Environ Dev Sustain (2013) 15:67–80
DOI 10.1007/s10668-012-9374-4

A modeling analysis of the sustainability of ecotourism in Belize

David M. Blersch · Patrick C. Kangas

Received: 5 January 2012 / Accepted: 4 July 2012 / Published online: 25 July 2012

Abstract Over the past two decades, ecotourism has emerged as an important conservation strategy, especially in the Tropics where a diversity of species and habitats are threatened by traditional forms of development. However, questions remain about the sustainability of ecotourism in terms of distributions of income to local people and degradation of ecosystems visited by the ecotourists. In this study, a computer simulation model was used to study the possible long-term patterns of ecotourism at the country scale for Belize, Central America. The model includes state variables for natural ecosystems and tourism infrastructure with a submodel for global oil supply. It was simulated over a 100-year period as an EXCEL spreadsheet with a time step of 1 year. In all of the simulations, a decline over time in income from ecotourists was found due to increases in the price of oil and due to environmental impacts by tourism. Conservation efforts can slow the declines, but ultimately, the system is shown to be unsustainable. The results are discussed in the context of long-term conservation potential in Belize.

Keywords Systems model · Ecotourism · Belize · Conservation · Tropical ecosystems · Modeling

1 Introduction

Ecotourism is a form of development in which income is generated for local people and/or governments from visitors (e.g., tourists) attracted by natural ecosystems. Ceballos-Lascurain (1987) presented an early definition of ecotourism as “traveling to relatively undisturbed or uncontaminated natural areas with the specific objective of studying,

D. M. Blersch (✉)
Department of Civil, Structural and Environmental Engineering, State University of New York at Buffalo, 231 Jarvis Hall, Buffalo, NY 14260, USA
e-mail: dblersch@buffalo.edu

P. C. Kangas
Department of Environmental Science and Technology, University of Maryland, College Park MD 20742, USA

admiring, and enjoying the scenery and its wild plants and animals, as well as any existing cultural manifestations (both past and present) found in these areas". More recently, the conceptual basis of ecotourism has expanded along conservation, sustainability, and even ethical lines of thought (Blamey 2001). The concept has evolved rapidly, in particular as conservation scientists have recognized the potential of ecotourism to help protect sensitive environments and to support local economies, often in underdeveloped areas where other forms of development are not possible to achieve. As an example of this conceptual growth, Honey (1999) suggested the following seven characteristics for ecotourism: (1) involves travel to natural destinations, (2) minimizes impact, (3) builds environmental awareness, (4) provides direct financial benefits for conservation, (5) provides financial benefits and empowerment for local people, (6) respects local culture, and (7) supports human rights and democratic movements.

Ecotourism has grown to be an important economic force that globally involves millions of visitors and billions of dollars annually (Filion et al. 1994). Questions remain about the ability of this form of development to be sustainable, however, because of the various costs of travel, and of the potential limitations in managing the environmental impacts of ecotourists on the human communities and ecosystems that they visit (Beekhuis 1981; Duffy 2002; Gossling 1999, 2000; Young 2003). For this industry to provide a stable basis for the economy, it must be able to generate business and income on a long-term basis. In order to examine these long-term prospects, a computer simulation of ecotourism in Belize was developed and studied.

2 Methods

A model for the industry of ecotourism in Belize is shown in Fig. 1, using the energy circuit language for systems modeling (Odum 1994). For this model development, the major factors involved in the dynamics of ecotourism in Belize were identified, and storages and material flows were diagrammed. The energy circuit–diagramming method shows the major energy flows external to a system as forcing functions, flows internal to a system as material or energetic transfers between components, and state variables as accumulating storages of material or energy. The direction of energetic or material transfer between state variables can be defined by formalizing a system of first-order ordinary differential equations that allows computational simulation.

The model is centered around two-state variables modeled as storages that were determined as most relevant to the Belizean tourism industry: the natural ecosystems of the country, represented by N, and tourism infrastructure, represented by I. Natural sources of energy (sun, wind, rain) are the major inputs to the natural ecosystems, assumed here to represent the terrestrial rainforest. Other energy sources include labor, goods, and services as inputs to tourist infrastructure and tourists as a flow through the system interacting with components through material, energetic, and economic transfers. The energetic inputs to the maintenance and growth of local tourist infrastructure include the investment of local labor (modeled as the flow-limited source L_0 since Belize has a small population, and thus, there is a maximum number of man-hours of labor per year), and investment of goods and services from investors and developers based outside of Belize.

To describe the dynamics that draw tourists to Belize, it is assumed that it is the perception of some combination of extant tourist infrastructure and natural ecosystem that attracts tourists. The flow of tourists through Belize is simulated as a continuous source-limited flow (J_T) into and out of Belize and pulled from an overall pool of possible tourists. In the model

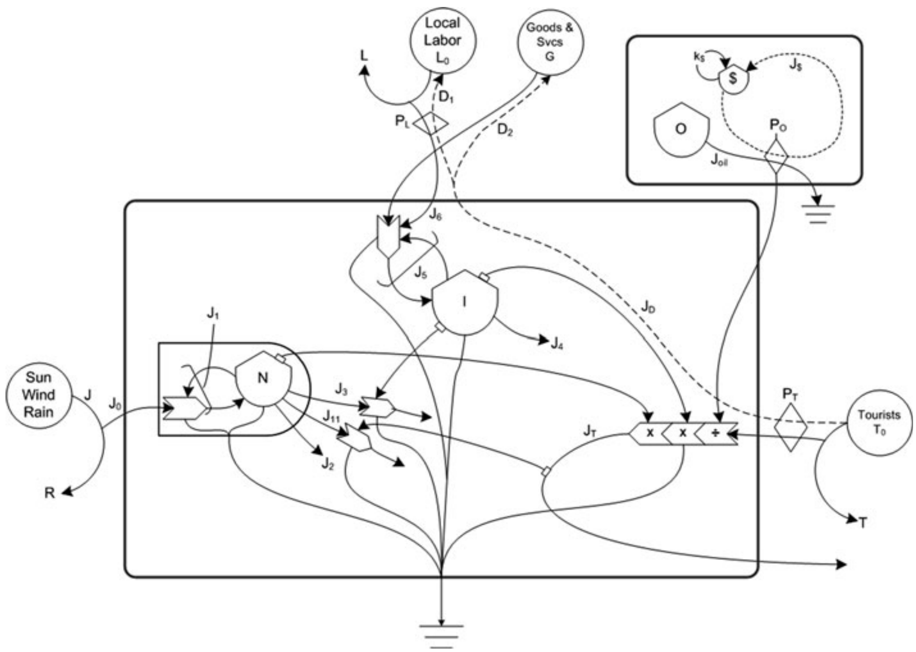


Fig. 1 Energy circuit diagram representing the model of the ecotourism industry in Belize

diagram, the tourist flow enters the system on the right-hand side and interacts with the system through a series of three workgates representing the ecotourism experience before leaving the system. The ecotourism workgates have multiplier inputs from natural ecosystems (*N*) and from tourist infrastructure (*I*) and a divisor input from the price of oil (P_O) in the global economy, shown in the top right of the diagram. In a functional sense, this means that tourists are attracted to the system in direct proportion to (1) the available pool of tourists (*T*), (2) the natural ecosystems that they would see during their visit (*N*), (3) the infrastructure in terms of lodging, etc. that they would use during their visit (*I*) and in inverse proportion to (4) the global price of oil (P_O). Mathematically, the expression for the flow of ecotourists (J_T) is:

$$J_T = k_T(T * N * I)/P_O$$

where k_T is a first-order proportionally constant that corrects for the dimensions of the units. Thus, this expression indicates that the flow of tourists into the Belize economy will increase if *T*, *N*, or *I* increases but it will decrease if P_O increases. This mathematical form of the ecotourist experience recognizes the critical relationship of the global price of oil in regulating the costs involved in the travel of tourists from their home countries to Belize. The mathematics thus capture the idea that as the global supply of oil declines, the price of oil increases, and in turn, the costs of travel increase. A submodel that generates the price of oil is shown in the upper right-hand portion of the diagram with oil (*O*) declining as a first-order loss, representing consumption of the supply by the global economy. Price is determined as the ratio of the consumption of oil (J_{oil}) to the flow of money in the global economy ($J_\$$), itself modeled as a first-order growth representing a 1 % annual increase in global gross domestic product (GDP).

Tourists bring money into the system in proportion to expenditures during their visit. This is shown as the dashed line from the tourist source (J_D). This money is in payment for services from the companies whose infrastructure helps drive the ecotourism experience. Some of this money ultimately goes for local labor (D_1), and the rest ultimately goes back out to the global economy to pay for investments, savings, etc.

Natural ecosystems (N) are obviously an important input to the ecotourism experience, but no money goes back to nature in this model. Optimal ecotourism involves these kinds of feedbacks, as discussed earlier, but most operations do not conduct activities that directly support ecosystems. In fact, ecotourism actually stresses ecosystems through impacts from infrastructure (J_3) and through impacts of the tourists themselves (J_{11}). In real terms, these impacts might include rainforest that is cleared for construction of hotels and resorts, for agricultural food production to support the tourism services, or reduced forest productivity because of damage from tourists themselves (for example, degradation and erosion from roads and trails). By reducing N, these impacts indirectly affect the total flow of ecotourists and the money they bring into the system.

The overall model shown in Fig. 1 is a set of hypotheses about the causal basis of the ecotourism industry in Belize. A system of equations (Fig. 2) was translated from the diagram according to the methodology described in Odum (1994) and Odum and Odum (2000), in which the change in time of each state variable is described by a first-order differential equation describing inflows and outflows. Each flow pathway is described by a first-order transfer coefficient determined through calibration with values for flows and storages developed from the literature. For this calibration, each of the flows on the right side of each of differential equations is equated to a numerical value determined for that flow from the literature. The value of each flow was divided by the known values of the storages to calculate the estimated value of the transfer coefficient for that process (Rivera et al. 2007). Calibration values for forcing functions, state variables, flows, and transfer coefficients calculated from these are provided ("Appendix 1"). The equations and coefficients were programmed into an EXCEL spreadsheet for numerical solutions using finite difference equations and the Euler method for integration of ordinary differential equations. The model was calibrated to conditions as close to the year 2000 as possible. It was then simulated over a time period of 100 years using a time step of 1 year.

Following calibration, a baseline simulation was run using calibrated values to determine dynamics and expected results. Additional simulations to test model sensitivity and to examine hypotheses about different scenarios were made by varying individual parameters and recording changes in output results. Three scenarios were tested for model sensitivity. First, the impact of increased oil prices that might result from lower estimates of remaining

Fig. 2 System of equations derived from the systems model to represent the ecotourism industry in Belize

$$\frac{dN}{dt} = k_1RN - k_2N - k_3IN - k_{11}J_TN$$

$$\frac{dI}{dt} = k_5GLI - k_4I$$

$$\frac{dO}{dt} = J_{oil} = -k_{oil}O$$

$$J_T = k_T\frac{TIN}{P_o}$$

$$R = \frac{J}{k_oN + 1}$$

$$T = \frac{T_0}{J_T + 1}$$

$$L = \frac{L_0}{1 + k_6GI}$$

$$P_{oil} = k_{O\$}\frac{J_\$}{J_{oil}}$$

$$J_D = P_TJ_T$$

$$D_1 = P_LJ_6$$

$$D_2 = J_D - D_1$$

$$\frac{dJ_\$}{dt} = k_\$J_\$$$

in-ground oil reserves was examined by decreasing the initial value for the state variable *O* in the oil supply sub-model. Second, the impact of greater availability of local labor for the support of the tourist industry was examined through increasing the value of the forcing function L_0. Finally, the impact of decreased environmental impacts, which might result from improved natural resource management policies, was examined through decreasing the transfer coefficients for flows J_3 and J_{11} that represent drains on the natural ecosystems precipitated by interactions with the tourist industry. For each of these scenarios, the model was run several times with incremental changes in the relevant parameter values to demonstrate the trend of the response of the system.

3 Results and discussion

The results for the baseline simulation, using initial values calibrated to year 2000, are shown in Fig. 3a–d. These figures show that, as tourism infrastructure (*I*) increases over time, the remaining natural ecosystems decrease over time (Fig. 3a). The flow of tourists into the country shows a steady decline for the entire simulation run (Fig. 3b). The flow of ecotourism money into Belize follows the same trend as the flow of tourists (Fig. 3c), decreasing steadily after an initial increase. Continual payments to local labor cause the exported money (in the form of investors' profits) to eventually become negative as returns from tourism drops. Finally, the price of oil increases over time as production drops due to a continually reduced supply (Fig. 3d). These baseline results are consistent with expectations. Tourism is high so long as both the amount of natural ecosystems (*N*) and tourist infrastructure (*I*) are moderate or high. Infrastructure development and increased tourist flow have an effect on the natural ecosystems, which cannot regenerate fast enough to keep up with environmental impacts. As natural ecosystems decline over time, the flow of tourists decreases, even despite the continually increasing tourist infrastructure development. Because tourist income is directly proportional to the flow of tourists, total money and exported money (profit to foreign investors) follow this same declining trend over time. Money paid to local labor approaches a constant, as it is a function only of the number of rooms and the percent of total work force employed. Overall, this simulation indicates that there is a balance point between tourist development and ecosystem conservation that maximizes tourist flow, and thus tourist dollar flow, into Belize; too much sustained impact on the natural ecosystems will eventually erode the tourist economic base as tourism falls.

The results from the scenario examining the impact of increased oil prices caused by a decreased total oil supply are shown in Fig. 4a–d. These results show that, as the total oil supply decreases, the impact upon natural ecosystems is lessened, although no change is seen in the hotel development *I* (Fig. 4a). The flow of tourists is seen to decrease with decreasing oil supply (Fig. 4b), thus explaining the decreasing impacts of natural ecosystems. Declining tourism also explains declining receipts of money along with decreasing oil supply (Fig. 4c), shortening the time when profits to foreign investors as export dollars fall below zero. Declining production of oil, as a result of lessened reserves in ground storage, creates increasing prices for oil over time (Fig. 4d). These results are also consistent with expectations. As oil prices increase, tourism decreases, thereby decreasing total and exported revenues accordingly. The amount and rate of tourist infrastructure development, and thus the money paid to local laborers, remains constant as with the baseline simulation. In one sense, this is reasonable where hotels and resorts are built by foreign investors who speculate on the future demand for ecotourism. In reality, however, few developments might be undertaken unless perceived demand exists. This

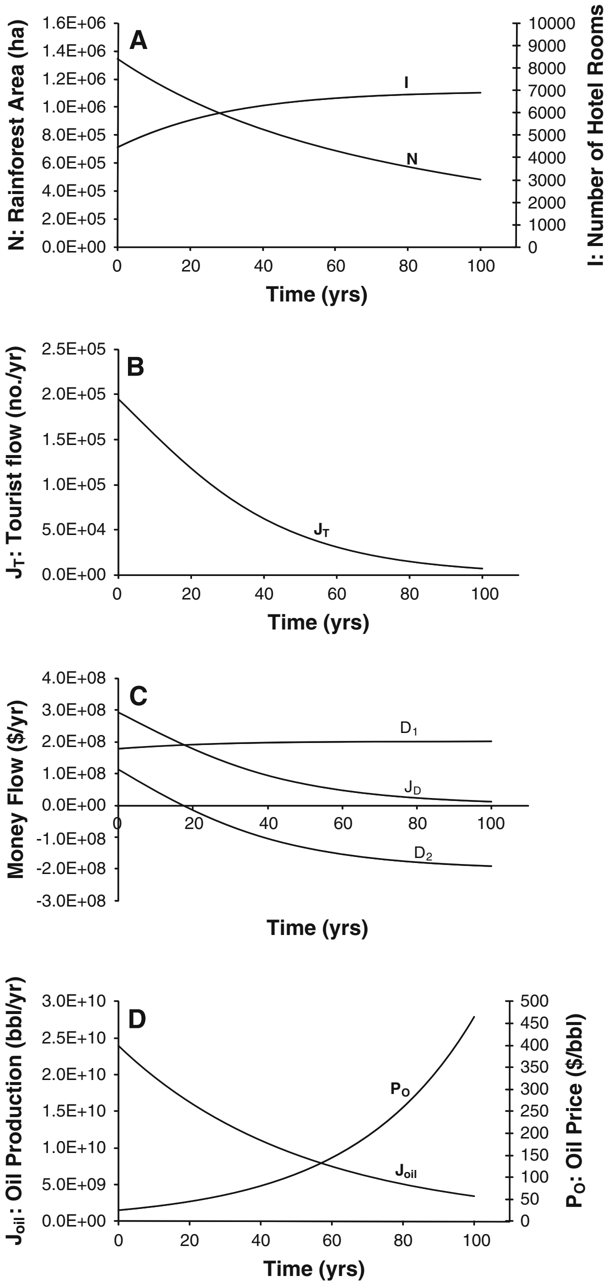
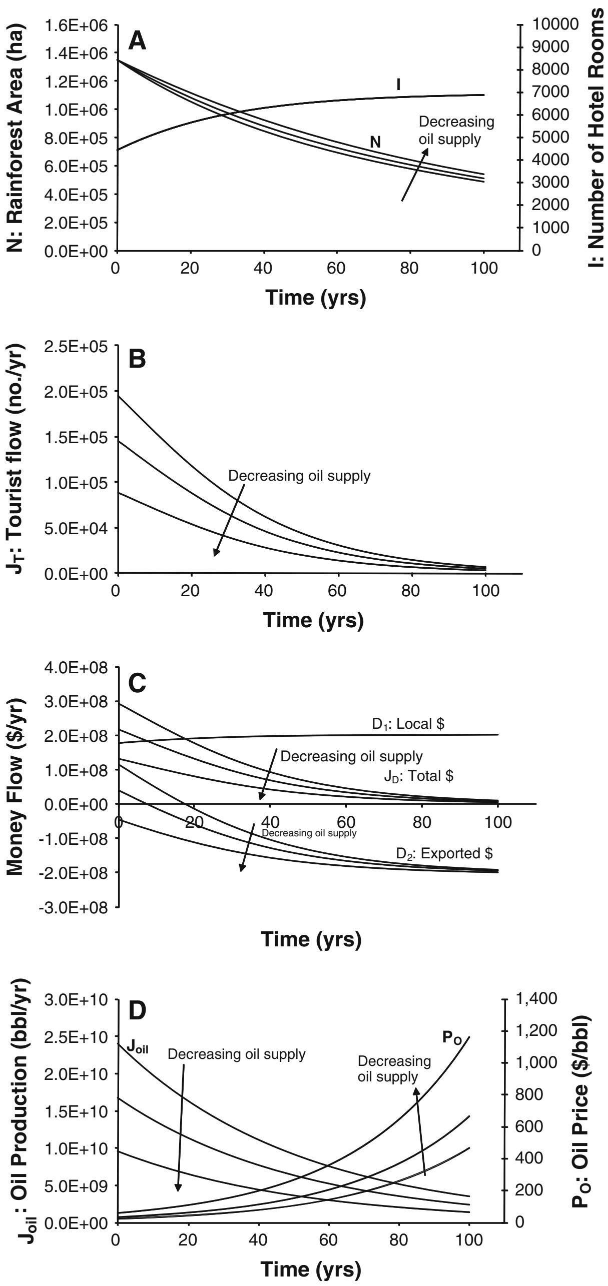


Fig. 3 Baseline results graphs for the simulation model of the Belize ecotourism industry, showing over time **a** natural ecosystems (*N*) and tourism infrastructure (*I*); **b** tourist flow (J_T); **c** local (D_1), exported (D_2), and total (J_D) money derived from tourism; **d** oil production (J_{oil}) and oil price (P_O)

points to one possible improvement to the model: the growth of tourist infrastructure, *I*, should be moderated by a feedback from the perceived tourist flow, J_T, or tourist dollar flow, J_D. This change would produce a growth in infrastructure that is scaled to a demand by the tourists.

The results from the scenario examining the impact of the availability of local labor revealed that the model dynamics are highly sensitive to the total available labor pool in

Fig. 4 The effects of decreasing projected world oil supply on various parameters of the Belize ecotourism economy, showing over time **a** natural ecosystems (N) and tourism infrastructure (I); **b** tourist flow (J_T); **c** local (D_1), exported (D_2), and total (J_D) money derived from tourism; (**d**) oil production (J_{oil}) and oil price (P_O)



Belize (Fig. 5a–d). For example, the rate of hotel infrastructure development (Fig. 5a) and tourist flow (Fig. 5b) increase significantly for moderate increases in the total labor pool. This result suggests that the local labor is a limiting factor to the growth of tourism infrastructure, the effects of which propagate through the model simulation. The total work force in Belize was estimated at 90,000 in 2001 with a 13 % unemployment rate (CIA 2005), but only a portion of this number is readily available for work in ecotourism. If

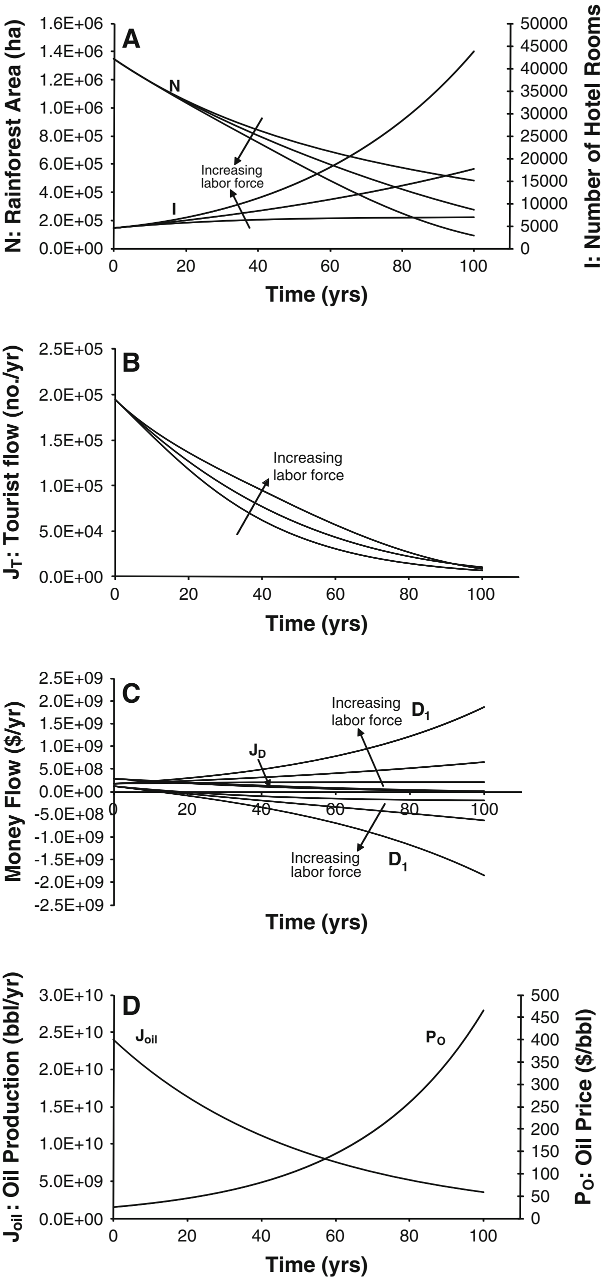


Fig. 5 The effects of an increased local labor force on various parameters of the Belize ecotourism economy, showing over time **a** natural ecosystems (N) and tourism infrastructure (I); **b** tourist flow (J_T); **c** local (D_1), exported (D_2), and total (J_D) money derived from tourism; **d** oil production (J_{oil}) and oil price (P_O)

shortages do occur, the demand for labor might be met by immigrants from nearby countries, and thus, the limiting effect of labor may be an unrealistic result of the model simulation. The additional feedback discussed previously may help to mitigate the sensitivity of the model to the labor parameter.

The results from the scenario examining the impact of decreased environmental impacts caused by ecotourism are shown in Fig. 6a–d. The decrease of environmental impacts results in reduced rates of decline of natural ecosystems over time even though tourist infrastructure increases gradually to a steady state (Fig. 6a) and oil prices rise (Fig. 6d) as in the baseline run of the model. The flow of tourists and their income is maintained over longer time periods with lessened environmental impacts (Fig. 6b, c), because of the improved conditions of the natural ecosystems.

While the model is an initial attempt at representing the role of ecotourism in Belize, a number of refinements in the conceptualization can be suggested for possible improvement

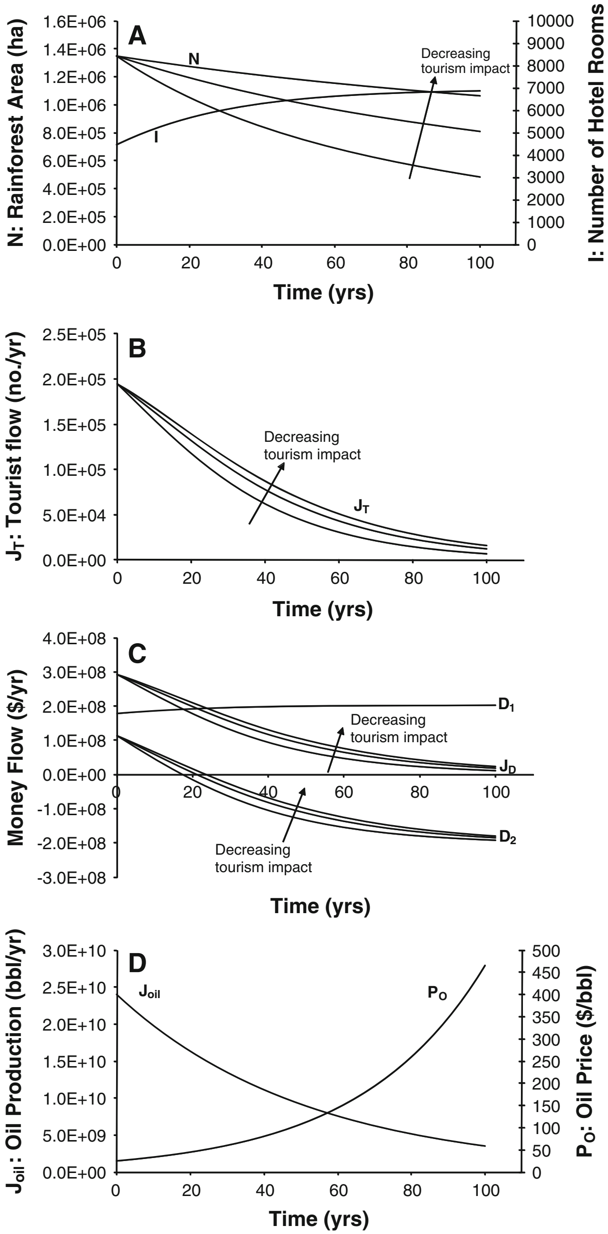


Fig. 6 The effects of decreased environmental impacts due to ecotourism on various parameters of the Belize ecotourism economy, showing over time **a** natural ecosystems (N) and tourism infrastructure (I); **b** tourist flow (J_T); **c** local (D_1), exported (D_2), and total (J_D) money derived from tourism; **d** oil production (J_{oil}) and oil price (P_O)

in the fidelity of the results. First, a possible shortfall of the model is the collection of all productive environmental energies as one state variable with lumped pathways to describe environmental impacts. The environmental resources of Belize that draw significant tourist attraction include both the inland rainforests and the coastal environment and barrier reef. It is arguable that the tourist presence in the country has rates of impact that are different for each of these two distinct ecosystem types, with the barrier reef possibly more sensitive to human presence than the terrestrial rainforest. Further development of the model concept using multiple environmental producer state variables to represent different ecosystems and their sensitivity to human impact would help to refine model predictions for more spatially refined applications in Belize. Another possible improvement to the model is the refinement of descriptive parameters and flows used as calibration values. Some flows used for calibration are based on assumptions as a result of incomplete or unspecified data. For example, to assess the environmental impacts due to tourism, it is assumed that 50 % of the loss of ecosystem productivity results from either the direct impact of tourists or from the clearing of land as a result of development for the tourist industry. This assumption can be tested and refined through improved data collection on the type of losses experienced by the Belizean ecosystems and their contributing causes. It is expected that changes in these parameters describing environmental impacts of the tourist industry might result in dynamic changes to results as demonstrated in the scenario testing on this model.

The benefits of ecotourism in Belize have been demonstrated over the last 20 years (Horwich and Lyon 1998; Lindberg and Enriquez 1994). In fact, our own work has quantified a case study that continues to operate in a small village in central Belize (Kangas et al. 1995). However, the overall conclusions of the modeling experiments described in this paper are that benefits of ecotourism are limited and temporary over the long run. The dominant factor controlling the simulations was the decline in oil production that drives up the cost of travel. None of the simulated experiments (increasing labor supply or decreasing environmental impacts of tourism) were capable of overcoming the effects of decline in oil production, though the economic benefits of ecotourism can be extended by policies that would result in these kinds of structural changes in the system. Even the possibility of increasing efficiency in travel over the next few decades would not appreciably change this dynamic, as the continued increase in the price of oil would affect overall costs of local and regional transportation. The model predicts that the decline in the ecotourism economy of Belize will be apparent within a few decades of the initial conditions, which were calibrated for the year 2000, and will take place gradually. Because of the proximity of Belize to the ecotourism market in the United States, economic inflows to the country will continue but ultimately the industry will be limited. Thus, while important to Belize in the short run, ecotourism is not sustainable in the long run. Although not shown in the simulations, the tourist infrastructure will ultimately decline and natural ecosystems will be able to recover, assuming no other land use emerges. History may then repeat itself, as occurred after the fall of the Maya civilization, and the forest will again cover over the developments built by humans.

Acknowledgments The authors would like to gratefully acknowledge Dr. David Tilley of the Department of Environmental Science and Technology for guidance and review of the concepts and model presented in this research.

Appendix 1: Tables of parameters

See Tables 1, 2, 3 and 4.

Table 1 Forcing functions, calibration values

Symbol	Parameter	Value	Note
J	Rainfall energy	4.60E+10 m^3 $year^{-1}$	1-1
R	Unused rainfall energy	2.32E+10 m^3 $year^{-1}$	1-2
R'	Historical unused rainfall energy	6.40E+09 m^3 $year^{-1}$	1-3
G	Goods and services imported to tourist industry	2.16E+06 US$ $year^{-1}$	1-4
T_0	Total potential supply of tourists	1.00E+06 tourists $year^{-1}$	1-5
L_0	Total potential labor pool	2.40E+08 man-hour $year^{-1}$	1-6
T	Untapped tourism potential	8.05E+05 tourist $year^{-1}$	1-7
L	Untapped labor pool	1.25E+08 man-hour $year^{-1}$	1-8

1-1 Rainfall energy calculated as the average annual rainfall of Belize of 2.00 m $year^{-1}$ (NASA LARC 2005) multiplied by the total land area of 2.30E+10 m^2 (World Bank 1984)

1-2 R determined by the estimated evapotranspiration (ET) rate. Total forested land area (in year 2000) is 1.348E6 ha (World Resources Institute 2003). Estimated ET rate of 1.75 m $year^{-1}$ yields a total ET of 2.359E10 m^3 $year^{-1}$, subtracted from the total rainfall of 4.60E10 m^3 $year^{-1}$ to yield 2.32E10 m^3 $year^{-1}$

1-3 Historical R determined by the estimated evapotranspiration rate. Total historical (pre-settlement) forested land area is reported as 92 % of land area, thus 2.112E ha (World Resources Institute 2003). Estimated ET rate of 1.75 m $year^{-1}$ yields a total ET of 3.96E10 m^3 $year^{-1}$. This is subtracted from the total rainfall of 4.60E10 m^3 $year^{-1}$ to yield 0.64E10 m^3 $year^{-1}$

1-4 Estimate of annual outside foreign investment in tourism infrastructure. US Embassy Belize (2002) reports two major investors in Belize tourism: Caye Chapel Ventures, investing US$10.0E6 from 1996 to 2002, yielding an average of US$1.667E6 $year^{-1}$, and Ramon's Village, investing US$5.0E6 from 1981 to 2002, yielding an average of US$250,000 $year^{-1}$. Total annual investment of US$1.917E6 $year^{-1}$ is rounded up to US$2E6 $year^{-1}$. In addition, two oil companies invested in Belize: Esso, investing US$9.6E6 from 1954 to 2002, yielding an average of US$2.0E5 $year^{-1}$, and Texaco, investing US$4.5E6 from 1964 to 2002, yielding an average of US$1.2E5 $year^{-1}$. Thus total oil investments is US$3.2E5 $year^{-1}$, of which 50 % is assumed to support tourism, yielding a total foreign tourism investment of US$2.16E6 $year^{-1}$

1-5 Arbitrary estimate of total number of possible international tourists

1-6 Total potential labor pool in man-hours. Population of Belize in 1999 approximately 240,000 (CSO Belize 2003). Assumed that half of population (thus 120,000 people) is employable. This is multiplied by the number of man-hours per year (assumed to be 8 h per day, 5 days per week, 50 weeks per year) to yield 2.40E+08 man-hour $year^{-1}$

1-7 Remainder of tourists, equal to total possible (T_0) minus the annual flow to Belize (J_T)

1-8 Remainder of labor available, calculated by subtracting the labor input to tourism (J_6) from the total labor (L_0)

Table 2 State variables, initial conditions

Symbol	Parameter	Value	Note
N	Current area of rainforest	1.35E+06 ha	2-1
N'	Historical area of rainforest	2.11E+06 m^3 $year^{-1}$	2-2
I	Hotel infrastructure	4,450 rooms	2-3
O	Estimated global oil reserves	1.25E+12 bbl	2-4

2-1 Estimated area of rainforest in FY2000, as reported by World Resources Institute (2003)

2-2 Original, prehistoric area of rainforest, reported by World Resources Institute (2003) as 92 % of total land area of Belize

2-3 Estimated total number of hotel rooms in Belize in 2000. Sluder (1995) reported 3,400 guest rooms in some 300 hotels for year 1995. Estimation from current hotel listings (Belize Tourism Board 2005) yields 5,500 guest rooms in some 523 hotels for year 2005. Interpolation yields 4,450 rooms for year 2000

2-4 Estimate of world oil reserves remaining (2007), averaged from figures found (US Energy Information Agency 2008)

Table 3 Flows, calibration values

Symbol	Parameter	Value	Note
J_1	Natural expansion rate of rainforest	2,323 ha $year^{-1}$	3-1
J_2	Natural loss rate of rainforest	2,323 ha $year^{-1}$	3-2
J_3	Loss rate of rainforest due to tourism infrastructure impacts	8,950 ha $year^{-1}$	3-3
J_{11}	Loss rate of rainforest due to tourist impact	8,950 ha $year^{-1}$	3-4
J_6	Local labor input to tourist industry	1.15E+08 man-hour $year^{-1}$	3-5
J_T	Annual number of tourists	1.95E+05 tourists $year^{-1}$	3-6
J_4	Loss of assets from tourist industry	2.10E+05 rooms $year^{-1}$	3-7
J_5	Gain of assets for tourist industry	2.10E+02 rooms $year^{-1}$	3-8
J_{oil}	Global oil production rate	2.40E+10 bbl $year^{-1}$	3-9
$J_\$$	World GDP in year 2000	3.22E+13 US$ $year^{-1}$	3-10

3-1 Natural expansion rate of rainforest, estimated by multiplying rainforest primary productivity by total prehistorical rainforest area (N') and dividing by average biomass density of rainforest, assuming that 1 % of productivity is available for spatial expansion. Tropical rainforest mean net primary productivity estimated as 22 t ha^{-1} $year^{-1}$ by Holdgate (1996). Average biomass density of rainforest estimated at 351 t ha^{-1} for Colombia (Overman et al. 1994) and 149 t ha^{-1} for Brazil (Santos et al. 2002); thus an estimate of 200 t ha^{-1} is used here for Belize. Thus, (0.01)(22)(2.11E6)/(200) = 2,323 ha $year^{-1}$

3-2 Assumed equal to natural expansion rate (J_1) at prehistoric steady state

3-3 Estimate of annual losses of N due to construction of tourist infrastructure. Total forest lost from 1990 to 2000 reported to be 3.58E5 ha (World Resources Institute 2003). Thus, annual average forest lost was 35,800 ha $year^{-1}$. Assumed that 50 % (thus, 17,800 ha $year^{-1}$) of this lost was for all tourism activities, and 50 % of this (thus, 8,950 ha $year^{-1}$) was due to impact from tourism infrastructure

3-4 Estimate of annual losses of N due to impact from tourists themselves. Assumed equivalent to J_3

3-5 Estimate of local labor input to tourist infrastructure and services. Calculated from total work force of 90,000 persons (US Embassy Belize 2002; US Central Intelligence Agency 2005). Assuming an 8-h day and a 5-day work, week yields 1.8E+08 man-hour $year^{-1}$. US Central Intelligence Agency (2005) reports 55 % (thus, 9.9E+07 man-hour $year^{-1}$) occupied in services and 18 % (thus, 3.24E+07 man-hour $year^{-1}$) occupied in industry. Assuming all the service and half of industrial labor supports, the tourism industry yields a resulting 1.15E+08 man-hour $year^{-1}$

3-6 Annual flow of tourists in 2002, as reported by US Department of State (2004)

3-7 Number of hotel rooms in Belize increased from 3400 (Sluder 1995) to 5,500 (Belize Tourism Board 2005) in 10 years, thus averaging an increase of 210 rooms $year^{-1}$. This is assumed to be the number of rooms lost at steady-state conditions

3-8 Number of hotel rooms in Belize increased from 3,400 (Sluder 1995) to 5,500 (Belize Tourism Board 2005) in 10 years, averaging an increase of 210 rooms $year^{-1}$

3-9 Annual average world crude oil production rate calculated from daily average for 1997, reported by US Department of Energy (2002)

3-10 Estimate of world GDP for 2000, as reported by World Bank (2005)

Table 4 Parameters and calibrated transfer coefficients

Symbol	Parameter	Value	Note
P_O	Price of oil, annual average	25 US$ bbl^{-1}	4-1
P_L	Labor rate for Belize	1.13 US$ man-hour^{-1}	4-2
P_T	Expenditures by tourists	1,500 US$ tourist^{-1}	4-3
k_0	Rate constant, delivery rate of rainfall energy	7.82E−07	4-4
k_1	Rate constant, growth of rainforest	1.72E−13	4-5
k_2	Rate constant, natural loss of rainforest	1.10E−03	4-6
k_3	Rate constant, loss of rainforest due to tourism infrastructure	1.49E−06	4-7
k_4	Rate constant, loss of hotel infrastructure	4.72E−02	4-8
k_5	Rate constant, growth of hotel infrastructure	1.75E−16	4-9
k_6	Rate constant, labor supply to hotel industry	9.60E−11	4-10
k_T	Rate constant, supply of tourists	1.01E−09	4-11
k_{11}	Rate constant, loss of rainforest due to direct tourist use and impact	3.40E−08	4-12
k_{oil}	Rate constant, loss of crude oil reserves from use	1.91E−02	4-13
$k_{O\$}$	Proportionality constant for price of oil	1.86E−02	4-14
$k_{\$}$	Rate constant, growth of GDP	1.0E−01	4-15

4-1 Annual average of oil prices for FY2000, estimated from WTRG (2002)

4-2 National minimum wage for Belize reported at US$1.13 (US Embassy Belize 2002)

4-3 Assumed average expenditure of tourist money

4-4 Calculated from $k_0 = (J - R)/(N * R)$

4-5 Calculated from $k_1 = J_1/(N'*R')$

4-6 Calculated from $k_2 = J_2/N'$

4-7 Calculated from $k_3 = J_3/(N * I)$

4-8 Calculated from $k_4 = J_4/I$

4-9 Calculated from $k_5 = J_5/(G * L * I)$

4-10 Calculated from $k_6 = J_6/(G * L * I)$

4-11 Calculated from $k_T = (J_T * P_O)/(T * I * N)$

4-12 Calculated from $k_{11} = J_{11}/(J_T * N)$

4-13 Calculated from $k_{oil} = J_{oil}/O$

4-14 Calculated from $k_{O\$} = (J_{oil} * P_O)/J_{\$}$

4-15 Assumed rate of growth of world GDP

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