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A Theoretical Approach to Tourism Sustainability

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Contents

Abstract

The aim of this paper is to show that it is difficult, if not impossible, to find policies that guarantee that tourism can be maintained for a long time without severely impacting on the environment. The analysis is purely theoretical and is based on very simple and general assumptions on the interactions between the three main compartments of the system: tourists, environment, and capital. These assumptions are encapsulated in a so-called minimal model which is used to predict the economic and environmental impact of any given policy. The paper has three merits. Firstly, it introduces the approach of minimal descriptive models in the context of tourism, which has been traditionally dominated by the use of black-box econometric models. Secondly, the specific results are quite interesting. It is shown, in fact, that tourism sustainability can be obtained provided the agents are cautious in reinvesting their benefits and willing to protect the environment, and that sustainability is very often at risk, since accidental shocks can easily trigger a switch from a profitable and compatible behavior to an unprofitable or incompatible one. All these results are in line with conventional wisdom and observations, but the interesting fact is that they are here theoretically derived from a few very simple and abstract premises. Finally, the third merit is not strictly related with the problem of tourism but with the general topic of sustainability. In fact, this is one of the first times that the notion of sustainability, which is more and more pervasive in the field of resource management, is strictly interpreted in terms of structural properties of the attractors of a dynamic system. This creates an important and promising bridge between sustainability and bifurcation theory, one of the most important chapters of systems analysis.

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A Theoretical Approach to Tourism Sustainability

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Introduction

The tourism industry has increased remarkably in the last decades and has become one of the major sources of income in many countries (Williams and Shaw 1988, Coccossis and Nijkamp 1995). In many touristic sites the rewarding phase of development is characterized by a long and intense growth of infrastructures, superstructures and facilities that, sooner or later, seriously impact on the environment, thus creating a critical situation. In fact some destinations, after a long flourishing period, are abandoned by tourists in favor of more attractive sites newly available on the market (Butler 1991). In order to compensate this instability, local agents can increase investment and develop special facilities to attract tourists. Sometimes they are successful, but at the expenses of the environment, which may be severely degradated.

The aim of this paper is to show why it is difficult, if not impossible, to find policies that guarantee that tourism can be maintained for a long time without severely impacting on the environment. The analysis is very abstract. It is not based on data of one or more special cases, but on very simple and general assumptions on the interactions between three important compartments of the system: tourists, natural environment, and capital. These assumptions are encapsulated in a so-called minimal (or stylized) model which is used to predict the economic and environmental impact of any given policy. The approach we use here is similar to that used by Anderies (1998, 2000) for analyzing agro-ecosystems dynamics and is new in the context of tourism studies. As some extensive reviews on the topic clearly evidence (Witt and Witt 1995, Kulendran and King 1997) the classical models for tourism are black-box econometric models mainly aimed to forecast the demand for travel services or the number of tourist arrivals as a function of the income, the transportation costs, the relative prices, the currency exchange rates, and some other ‘qualitative factors’ – among which the environment has never been taken into account, at least in the 100 papers reviewed by Lim (1997). These econometric models have been tuned with different techniques, either cointegration or least squares (Kulendran and Witt, 2001), on data referring to various target places, ranging from the North East of England (Seddighi and Shearing, 1997) to Australia (Morley, 1998) and from Barbados (Dharmaratne, 1995) to Turkey (Akiş, 1998). The study we present is instead carried out by varying some abstract, but meaningful parameters that interpret the attitude of the agents toward the two main conflicting objectives: economic development and environmental protection (Lindberg

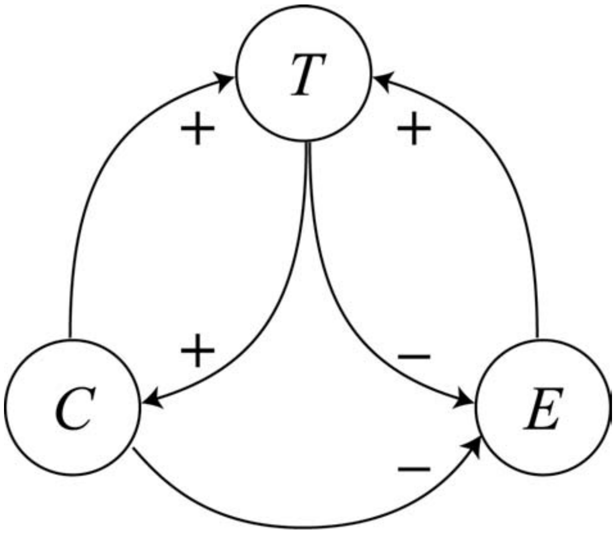

Figure 1. The interactions between the three compartments of our minimal model.

1991, Smith and Eadington 1992). The results are in agreement with conventional wisdom and, more generally, with the impression that human short-sightedness and greed can make sustainability an unattainable goal (Ludwig et al.1993, Ludwig 1993, Arrow et al. 1995, Roe 1996, Brown et al. 1996).

A Minimal Model

The minimal model on which the analysis is based is so crude and abstract that it cannot represent any specific system in detail. Nevertheless, it incorporates the core features of many systems. The model refers to a generic site and has only three variables: the tourists $T(t)$ present in the area at time t, the quality of the natural environment $E(t)$ and the capital $C(t)$ intended as structures for touristic activities. Note that $C(t)$ is a stock that should not be confused with the flow of services provided to tourists. While the choice of these three compartments is rather obvious, their description via a single variable definitely poses some problems. In fact, one might be reluctant to aggregate into a single variable tourists of different incomes, lifestyles and socio-cultural backgrounds, and infrastructures ranging from hotels to parks and from sport facilities to transportation systems. The same holds for the quality of the environment which is very often a mix of various indicators as diverse as air quality, water quality, biodiversity and wildlife and landscape conservation. But this aggregation process is mandatory, because we must keep the number of variables and parameters reasonably low in order to obtain a tractable problem. Seasonal effects are not taken into account here, since we are interested only in the long term behavior of the system.

For all these reasons, our minimal model cannot be considered as an operational tool for managers even if it will be used to derive the ultimate consequences of different development policies. The nature of the model is so abstract that these consequences will not point out new and sharp suggestions of practical interest to managers, but, instead, allow a theoretical derivation of a rich catalogue of development scenarios confirming empirically observed patterns (see below). The fact that the results we will derive are already known from history, confirms that general theories can sometimes be as powerful as empirical observations.

The interactions among the three compartments of our minimal model are sketched in Figure 1. Tourists (T) and touristic facilities (C) impact negatively on environmental quality (E), while environmental quality and infrastructures are attractive for tourists. The positive arrow from T to C represents the investment of part of the benefits associated with tourism into new facilities for visitors. In the following we report in detail the functional forms of the influences pointed out in the graph of Figure 1.

The Tourists

Imagining that tourists are used to report about the attractiveness A of the sites they have visited and assuming that these reports influence the decisions of new potential visitors (the "mouth information spread", Morley 1998), we can spontaneously write that the rate of change of tourists in a given site $\dot{T}(t) = dT(t)/dt$ is proportional to the product TA, i.e., measuring A in suitable units, $\dot{T}(t) = T(t) \cdot A(T(t), E(t), C(t))$. Of course, A must be a relative attractiveness, namely the difference between the absolute attractiveness, $\hat{a}$, of the specific site (for which information on T, E and C is available) and a reference value a which might be thought of as the expected attractiveness of a generic site (i.e., the average value of the attractiveness of all potential touristic sites). Thus $A(T, E, C) = \hat{a}(T, E, C) - a$ where a is influenced by a number of factors, among which the price of the alternative sites. In an abstract sense, a is a measure of the *competition* exerted by the alternative touristic sites on the site under study. The attractiveness $\hat{a}$, being that perceived by the tourists, depends upon the culture of the tourists and, in particular, upon their sensitivity to the quality of the natural environment and to their capability of detecting it. It is the algebraic sum of three terms since tourists can be sensitive to environmental quality, availability of facilities, and congestion. The attractiveness of the environment can be modeled as an increasing and saturating function of E. In the following, it will be described as a Monod function

$$\mu_E \frac{E}{E + \varphi_E} = \mu_E$$

where μ_E is the $E \to \infty$ attractiveness associated to high environmental quality and E is φ_E the half saturation constant, namely the environmental quality at which tourist satisfaction is half maximum. Thus, tourists characterized by low values of φ_E are satisfied by low qualities of the environment because they are unable to perceive environmental quality. For example, a tourist who is unable to perceive if a river is polluted or not, will associate to the river a constant attractiveness μ_E independently upon its water quality, because

$$\lim_{\varphi_E \to 0} \mu_E \frac{E}{E + \varphi_E} = \mu_E$$

The second component of the attractiveness, namely that associated with infrastructures, can also be modeled through a Monod function of the estimated available facilities per capita $C/(T+1)$, i.e.

$$\mu_C \frac{C/(T+1)}{C/(T+1)+\varphi_C} = \mu_C \frac{C}{C+\varphi_C T+\varphi_C}$$

Notice that the attractiveness associated to the natural environment is a function of E and not of $E/(T+1)$ as prescribed by the theory of public-goods and non-consumptive use (Herfindahl and Kneese 1974). By contrast, facilities are used by tourists and, therefore, the attractiveness associated with them is a function of $C/(T+1)$. Finally, if we assume that congestion is proportional to T and that attractiveness is linearly decreasing with congestion, we end up with the following formula for $\hat{a}$

$$\hat{a} = \mu_E \frac{E}{E+\varphi_E} + \mu_S \frac{S}{S+\varphi_S T+\varphi_S} - \alpha T$$

where the five parameters ($\mu_E, \varphi_E, \mu_C, \varphi_C, \alpha$) identify the culture of the tourist population. It is worth noticing that the absolute attractiveness, $\hat{a}$**,** of a touristically unexploited site ($C = T = 0$) is positive and can be greater than the reference attractiveness a. This means that the relative attractiveness A can be positive even when $C = T = 0$. This explains the well know phenomenon that Butler (1980) called "tourist-area cycle of evolution".

The Environment

The quality of the environment $E(t)$, in the absence of tourists and capital, is described by a classical logistic equation

$$\dot{E}(t) = rE(t)\left(1 - \frac{E(t)}{K}\right)$$

where the net growth rate r and the carrying capacity K are influenced by all activities except those related to tourism industry. In other words, K is not the quality of the environment in unrealistic (i.e., pristine) conditions, but, instead, the quality of the environment at the equilibrium in the presence of all civil and industrial activities (except for tourism) characterizing the site under study. If tourists and facilities impact negatively on the environment, the complete dynamics of $E(t)$ is

$$\dot{E}(t) = rE(t)\left(1 - \frac{E(t)}{K}\right) - D(T(t), C(t), E(t))$$

where $D(T(t), C(t), E(t))$ represents the flow of damages induced by tourism. Generally, this flow is positively correlated with tourists and capital. Moreover, the damage is higher when the environment is still unexploited. The simplest functional form consistent with these properties is the following

$$D = E(\beta C + \gamma T)$$

where the two parameters β and γ are positive. For example, heating of hotels, which impacts on air pollution, has a first component which is basically independent upon the number of tourists (heating the hall, the cafeteria, the rest-rooms, …) and a second component which is proportional to the number of visitors (heating the bed-rooms).

This is perfectly consistent with our eq. (14). The same is true for many other touristic facilities, like ski lifts and discothèques (noise pollution), bus services (air pollution), artificial snow facilities (downstream water pollution) and many others. Exceptionally, β and γ can be negative, for example, when high reclamation efforts are associated to tourism development. This means that if T and C would be kept constant, the environment would still be described by a logistic equation

$$\dot{E}(t) = r^* E(t)\left(1 - \frac{E(t)}{K^*}\right)$$

with

$$r^* = r\left(1 - \frac{\beta C + \gamma T}{r}\right)$$

$$K^* = K\left(1 - \frac{\beta C + \gamma T}{r}\right)$$

In other words, if β and γ are positive, tourism activities (C and T) reduce the carrying capacity and the net growth rate of the environment in the same proportion.

The Capital

Finally, the rate of change of the capital is the difference of the investment flow I and a depreciation flow which is proportional to C, i.e.

$$\dot{C}(t) = I(T(t), E(t), C(t)) - \delta C(t)$$

The parameter δ must be very small because the degradation of touristic structures is very slow. The fact that the time constants of the socio-economic compartment are longer than those of the environmental compartment has been emphasized in Carpenter et al. (1999a). In our simulations δ is one order of magnitude smaller than r, the net growth rate of the environment. The function I could be specified in many different ways for interpreting different investment policies. Indeed, one might imagine to impose special constraints on the function in order to avoid degenerate dynamics as done in Rinaldi et al. (1996) for a study on pollution control. Alternatively, one could derive the structure of the function $I(T, E, C)$ using optimality arguments, like in Gatto et al. (1991), Shah (1995) or Carpenter et al. (1999b). Here we will assume that investments are a fixed proportion of total revenues due to tourism activities and that such revenues are proportional to the number of tourists, i.e.

$$I(T, E, C) = \varepsilon T$$

Thus, the parameter ε, or *investment rate*, is increasing with local prices.

In conclusion, our minimal model turns out to be

$$\dot{T}(t) = T(t)\left[\mu_E \frac{E(t)}{E(t) + \varphi_E} + \mu_C \frac{C(t)}{C(t) + \varphi_C T(t) + \varphi_C} - \alpha T(t) - a\right] \quad (1)$$

$$\dot{E}(t) = E(t)\left[rE(t)\left(1 - \frac{E(t)}{K}\right) - \beta C(t) - \gamma T(t)\right] \quad (2)$$

$$\dot{C} = -\delta\, C(t) + \varepsilon\, T(t) \tag{3}$$

This model is new, since it can not be interpreted as a consumer-resource model. In fact, tourists and capital that could be thought to be predators do not growth on the basis of the damages (predation) they produce on the environment. The model has twelve parameters, among which the rate of investment ε is the one that local agents and decision makers can more easily control. Price control is also feasible in some cases but influences two parameters namely ε and a. Reclamation of the environment gives rise to lower values of β and/or γ which can become negative in extreme cases, while increased competition of alternative touristic sites can be viewed as an increase of a.

The Tourist Destination Life Cycle

Since model (1)-(3) has been proposed on the basis of purely theoretical arguments, one should check, before proceeding further, if the model compares favorably with the data concerning the development of a few significant touristic sites. This could be done by suitably tuning the parameters of the minimal model in order to have a good fit with time series of tourists arrivals in different destination areas. But this would somehow suggest that the minimal model could be used by decision makers as an operational tool. In order to avoid this misleading impression we do not perform any validation test based on particular data sets. Instead, we show that the minimal model is capable of mimicking all the qualitatively different development scenarios discussed by Butler in his work on life cycle (Butler 1980) which has been widely accepted in a variety of empirical contexts. From the southern coasts of Britain (Agarwal 1997) to Indonesia (Dahles and Bras 1999), from Peru (O'Hare and Barrett 1997) to Swaziland (Harrison 1995), from Melanesia (Douglas 1997) to Cyprus (Akiş et al. 1996), the curve of tourists arrivals over the years in every place seems to follow the pattern described by Butler. In order to study the initial phases of tourism in Europe, one should of course refer to works that date back at least to the beginning of the last century. In a paper appeared in 1939 on the Scottish Geographical Magazine, Gilbert tried to understand why and how many seaside resorts in England were growing so fast. The development of infrastructures was indeed crucial for the transformation of ancient ports or fishing harbors into seaside resorts. To give a vivid description of how tourism changes the nature of a place, Gilbert (1939) quoted part of an article published by *The Times* in 1860 (August 30th):

> *"Our seaport towns have been turned inside out. So infallible and unchanging are the attractions of the ocean that it is enough for any place to stand on the shore. That one recommendation is sufficient. Down comes the Excursion Train with its thousands – some with a month's range, others tethered to a six hours' limit, but all rushing with one impulse to the water's edge. Where are they to lodge? The old 'town' is perhaps half a mile inland, and turned as far away from sea as possible, for the fishermen who built it were by no means desirous of always looking at the sea or having the salt spray blowing in at their windows. They got*

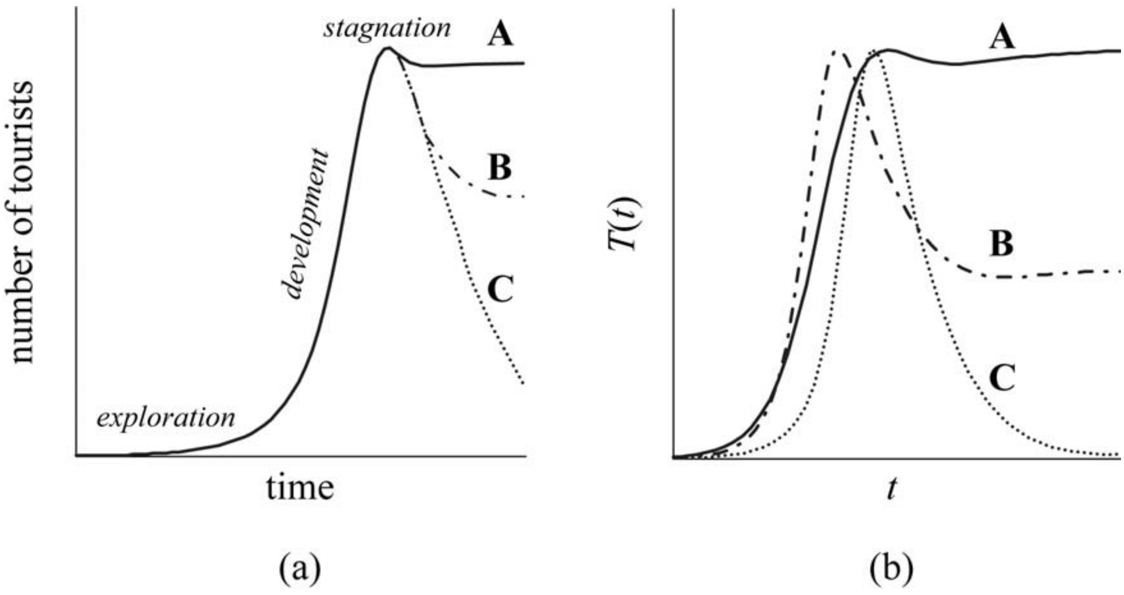

Figure 2. Scenarios of tourism development: (a) Butler's diagram (modified from Butler 1980); scenarios obtained with the minimal model (1)-(3) (parameter values are: $r = K = \alpha = \beta = \gamma = \varphi_S = 1$, $\delta = 0.1$, $\varphi_E = 0.5$, $a = 6$, $\mu_E = \mu_S = 10$, and $\varepsilon = 0.01$ in case A, $\varepsilon = 0.25$ in case B, and $\varepsilon = 0.45$ in case C.)

> *as far back as they could, and nestled in the cliffs or behind the hill for the sake of shelter and repose. But this does not suit visitors whose eyes are always on the waves, and so a new town arises on the beach. Marine Terraces, Sea Villas, 'Prospect Lodges', 'Bellevues', hotels, baths, libraries and churches soon accumulate, till at length of the old borough is completely hidden and perhaps to be reached by an omnibus."*

The story of that hypothetical village summarizes very well the core of Butler's theory, according to which there are basically three different scenarios, as sketched in Figure 2a. In an unexploited area the tourists are initially only a few people and their number grows very slowly (*exploration*). After this discovery period, there is a phase of rapid growth, in general accompanied by a consistent capital *development*, and finally a *stagnation* stage. After these phases, which are present in all cases, there are three different possible long term scenarios:

A. the tourists remain roughly constant at their maximum
B. after a decline, the tourism activities settle down to a plateau
C. tourism activities dramatically decline.

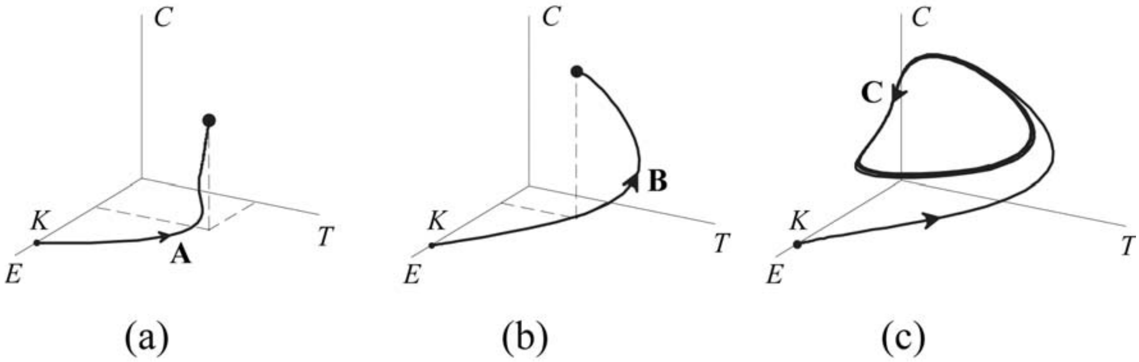

Figure 3. Trajectories in state space corresponding to the scenarios A, B, and C of Figure 2b.

Butler (1980) envisioned also two ways for having a *rejuvenation* stage, i.e. the number of tourists still increasing after the stagnation phase: the first one requires the addition of man-made attractions (as for example the Atlantic City's gambling casinos), the second requires to taking advantage of previously untapped natural resources (Butler cites some summer holiday village that reorient to winter sports). In any case, as Butler clearly states, "it is almost certain that this [rejuvenation] stage will never be reached without a complete change in the attractions on which tourism is based". Figure 2b shows that model (1)-(3), can reproduce the three scenarios provided the parameters are suitably tuned. This means that model (1)-(3) is sufficiently flexible to qualitatively adapt to all significant cases.

Butler's diagram is only a partial view of tourism dynamics, since it does not say anything about environmental quality and infrastructures. A full description of the tourism dynamics of a given site would require to plot three time series, one for each compartment, or, equivalently, the line (*trajectory*) along which T, E and C evolve in their three-dimensional space (*state space*). Figure 3 shows the trajectories corresponding to the three scenarios of Figure 2b: they all start close to point K on the E axis, because the initial conditions are characterized by almost absence of tourists and capital.

The trajectories develop in time (as shown by the arrow) and tend for $t \to \infty$ toward a point (*equilibrium*) in cases A and B, and toward a closed line (*limit cycle*) in case C. In the last case, tourism activities periodically recover after long and dramatic declines. The possibility that tourism activities recover after a severe decline has been observed and discussed by various authors (Christaller 1963, Plog 1973, Butler 1991). The fact that humans and their cultural practices can impact periodically on an ecosystem has actually been remarked also in other contexts (Anderies 1998).

Equilibria and limit cycles are called *attractors* and represent the long term behavior of the system. As such, they are the appropriate tool for discussing sustainability, which is, indeed, a long term property of the system. By contrast, Butler's diagrams are not appropriate for discussing sustainable tourism, because they point out only the initial parts of the transients toward the attractors.

Analysis of the Model

The aim of this section is to identify all long term modes of behavior (i.e., the attractors) of model (1)-(3) for different values of two parameters, namely investment rate ε and competition a. Our analysis shows that the attractors of model (1)-(3) are either equilibria or limit cycles. Nevertheless, for parameter values in suitable ranges, the model can have two or three attractors. In such cases, each attractor has its *basin of attraction* which is the set of all initial states giving rise to trajectories tending toward the attractor. Thus, when there are multiple attractors, the initial conditions of the system play a crucial role because they determine the long term behavior of the system.

Each point of the two dimensional parameter space (ε, a) corresponds to a particular model of our family of models (1)-(3) and therefore to one specific set of attractors. If at least one of the two parameters is slightly perturbed, by continuity the position and the form of the attractors will vary smoothly in state space (e.g. a limit cycle might become slightly bigger and faster) but all trajectories will remain qualitatively the same (e.g., an attracting cycle will remain an attracting cycle). Only at some particular points in parameter space the above continuity argument will fail. At these points, called *bifurcation points* (Kuznetsov 1995), small variations of the parameters entail significant changes in the model behavior. For example, an equilibrium ($\overline{T}, \overline{E}, \overline{C}$) which is strictly positive (i.e., $\overline{T} > 0, \overline{E} > 0, \overline{C} > 0$) can be stable (i.e., attract all nearby trajectories) for a given parameter setting, but loose its stability if competition a is increased even of an infinitesimal amount. If this is the case, after the parameter has been varied, the state of the system will not tend toward the equilibrium ($\overline{T}, \overline{E}, \overline{C}$) but toward another attractor. If this new attractor is infinitely close to the old one, the bifurcation is called *non catastrophic*. By contrast, it is called *catastrophic* if a microscopic variation of the parameter gives rise to a macroscopic transition from one attractor to another. For example, this would be the case if a small increase of competition would force the system to switch from a strictly positive equilibrium ($\overline{T}, \overline{E}, \overline{C}$) to an equilibrium $0, \overline{E}, 0$ characterized by the absence of tourists and capital.

The unions of bifurcation points are *bifurcations curves* which partition the parameter space (ε, a) into subregions. All the models corresponding to the same subregion have qualitatively the same long term behavior, because they have the same attractors. The determination of all bifurcation curves can be done numerically using specialized software such as AUTO (Doedel and Kernévez 1986), LOCBIF (Khibnik et al. 1993) or CONTENT (Kuznetsov and Levitin 1997). Once a single bifurcation point in the parameter space is found, these packages produce automatically the entire bifurcation curve passing through that point. The reader interested in performing numerical bifurcation analysis of model (1-3) for various parameter settings can visit the http://indy.cs.concordia.ca/auto/ AUTO site or download CONTENT http://www.cwi.nl/ftp/CONTENT/ here.

Without going into more details, we show the results of our analysis in Figure 4, for the parameter setting indicated in the caption. There are five bifurcation curves denoted I, II, …, V which identify ten different regions denoted 1, 2, …, 10. The attractors of each region are also sketched in Figure 4 (the reader skilled in bifurcation analysis will recognize that curves I, II, III, IV, and V are, respectively, a transcritical of equilibria, a

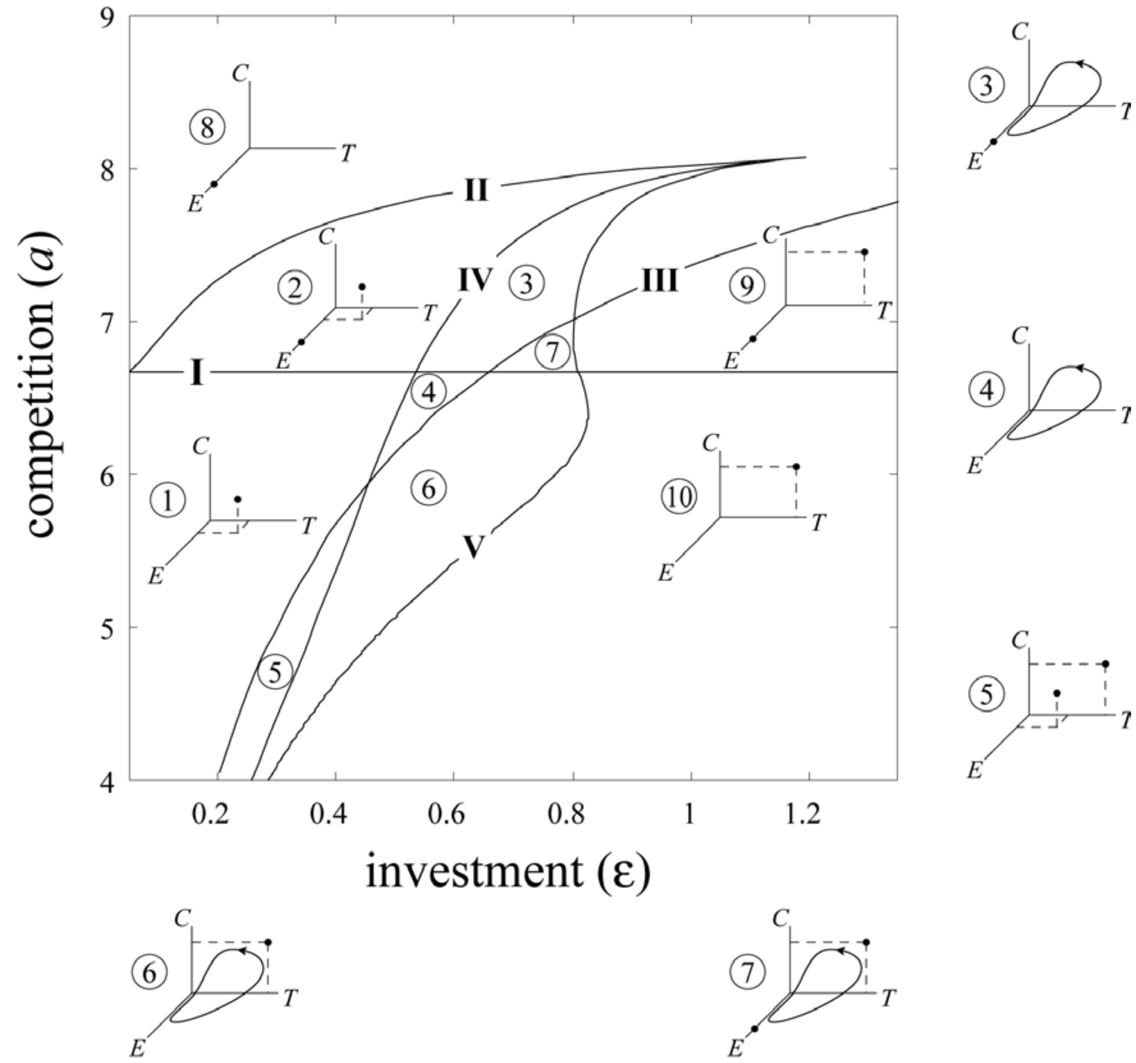

Figure 4. Bifurcation diagram of model (1)-(3) in the parameter space ε, a). Other parameter values are as in Figure 2b.

fold of equilibria, a planar fold of equilibria, a Hopf, and a homoclinic bifurcation curve). In regions 1, 4, 8, 10 the attractor is unique, while in the other regions there are two or even three (region 7) alternative attractors. In these cases the system is “fragile” because an accidental shock can suddenly perturb the state of the system and bring it from an attractor A_i into the basin of attraction of another attractor A_j. Thus, after the perturbation has ceased, the state of the system will tend toward the new attractor A_j and remain there until a new shock comes. Another important remark is that the strictly positive attractor is unique (when it exists). Moreover, in regions 3, 4, 6, 7 the strictly positive attractor is a limit cycle. This means that in these regions the long term behavior of the system can be characterized by recurrent ups and downs of the three state variables.

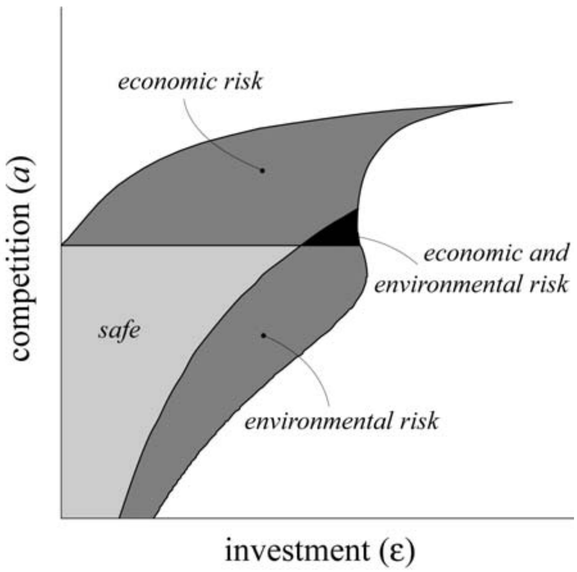

Figure 5. Sustainability diagram of model (1)-(3) with respect to investment and competition. Parameter values as in Figure 2b.

Profitable, Compatible, and Sustainable Policies

The parameters of the model can be subdivided into *policy parameters* and *system parameters*. The first ones identify the behavioral characteristics of agents and decision makers, while system parameters describe the other actors involved in the game, namely the environment, tourists and alternative touristic sites. A particular parameter setting can therefore be viewed as a particular policy applied to a particular system. In order to judge the economic impact of a policy in a given destination area, we should therefore be able to associate a value judgment concerning the tourism industry to each parameter setting. Of course, the sharpest choice is to associate a zero-one value judgment (i.e. "bad'' or "good'') to each parameter setting. This is somehow what has been done in the last decade, with the introduction of various notions of sustainability (Ludwig et. al 1993, Bramwell and Lane 1993). Many of these notions refer to extreme compromise solutions between economic development and environmental protection. For many economists, sustainability means guaranteed economic growth under the weak constraint of no irreversible damage to the environment (Goodland and Ledec 1987, Solow 1991, Turner 1993, Beltratti 1997). Conversely, for environmentalists, sustainability is simply viewed as no further deterioration of the environment due to the use of natural resources (Rubenstein 1993). By contrast, our definition of sustainability (see below) will give the same emphasis to economic and environmental aspects, as supported by various authors (Bender et al.1994, Gatto 1995, Wall 1997).

Let us qualify the economic impact of a policy applied to a given site by saying that the policy is *profitable* if it can sustain the tourism industry forever. In the economic literature this aspect is usually dealt with through the maximization of discounted utility (Beltratti 1997, Cheve 2000). Here we follow a simpler approach, namely we say that a policy is profitable if at least one of the associated attractors is characterized by $T(t) > 0$

for all t (notice that this implies $C(t) > 0$ for all t). The property $T(t) > 0$ is a structural property of the attractors, as it can be verified from Figure 4. From the same figure it follows that only region 8 corresponds to non-profitable policies. Indeed, in all other regions, at least one attractor is characterized by a permanent touristic activity. There is, nevertheless, an important difference among these regions. In fact, in some of them there are also attractors characterized by the absence of tourism industry (i.e. $T(t) > 0$). In these cases, we say that the policy is profitable but *risky*, because an unexpected accidental shock, like a war, an epidemic or an episode of xenophobia, can perturb the state of the system and cause a transient ending in an attractor characterized by no tourism industry. Regions 2, 3, 7, 9 of Figure 4 correspond to profitable but risky policies, while all regions below curve I are profitable and *safe*. Thus, if competition is sufficiently low, all policies are profitable and safe, while if competition is sufficiently high all policies are non-profitable, a quite reasonable result.

Following a similar line of reasoning for judging the environmental impact of a policy in a given area, we can say that a policy is *compatible* when it can avoid the complete degradation of the environment. In purely mathematical terms, this means that at least one of the associated attractors has $E(t) > 0$ for all t. From this definition it follows that only region 10 in Figure 4 is not compatible. Again, we can distinguish between safe and risky policies and find out that all regions above curve III correspond to safe compatible policies.

Finally, in line with the theory of conflict resolution in multiobjective analysis (Keeney and Raiffa 1976) and in accordance with some of the most recent ideas on sustainability (Forum on “Science and sustainability", 1993, Ecological Applications **3**: 545-589), we say that a policy is *sustainable* if it has the chance to maintain the tourism industry forever without jeopardizing the environment. Thus, a policy is sustainable when one of its associated attractors is characterized by $E(t) > 0$ and $T(t) > 0$ (and hence $C(t) > 0$) for all t, i.e. when one of its attractors is strictly positive. As already noticed, this definition is not as partisan as those proposed by economists (who pretend that $\dot{T}(t) \geq \xi > 0$ or environmentalists (who pretend that $\dot{E}(t) \geq 0$.) Obviously, a sustainable policy is profitable and compatible, while the converse is not true, as one can easily check by looking at the attractors in region 9 of Figure 4. Of course, a sustainable policy can be safe (and is certainly such if the attractor is unique). But it can also be risky for the environment and/or for the economy. Following these definitions, one can easily derive from Figure 4 the region of sustainable policies and subdivide it, as shown in Figure 5, into a region of safe policies and various regions of risky policies. Such a diagram, from now on called *sustainability diagram*, shows that the region of sustainable policies is bounded. Moreover, it can be shown that the two bifurcation curves delimiting the sustainability region are catastrophic. This means that any parameter variation implying the loss of sustainability will be accompanied by a catastrophic collapse of the environment and/or of the tourism industry. By contrast, the subregion of sustainable and safe policies is delimited by two bifurcation curves which are non-catastrophic for the strictly positive attractor. Such a region is rather small and characterized by low competition and investment rate. As soon as competition becomes

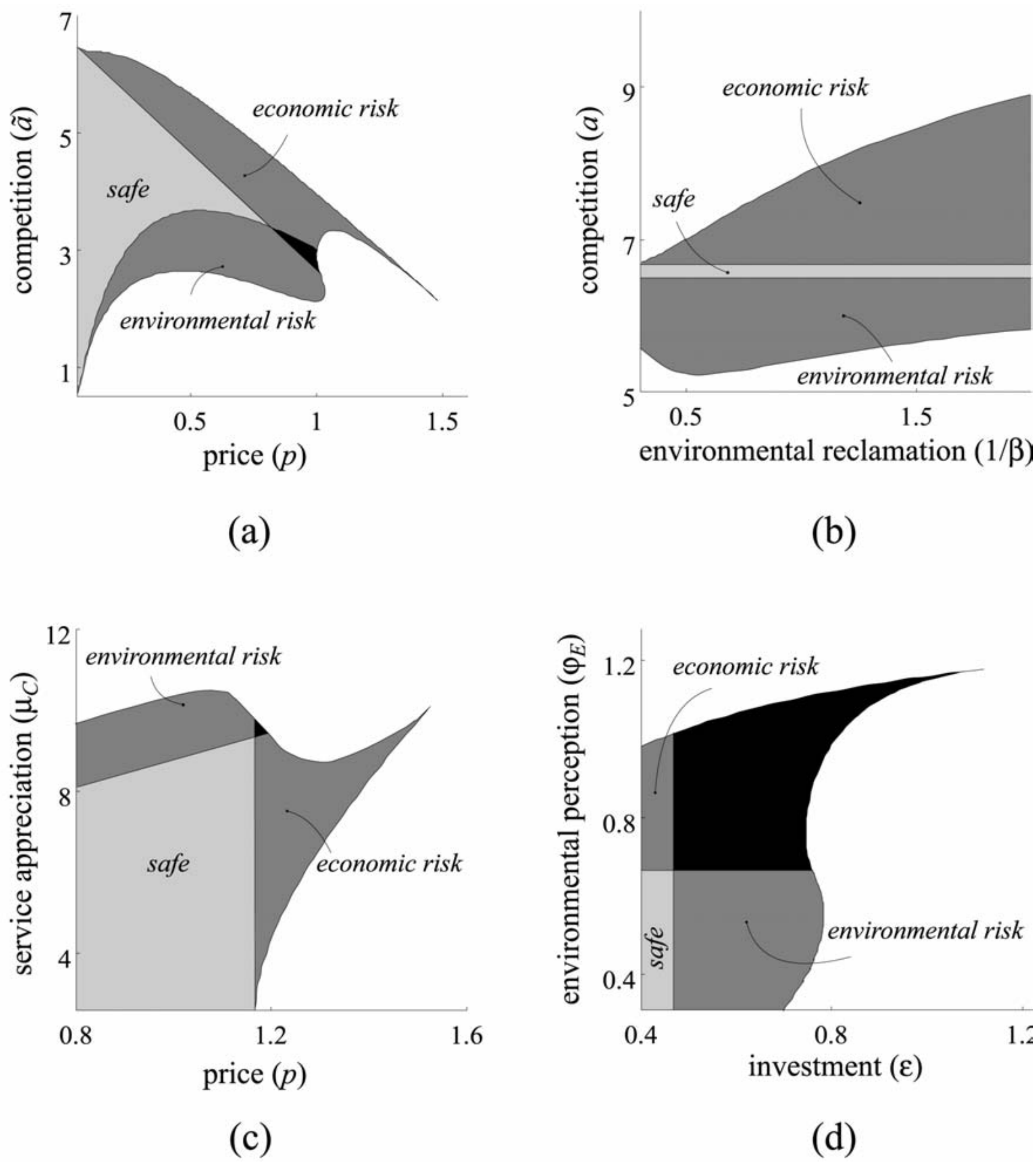

Figure 6. Sustainability diagrams of model (1)-(3) with competition a and investment ε depending upon price p through the formulas $a = \tilde{a} + 4p$ and $\varepsilon = 0.8p$. The darkest regions correspond to sustainable policies which are risky both for the economy and for the environment. In (a) the component $\tilde{a}$ is on the vertical axis. In (b) $\varepsilon = 0.6$. In (c) $\tilde{a} = 2$. In (d) $a = 6$. All other parameters are as in Figure 2b.

too strong, the policy becomes risky for the economy, while if local agents are too greedy, the policy is risky for the environment.

The analysis described in Figs. 3 and 4 concerning the effects of competition and investment, has been repeated for other pairs of parameters in order to obtain a better understanding of the problem. The results are shown in Figure 6, where four different sustainability diagrams are reported. In all diagrams on the horizontal axis we have a policy parameter, like price, environmental reclamation, and investment, while on the vertical axis there is a system parameter describing the attractiveness of alternative sites (competition) or some behavioral characteristics of the tourists, like their appreciation of facilities μ_C in eq. (1)) and their capability of perceiving the quality of the environment (φ_E in eq. (1)). In all cases, the boundary of the sustainable region is composed of two catastrophic bifurcation curves.

Safe policies are “surrounded” by risky policies, and a continuous increase of the system parameter transforms a safe sustainable policy first into a risky sustainable policy and then into a non sustainable policy. In general, sustainability requires low prices, low investments and high environmental reclamation.

Another property which is often mentioned in the context of sustainability is *adaptivity* (Holling 1986, Walters 1986, Holling 1993). It corresponds to the possibility of changing policy parameters on the basis of perceived variations of system parameters in such a way that sustainability can still be guaranteed. A typical question that agents must be able to answer is, for example, the following: if competition increases slowly but continuously, should the policy also be varied in order to avoid or, at least, delay negative consequences? A question like this can be answered qualitatively by looking once more at our sustainability diagrams. In the specific case one should look at Figs. 4, 5a and 5b which have on their vertical axis the system parameter “competition” and on the horizontal axis a policy parameter. Thus, if competition increases and the policy remains unchanged the consequences can be detected by looking at what happens when moving up vertically in each diagram. The three figures show that a safe sustainable policy will first become economically risky and finally non sustainable, so that the problem of avoiding these consequences through adaptation is a well posed problem. Figure 5 indicates that nothing can be done to avoid or delay the time at which the policy becomes risky by varying the investment rate, because the upper boundary of the safe region is horizontal. The same happens in Figure 6b, while Figure 6a points out that the policy can adapt to increasing competition and remain safe, at least for a longer time, if prices are slowly decreased. Thus, in conclusion, if the aim is to avoid economically risky situations, price control seems to be the proper action to cope with increasing competition. By contrast, if risk is accepted and the target is to avoid or delay the time at which the policy becomes non sustainable, all three policy parameters are good control candidates for achieving the task, and the diagrams suggest to increase investment rate and environmental reclamation, and decrease prices. In practice it might be rather hard to find the right mix of control actions and one can see from the diagrams that exaggerated reactions could actually generate an environmental crash instead than simply avoid an economic crash. Moreover, when many system parameters vary at the same time it becomes more difficult to adapt the policy, because some of the sustainability diagrams may suggest conflicting actions. For example, if facilities appreciation also increases (as it does nowadays) Figure 6c suggests to increase prices to maintain safe conditions, while Figure 6a suggests just the opposite to cope with increasing competition.

Conclusions

The problem of sustainable tourism has been dealt with theoretically in this paper using a minimal model with three state variables: tourists, environment and capital. Although simplistic, the paper has three merits.

Firstly, it introduces the approach, of minimal descriptive models in the context of tourism, which has been traditionally dominated by the use of detailed simulation models. In other fields of sciences, like epidemiology (Ross 1909), plant and animal ecology (Volterra 1926), renewable resources management (Clark 1976), and economics (Forrester 1961, Brock and Malliaris 1989), this happened long ago and the approach is now appreciated and well established. Indeed, minimal (stylized) models have been recently used to discuss the role of human actors in ecological-economic systems (Anderies 2000).

Secondly, the specific results are quite interesting. We have shown in fact that sustainable tourism can be obtained, provided the agents are cautious in reinvesting their benefits and inclined to protect the environment. We have also seen that sustainability is very often at risk, since accidental shocks can easily trigger a switch from a profitable and compatible behavior to an unprofitable or incompatible one. Moreover, adaptivity of sustainable policies is also possible, but is very difficult to be realized in practice, and can at most delay the occurrence of a catastrophe but not avoid it, if competition among touristic sites continues to grow. All these results are in line with conventional wisdom and observations, but the interesting fact is that they are here theoretically derived from a few very simple and abstract premises.

Finally, the third merit is not strictly related with the problem of tourism but with the general topic of sustainability. Here we base the notions of profitability, compatibility and sustainability, which are more and more pervasive in the field of resource management, on structural properties of the attractors of a dynamic system. Similarly to what has been done for resilience by Ludwig et al. (1997), this creates an important and promising bridge between sustainability and bifurcation theory, one of the most important chapters of systems theory.

The weaknesses of the paper are the typical weaknesses of minimal models. First of all, the three compartments used in the model cannot cover social, cultural and political aspects involved in tourism development. This means that our conclusions should not be applied to those cases in which such aspects are dominant. For example, a fourth variable, namely local labor population, should be added to the model if one would like to discuss the social implications of tourism development. Moreover, the three compartments are too aggregated. For example, one feels the need for a more detailed description of the tourist population. Indeed, different tourists have different cultures and can be described by eq. (1) with different parameter values. Our analysis shows (see for example Figs. 5c and 5d) that the behavior of the system can be radically different if tourists are different, at the point that in some cases tourism cannot persist. On the other hand, we know that a touristic site is rarely abandoned by tourists but is more likely visited by lower and lower classes of tourists (Butler 1980). This fact can be studied through a slightly extended minimal model with two or three different classes of tourists acting as competing exploiters of the same resource, thus obeying the principle of competitive exclusion (Hardin 1960). In a rather similar way, one can substitute eq. (3) describing capital by two similar equations with different parameter values in order to study the case of diversified investments for infrastructures and facilities. But even without modifying the present aggregation level, some of the assumptions encapsulated in the minimal model can be relaxed in order to study other cases of interest. For example, one could try to see if the introduction of suitable investment constraints, based on environmental quality and/or services, have the power of amplifying the class of sustainable policies.

References

Agarwal, S. 1997. The resort cycle and seaside tourism: An assessment of its applicability and validity. Tourism Management **18**: 65-73.

Akis, S. 1998. A compact econometric model of tourism demand for Turkey. Tourism Management **19**:99-102.

Akis, S., N. Peristianis and J. Warner 1996. Residents' attitudes to tourism development: The case of Cyprus. Tourism Management **17**: 481-494.

Anderies, J. M. 1998. Culture and human agro-ecosystem dynamics: the Tsembaga of New Guinea, Journal of Theoretical Biology, **192**:515-530.

Anderies, John M., 2000. On modelling human behavior and institutions in simple ecological economic systems, Ecological Economics, **35**: 393-412.

Arrow, K., B. Bolin, , R. Costanza, P. Dasgupta, C. Folke, C. S. Holling, B. Jansson, S. Levin, K. Mäler, C. Perrings, and D. Pimental. 1995. Economic growth, carrying capacity and the environment. Science **268**: 520-521.

Beltratti, A., 1997. Growth with natural and environmental resources. Pages 7-42 *in* Carraro, C. and D. Siniscalco editors *New Directions in the Economic Theory of the Environment*. Cambridge University Press, Cambridge, U.K.

Bender, M. J., G. V. Johnson, and S. P. Simonovic. 1994. Sustainable management of renewable resources: a comparison of alternative decision approach. International Journal of Sustainable Development **1**: 77-88.

Brock, W. A. and A. G: Malliaris. 1989. Differential equations, stability and chaos in dynamic economics. North-Holland, Amsterdam, The Netherlands.

Brown, K., R. K. Turner, H. Hameed, and I. Bateman. 1996. Tourism and sustainability in environmentally fragile areas: case studies from the development and cultural theory. The International Journal of Sustainable Development and World Ecology **3**: 1-14.

Bramwell, B. and B. Lane. 1993. Sustainable tourism: an evolving global approach. Journal of Sustainable Tourism **1**: 6-16.

Butler, R. W. 1980. The concept of a tourist area cycle of evolution: implications for management of resources. Canadian Geographer **24**: 5-12.

Butler, R. W. 1991. Tourism, environment, and sustainable development. Environmental Conservation **18**: 201-209.

Carpenter, S. R., D. Ludwig, and W. A. Brock. 1999a. Management of eutrophication for lakes subject to potentially irreversible change. Ecological Applications **9**:751-771.

Carpenter, S., W. Brock, and P. Hanson. 1999b. Ecological and social dynamics in simple models of ecosystem management. Conservation Ecology **3**(2): 4. [online] http://www.consecol.org/vol3/iss2/art4

Cheve, M., 2000. Irreversibility of pollution accumulation. Environmental and Resource Economics, **16**:93-104

Christaller, W. 1963. Some considerations of tourism location in Europe: the peripheral regions - underdeveloped countries - recreation areas. Papers of the Regional Science Associations **12**: 95-105.

Clark, C. W. 1976. Mathematical Bioeconomics: The Optimal Management of Renewable Resources. John Wiley & Sons, New York, USA

Coccossis, H. and P. Nijkamp, editors. 1995. Sustainable Tourism Development. Avebury, Aldershot, UK.

Dahles, H. and K. Bras 1999. Entrepreneurs in romance - Tourism in Indonesia. Annals of Tourism Research **26**: 267-293.

Dharmaratne, G. S. 1995 Forecasting tourist arrivals in Barbados. Annals of Tourism Research **22**: 804-818.

Doedel, E. J. and J. P. Kernévez. 1986. AUTO: Software for continuation and bifurcation problems in ordinary differential equations. Applied Mathematics Report. California Institute of Technology, Reading, Massachusetts, USA.

Douglas, N. 1997 Applying the life cycle model to Melanesia. Annals of Tourism Research **24**:1-22.

Forrester, J. W. (1961). Industrial Dynamics. MIT Press, Cambridge, Massachusetts, USA.

Gatto, M., L. Ghezzi and S. Rinaldi. 1991. Optimal investment in the reclamation of eutrophic water bodies. Journal of Optimization Theory and Applications **71**: 389-398.

Gatto, M. 1995. Sustainability: is it a well defined concept? Ecological Applications **5**: 1181-1183.

Gilbert, E. W. 1939. The growth of inland and seaside health resorts in England. Scottish Geographical Magazine **55**:16-35.

Goodland, R. and G. Ledec. 1987. Neoclassical economics and principles of sustainable development. Ecological Modelling **38**: 19-46.

Hardin, G. 1960. The competitive exclusion principle. Science **131**: 1292-1298.

Harrison, D. 1995. Development of tourism in Swaziland. Annals of Tourism Research **22**:135-156.

Herfindahl, O. C. and A. V. Kneese. 1974. Economic Theory of Natural Resources. Merrill Publishing Company, Columbus, Ohio, USA.

Holling, C. S. 1986. The resilience of terrestrial ecosystems: local surprise and global change. Pages 292-317 *in* W. C. Clark and R. E. Munn, editors. Sustainable Development of the Biosphere. Cambridge University Press, Cambridge, UK.

Holling, C. S. 1993. Investing in research for sustainability. Ecological Applications **3**: 552-555.

Keeney, R. L. and H. Raiffa. 1976. Decision with Multiple Objectives: Preference and Value Trade-offs. Wiley, New York, USA

Khibnik, A. I., Y. A. Kuznetsov, V. V. Levitin, and E. V. Nikolaev. 1993. Continuation techniques and interactive software for bifurcation analysis of ODEs and iterated maps. Physica D **62**: 360-371.

Kulendran, N. and M. L. King 1997. Forecasting international quarterly tourist flows using error-correction and time-series models. International Journal of Forecasting **13**: 319-327.

Kulendran, N. and Witt, S. F. 2001. Cointegration versus least squares regression. Annals of Tourism Research **28**: 291-311.

Kuznetsov, Y. A. 1995. Elements of Applied Bifurcation Theory. Springer Verlag, New York, USA

Kuznetsov, Y. A. and V.V. Levitin. 1997. CONTENT: A multiplatform environment for continuation and bifurcation analysis of dynamical systems. Centrum voor Wiskunde en Informatica, Kruislaan 413, 1098 SJ Amsterdam, The Netherlands

Lim, C. 1997. Review of international tourism demand models. Annals of Tourism Research. **24**: 835-849.

Lindberg, K. editor. 1991. Policies for Maximizing Nature Tourism's Ecological and Economic Benefits. World Resources Institute, Washington DC, USA.

Ludwig, D. 1993. Environmental sustainability: Magic, science, and religion in natural resource management. Ecological Applications **3**: 555-558.

Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, resource exploitation, and conservation: lessons from history. Science **260**: 17-36.

Morley, C. L. 1998 A dynamic international demand model. Annals of Tourism Research **25**: 70-84.

O'Hare, G. and H. Barrett 1997. The destination life cycle: international tourism in Peru

Scottish Geographical Magazine. **113**:66-73.

Plog, S. C. 1973. Why destination areas rise and fall in popularity. Cornell Hotel and Restaurant Association Quarterly **13**: 6-13.

Rinaldi, S., W. C. Sanderson, and A. Gragnani. 1996. Pollution control policies and natural resources dynamics: a theoretical analysis. Journal of Environmental Management **48**: 357-373.

Roe, E. M. 1996. Sustainable development and cultural theory. The International Journal of Sustainable Development and World Ecology **3**: 1-14.

Ross, R. 1909. The Prevention of Malaria. Murray , London, UK.

Rubenstein, D. I. 1993. Science and the pursuit of a sustainable world. Ecological Applications **3**: 585-587.

Seddighi, H. R. and D. F. Shearing 1997. The demand for tourism in North East England with special reference to Northumbria: An empirical analysis. Tourism Management **18**: 499-511.

Shah, A. 1995. The Economics of Third World National Parks. Edward Elgar, Aldershot, UK.

Smith, V. L. and W. R. Eadington editors. 1992. Tourism Alternatives: Potential and Problems in the Development of Tourism. University of Pennsylvania Press, Varphiladelvarphia, USA.

Solow, R. M. 1991. Sustainability: an economist’s perspective. Marine Policy Center, Woods Hole Oceanogravarphic Institution, Massachusetts, USA.

Turner, R. K. 1993. Sustainability: principles and practice. Pages 3-36 *in* R. K. Turner, editor. Sustainable Environmental Economics and Management. Belhaven, London, UK.

Volterra, V. 1926. Variazioni e fluttuazioni del numero d'individui in specie animali conviventi. Memorie dell' Accademia dei Lincei **6**: 31-113.

Wall, G. 1997. Is ecotourism sustainable? Environmental Management **21:** 83-491.

Walker, P. A., R. Reiner, D. McDonald and V. Lyne 1998. The Tourism Futures Simulator: A systems thinking approach. Environmental Modelling & Software **14**:59-67.

Walters, C. J. 1986. Adaptive Management of Renewable Resources. McGraw Hill, New York, USA.

Williams, A. M. and G. Shaw editors. 1988. Tourism and Economic Development: Western European Experiences. Belhaven, London, UK.

Witt, S. F. and C. A. Witt 1995. Forecasting tourism demand: A review of empirical research. International Journal of Forecasting **11**: 447-475.