity value of the downstream wetland, thereby reducing the direct and indirect income generated. Significant trade-offs between different kinds and levels of economic activity may arise, a number of which work through the impact they have on ecological structure. This paper studies such linkages in the context of the Keoladeo National Park (KNP), a Ramsar site in Northern India by setting up an integrated dynamic ecological economic model. It derives sensitivity of tourist visits to ecological health indices in a series of simulated scenarios with respect to future pressures on the park. In the process, a more complete characterization of factors impacting economic value is arrived at and its linkages with ecological value explored.

The forces impacting on the park can be viewed in a DP-S-I-R framework where a continuous feedback between socio-economic drivers, environmental pressures created, changes in the 'state' of the eco-system and consequential impact on economic activity is envisioned to describe economy–ecology interactions. At times, the impacts may induce responses which feedback into the socio-economic drivers and result in the initiation of a new set of interactions.[9] The framework was originally developed by OECD and is a useful device for establishing a conceptual link between eco-system change and the effects of that change on well-being. We use the framework to set up scenarios for studying the impact of different driving pressures on KNP and, in turn, their impact on aspects of economic activity and well-being.

In the case of the KNP, agricultural activity in the catchment and other competing demands upstream constitute the pressures that regulate the release of water into the park. The state of the wetland is determined by changing stocks of water, biomass, and birds in it. These stocks in turn impact extraction and amenity values, determining the flow of use-value or direct and indirect income accruing from it. Figure 1 gives a schematic presentation of the nature of the economy–ecology linkages and their relationship with economic and ecological value. The ecological functioning and health of the wetland has links with upstream agricultural activity, which, together with rainfall, determines the amount of surface water released into it. This water flow together with other factors such as evapotranspiration and infiltration determine the stock of biomass. Changes in

[9] For a description of the DP-S-I-R framework in the context of wetlands see Turner *et al*. (2000).

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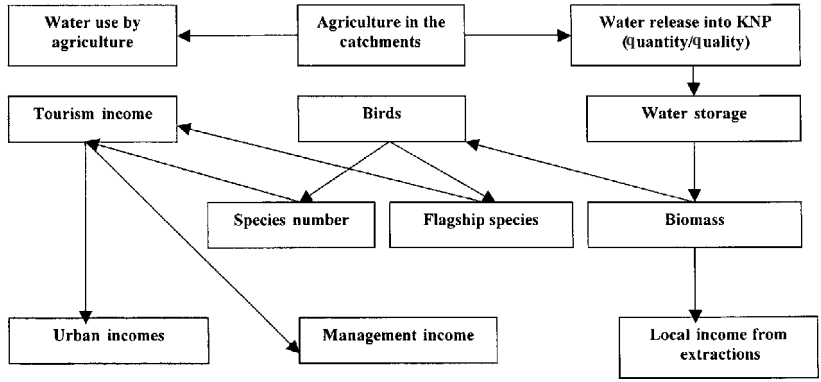


Figure 1

biomass and water storage in the park determine bird inflow prior to the tourist season. Bird inflow is measured by:

(i) the numbers of species of migrant and resident birds and
(ii) arrival of the flagship species.

These inflows are postulated to be one of the major determinants of the magnitude and nature of tourist arrivals and the direct and indirect incomes derived from them. The methodology envisages capturing:

short-term behavioural response of tourists to indicators of changing ecological health by the travel cost function;
the longer-term impact by the scenarios built up in the integrated economic–ecological model.

We postulate that such an approach throws light on the relative significance of ecological and economic value and the links between the two.

3. Keoladeo National Park: history and ecology–economy linkages

The Keoladeo National Park, located about 200 km from Delhi on the Indo-Gangetic Plain near the town of Bharatpur (27°13′N, 77°32′E), is a Ramsar and a designated World Heritage site since 1985. Keoladeo National Park is part of the Yamuna sub-basin floodplains. The vegetation, with many species of terrestrial and aquatic fauna, is characteristic of the north Indian floodplains. The park is a resting place for many migratory birds, including the Siberian crane. Located within easy access from a number of other tourist sites, it has a very high tourism value. The KNP is a 29 sq km mosaic of monsoonal wetlands, seasonally flooded grasslands and thorny woodlands. The wetland area of the park covers a central depression of about 8.5 sq km which is divided by dykes into a number of compartments or blocks. These blocks are interconnected by gates or bunds. In some of the blocks small mounds have been constructed and planted with *Acacia* trees

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to provide nesting and breeding sites for the heron species. Though the maximum potential depth of water in the blocks is about 2 metres the mean depth is usually around 1–1.5 metres. The variety of habitats available, that is wetland, part grassland, and part semi-arid forested grassland, give an idea of the multitude of niches present within the area. The wetland itself is at places grassy meadows, reed beds and open water regions with submerged plants, and at other places, free flowing deeper water teeming with fish. A variety of organisms inhabit these niches, and it is especially favoured as waterfowl habitat.

The destruction and fragmentation of natural floodplains due to use of land for agriculture, housing and industry has made such systems unique. As such Keoladeo National Park is one of the few surviving typical floodplain wetland systems found in the region. Even so, agriculture upstream of the park represents one of the major sources of pressure on this wetland. Surface water releases into the park depend on rainfall in the catchment and on the requirements of upstream agriculture.

The unique character of Keoladeo National Park arises from the fact that the park was created by humans. The construction of a succession of tanks and the intricate system of water movement used the natural topography and hydrology of the area to provide for the requirements of the numerous species naturally found in the floodplains. The area was first flooded in 1901 and for a long time was treated as an important duck shooting area by the Maharaja of Bharatpur. Since that time, water has perhaps been the most important constituent of the park's ecology and economy. Its presence resulted in the inflow and growth of fish as well as biomass. And on these thrived the large varieties of birds, both resident and migratory, that gave the park both its economic and ecological value.

Figure 1 illustrates this link between ecological health and economic value emanating from use by users, both rural and urban. Two examples of economic value are: extraction of grass and other articles of use-value by villagers from nearby villages and recreation value derived by tourists

Since the creation of the park, locals have had access to it for use. They collected fuel wood, and a variety of grasses that had economic value. A significant change in the management of the park came in 1981 when it was declared a National Park and officials of the Forest Department were required, by law, to end all human interference within the boundaries. There followed a period of conflict, at times marked by violence between the villagers and the management of the park. The next important watershed in the park–people interaction was a 1985 Report of the Bombay Natural History Society (BNHS), which concluded that grazing per se was not damaging the ecology of the park. On the contrary, the excess growth of *Paspalum*, an important grass species (which was earlier grazed on and controlled by cattle) restricted the growth of bulbs, tubers, and roots. Avifauna such as the Siberian Cranes that fed on these found that their habitat had become less friendly. The probability of grassland fires also increased. As a result of the BNHS Study, villagers were allowed to purchase permits to enter the park during summer months and remove limited amounts of grasses since 1986. This, in turn also provided income for the management.

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As presented in Figure 1, the following kinds of income accruals are the direct outcome of the maintenance of KNP:

tourist activity and the resulting income for management of the park and the local economy, both direct and indirect through the proliferation of hotels and other tourism related economic activity;
extraction of grass and other wetland products by the local people, both legal and illegal

On the other hand, intensification of agriculture in the catchment may impact the wetland negatively by increased water demand, resulting in reduced surface water inflow and by inflow of nitrate and other kinds of pollution of water.

Additionally, development expenditure is incurred on maintenance of the park. This has increased considerably since it became a national park. It has catered to the creation of open water bodies, desilting, building boundary walls and control of weeds and grasses.[10]

4. Modelling ecology–economy linkages in KNP

4.1. Model structure

This section of the paper develops alternative scenarios with respect to linkages between ecological functions and incomes derived from KNP. Linkages between different components of the model are studied through a generic computer simulation model using 'STELLA'.[11] The DP-S-I- R framework set up in section 2 and figure 1 to illustrate these relationships is represented by the following modules in the 'STELLA' model:

- the water module, which has 'water storage' as the stock variable, which monitors the state of the wetland;
- the biomass module, which examines factors impacting biomass and changes in it – biomass quantity in the park is the stock variable in this module;
- the birds module, which has the number of birds as the main stock variable and which then monitors factors impacting bird inflow and outflow and their impact on tourism arrivals;
- the net income module, which sums up the impact of changes in each of the preceding modules on income from tourism and resource extraction.

The modules are linked by control variables, determined by physical, ecological, and behavioural relationships to define changes that take place in the stocks and flows. The model is run with the month as the unit of time since both ecological and economic activity is characterized by seasonality. Water releases take place after the monsoon; growth of biomass and of bird populations, both resident and migratory follows; and tourism

[10] Details with respect to income and expenditure for the park are given in appendix 1.

[11] See Hannon and Ruth (1997) and Costanza and Ruth (2001) for details of the modelling framework.

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activity picks up during the winter. In fact, the arrival of the Siberian crane, much announced in the media, heralds the beginning of the tourist season. A business as usual scenario is developed as the first alternative. Later, two alternative scenarios capturing the impact of changes in surface water availability and ecological health indices on other variables are specified. An elasticity measure is derived to capture the impact of ecological health of the park on tourist visitations.

Variables and model equations

Table 1 lists variables and parameters used in the modelling. In the present study, ecological information has been drawn from the BNHS study for the period 1984–1988 (Vijayan, 1991) and the economic data from two recent studies carried out in KNP during 1992–1993 (Murty and Menkhaus, 1998), and 1997–1998 (Chopra *et al.*, 1997). Table 1 shows the list of variables used in the analysis and their descriptions.

Statistical relationships are set up among variables, using monthly data for the period 1981–1988, and sometimes from 1984 to 1988.[12] Since the model uses monthly data, the analysis is based on a reasonably large number of observations.

The model equations

As stated above, the stock variables in the three sub-modules, that is water storage, biomass, and number of birds are central to the links between ecology and economy in the park. Factors affecting these stock variables are defined either as flow variables or as convertors and are estimated on the basis of econometrically or statistically defined relationships derived from historical data.

A description of the sub-modules and the equations follows.

Water module: In the water sub-model, four flows (surface inflow, rainfall, evapotranspiration, and infiltration) are identified as affecting the stock of WATER STORAGE in the park. Surface inflow from the catchment outside the park is monitored by human intervention (depicted as control inflow) to determine the release of water from Ajanbund reservoir (WATER-AJ), which has been treated as a time-dependent graphical function, which drives the model. While surface inflow has been subjected to a control variable, RAINFALL is an independent driving variable introduced as a time-dependent graphical function. Evapo-transpiration and infiltration are determined on the basis of parameters obtained as indicated in appendix I.

$$\text{WATER STORAGE}(t) = \text{WATER STORAGE}(t - dt) + (\text{rainfall} + \text{WATER-AJ} - \text{Evapotranspiration-Infiltration})\, dt \quad (2)$$

[12] Data sources and methodology used for estimation (for selected variables) are given in appendix I.

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Table 1. *List of variables used in the modelling*

S. No	*Variable name*	*Unit*	*Variable type, description and data source*
1.	WATER STORAGE	10^6 metre cubed	State variable defining stock Monthly water storage in KNP Initial value from water depth at fixed sampling points in KNP: data for 1984–1990 (Vijayan, 1991)
2.	BIOMASS	GM/M^2	State variable defining stock Biomass of aquatic macrophytes Initial value from monthly data for 1984–1990 (Vijayan, 1991)
3	WATER-AJ	10^6 metre cube	Driver variable: flow variable; released in July–September each year: initial value from analysis of historical series, 1966–1990
4.	AREA	Km^2	Monthly waterspread area in the park: also from the BNHS (Vijayan, 1991) study
5.	RAINFALL	mm.	Rainfall in Bharatpur: Initial value from historical data series, 1901–1990
6.	RAINVOL	mm (km^2)	Volume of rainwater (*waterspread area*rainfall*)
7.	EVAPO	cm.	Monthly average evapo-transpiration from Rhower's method
8.	EVAPOVOL	10^6 m^3	Loss of water from the aquatic area through evapo-transpiration (*waterspread area*evapo-transpiration*)
9.	BIRDS	Nos.	State variable: monthly abundance of waterfowls in the park Source of data: Vijayan study and KNP Authorities
10.	CRANE	Nos.	No. of Siberian crane visiting the park (annual)
11.	DEVEXP	Rs. million	Development expenditures in the park (annual): KNP Park Authorities Data
12.	DE	Rs million	Development expenditure per square metre area of the park
13.	GRASS	000 tonnes	Wet grass weight (from the KNP park area of 29 sq. km)
14.	GRASSWT	Kg	Wet grass weight per square metre area
15.	TOURIST	Nos	No. of tourists visiting the park (annual)
16.	INCOME	Rs. million	Income from tourists' fees, tourism dependent income and extraction income

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Biomass module: In this module, two flow variables (CHANGE IN BIOMASS, EXTRACTION) determine the stock of BIOMASS (aquatic biomass). Further, the data available yield a non-linear (quadratic) relationship between the CHANGE IN BIOMASS and WATER STORAGE in the following form

$$\begin{aligned}&\text{CHANGE_IN_BIOMASS} = \\ &\underset{(2.32)}{186.85} + \underset{(3.08)}{131.04} * \text{WATER STORAGE} - \underset{(2.56)}{11.40} * (\text{WATER STORAGE})^2 \end{aligned} \quad (3)$$

(Figures in brackets are *t*-values. All are significant at 5 per cent level of significance)

This equation, arrived at by regressing known time series of the two sets of variables provides the link between the two modules, biomass and water.

EXTRACTION is the wet grass weight (per sq. metre area of the park), collected by the villagers during the period of the year (normally from November to March) when extraction is allowed. This is one of the management practices adopted by the park authority since 1986. It is found that on an average annually about 6 per cent of the total aquatic biomass is utilized by the villagers as fodder. Since the extraction rate for fodder and grasses are determined by policy with respect to permits, it is introduced as a converter variable, with a constant value, proportionate to biomass stock.

Birds module: Birds/waterfowl and Siberian Cranes are major attractions for the tourists visiting the park. To capture the seasonal fluctuation in the stock of birds, two variables, BIRD INFLOW and BIRD OUTFLOW, have been introduced in to the model. As explained earlier, inflow takes place in the months after the monsoon and refers to both migration and increased population of resident birds. The following statistical relationship between BIRD INFLOW, WATER STORAGE, and CHANGE IN BIOMASS is found to exist

$$\begin{aligned}&\text{BIRD INFLOW} = \\ &\underset{(0.75)}{930.23} + \underset{(4.09)}{844.13} * [\text{WATER STORAGE}] - \underset{(1.65)}{2.14} * [\text{CHANGE IN BIOMASS}] \end{aligned} \quad (4)$$

(Figures in brackets are *t*-values. All are significant at 5 per cent or 1 per cent level of significance)

Water storage is clearly the most important factor determining bird inflow. However, the stock of birds in any month depends on both inflow and outflow. Some birds migrate back to cooler regions at the outset of the summer. Natural decline rate of the resident birds in the six months prior to the onset of the monsoon is estimated on the basis of historical data and is found to depend on water storage in that period. If water availability falls below a critical level the rate of decline increases to twice its normal rate.

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This is modelled as a step function at the critical level of water storage.

BIRD OUTFLOW = BIRDS × Decline rate

$$\text{Decline rate} = \text{IF (WATER STORAGE} > 0.90\text{) THEN } 0.10 \text{ ELSE } 0.20 \quad (5)$$

Finally

$$\text{BIRD}(t) = \text{BIRDS}(t - dt) + (\text{BIRD INFLOW} - \text{BIRD OUTFLOW}) \quad (6)$$

ECOLOGICAL HEALTH INDICES AND TOURISTS, TOTAL INCOMES

Two alternative indices of ecological health are introduced in the model. The first is based on the tourists' perception that presence of the flagship species, Siberian canes, in winter months is the index of the ecological health of KNP.

The ECOLOGICAL HEALTH INDEX in the model is defined as

$$\text{ECOLOGICAL_HEALTH_INDEX} = \text{EHI} = (\text{SIBERIAN CRANES}/K) \times 100 \quad (7)$$

where K is the maximum number of cranes that visited the park during preceding years.

An alternative definition of ecological health in terms of species diversity in the park is also introduced. A species diversity index, referred to as 'Shannon–Weiner Diversity index (SWI) is set up on the basis of data available on species found in KNP This is defined as

$$\text{SWI} = -\sum S p_i \log p_i \quad (8)$$

Where $p_i = n_i / N$; summation is over all species, s in the sample; p_i = relative abundance of the Ith species N = total number of individuals.

It is then postulated that tourist arrivals are a function of the stock of birds obtained from equation (6), and the two ecological health indices, EHI and SWI obtained from (7) and (8).

The dependence of the number of TOURISTS on BIRDS and the two indices, EHI and SWI is determined by the following relationships, (9) and (10)

TOURISTS =

$$\underset{(3.50)}{1754.17} + \underset{(3.85)}{0.314} \times \text{BIRDS} + \underset{(9.90)}{108.55} \times \text{ECOLOGICAL_HEALTH_INDEX} \quad (9)$$

(Figures in brackets are t-values. All are significant at 5 per cent or 1 per cent level of significance)

$$\text{TOURISTS} = \underset{(-1.414)}{-2349.37} + \underset{(4.11)}{0.48}\ \text{BIRDS} + \underset{(4.59)}{6735.58} \times \text{SWI} \quad (10)$$

(Figures in brackets are t-values. All are significant at 5 per cent or 1 per cent level of significance)

Income module: Two types of income are derived from the park: income from the tourists, both direct and indirect, and income from extraction to

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the villagers. Direct tourism income is obtained from the gate fees collected by the park authority; whereas indirect incomes are those earned by the transporters, hotels, and restaurants in the area due to the arrival of tourists. It is estimated that on an average indirect income from tourists is about 12–37 times that of the direct income from the tourists (calculated using data in Murty and Menkaus, 1998).

Also considering the price of the fodder collected from the park by the villagers, income from the extraction of biomass is calculated. To estimate net income, average expenditure incurred for the development of the park (DEV EXP) is subtracted from gross income

$$\begin{aligned}\text{NET INCOME} = {} & \text{DIRECT TOURISM INCOME} \\ & + \text{INDIRECT TOURISM INCOME} \\ & + \text{EXTRACTION INCOME} \\ & - \text{DEVELOPMENTAL EXPENDITURE} \end{aligned} \tag{11}$$

5. Scenario analysis and results

The model set up uses equations (2) to (11) to define alternative scenarios with respect to the future. Simulation runs of the model in a dynamic framework yield values of the important variables over the time period of the model (monthly runs from 1983 to 2010). The variables and relationships set up capture the ecology–economy linkages and extrapolate them over the future. This is done in the tradition of dynamic system modelling to capture some aspects of human–eco-systems interactions.[13] Regional development models have also been set up using such simulation modelling.[14] Such modelling is of use when the impact of exogenous system or policy changes on a natural system need to be captured and compared with 'business as usual' scenarios. It is particularly useful when the exogenous change is outside the optimizing context of individual stakeholders in a multi-stakeholder context. Multiple stakeholders may imply that optimization with respect to one set of variables is not what the policy maker (or the analyst) is looking for. When the problem at hand is posed such that the impact of exogenous change on slowly changing long-run ecological patterns needs to be determined, a long-run simulation model provides the appropriate methodology. In addition, it augments a short period view of economic value that is the focus of static optimization maximizing consumer's surplus or producer's surplus based studies. Further, such simulation models do not make unrealistic demands on data and assumptions as may happen in the case of long-run optimizing models. This paper suggests that they comprise invaluable tools for policy decisions in the face of limited information. It is in this spirit that runs of the

[13] See Costanza and Ruth (2001) and Low, Ostrom, Costanza, and Wilson (2001).

[14] See, for instance, chapter 9 in van den Bergh (1996) which describes such a model set up for the Peel region in the Netherlands. Also see Chopra and Kadekodi (1999) for a model for a region in India.

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model presented above are interpreted to examine how changes in driving variables or ecological characteristics of the park as exemplified by surface water inflow (WATER-AJ) and the two bio-diversity indices (EHI and SWI) impact incomes from tourism in the long run.

5.1. Baseline BAU scenario

Figures 2a and 2b show the baseline scenario of the model obtained after a series of iterations. As can be seen from figure 2a, there are seasonal fluctuations in the ecological state variables water storage and biomass. Perusal of figure 2b shows additionally that the bird population and the net income derived exhibit a trend superimposed on the seasonal fluctuations. It is found that both variables show a downward trend during the first six years (81 months), followed by fluctuation till 243 months and a little upward swing from that point up to 324 months. This presents the picture as extrapolated from the past, that is 'business as usual'. Further, it is found that these variables follow the same pattern irrespective of which of the two ecological health indices (EHI and SWI) are selected to represent biodiversity.

5.2. Scenario I: Inflow of surface water is reduced by 5 per cent annually

Under an alternative scenario, we assume that the inflow of surface water decreases at the rate of 5 per cent annually resulting in a similar decrease in WATER-AJ. This is treated as an exogenous change consequent on the additional demand from agriculture in the catchment. In other words, this simulation captures the effects of increased use of water outside the park. It is observed that the stock of BIOMASS in the park decreases considerably having a linear pattern in its fluctuations over the years. This in turn affects the bird and tourists population as well as the net income. Figure 3 shows the time pattern in the population of birds and in net income consequent on this change.

Further, two versions of the model are developed with EHI and SWI respectively used to determine number of tourists and net income as given in equations (6) and (7). Sharp fluctuations are observed in the tourist and income variables when the SWI index is used to capture biodiversity. This implies that bird species diversity index influences the tourist out-turns more than the index derived from presence or otherwise of the flagship species, the Siberian cranes (EHI). Net income falls by around Rs. 3 million, a fall of 80 per cent compared with the BAU scenario. The upturn in these variables that is observed in the BAU scenario in the period from year 20 (month 243) onwards is no longer found to take place.

5.3. Scenario II: Surface inflow (SI) and ecological health index (EHI) are both reduced by 5 per cent annually

Figure 4 gives the simulated values for the number of birds and the income from the park in a situation where both the surface water inflow and the ecological health index decrease by 5 per cent annually. The cumulative impact of the decrease in biomass and species diversity on incomes can be seen clearly. Whereas in scenario I, the number of tourists fluctuate between 6,000 and 10,000 per month after month 243, they fall to less than

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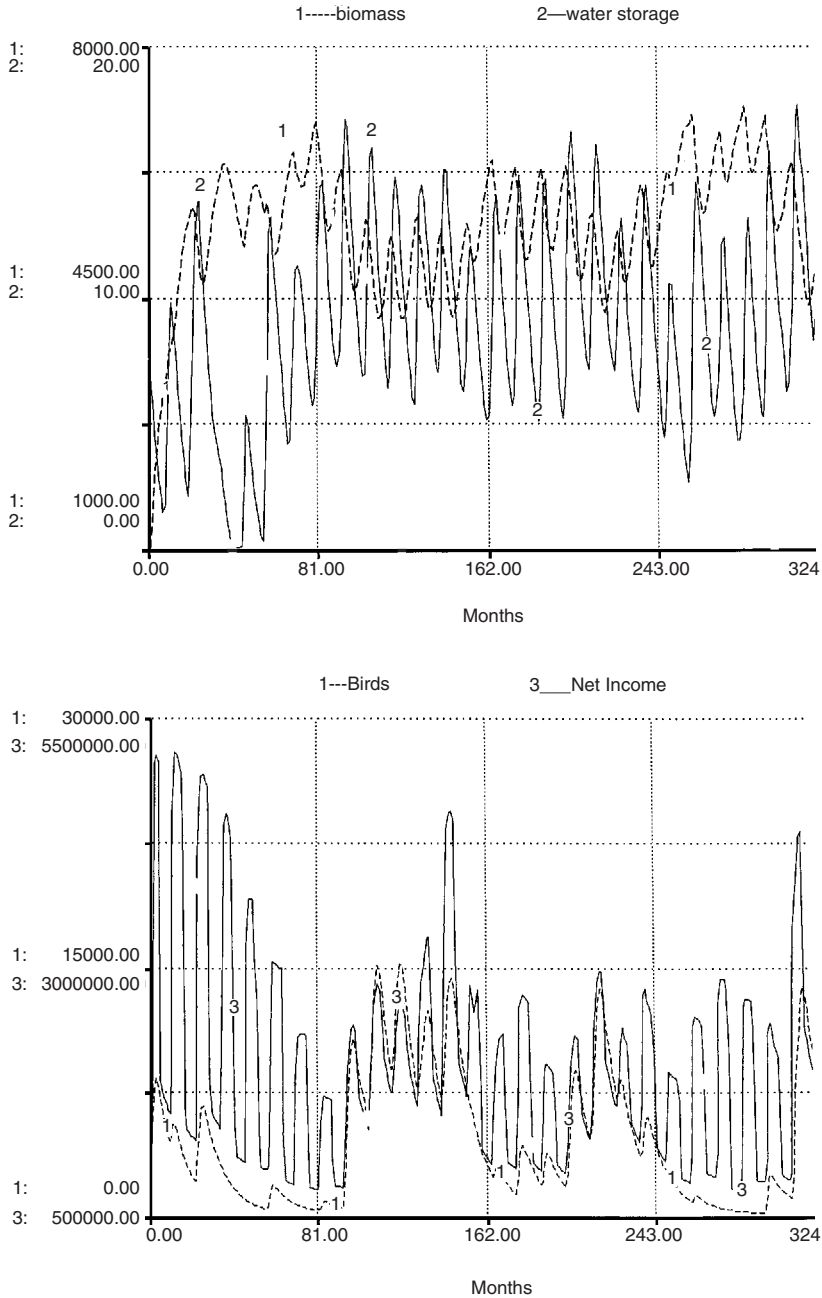


Figure 2. *(a, b) Simulation under base line scenario*

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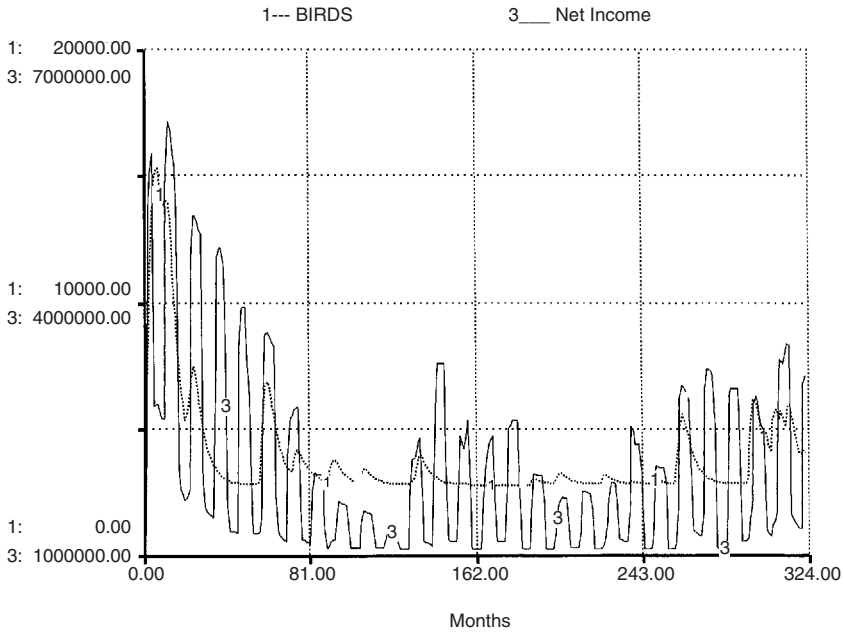


Figure 3. *Simulation under scenario I (Surface Inflow reduced by 5% annually)*

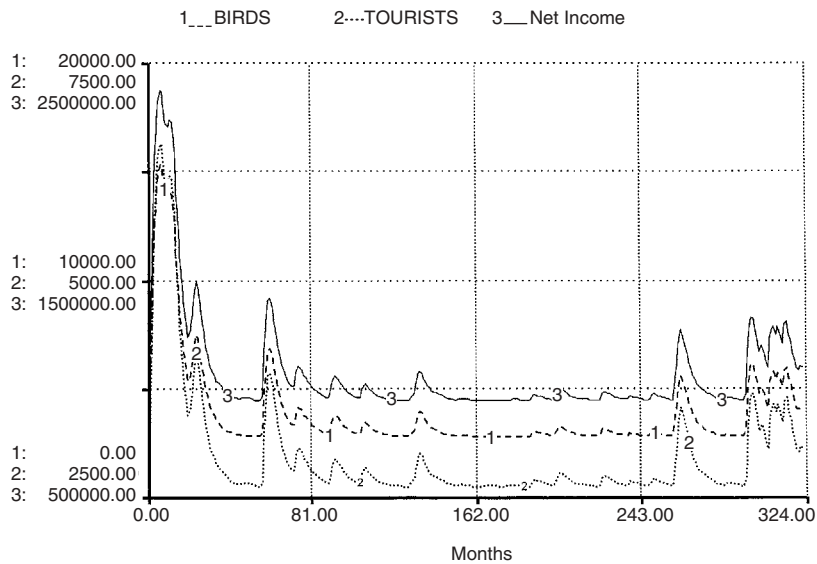


Figure 4. *Simulation under scenario II (Both Surface Inflow and Ecological Health Index reduced by 5% annually)*

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5,000 per month in the same period under this scenario. Total income (which, to recapitulate, includes that from extraction to village residents and from the tourism industry to the forest department and the residents of Bharatpur) correspondingly falls from 35–40 million to less than 15 million. It is clear that economic value is a function of ecological health and water inflow.

An examination of the elasticity of tourist numbers with respect to ecological health index from the results of the simulation model yields interesting results. The elasticities exhibit wide ranges of variation from month to month as expected. For the six months in the winter when tourist traffic is high, the number of tourists is critically dependent on the ecological health index measured by the arrival or otherwise of Siberian cranes. Elasticities vary from 0.6, 0.7 to 1.5 or even 1.7 in the BAU and scenario 1. However, the values of the elasticities decrease to a range varying from 0.04 to 0.124 in scenario II. In other words, as biotic pressure increases and the wetland becomes less attractive as an ecosystem, one can expect a fall in elasticity. A non-linearity is to be seen in the degree of impact on tourist traffic. This can be interpreted to mean that a less attractive bird habitat reduces both number of tourists and the responsiveness of their numbers to further changes in the habitat attractiveness. Perhaps the arrivals get limited to the hard core of enthusiasts.[15]

5.4. Economic value of tourism: an alternative approach

In an alternative approach,[16] the economic value accruing to tourists has been captured though the use of travel cost method. A demand function for tourism is set up in which the probability of visiting KNP depends on amount spent on travel, either by way of total cost or by way of local cost, opportunity cost of time spent (which in turn reflects household income), educational levels, and reason for visiting the park. This demand function represents revealed preferences of an important segment of stakeholders in KNP, the tourists. Further, it illustrates the extent to which value of biodiversity conservation in a geographical area is reflected in the market for tourism.

As documented in the literature, the travel cost method hypothesizes that the costs incurred by the tourist to reach the site and the expenditure he/she incurs while there are measures of the price he/she is willing to pay for visiting the site. Since the travel costs vary across individuals living at different distances from the site, these data can be used to derive a demand curve for the services provided by the site. The dependent variable in the demand function is the visitation rate, $V(i, j)$, defined as tourist number in group i/number of tourists visiting from zone j to which the group belongs. This is regressed on price as approximated by total and local cost variants in the two specifications[17] which we set up for KNP. Other independent

[15] In the context of KNP, it could be the ones who visit to study species changes.

[16] See Chopra (forthcoming). We reproduce the methodology and results in brief in this section.

[17] Total travel cost is defined to include travel from place of residence, cost of travel within park, cost of boarding and lodging during stay, and any other miscellaneous

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variables depicting the socio-economic characteristics of the respondent tourists are also introduced. Thus

$$V(i, j) = F(\text{TTCP/TLCP, EVM, OPPTIME, HIPF}),$$

where $V(i, j)$ = tourist number in group i/number of tourists from zone to which group i belongs

TTCP/TCLP = total travel cost or local travel cost in two different specifications of the model
EVM = reason for visiting park (education, recreation, religious, etc.)
OPPTIME = opportunity cost of time spent
HIPF = household income

Using survey-data collected regarding tourists' travel and stay expenses,[18] duration of stay, and various socio-economic characteristics, a semi-log demand function (both in its total and local cost specifications) indicates that travel cost is a valid proxy variable for price in determining demand for tourism services.[19] Visitation is impacted significantly by travel cost in the semi-log demand function. The opportunity cost of time also affects the visitation rate, as does household income.

In view of the joint product nature of the services provided by the park, it is considered more appropriate to estimate consumer's surplus from local cost estimates. This amounts to about Rs. 202 per visit if average local travel cost is taken as the reference point. This figure reflects the surplus value (utility gain) that the tourists place on visits to the park.

The demand functions were also used to estimate price elasticities of demand at the mean value of the variables. The demand for the services of KNP turns out to be inelastic. The elasticity ranges from 0.05 to 0.24 or tourists coming from the five geographical zones from which the tourists come.

The travel cost model estimates economic value as reflected in the tourism service pricing. The inelastic nature of the demand signifies that visitation rates are not very responsive to cost incurred to avail of these services. This is of interest in view of the larger elasticity figures with respect to ecological health reported in section 5.3.

6. Conclusions: ecological and economic value

The simulation model presented in section 5 studies ecology–economy interactions in the Keoladeo National Park and provides projections for key variables for a period of 23 years on a monthly basis. Alternative scenarios

expenditure. Local travel cost excludes the first component on the assumption of the joint product nature of the visit to the park located as it is in a tourism region. For details see Chopra (forthcoming).

[18] The final set of usable responses consisted of 111 respondents, of which 68 were Indians and 43 were foreigners. Each respondent gave information on the number of members in his group/family. Hence, the total number of tourists covered in this manner were 305 consisting of 235 Indians and 70 foreign nationals.

[19] A non-linear specification using local travel cost as the proxy for price and using a semi-log function was found to be the best fit in this case.

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illustrate the impact of exogenous changes, such as reductions in water inflow on account of development of upstream agriculture and reductions in indices of ecological health on economic value derived from the park. The simulations point towards a critical dependence of economic value (direct and indirect income derived from the park) on ecological health indices. Elasticities obtained vary from 0.6, 0.7 to 1.5 or even 1.7 in two scenarios. However, as biotic pressure increases and the wetland becomes less attractive as an ecosystem, the values of the elasticities decrease to a range varying from 0.04 to 0.124. A non-linearity is to be seen in the degree of impact of an increase in ecological health indices on tourist traffic.

Benefits to be had from improved maintenance for ecological conservation are more per unit of effort at higher levels of conservation. Simultaneously, results from a conventional travel cost model reveal low elasticities with respect to costs incurred by visitors. Together, these results indicate:

- with the present profile of visitors to KNP, visitation rates are not responsive to private costs incurred
- however, direct and indirect income obtained from the park is more responsive to ecological health indices, measured as given above
- this response or elasticity with respect to ecological health is more at higher values of the indices, indicating thereby that once efforts at conservation increase attractiveness of the park above a certain level, the impact is cumulative and returns in terms of income rise more than proportionately.

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Appendix I: Data sources and methodology

1. Surface inflow

The main source of water for the park is a temporary reservoir, Ajanbund, situated about one kilometre south-west of its boundary. Water from

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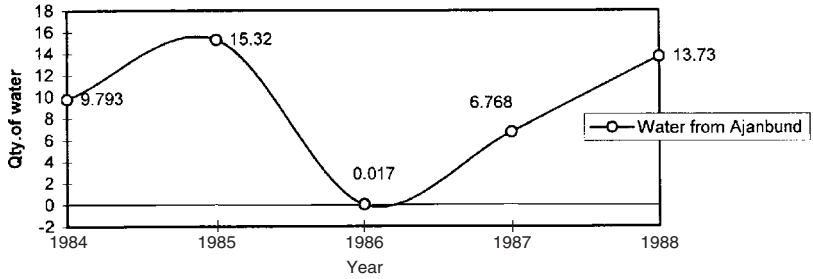


Figure A1. *Water released from Ajanbund into the KNP*

Ajanbund is taken to the park through a narrow canal. Ajanbund receives its water through two canals from two rivers, viz. Gambir and Banaganga. In the recent past, Bangaganga has not contributed much water to Ajanbund. The water input into the park takes place during the period from July to September. In the years from 1966 to 1990 the water input showed wide fluctuations, the lowest being 0.017×10^6 m^3 and the highest 15×10^6 m^3. Figure A1 shows the annual water inflow from the reservoir during 1984–1988.

2. Water storage and waterspread area

Monthly water storage and waterspread area in the park were estimated from the water depth recorded at fixed sampling points from 1984 to 1989 (BNHS study by Vijayan, 1991). Since water is released into the park between July and September, the highest average water depth in a year is during September or October and it decreases considerably during summer because of high evapo-transpiration. The highest water storage inside the park was in September 1984 and the lowest in June 1987 (table A2) as a severe drought situation prevailed in the area during summer of 1987. The water storage of any year is determined by the water input of that year and the quantity carried over from the previous year, which turn in determined by the hydro-meteorological features. The waterspread area of the park

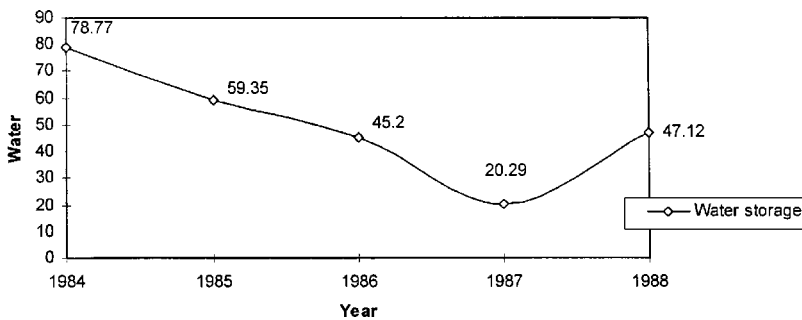


Figure A2. *Water storage in KNP (10^6 m^3)*

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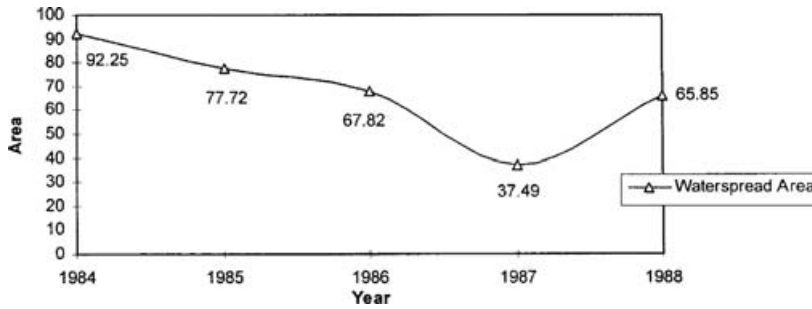


Figure A3. *Waterspread area in KNP(km^2)*

follows the same pattern as that of water storage. The highest waterspread area was about in September 1984 and the lowest in June 1987.

3. Inflow from rain

The Park is located in Bharatpur district of Rajasthan. Bharatpur receives rain mainly from the south-west monsoon, which sets in June and continues up to September. Of the annual rain fall 70–96 per cent occurs during July, August, and September. The average annual rainfall in Bharatpur from 1901 to 1990 was approximately 655 mm. During the 1980s, the average rain fall was 495.7 mm.

The contribution of run-off from the terrestrial area to the water budget of the park is negligible, and the only major input from precipitation is the rain directly received in the water spread area. Therefore, the contribution of rain to the water budget was computed by multiplying the monthly rainfall with the waterspread area of the corresponding month (BNHS Study, 1991). The highest monthly input from rainfall was in July 1988 (1.94×10^6 m^3) and the lowest in December 1986 and June 1987 (0.01×10^6 m^3).

4. Evapotranspiration

The loss of water from the aquatic area through evapo-transpiration was estimated using Rhower's equation and the water spread area. The water

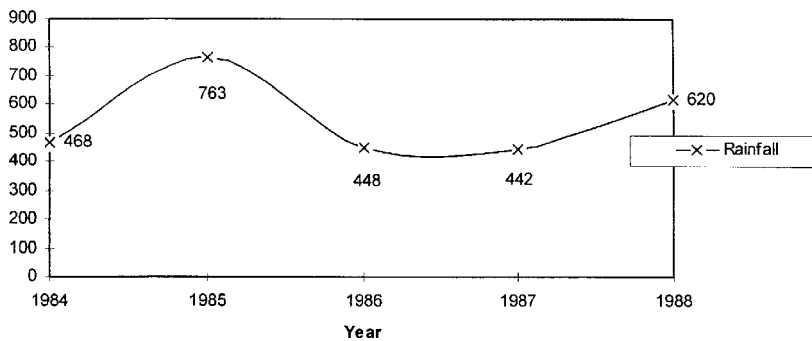


Figure A4. *Rainfall in Bharatpur (mm.)*

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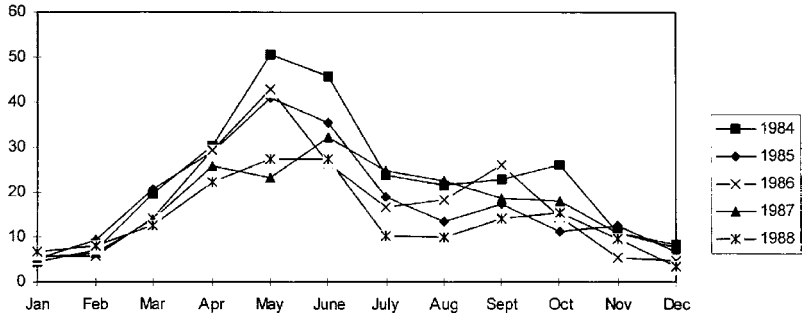


Figure A5. *Monthly average evapo-transpiration (Rhower's method)*

body in the park looses a massive quantity of water through evapo-transpiration. The highest monthly loss was in May 1984 (2.99×10^6 m^3) and the lowest (0.15×10^6 m^3) during January and February 1987.

5. Infiltration

Infiltration measurements were taken using infiltrometers installed at seven sites inside the park (BNHS Study, 1991). The overall average rate of infiltration for the aquatic areas was 0.062 mm/hr (44.64 mm/month). It is estimated (during 1984–1988) that an average loss of 0.3 per cent of the total water budget is due to infiltration.

6. Biomass

Biomass plays an important role in the park's ecology and economy. The biomass of the park is of two kinds: terrestrial and wetland. The terrestrial biomass consists of trees, shrubs, and grasses, while the wetland or aquatic biomass constitutes submerged, floating and emergent species. The macroscopic forms of aquatic vegetation denoted as aquatic macrophytes include macroalgae, some species of ferns and angiosperms inhabiting a wetland.

The wetland vegetation depends predominantly on the availability of water, hence the input of canal water and the annual rains are the determining factors for its growth. The terrestrial vegetation depends on the rains and possibly the ground water. Aquatic biomass may sometimes

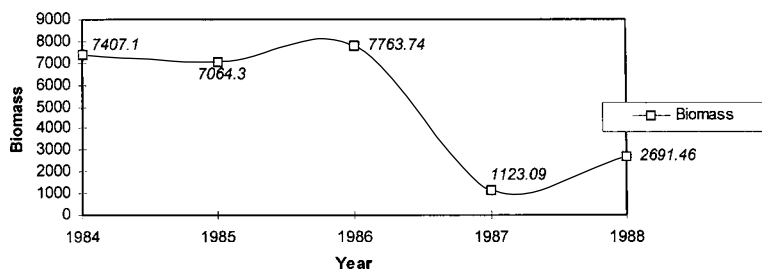


Figure A6. *Biomass of aquatic macrophytes in KNP (gm/m^2)*

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be abundant even in the absence of adequate rainfall, if the previous year's water input was good. A lagged effect exists. This in turn also follows for the bird species. However the birds also depend on the population of fish fry which depends on the current year's canal water flow alone.

An important grass species called *Paspalum distichum* is the major constituent of the total aquatic biomass in the park. The average biomass of Paspalum distichum was 192.64 gm/m^2 during December 1988. There exists high monthly variation in the average biomass of macrophytes (for example it was at a maximum level (1022 gm/m^2) in June 1986 and a minimum (38.3 gm/m^2) in August 1987). Total biomass also varies according to the nature of the species present: the emergent species constituting high amount of biomass in comparison to the submerged and floating plants, which are purely aquatic forms. Further, biomass of the major species, especially Paspalum, did not show any significant correlation with water depth mainly because of the nature of this wetland, with shallow water over most of the area.

It is interesting to note that biomass of the above-ground vegetation during 1984–1985 was higher inside the enclosure from which animals were kept away in most of months, except at the beginning and during spring. This shows that herbivorous waterfowl (mainly geese) and mammals do check the growth of wetland vegetation. The higher spring growth outside the enclosure might be the result of mild grazing, which stimulates growth in grasslands (as widely documented in the literature).

7. Extraction: grass permits

The impact of grazing on the ecology of KNP has been a contentious issue. Since its creation at the end of the nineteenth century, local people from nearby villages were permitted to graze their cattle in the park except during the months of December to March. They also collected fuelwood, and a variety of grasses that had economic value. The area was taken over by the State Government of Rajasthan in 1956. A significant change in the management of the park came in 1981 when the park was declared a national park and officials of the Forest Department were required, by law, to end all human interference within the boundaries. There followed a period of conflict, at times marked by violence between the villagers and the management of the park. The next important watershed in the park–people interaction was a 1985 Report of the Bombay Natural History Society (BNHS), which concluded that grazing per se was not damaging the ecology of the park. On the contrary, the excess growth of Paspalum, an important grass species (which was earlier grazed on and controlled by cattle) restricted the growth of bulbs, tubers, and roots. Species such as the Siberian Cranes that fed on these found that the habitat was now less favourable. It also increased the probability of grassland fires. As a result of the BNHS study, villagers were allowed to purchase permits to enter the park during summer months and since 1986 remove limited amounts of grasses.

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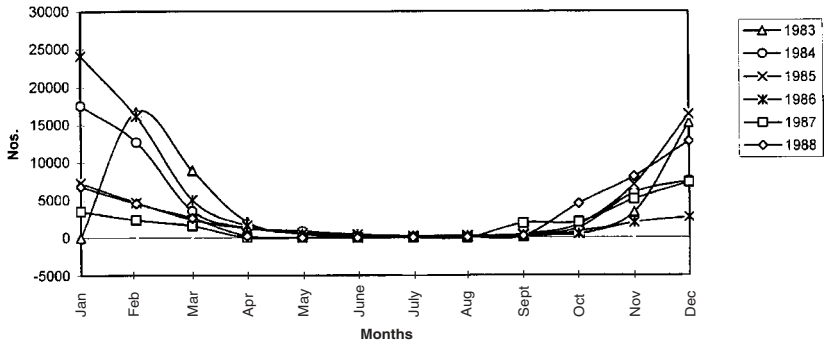


Figure A7. *Fluctuations in the abundance of water fowl*

8. Birds

One of the major conservation values of the Keoladeo National Park is its role as wintering habitat for a multitude of migratory waterfowl belonging to 21 species. Monthly fluctuation in the abundance of waterfowl followed a uniform pattern in all the years under study (BNHS, 1991) with a peak in winter (November, December, or January) (see figure A7) and a lean period in summer. It was found that the abundance of waterfowl had a significant positive correlation with water input from 1981–1982 to 1990–1991 ($r = 0.88$, $P < 0.001$) (BNHS, 1991).

During winter a major attraction for the tourists to the park is the Siberian Cranes. But the population of these visiting the park has declined from around 200 to ten in the last three decades. Of late they started deserting the park during the winter, itself indicating the deteriorating conditions inside the Park. Since 1991–1992 the figures of Siberian Cranes has come down to single digit numbers and none visited during 1993–1994 and 1994–1995. The decreasing trend in population might be due to various factors such as casualties during transit, habitat changes in the park and change of wintering ground (BNHS, 1991).

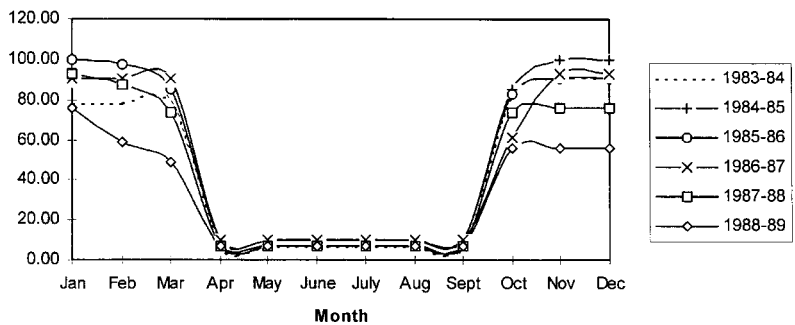


Figure A8. *Number of Siberian Cranes visited KNP (indices)*

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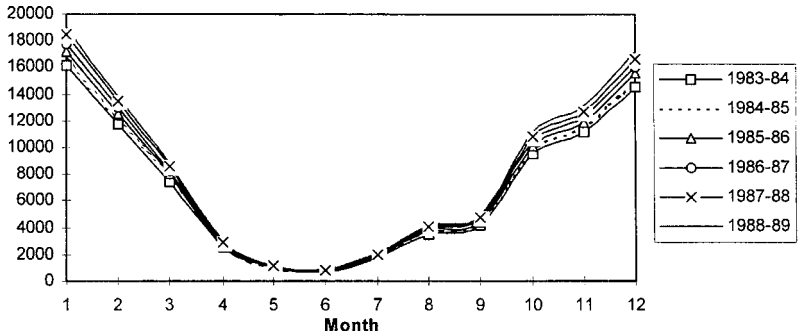


Figure A9. *Number of tourists visited the park (estimated)*

9. Tourists vis-à-vis the park's economy

Tourists are one of the most important stakeholders in the park's economy. The park, being the home of several migratory birds, attracts the largest number of domestic and international visitors during the winter months. In the past few years tourist numbers have increased from 95,000 to 125,000, which means that a large and growing tourism industry has developed in Bharatpur town, with accompanying income-generation benefits to the region. Thus the urban economy of the region benefits from this growth and has a stake in the efficient management of the tourist traffic (Chopra *et al.*, 1998).

The park authorities have collected revenue equivalent to Rs. 2.126 million through visitors charges during the year 1992–1993, while about Rs. 36.00 million was earned by the hotels, restaurants etc. (See table A1). Another source of income to the park is from the license fees charged to the villagers for grass collection from the park and the sale of babool seeds collected from the park (table A2). This income was around Rs. 0.057 million during the year 1992–1993 (Murty and Menkhuas, 1994).

Table A1. *Direct and indirect income from tourists during 1991–1992 and 1992–1993 (in Rs. million)*

	1991–1992		*1992–1993*	
Income from tourists	*Peak season (Sept.–March)*	*Off-season (April–Aug.)*	*Peak season (Sept.–March)*	*Off-season (April–Aug.)*
Direct (by the park authority)	1.546	0.191	1.757	0.369
Indirect (by the transporters, hotels etc)	N.A.	N.A.	22.754	13.688
Ratio (I/D)	–	–	12.95	37.11

Source: Murty and Menkhaus, 1998.

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Table A2. *Revenue collected by the park from gate fee and grass permits and babool seed sales (Rs. millions)*

Year	*Gate fee*	*Grass collection and sale of babool seeds*
1983–84	–	0.023
1984–85	–	–
1985–86	–	–
1986–87	–	0.046
1987–88	–	0.016
1988–89	0.6	0.002
1989–90	0.756	0.013
1990–91	1.335	0.024
1991–92	1.738	0.057
1992–93	2.126	0.057
1993–94	2.028	–
1994–95	1.976	–
1995–96	2.452	

10. Development expenditure

Since the park was declared a national park, there has been considerable expenditure incurred on it by the Government of Rajasthan and the Union Government. The development expenditures in the park have catered to the creation of open water bodies, construction and repairs of the boundary wall, eradication of water weeds, desilting of canals carrying water to water bodies, as well as construction of research labs and the residential quarters for the park staff. During the period 1989 to 1993 the annual development expenditure on the park is higher than Rs. 3 million. It can be noted that during 1990s the expenditure on grass control has been well over 15 per cent of the total expenditure (Table A2).

Table A3. *Expenditure for grass control in KNP (in Rs. millions)*

	Year			
	1990–91	*1991–92*	*1993–94*	*1995–96*
(i) Expenditure	0.258	0.280	0.355	2.140
(ii) Total expenditure	1.748	1.479	1.980	3.707
% of Total expenditure [(i) as % of (ii)]	14.76	18.93	17.93	57.71

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