A Dynamic Model of Sustainable Tourism

ROBERT J. JOHNSTON AND TIMOTHY TYRRELL

Operational definitions of tourism sustainability require details regarding what is to be sustained, for whom it is to be sustained, and the level at which it is to be sustained. This article develops a dynamic model illustrating the interrelated behavior of tourism-related economic and environmental conditions throughout time. We characterize fundamental notions of sustainable tourism from the perspectives of both a profit-maximizing tourist industry and that of permanent residents of a tourist community. The model illustrates findings relevant to the search for sustainable outcomes and characterizes potential conflicts implicit in different sustainable and nonsustainable paths. The model demonstrates that (1) in all but the most rare of circumstances, there is no single, universal sustainable optimum; and (2) a policy that maintains overly pristine environmental quality may be just as unsustainable—from the perspective of either the tourism industry or residents—as a policy that causes excessive environmental decay.

Keywords: *tourism; sustainability; optimal control; economics*

Notwithstanding the substantial empirical and conceptual literature addressing aspects of sustainability in recreation and tourism (see Clarke 1997; Collins 1999), there remains "no widely accepted definition of sustainable tourism" (Swarbrooke 1998, p. 13). The concept remains subject to substantial confusion, with regard to its both precise implications and the specific patterns of resource use it implies (Collins 1999). This confusion is particularly evident with regard to specific tradeoffs, policies, actions, or indicators that are consistent with notions of sustainable tourism, leading some to suggest that sustainability as a concept may represent more of a guiding fiction or commercial mantra than a meaningful concept (Shumway 1991; McCool, Moisey, and Nickerson 2001; Collins 1999; Clarke 1997). To a significant extent, this may reflect a broader lack of formalism in common definitions of sustainability (Chichilinsky 1997; Tyrrell 1999). As noted by Collins (1999, p. 99), "much of the work [in sustainable tourism] seems not to be based on any explicit delineation of [sustainable development] principles."

Although empirical analyses provide substantial information relevant to tourism planning in specific case studies,[1] such work remains largely divorced from formal theoretical constructs of sustainable development (Collins 1999). Moreover, unlike other resource-intensive industries characterized by a search for sustainable outcomes subject to resource constraints and tradeoffs among stakeholder groups (e.g., fisheries and forestry), the tourism literature has thus far provided no generally accepted theoretical framework(s) through which one may assess progress toward sustainability. Indeed, the few theoretical works that have been proffered in this area have been met with skepticism (e.g., Collins 2001).

Given the highly applied nature of the tourism literature, such skepticism is understandable; formal theoretical models may be viewed as little more than complex mathematical abstractions, whose outcomes are largely driven by ad hoc assumptions. From an economic perspective, however, it is precisely the abstract nature of these models that allows for the provision of insights unavailable through empirical case studies. As stated by Henderson and Quandt (1971, p. 2),

> Theories represent simplifications and generalizations of reality and therefore do not completely describe particular situations. . . . [G]eneral theories are fruitful because they contain statements which abstract from particulars and find elements which many situations have in common. Increased understanding is realized at the cost of sacrificed detail.

The complementary role of theoretical and empirical treatments of sustainability may be seen in the renewable resource literature. For example, the fisheries literature complements a substantial body of empirical work with a theoretical literature illuminating the role of tradeoffs in optimal steady-state outcomes (e.g., Clark 1990; Clark, Clarke, and Munro 1979). These formal mathematical models—often denoted bioeconomic models—assist in identifying tradeoffs associated with different variants of sustainability, assessing the optimality of different resource trajectories, and identifying implications for stakeholder groups (e.g., Dasgupta and Heal 1974; Johnston and Sutinen 1996; Reed 1984). Although such models are often based on general notions of social outcomes (e.g., net economic benefits) and relatively abstract specifications of natural phenomena (e.g., general mathematical specifications of growth functions and carrying capacity), such abstractions allow less obscured focus on fundamental questions of interest.

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Following in the tradition and methods of bioeconomic modeling in the renewable resource literature, this article develops a dynamic model illustrating the interrelated behavior and change of tourism-related economic and environmental conditions throughout time. Specifically, a theoretical dynamic optimization model is developed for a region seeking to maximize sustainable benefits from tourism. Based on this model, we characterize and contrast fundamental notions of sustainable tourism from the perspectives of two key stakeholder groups: a profit-maximizing tourist industry and permanent residents of the tourist community. Even at the general level presented, the model illustrates key findings relevant to the search for sustainable outcomes and characterizes the potential conflicts, hazards, and tradeoffs implicit in the choice among different sustainable (or nonsustainable) futures.

TRADEOFFS AND ENVIRONMENTALLY SUSTAINABLE TOURISM

Theoretical analysis of sustainable tourism requires a functional definition of sustainability. As noted above, the functional definition of sustainability applied here draws from the renewable resource literature and is related to the concept of carrying capacity in the tourism literature (Swarbrooke 1998). Environmentally sustainable tourism may be thought of as a level of tourism that may be realized based on a sustainable or steady-state environment. More specifically, we define an environmentally sustainable optimum as the maximum level of a desired outcome (e.g., economic profits and quality of life) that may be maintained in a steady-state solution, subject to constraints imposed by the local environment. The goal of the analysis is to illustrate tradeoffs implicit in the search for sustainable (i.e., steady-state) outcomes that are optimal for different user groups and to illustrate implications for policies that seek steady-state solutions that are universally optimal for all groups.

Characterized in this way, it is clear that the concept of sustainable tourism is consistent with a wide variety of different outcomes for a tourist destination. This can lead to significant controversy regarding which version of sustainable tourism a region wishes to pursue. The World Commission on Environment and Development report, entitled *Our Common Future* (1987), also referred to as the Brundtland Report, provides the most widely recognized definition of sustainable development. Within this report, sustainability is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This definition suggests relatively undisputed social goals and an ability to agree on policies that meet, for example, the needs of the present. There is, however, general consensus among economists and others that nearly all public policies—tourism related or otherwise—create both winners and losers (Collins 1999; Boardman et al. 2001). Hence, there is rarely perfect agreement on those policies that are most appropriate for satisfying even the needs of the present, much less those that satisfy the complete Brundtland definition.

Conflicts with regard to the potential goals of sustainable tourism imply that the concept of sustainable tourism alone does not convey sufficient information to define a tourism policy. Operational definitions of sustainability require additional details regarding what is to be sustained, for whom it is to be sustained, and the level at which it is to be sustained (Pezzey 1997). For example, one may seek to sustain the number of visitors, the size or growth of industry profits, the quality of some or all environmental resources, the quality of the tourist experience, the number of tourist jobs, the quality of life of local residents, or some combination of these and other elements. It is unlikely that all may be sustained simultaneously.

Here, given the focus on *environmentally* sustainable tourism, primary emphasis is placed on maintaining a certain level of environmental quality (broadly defined), whereas secondary emphasis is placed on the economic viability of the tourism industry (Collins 1999). These emphases notwithstanding, environmentally sustainable tourism is impossible without both a sustainable environment and a viable tourism industry.[2] Maintaining an appropriate and sustainable balance between benefits realized by the tourism industry and environmental quality, however, is complicated by the relationship between tourist visitors and environmental quality—although visitors are often attracted by the environmental attributes of tourist destinations (e.g., Dixon and Hof 1997), these visitors can in turn degrade the environment (Briassoulis 2002).

In addition to considering the potential sustainability of environmental quality and the viability of industry, a third element that must be addressed when considering sustainable policies is the social well-being of local residents—which may be either commensurate or in conflict with industry goals (Mason and Cheyne 2000). Although residents may benefit from tourism income, jobs, and tax revenue (Haralambopolous and Pizam 1996), they react negatively toward such factors as tourism-related congestion, environmental degradation, and noise (Mason and Cheyne 2000). Nonetheless, the support of local residents may be critical to tourism sustainability, because the conservation behavior of residents may be necessary to sustaining the environmental resources that attract tourists.

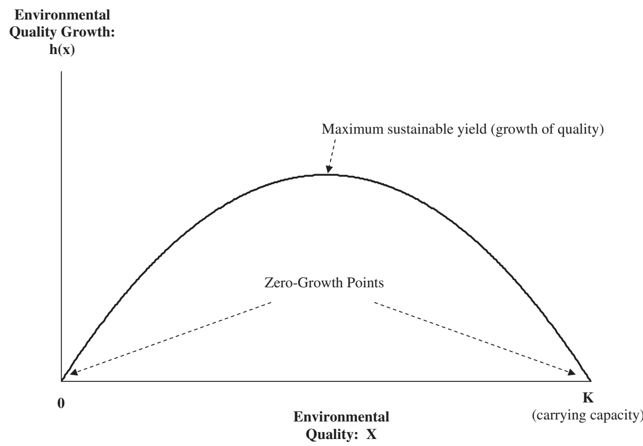
Although differences among the objectives of industry, residents, and/or other stakeholders are well known, the literature provides no formal definition or model that incorporates such differences into an operational concept of sustainable tourism (Collins 1999; Swarbrooke 1998). Indeed, one of the primary challenges of sustainable tourism is the large number of stakeholders involved, such that "it is not surprising that it is difficult to reach a consensus on what sustainable tourism means and how it can be achieved" (Swarbrooke 1998, p. 16). For simplicity, we focus here on two stylized groups—industry and residents—although the presented models may be easily adapted to accommodate greater numbers of stakeholder groups.

A DYNAMIC MODEL OF SUSTAINABLE TOURISM

The optimization model that follows is meant to assist tourism planners in conceptualizing choices and tradeoffs implicit in various options for environmentally sustainable tourism, at a general level. The formal mathematical structure of the proposed model is nearly identical to that used in certain applications of optimal control theory to fisheries (Clark 1990). Here, we adapt such models to address tourism in a stylized community where the number of visitors depends, at least in part, on the quality of the local environment. The precise definition of a *community* is not important—it can be a village or an entire province. It is simply viewed as a group of people who affect each other by their actions and who have some collective decision-making authority. Within this community, we assume that there are two groups with a primary interest in the existence and outcomes of tourism (although one may certainly develop a model in which more groups are considered)—local permanent residents and tourism industry planners. The benefits received by the two groups, however, may differ.

Although theoretical dynamic optimization models in the renewable resource literature are often rich in potential solutions and policy implications (Cropper 1976), they typically maintain a relatively high degree of abstraction to preserve generality and simplify analysis (Johnston 2003). We continue in this tradition. The rich exposition and detail often present in less formal models (or discussions) of tourism sustainability typically result in unmanageable mathematical solutions in the context of optimal control models. Hence, the basic model is kept simple to maintain a focus on the primary dynamics of interest and their implications for tourism.[3]

FIGURE 1
GROWTH (OR RENEWAL) OF ENVIRONMENTAL QUALITY AT A TOURIST SITE: GROWTH AS A FUNCTION OF THE STOCK OF ENVIRONMENTAL QUALITY



ENVIRONMENTAL QUALITY AND TOURISM: A SIMPLE SPECIFICATION

Renewable environmental resources such as fisheries and forests reproduce and grow, but are also subject to both natural mortality and human disturbance. If left undisturbed, renewable resources are typically assumed to reach a maximum level at which birth and growth exactly balance decay and death (Hartwick and Olewiler 1986, pp. 247-50). This point, denoted the natural carrying capacity of the resource, is sustainable (Clark 1990). Because, however, the carrying capacity is only obtainable for resources left undisturbed by human use, it is generally not a viable option for resources supporting a tourism industry.

Although most tourism depends on multi-attribute bundles of environmental resources, we simplify the model by assuming that the condition of all renewable resources in the community may be appropriately measured by one composite index variable, X, which we denote *environmental quality*. This index consolidates the notions of resource quality and ecosystem productivity for all types of renewable resources into a single index. Also for simplicity, we assume that all resources on which tourism depends are renewable to some degree; nonrenewable resources are not considered.[5] These simplifications allow us to emphasize the fundamental tradeoff between visitors and environmental quality (Dixon and Hof 1997).

For a renewable resource, we assume that environmental quality gradually renews itself, or grows, in proportion to the underlying stock of the resource. The growth function—here specified using the simple function $h(X)$—implies that natural renewal or growth of environmental quality is a mathematical function of X. Within the renewable resource literature, $h(X)$ is often assumed to follow a pattern similar to that shown in figure 1, based on an underlying logistic growth function (Hartwick and Olewiler 1986, p. 250). That is, when environmental quality is highly degraded (i.e., small), the natural improvement in quality, $h(X)$, will be relatively small. When environmental quality is pristine (at its maximum level or carrying capacity, K), there can be no natural improvement; by definition, $h(K) = 0$. Growth will be fastest at some point between zero and K, peaking at a point of maximum sustainable yield. This is shown by figure 1.

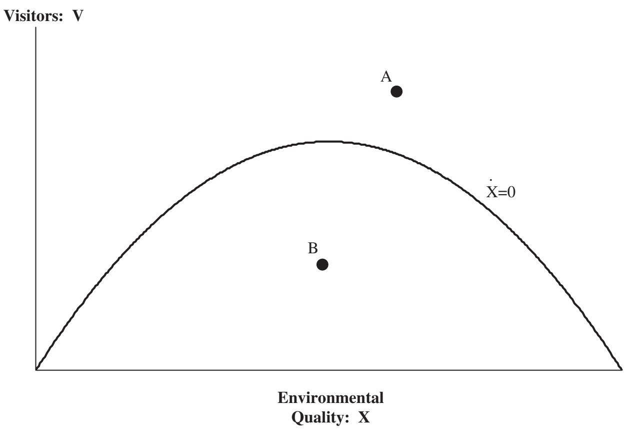
We assume that although tourist visitors are attracted by higher levels of X, they also cause environmental quality to degrade. In simple terms, each visitor consumes or degrades a small quantity of environmental quality during their visit. If not replaced by sufficient natural growth, the result will be a smaller stock of environmental quality remaining in the future (Dixon and Hof 1997). From another perspective, when visitors disturb the resource, some or all of its growth will be applied to recovery from this disturbance.

The number of visitors per period (e.g., per day, week, or year) is given by V. For simplicity, we assume that each visitor uses up a constant m units of environmental quality per period. That is, V visitors will result in a loss of mV index-units of environmental quality per period.[5] The simplest mathematical case for analysis is the case in which $m = 1$, or in which each visitor causes exactly 1 index-unit of degradation per period. Hence, for the greatest possible mathematical simplification, we scale the environmental quality index such that $m = 1$. The result is that V visitors will cause exactly V index-units of environmental quality to be lost per period. Although this simplification may be easily relaxed, doing so does not alter fundamental aspects of the model discussed here.

The equation describing the total per period change in environmental quality combines the negative influence of visitors (V) and the positive influence of natural growth $h(X)$, such that

$$\ddot{X} = h(X) - V \quad (1)$$

FIGURE 2
LOCUS OF SUSTAINTABLE ENVIRONMENTAL QUALITY WITH REGARD TO VISITOR NUMBERS: VISITOR-QUALITY PAIRS IN WHICH QUALITY REMAINS CONSTANT



where $\ddot{X}$ is the change in X during a time period.[6] That is, $\ddot{X}$ indicates the *change* in environmental quality from period to period, which may be positive, negative, or zero.

Sustainability of environmental quality occurs when $\ddot{X}$ = 0 (i.e., no change in environmental quality throughout time) and depends on finding a balance between natural growth and visitor damage. At its natural carrying capacity, K, environmental quality is sustainable only if there is no use by visitors. At a level of X slightly lower than this maximum, some growth could occur and some visits could be made without changing quality. In the middle of the range of environmental quality when the natural rate of growth is highest, the level of sustainable visitation is also highest. Sustainable environmental quality occurs when natural growth exactly offsets tourist-related degradation, or when $h(X) - V = 0$. Based on this mathematical relationship, figure 2 illustrates all sustainable levels of environmental quality and tourist visits.

Each point along the curve in figure 2 identifies a sustainable pair of visitation and environmental quality levels, based on natural environmental relationships. Points higher than the curve (e.g., point A) represent conditions in which visitor damage exceeds natural renewal—hence, environmental quality will degrade throughout time. Points lower than the curve (e.g., point B) represent conditions in which natural renewal exceeds visitor damage—hence, environmental quality will improve throughout time. (Continuous positive changes in environmental quality, although perhaps desirable, cannot be sustained indefinitely and hence violate our definition of *sustainable*.) Only along the curve does natural renewal exactly balance visitor damage throughout time—a sustainable condition.

THE BENEFITS OF SUSTAINABLE TOURISM

Although figure 2 shows the loci of sustainability with regard to the natural environment, it does not yet account for sustainability with regard to the economic viability or benefits of tourism. To introduce this aspect of the model, we must specify the objectives of different groups—in this case, the tourism industry and local residents. We assume that the goal of the tourism industry—as a collection of businesses—is profits. Although this is a stylized representation of industry goals, it allows us to retain a focus on the central aspects of the model. From year to year, it is the goal of the industry to maintain and, if possible, increase net profits. This translates to a long-term goal of maximizing the sum of discounted profits throughout time.

We assume that industry maximizes the sum of *discounted* profits to account for the time value of money. That is, although the primary goal of sustainability is to maintain the flow or stock of some variable(s) throughout the indefinite future, we also recognize that most individuals prefer benefits received in proximate time periods (i.e., close to the present), compared to identical nominal benefits received in the distant future. Formally, we assume that profits are discounted when summing throughout time to account for the time value of money. Just as a bank recognizes the time value of money by charging borrowers interest, a long-term industry objective must recognize the cost of waiting for its profits by discounting those received in the distant future. This follows a long tradition of models addressing the dynamics of resource use (Clark 1990). Here, individuals' collective rate of time preference is indicated by the discount rate (Boardman et al. 2001), which here is denoted by the variable r. Although r may in theory vary between 0 and ∞, practitioners often recommend discount rates from 0.01 to 0.04 (Freeman 2003, p. 199).

We presume that tourist industry profits may be represented as a general mathematical function of the number of visitors, V, and of environmental quality, X, given by $\Pi(V, X)$.[7] This matches the form of profit functions found in Clark (1990), Johnston and Sutinen (1996), and other theoretical assessments of optimal resource use. We assume that profits are increasing in both V and X, but increase with respect to both variables at a decreasing rate. That is, profits increase as the number of visitors increases, holding all else constant, but each additional visitor adds a little less to industry profits on the margin. Similarly, profits increase as environmental quality increases, holding all else constant, because visitors will pay more to visit higher-quality locations. Each successive improvement to environmental quality, however, results in a slightly smaller gain in industry profits—reflecting diminishing marginal returns.

Although this general specification of the profit function may seem unusual to those accustomed to structural definitions of profit functions incorporating explicit specifications of revenues and costs, the general form $\Pi(V, X)$ in fact subsumes more familiar structural specifications of profit functions. Mathematical relationships between such general functional forms and those that explicitly distinguish revenues and costs are illustrated by Clark (1990) for the case of bioeconomic fisheries models—analogous relationships apply here.[8] The general functional specification allows for a wider range of outcomes than is typically possible given more highly constraining (and cumbersome) functions that specify explicit functional forms.[9]

The challenge facing the tourist industry is to find the location on the sustainable environmental locus (figure 2) that maximizes the sum of discounted profits, $\Pi(V, X)$, throughout time. Following standard notation, one may represent the sum of profits in continuous time units as $\int_0^\infty [\Pi(V, X)]e^{-rt}dt^x$.[10] Profits may be controlled directly through the number of visitors, V, which may be manipulated through advertising, promotion, and infrastructure development. Profits may also be controlled indirectly through environmental quality. Sustainable, profit-maximizing solutions attain the balance between visitor numbers and environmental quality that results in the greatest sum of discounted net profits throughout all time periods.

Although the tourism industry seeks to maximize profits, local permanent residents may have different goals (Mason and Cheyne 2000).[11] In the simple model that follows, we follow standard neoclassical economic models and assume that permanent residents maximize utility, or well-being. We assume that utility is positively related to tourism industry profits, $\Pi(V, X)$, due to the positive relationship among profits, jobs, and resident income. (Moreover, if tourist business owners reside in the tourist community, then they are also residents.) Residents' utility is not, however, determined solely by industry profits. Utility is also influenced by other factors directly related to tourist numbers; these include congestion, traffic, environmental quality, and other attributes that directly influence quality of life (Mason and Cheyne 2000).

Here, we add additional structure to the model by assuming that residents' utility, $U(V, X)$, may be specified as an additively separable function,

$$U(V, X) = \Pi(V, X) + B(V, X) \tag{2}$$

where the function $B(V, X)$ represents the *difference* between industry profits and net utility (or quality of life) realized by local residents. Specifying utility as in (2)—although not necessary to the model—allows for greater specificity in the discussion of model results, because it provides a distinct element of the model ($B[V, X]$) that distinguishes industry profits and residents' utility. In general, we assume that $B(V, X)$ is positively influenced by environmental quality and negatively influenced by the number of visitors. Hence, compared to industry, residents receive a relatively greater benefit from their enjoyment of environmental quality and a relatively lower benefit from increases in visitor numbers.

OPTIMAL DYNAMIC SOLUTIONS

The control variable—or the variable over which policy makers are assumed to have influence—is the number of visitors. The resulting number of visitors, in turn, influences environmental quality. This is a simplification of the situation in which the industry or government seeks to manipulate the number of tourists in different market segments through advertising, capacity controls, fees, or direct investment in the resource and its protection.[12] Although the presented model allows only a single control variable representing the total number of visitors, it may be extended to allow multiple visitor types, each with a distinct effect on environmental quality as well as on tourism benefits and costs (e.g., see Perdue 2003). More elaborate models could also be specified to allow for additional policy controls such as the allocation of promotional budgets to different target markets, restrictions aimed at specific tourist activities, and/or education aimed at reducing the environmental impact per visitor. Although such extensions would not require fundamentally new quantitative methods, they would significantly add to the complexity of the mathematical presentation. Hence, such extensions—although clearly relevant to tourism development—are left for future work.

The optimal steady-state solution to the model (or optimal control solution) specifies a point or set of points that maximizes the objective function for any particular group given the requirement that environmental quality remains sustainable. In other words, it provides a sustainable path of visitor levels that maximizes an objective (profits or utility) throughout time while accounting for indirect changes in environmental quality.

OPTIMAL SOLUTIONS, PATHS, AND INTERPRETATIONS

The following section formalizes the objectives of industry and residents, and illustrates implications for optimal steady-state (or sustainable) tourism. For the tourism industry, we maximize the sum of discounted profits,

$$\int_0^\infty [\Pi(V, X)]e^{-rt}dt^x \tag{3}$$

with respect to the number of visitors, V. That is, industry wishes to choose the number of visitors in each time period to maximize the sum of discounted profits throughout time. The choice of visitors will also, indirectly, determine the level of environmental quality in each time period, based on equation (1).[13] The integral represents the sum of net profits throughout all time periods from time 0 (today) to infinity, given a continuous concept of time (i.e., time periods are allowed to become infinitesimally small). The discounting term (e^{-rt}) accounts for the continuous, gradual discounting of profits as one moves further into the future (Chiang 1992), where e is the exponential operator, t is the time period, and r is the discount rate.

The maximization problem is solved using optimal control theory (Chiang 1992). Formally, we maximize the profit function (3) subject to (1), which specifies constraints related to the natural renewal of environmental quality. To minimize mathematical notation—and to maintain clarity for those unfamiliar with such methods—we suppress the full set of necessary and sufficient conditions for a maximum. Instead, we move directly to the equations characterizing implications for the optimal number of visitors and environmental quality throughout time. More complete mathematics characterizing the optimal solution—for those more familiar with dynamic optimization—are presented in the appendix.

The equation characterizing the *change in visitors throughout time consistent with the maximization of tourism industry profits* is given by

$$\ddot{V} = \frac{(\bullet_V)(r - h_X) - \bullet_X}{\bullet_W}. \tag{4}$$

Following standard mathematical notation, subscripts denote partial derivatives.[14] For example, Π_X represents the partial derivative of profits with respect to changes in environmental quality, Π_V represents the partial derivative of profits with respect to changes in the number of visitors, and h_X represents the partial derivative of the environmental growth or renewal function with respect to changes in baseline environmental quality. The dot (•) represents a change with respect to time (or a change throughout time), such that $\dot{V}$ is the change in visitors in each time period.

Equation (4) shows the change in visitors consistent with the maximization of the present value of net profits for the tourism industry. It reflects mathematically how the number of visitors would be ideally changed (i.e., in a way that maximizes the discounted sum of profits) by the tourism industry at any point in time, given specific baseline combinations of visitation and environmental quality. In more formal terms, equation (4) characterizes an *optimal path* with regard to the number of visitors in each time period, from the perspective of the tourism industry. It does not, however, give the path—an integration is involved to transform changes in visitors into numbers of visitors at any point in time.

In contrast to the optimal industry solution, permanent residents seek to maximize

$$\int_0^{\infty} [U(V,X)]e^{-rt}dt = \int_0^{\infty}[\Pi(V,X)+B(V,X)]e^{-rt}dt \tag{5}$$

based on equation (2). Note that if we set $B(V, X) = 0$ in (5), the only benefits remaining are the profits earned by the tourism industry, $\Pi(V, X)$. Analogous to the optimal control solution for industry, the benefit function for residents (5) is maximized subject to (1), which specifies constraints related to the natural renewal of environmental quality.[15] Technical details of the solution are shown in the appendix.

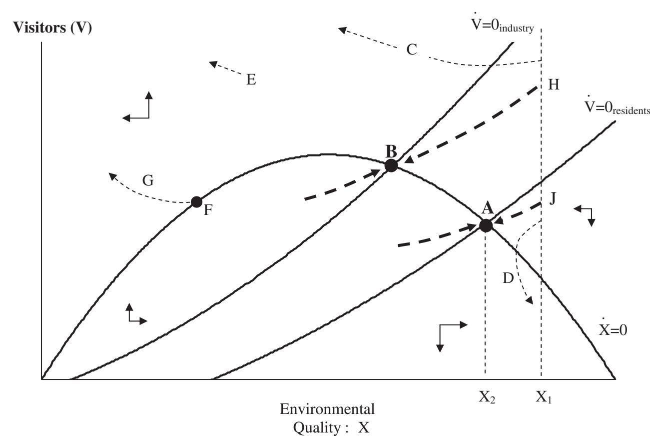
The optimal control solution characterizes the *change in visitors throughout time consistent with the maximization of residents' quality of life* (or utility), and is given by

$$\dot{V} = \frac{[(\bullet_V + B_V)(r - h_X)] - [\bullet_X + B_X]}{\bullet_W + B_W}. \tag{6}$$

Equation (6) is analogous to (4), except that it characterizes the optimal path of visitors from the perspective of local residents. Again, the subscripts denote partial derivatives, such that B_V represents the partial derivative of $B(V, X)$ with respect to changes in the number of visitors, and B_{VV} represents the second derivative of $B(V, X)$ with respect to changes in the number of visitors. Note that (4) may also be obtained by setting all partial derivatives of $B(V, X)$ in (6) equal to zero, because by definition $B(V, X) = 0$ for industry.

Sustainable solutions are characterized by zero changes throughout time in both environmental quality (X) or the number of tourist visitors (V)—that is, solutions in which both $\dot{X} = 0$ and $\dot{V} = 0$ based on (1), (5), and (6). Figure 2 characterizes the points in which $\dot{X} = 0$. Figure 3 combines this environmental locus (curve) with additional visitation loci characterizing $\dot{V} = 0$ for both local residents and for industry. The residential visitation locus represents points that maximize utility to local residents, given the constraint that the number of visitors does not change throughout time, based on (6).[16] This locus is labeled $\dot{V} = 0_{\text{residents}}$. The industry visitation locus represents points that maximize profits to the tourism industry, given the constraint that the number of visitors

FIGURE 3
PHASE DIAGRAM FOR ENVIRONMENTALLY SUSTAINABLE TOURISM: STEADY STATES AND OPTIMAL PATHS



Note: A = resident sustainable optimum; B = industry sustainable optimum.

does not change throughout time.[17] This locus is labeled $\dot{V} = 0_{\text{industry}}$.

The points at which these two visitation loci cross the locus of environmental sustainability ($\dot{X} = 0$, as described above) represent two different steady-state, sustainable solutions for tourism. For example, the intersection of $\dot{V} = 0_{\text{residents}}$ and $\dot{X} = 0$ (point A, figure 3) represents the point at which the present value of net benefits for local residents is at a maximum level throughout time, given the constraint that both the number of visitors and the environmental quality are sustained at a fixed level indefinitely. In contrast, the intersection of $\dot{V} = 0_{\text{industry}}$ and $\dot{X} = 0$ (point B, figure 3) represents the point at which the present value of tourism industry profits is at its maximum possible level throughout time, given the constraint that both the number of visitors and the environmental quality are sustained at a fixed level indefinitely. Hence, unlike less formal presentations of sustainability, the dynamic model presented here allows one to identify feasible, sustainable solutions that maximize benefits to either industry or local residents.[18]

Although figure 3 may seem unfamiliar to some, phase diagrams are a common means to illustrate an infinite variety of optimal solutions to dynamic problems. One may think of this diagram as a road map. Each point on the map lies on some optimal route that might be taken between places. The differences between the routes are the initial locations and where each path leads. In terms of environmental quality and tourism, we are given the former (X-axis) and are allowed to choose the latter (V-axis). Ideally, one would specify the entire path as part of a tourism plan, with the goal of ultimately reaching a particular sustainable (steady-state) endpoint.

IMPLICATIONS FOR SUSTAINABLE TOURISM

Although the dynamic model is simplified to reduce mathematical complexity, it offers numerous insights relevant to sustainable tourism development. If one accepts the assumptions on which the model is built, these implications follow necessarily—they are not contingent on conditions present in a particular region or empirical case study. This is one of the strengths of such models: the capacity to transcend limited case study evidence and provide general results applicable over a wide range of conditions.

Perhaps the most fundamental result is that many environmentally sustainable outcomes are feasible for tourism. For example, zero visitors is an environmentally sustainable outcome—however, this is a largely trivial result. Sustainable outcomes that maximize discounted benefits to different user groups are fewer, however, and indeed may be unique. Perhaps more importantly, model results also indicate that sustainable solutions that are most desirable for the tourism industry will not, in general, be the same as those that are most desirable for local residents. Given that the most desirable sustainable outcomes differ across groups, the search for sustainable tourism outcomes must combine the search for environmentally sustainable outcomes (which are many) with socially acceptable compromise solutions that lie somewhere among the optima for each distinct group.

Put another way, the model demonstrates that in all but the most rare of circumstances, there is no single, universal sustainable optimum for visitor numbers. No amount of searching, bargaining, or stakeholder education will reveal a single sustainable solution that maximizes profits to industry and utility to residents; even in the fairly general case presented here, such a solution does not exist. The search for sustainability implies that at least one group will be worse off compared to their most preferred environmentally sustainable outcome. Hence, even if a tourist destination is at an environmentally sustainable, optimal solution from the perspective of one group (e.g., industry at point B), there may nonetheless be political pressure from other groups (e.g., residents) to depart from that point.

A second significant result of the model is that a policy that maintains an overly pristine level of environmental quality may be just as unsustainable—from the perspective of either the tourism industry or local residents—as a policy that causes excessive environmental decay. For example, a policy that forces a community to maintain an environmental quality of X_1 (shown in figure 3) may result in a long-term loss of benefits to both industry and local residents, compared to those that could be achieved were industry allowed to follow a more optimal path (e.g., to either point A or B).

Hence, compared to that which is maintained in optimal sustainable solutions, environmental quality can be either *too high* or *too low*. The careful balance that must be achieved in both sustaining the environment and sustaining a viable tourism industry (and local population) is one of the key illustrations of the model.

APPROACH PATHS TO SUSTAINABLE OUTCOMES

The optimal paths to the steady-state solutions are given by the bold dashed arrows in figure 3. These show approaches to the optimal, sustainable tourism solutions that maximize either residents' utility or industry profits, from any given level of environmental quality to the steady-state, sustainable level. In some instances, the profit- (or utility-) maximizing paths may be unexpected and counter to practices often encountered in tourism development.[19]

For example, beginning at a high level of environmental quality (e.g., X_1 in figure 3), the profit-maximizing path for industry begins with a relatively high number of visitors (e.g., point H), which then declines gradually throughout time as environmental quality declines. This continues until point B is reached, at which point the profit-maximizing strategy is to maintain that level of visitors and environmental quality indefinitely—the optimal sustainable outcome. For residents beginning at the same level of environmental quality, the most desirable path starts with a lower number of visitors (e.g., point J), falling gradually to point A. This sustainable point is characterized by fewer visitors and a higher environmental quality than is optimal for industry.

In both cases, the optimal strategy begins with a relatively large number of visitors, with reductions in visitor numbers throughout time. This might reflect, for example, the almost instantaneous development of a large megaresort in a previously pristine environment, with very large numbers of initial visitors slowly declining to a more sustainable level. This stands in contrast to slow-growth tourism patterns characterized by the initial stage of the rise of a tourist destination (Plog 1974). Although results here suggest that slow-growth tourism patterns may not be optimal given a pristine environmental starting point, they may be unavoidable in some instances, given the time required to develop necessary tourism infrastructure.

Expanded (and more complex) variants of the illustrated model might incorporate the impacts of such infrastructure constraints on optimal tourism development. In addition, it might be possible to discover a type of environmental quality dynamic that would imply that slow growth is the most optimal development strategy. More complex models might also be developed to allow for patterns such as those described by Perdue, Long, and Kang (1999), who found that the local effects of casino development may be negative in the short run due to social disruption, followed by positive change as the community adjusts to its new situation.

MYOPIA AND SUSTAINABLE TOURISM

As shown in figure 3, the two optimal steady states (A and B) require the maintenance of relatively high levels of environmental quality. This reflects the fact that environmental quality directly influences profits per visitor (visitors are willing to pay more to visit pristine locations) and residents' utility. The tourism industry controls profits directly through its influence on visitor numbers and indirectly though the influence of tourism on environmental quality. The tradeoff between visitor numbers and environmental quality may, however, lead to numerous traps, in which a myopic goal of short-term profits will render unattainable sustainable benefits that would otherwise be greater in the long term.

For example, if the industry is myopic, it may not realize its role in maintaining environmental quality and may view changes in visitor numbers as the sole or primary means to improve profitability. In such cases, industry may follow paths that will increase short-term profits in an unsustainable manner. For example, beginning at a quality level (X_1), the tourism industry might seek to increase visitors too quickly in pursuit of short-term profits. The dashed curve labeled *C* might result, characterized by ever-larger numbers of lower-paying tourists and a long-run decline of industry profits. Ultimately, this path leads to a total degradation of environmental quality and a collapse of the tourism industry.

Contrasting myopic—and similarly unsustainable—paths may also be chosen by those representing local residents. Beginning at the same quality level, X_1, residents may react to declining environmental quality by seeking to decrease visitor numbers too rapidly. The result is rapidly declining visitor numbers and a concurrent decline in industry profits—and with those profits, long-term income and jobs for residents. Although environmental quality improves throughout time, the benefits lost due to losses in jobs and local income more than offset gains in quality of life due to changes in environmental quality. Such a path is represented by the dashed line labeled *D*. Like C, it represents a path that may be chosen based on the best of short-term intentions but is one that results in nonsustainable, dynamically unstable changes in tourism and environmental quality. It should be noted that the paths represented by C and D are optimal in the sense that they produce the greatest long-term profits from any starting point along their paths; however, they do not lead to a steady-state, sustainable solution.

NONSUSTAINABLE TOURISM AND THE ROLE OF GOVERNMENT

Tourism planners may also attempt to maintain points that are distinct from either points A or B. Such points will, however, necessarily be inferior by at least one measure. For example, planners seeking to sustain point E will find that environmental damage due to tourism exceeds the natural capacity of the environment to renew itself. The resulting decline in environmental quality implies that an increasing number of visitors is required to sustain industry profitability—still further exacerbating the decline in the environment in a dynamically unstable path away from this initial point (the dashed line).

Even some points that are environmentally sustainable (i.e., on the $\dot{X} = 0$ locus) may be unsustainable from a social perspective (industry or resident) unless they also fall along one of the $\dot{V} = 0$ loci. For example, point F represents a point at which environmental damage due to visitation exactly offsets natural renewal—an environmentally sustainable outcome. Nonetheless, *both* profits and residents' quality of life may be improved by increases in visitation at this point (unlike optimal points A and B, at which increases in long-term benefits to one group will *necessarily* diminish those of the other group). This leads to pressure to increase visitation on the nonsustainable path, *G*, characterized by long-run declines in the environment and increases in ever lower-paying visitors. Hence, although point F is environmentally sustainable, it is not consistent with the maximization of benefits to either stakeholder group.

Similarly, certain target levels of profits may not be sustainable, because they may require combinations of visitors and environmental quality that are unsustainable in the long run. For example, profits attainable at point H—a point of very high visitation and environmental quality—may not be sustained regardless of the efforts of tourism planners. At this point, environmental quality will decline sharply due to the large number of visitors, and there will be associated pressure from industry to reduce visitor numbers, leading to the maximum sustainable level found at point B. Short-term efforts to maintain profits higher than this level will only further diminish the benefits of tourism in the long run.

Despite these many constraints, government officials may in some cases encourage more beneficial long-term tourism by imposing minimum environmental standards. Care must be taken when establishing this standard, however, because as discussed above, most pairs of environmental quality and visitor numbers are unsustainable from either a natural ($\dot{X} = 0$) or social ($\dot{V} = 0$) perspective. Nonetheless, if government sets a minimum level of environmental quality near X_2, for example, and the starting point is one of high quality (e.g., X_1), the optimal steady-state solution for industry (B) will be approached simply as a result of short-term attempts to maximize profits. Such possibilities illustrate that, given the careful use of environmental standards, government may be able to create situations in which short-term incentives facing the industry lead to sustainable long-term outcomes. Inappropriate standards may, however, have the opposite effect—encouraging unsustainable behavior and an ultimate decline of tourism.

CONCLUSIONS

This article presents a formal optimal control model of tourism dynamics based on theoretical approaches used to assess resource use in fisheries, forests, and other natural resources. Such models follow in the tradition of economic theory summarized by McClements (1973, p. 107):

> [T]heory provides a set of statements about economic relationships on the basis of simple, but approximate behavioral assumptions. These assumptions may be unrealistic and require replacement or elaboration. [Nonetheless] . . . [t]he application of the body of logical constructs which constitute an economic theory enables us to focus on the important features of a particular economic question.

Although results are of course dependent on the structure and assumptions of the model, similar fundamental results will often apply in cases in which simplifying assumptions are relaxed. Although the model is purposefully kept simple, it illustrates a range of findings not present in the tourism literature.

It is not the argument of this article that the presented model is the sole way that such analytic tools may be applied to sustainable tourism issues. Rather, we present the model as a template—an alternative mechanism that may be added to the toolbox available to those assessing tradeoffs in sustainable tourism. Although much work would be required to apply such a tool to a specific tourist community or region, it is hoped that the general insights forthcoming from such models may be broadly useful to those seeking alternatives for sustainable tourism.

The primary purpose of the model is to conceptualize tradeoffs implicit in the search for sustainable tourism outcomes and to provide greater understanding of that which is necessarily implied—and not implied—by environmentally sustainable tourism. As such, the model is meant to provide a preliminary step toward greater structure and clarity in the discussion of tourism sustainability—a concept that has been subject to considerable ambiguity in the prior literature. Although theoretical results such as those presented here do not provide quantitative formulas that communities may use to determine specific tourism targets, they nonetheless provide insight into concepts and tradeoffs associated with environmentally sustainable tourism.

Of particular relevance here is the conclusion that the dual goals of sustaining visitor numbers together with the quality of the environment are feasible and may also be designed so as to maximize social benefits (either profits or quality of life). Nonetheless, the environmentally sustainable solutions that are considered optimal will likely vary across stakeholder groups, unless the objective functions of these groups are identical. Hence, the search for a universal, sustainable optimum will result in a null set. Moreover, other goals, such as sustainable *growth* in profits or quality of life, may not be compatible with environmental sustainability and are likely nonattainable—at least given fixed technology. Furthermore, target levels of visitation, environmental quality, or profits must be chosen carefully, because many target levels are also unsustainable.

Aside from the fundamental finding that the optimal point of tourism sustainability is not the same for residents and industry, the model finds that the myopic paths of each group may react to identical levels of initial environmental quality in opposing directions—with residents maintaining visitors at a lower-than-optimal level and industry seeking to increase visitors too rapidly. In both cases, the result is unsustainable tourism and a diminution of net social benefits. Similar loss of profits may result from well-intended constraints on environmental quality that might be imposed by governments.

In some instances, insights into optimal policy provided by optimal control models may run contrary to common wisdom. For example, solutions shown above illustrate that pristine levels of environmental quality may be just as unsustainable as overly degraded levels with regard to the optimization of social benefits to either residents or industry. Other findings may be more intuitive, such as the finding that myopic policies may reduce industry profits in the long run. Even in such cases, however, dynamic models may provide useful insights—for example, when and how environmental quality standards may encourage sustainable outcomes that maximize social benefits, and when such policies may hinder the search for sustainability.

Finally and perhaps most importantly, the model suggests research needs that are critical to an improved understanding of sustainable tourism. Although the specific functional forms and assumptions of the illustrated model may be subject to revision, the fundamental relationship among tourism, environmental quality, and the benefits realized by different stakeholder groups will almost certainly be central to any formal treatment of tourism sustainability. Among other needs, operational treatments of tourism sustainability will require appropriate, mathematically formal measures of the short- and long-term benefits (and costs) of tourism, as related to operational measures of tourism development or visitation. Such measures extend beyond simple measures of economic activity commonly reported in the tourism literature. Also needed is an improved understanding of the dynamic relationships among environmental quality, visitor numbers, and tourism benefits.

Such research needs are far from trivial. As a result, a full and comprehensive application of dynamic optimization models to tourism development will likely remain impractical for many tourist destinations. Nonetheless, exploration of such models may provide tourism researchers and practitioners with improved tools for the conceptualization of tradeoffs implicit in tourism sustainability and with a means to incorporate guiding structure to an area of debate often characterized by a lack of theoretical and conceptual clarity.

TECHNICAL APPENDIX

This appendix characterizes the optimal steady-state solution and paths for both the tourism industry and local residents. It is meant for readers more familiar with technical aspects of dynamic optimization and is not necessary for comprehension of the main text. We begin with the more general resident case, from which the industry case may be derived by setting $B(V, X) = 0$. As above, the optimal solution for residents maximizes (5) subject to (1) with respect to the number of visitors per period. Maximization is conducted using a standard Hamiltonian (Chiang 1992). The necessary conditions defining optimal visitor numbers include

$$\lambda = (\Pi_V + B_V)e^{rt}, \tag{A1}$$

$$-\ddot{\bullet} = (\Pi_X + B_X)e^{-rt} + \lambda({}^{h}{}_{X}), \tag{A2}$$

where the subscripts represent partial derivatives with respect to V and X, λ is the co-state variable, and subscripts denote partial derivates with respect to the variable in question. Following standard notation, r represents the discount rate, t the time period, and e the exponential operator. The dot (•) represents a partial derivative with respect to time. The steady-state solution is found by solving (1) and (A2) when $\ddot{X} = \ddot{\lambda} = \ddot{V} = 0$. The steady-state is characterized by $\ddot{X} = 0$ and

$$[(\Pi_V + B_V)(r - h_X)] - [\Pi_X + B_X] = 0. \tag{A3}$$

The optimal approach paths to the steady state are characterized by equations (1) and (6). These conditions are shown in the phase diagram for the optimal solution (figure 3).

The optimal solution for the tourism industry maximizes (3) subject to (1), with respect to the number of visitors per period, given the constraint that $B(V, X) = 0$. The necessary conditions defining optimal visitor numbers include

$$\lambda = (\Pi_V)e^{-rt}, \tag{A4}$$

$$-\ddot{\bullet} = (\Pi_V)e^{-rt}\ \ \lambda({}^{h}{}_{X}), \tag{A5}$$

where the subscripts represent partial derivatives with respect to V and X, and λ is again the co-state variable. The steady-state solution is found by solving (1) and (A5) when $\dot{X} = \dot{\lambda} = \dot{V} = 0$. The steady-state is characterized by $\dot{X} = 0$ and

$$\Pi_V(r - h_X) - \Pi_X = 0 . \tag{A6}$$

The optimal approach paths to the steady state are characterized by equations (1) and (5). These conditions are also shown in the phase diagram for the optimal solution (figure 3).

Following standard economic conventions, we assume that profits are increasing at a decreasing rate with respect to both visitors and environmental quality, such that $\Pi_V > 0$, $\Pi_X > 0$, $\Pi_{VV} < 0$, and $\Pi_{XX} < 0$.We assume that additional benefits to local residents (i.e., those not related to industry profits or employment) are increasing at a decreasing rate with respect to environmental quality but decreasing at a decreasing rate with respect to increases in visitors, such that $B_V < 0$, $B_X > 0$, $B_{VV} < 0$, and $B_{XX} < 0$. In the region of the phase plane where the steady-state solutions lie, $h_X < 0$.

Comparing (A3) and (A6), and given the above assumptions, h_X must be *more negative* within the solution characterizing the steady state for local residents. Accordingly, compared to the optimal steady state for the tourism industry, the steady state for residents is characterized by a *greater* sustainable stock of environmental quality and a *lower* sustainable number of visitors. The optimal steady state for industry is characterized by a *lower* sustainable stock of environmental quality and a *greater* sustainable number of visitors.

NOTES

1. For example, empirical assessments provide myriad criteria to assess sustainability (e.g., Mak and Moncur 1995; McCool, Moisey, and Nickerson 2001; Ritchie 1999), whereas policies suggested to promote sustainable tourism are often found in the form of divergent lists of recommended actions (World Travel and Tourism Council 1991; Conservation International 1999). The literature is also replete with examples of applied multicriteria and linear programming (LP) optimization (e.g., Aylward 2003; Kottke 1987; Powers and Powers 1977; Hill and Shecter 1978), with objectives for such analyses defined by case study contexts.

2. Sustaining a viable tourism industry is not trivial, because the returns from tourism can be critical to the well-being of regions or even entire nations (e.g., Dixon and Hof 1997).

3. For example, we abstract from issues such as the substitutability of natural and manmade capital discussed elsewhere (Collins 1999).

4. Nonrenewable resources in general do not support steady-state (sustainable) solutions, unless one allows for renewable "backstop" resources that replace nonrenewable resources once depletion is imminent or for substitution between natural and manmade capital (Hartwick and Olewiler 1986). Hence, they are not addressed here.

5. This model assumes constant technology, such that the model is autonomous and fixed steady-state solution exists. It is possible, however, that advances in technology throughout time (e.g., the addition of more advanced sewage treatment) might reduce the damage per visitor. The result would be that the optimal solution would change throughout time—a much more complex solution. More generally, numerous relationships between the number of visitors and the rate of environmental damage are possible. For example, one may assume that increasing visitor numbers degrade the environment at an ever-increasing marginal rate per visitor. In general, such changes do not alter fundamental model implications. Hence, we retain a simple linear environmental damage function.

6. Formally, the dot (•) represents a partial derivative of X with respect to time.

7. Obviously, profits are influenced by other factors as well, including capital development, tourism infrastructure, and so on. We abstract from these features, because they do not play a fundamental role in the model.

8. As an example, consider the simple case in which revenues are a Cobb-Douglas function of V and X, such that $R(V, X) = \varphi V^{\alpha} X^{\gamma}$ represents revenues, where φ, α, and γ are constant parameters. For illustration, we may further assume that costs are quadratic in the number of visitors, such that $C(V) = \tau V + \upsilon V^2$ represents costs, where both τ and υ are constant parameters. As the constant parameters φ, α, γ, τ, and υ are implicit in $R(V, X)$and $C(V)$, they may be suppressed from the general functional specifications. Defining profits as revenues minus costs, we may specify the general profit function $\Pi(V, X) = [R(V, X) - C(V)] = \varphi V^{\alpha} X^{\gamma} - \tau V - \upsilon V^2$. Based on similar derivations, the general function $\Pi(V, X)$ may be shown to subsume an infinite number of explicit specifications of revenues and costs.

9. One could just as easily specify the model such that the industry would seek to maximize some broader measure of utility. The mathematics and fundamental model implications, however, would be unchanged.

10. The use of continuous time (i.e., the continuous summation of an infinite number of very small time units) allows for simpler, more elegant mathematical results.

11. These goals are likely myriad and heterogeneous (e.g., jobs, income, environmental quality, and lack of congestion). A more complex model could assess heterogeneous objectives of different resident groups. This is not, however, a necessary component of a basic model of tourism dynamics.

12. Bermuda, for example, set a strict limit on the number and arrival times of cruise ships to preserve environmental quality (Riley 1991).

13. To simplify the model, we ignore potential environmental damage caused by residents themselves. Such issues are discussed by Briassoulis (2002).

14. Partial derivatives measure the average change in a variable caused by a 1-unit change in another evaluated at a specific point.

15. Here, we assume that the discount rate is the same for both industry and residents. Again, a more elaborate model might use different rates.

16. To the left of this locus, the maximization of profits requires increasing visitors throughout time. To the right of this locus, it requires decreasing visitors throughout time.

17. To the left of this locus, the maximization of profits requires increasing visitors throughout time. To the right of this locus, it requires decreasing visitors throughout time.

18. In the general case, this solution is known as the utilitarian stationary solution (Chichilnisky 1997).

19. Of course, on the optimal approaches to the sustainable, steady-state optima (A or B), both environmental quality and visitors (and consequent benefits to residents and industry) change. Hence, one only reaches a truly steady-state situation once the points A or B are reached.

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