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Integrating environmental, social and economic systems: a dynamic model of tourism in Dominica

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Abstract

This article describes an integrated dynamic model of The Commonwealth of Dominica, a small Caribbean island state. The modeling approach emphasizes whole-systems assessment and trans-disciplinary analysis, providing a framework to conceptualize the impacts of different tourism development strategies, accounting for interactions between ecology, economy and society. Our use of dynamic modeling differs from established techniques such as simulation, predictive, or mediated modeling; we use the modeling environment primarily as an accounting tool to track the *interaction* of a large set of heterogeneous data and assumptions. We believe that a model such as ours can provide a valuable tool for the synthesis of data and theories about development alternatives. New data can be added as it becomes available, structural elements can be included as deemed important within a given milieu, and the largely explicit assumptions of the model can be changed to examine alternative views.

Keywords: Dominica; Tourism; Dynamic model; Tourism carrying capacity; Subsistence; Quality of life; Social capital; Tourism multiplier; Integrated modeling

1. Introduction

This article describes an integrated dynamic model of the Commonwealth of Dominica, a small Caribbean island nation that generates much of its foreign exchange through tourism. We believe our dynamic model serves two goals in the context of the modeling literature: first, it illustrates the complex interactions between economic systems which can be modeled in detail and social and environmental systems which have often proved difficult to quantify. Second, the model integrates detailed quantitative information about the case study, while summarizing qualitative information. The result is a model which suggests specific areas for future research and allows for analysis of development scenarios and policies.

General systems theory (Ashby, 1956), game theoretic and agent-based modeling (Luna and Stefanson, 2000), and static-learning theory as reviewed by Grant and Thompson (1997) have informed efforts to dynamically model socio-environmental interactions through the use of either quantitative or 'soft system' approaches. However, as dynamic models

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are increasingly being used to illustrate trends in ecological–economic interaction when long-term experimentation is not feasible (Costanza et al., 1993; Costanza and Voinov, 2001), the mix of quantitative and qualitative data within the same dynamic model, while rare, is increasingly necessary to address problems of social and environmental importance (Kane and O'Reilly-de Brun, 2001).

Our modeling approach draws on the ideas of ecological economics (Cumberland et al., 1997), placing emphasis on whole-systems assessment. Our goal is to provide a framework to conceptualize the impacts of various tourism development strategies over a time scale of several decades, while taking into account interactions and feedback loops between ecology, economy, and society to the fullest extent allowed by available data and theory.

1.1. Case study selection

We selected Dominica as a case study due to the prominence of tourism issues as a development concern for the island (Patterson and Rodriguez, 2003). Furthermore, we were compelled by anecdotal reports of relatively intact forest cover, the high prevalence of people subsisting directly from forest and marine resources, and the presence of a West-African matrilineal heritage which suggested the importance of non-market economic activity among extra-familial networks. Because the benefits of non-market exchanges and subsistence activities are rarely fully integrated into cost–benefit analyses, we felt an attempt to model some of these interactions within the context of system dynamics would make a needed contribution to the discussion concerning tourism development, for small island nations as well as other traditional communities.

2. Methodology

We used the STELLA programming environment (HPS, 1998) to explore tourism on the island of Dominica, and to model the consequent interactions of the island's social, ecological, and economic domains.

Two choices need to be made at the beginning of any modeling effort. First, one has to decide which system elements need endogenous treatment, and which can be considered exogenous or ignored altogether. Second, one has to decide on the level of detail within each part of the system that is to be modeled. The selection of domains to be modeled was informed by the literature and by interviews. The level of detail in each of the domains was dictated by the relevance of such detail to the central concerns of the project, as well as by the quality of available information. To achieve the greatest precision with a minimum of measurement bias, we modeled the subsystems at different levels of specificity (Costanza and Maxwell, 1994).

Whenever possible, we used specific data sets from a range of published sources. When quantitative data was not available in the literature, we used quantitative proxies from nearby islands, or designed qualitative proxies based on available theory. Direct and indirect links between state and auxiliary variables capture important feedback among components of the model.

We calibrated the model to reproduce measured data where it was available, and to produce realistic dynamics where it was not. Unexpected behavior of the model led us to re-check many of our assumptions, as well as to seek additional information from the literature to affirm our conclusions. Where little is known about the magnitude and timing of interactions within sub-sectors of the model, we include sliders to allow exploration among possible parameter values.

While the empirical and theoretical foundations for the model were well-researched, it is important to consider the model experimental. In our conclusion, we emphasize the interaction effects that are not commonly reflected in short-run or non-integrative analyses, yet are likely important for tourism development planning.

3. Model description

After identifying exogenous factors such as global economics, climate, and political forces, we chose to conceptualized Dominica in terms of three broad endogenous domains: *society*, *ecosystem* and *economy* (see Fig. 1). The following model description addresses each domain independently, followed by three sections which detail interactions among the three pairs of two domains: social–ecological, ecological–economic and social–economic.

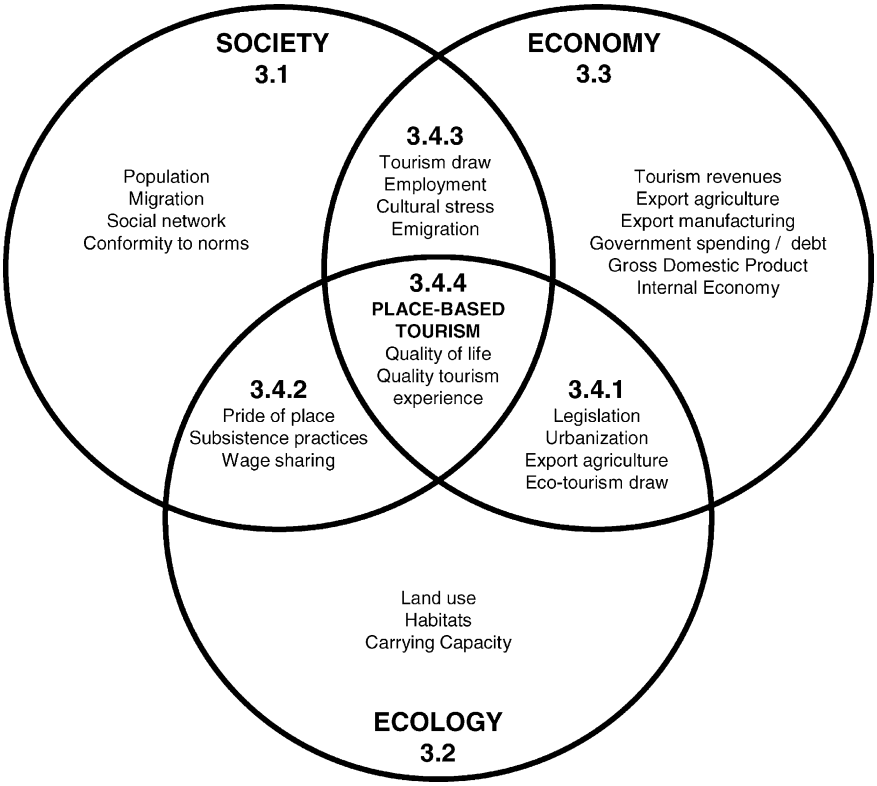

Fig. 1. A conceptual map of economic, ecological, and social factors of ecotourism in the Commonwealth of Dominica.

3.1. The social domain

The social domain in this model includes the island's population and two stocks that represent an abstract conceptualization of social capital: social networks, and social norms. While both of these qualities are notoriously difficult to measure, the social capital literature provides enough insight into their qualitative dynamics to allow us to build a plausible model of their behavior.

3.1.1. Population

The island's population stock reflects birth, death, and migration rates. Due to emigration, Dominica's population has remained stable over the past decades despite a net positive reproduction rate (see Fig. 2). We described the drivers of migration and birth rates more explicitly in Section 3.4.3, which addresses interactions between social and economic domains.

In many developing nations, low GDP per capita is usually associated with elevated birth and death rates. Dominica, however, already has a birth rate similar to that of the United States (17 per 1000, compared to the 14.3 per 1000 for the US), and has a significantly lower death rate (6.3 per 1000, compared to 8.8 per 1000). As a result, the effect of increased per capita GDP on population growth is not clear. Therefore, we assumed that current birth and death rates hold constant, leaving migration as the only dynamic factor directly affecting population.

3.1.2. Modeling social capital

We defined social capital following the work of Coleman (1988) and Portes (1998) as "the ability of actors to secure benefits by virtue of membership in social networks or other social structures." We find it important to make this explicit, as definitions of social capital vary widely and have evolved over three decades (Portes, 1998; Durlauf, 1999; Dalton, 2000).

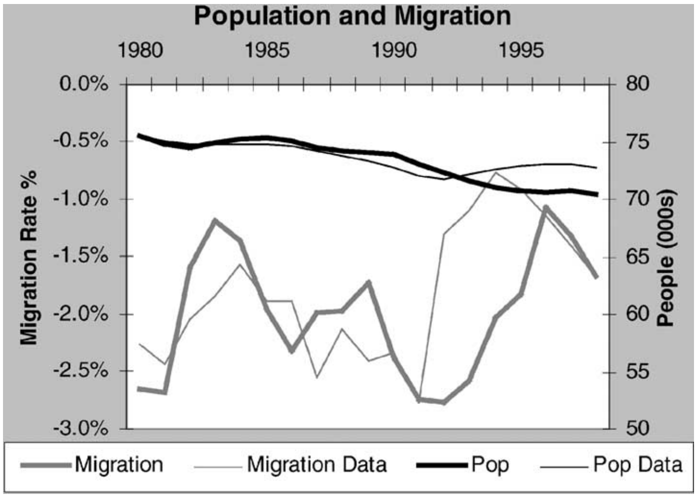

Fig. 2. Comparison of calibration data and model output for migration and population variable.

The conceptual range of phenomena attributed to social capital is broad (Loury, 1977; Bourdieu, 1985; Putnam, 1993, 1995; Fukuyama, 1995). However, few to any empirical measures occur in the literature. Our objective with the social capital stocks is to demonstrate that while practitioners have difficulty measuring social capital, its dynamics may be modeled to illustrate the conceptual interlinkages between social, economic, and ecological systems.

We represent social capital with two stocks: the social network stock, a proxy for social connections among individuals on the island; and the conformity to norms stock, which stands as a proxy for commonality between island individuals (see Fig. 3). This structure is based on a workshop scoping model which Boumans et al. developed in 1999, but does not include the most recent stock adaptations (Boumans et al., 2002). Other precedent exists for the 'networks' and 'norms' structure (Ostrom et al., 1997), and dynamic models have incorporated these (Carter, 1997). Others follow a game-theoretic logic (Carter and Zimmerman, 1994), or emphasize social 'rules' which model a 'tragedy of the commons' (Hardin, 1968), or other social traps.

In contrast, our model deals with island social dynamics in aggregate, as general functional relationships, informed by the literature and interviews with residents, historians, and sociologists of the island. This more general interpretation estimates social capital erosion and formation rates in response to various stimuli and stresses.

3.1.2.1. Social network stock. The social networks stock represents social connections among individuals on the island, as depicted by best available references. Dominica has a highly networked social system due to its insular, small (70,000 person) population, and its family structure which follow the tightly networked matrilineal West African tradition.[2]

3.1.2.2. Social norms stock. The social norms stock is structured to reflect a common identity among Dominicans, distinct from the norms of the tourist population. Norms, while well-studied in anthropological and sociological literature, have not been depicted as a stock prior to the efforts of Boumans et al. (2002). We illustrated reactions to the social norms stock that parallel theories in the literature concerned with tourism impact on host culture due, for example, to loss of tradition (Evans and Williams, 1997), or competition with globally dominant foreign norms (McElroy and de Albuquerque, 1998). Patterson and Rodriguez (2003) report on specific examples detailing the role social capital plays in tourism development in Dominica.

3.1.2.3. Aggregated social capital. The sum of social networks and social norms is our indicator of

[2] A discussion of the robustness of social networks can be found in (Watts, 1999; Newman, 2000). Social network analysis is explained more generally in Wasserman and Faust (1994).

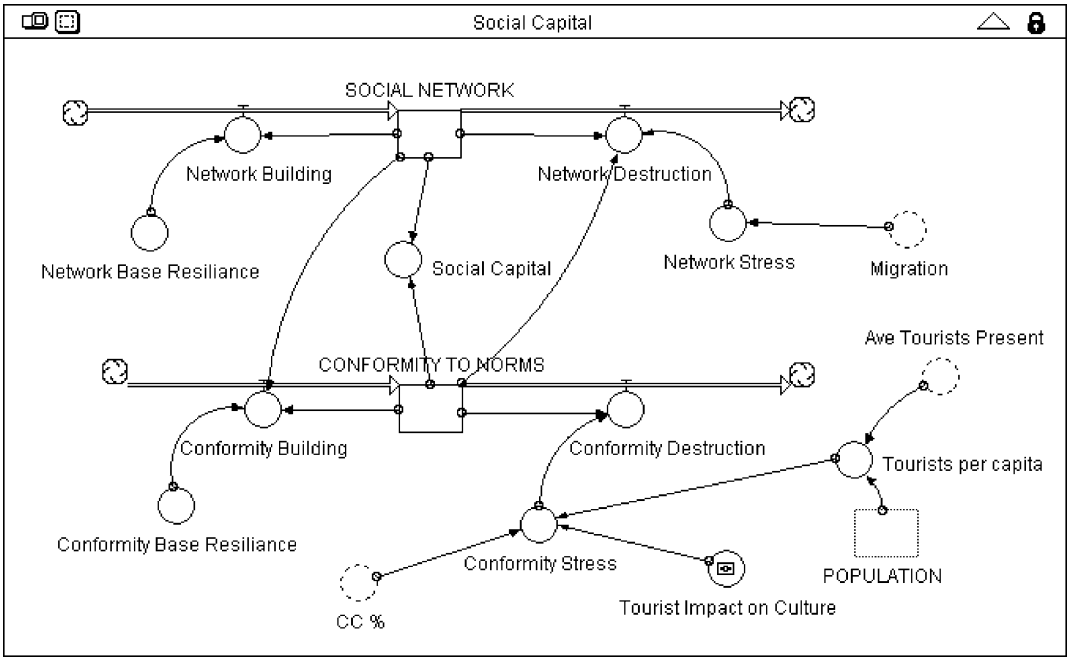

Fig. 3. STELLA diagram of social capital sector.

social capital. The stock of networks influences the stock of norms, consistent with the idea that highly networked groups will more rapidly establish shared norms within themselves (Costanza et al., 1993). The reinforcement between stocks allows social capital as a whole to stabilize at low and high levels, as some theorists in the literature have predicted (Fukuyama, 1995; Putnam, 1995).

3.1.2.4. Stresses on networks and norms. To demonstrate theories of tourism influence on host culture networks and norms, we designed variables to reflect the most common concerns in the literature: foreign values displacing traditional norms, conflict over natural resources eroding norms and trust, and emigration subtracting nodes from the network.

Stress on networks (i.e., a loss of network nodes) is caused by emigration (Costanza and Voinov, 2001), as well as from conflict over scarce shared resources, such as land, forest habitat, and fishing grounds. Increased contact with foreigners and foreign values has been projected to weaken traditional family ties and modify long-standing social structures (Evans et al., 1997; McElroy and de Albuquerque, 1998). Because little is known about the magnitude and timing of the impact that tourists might have on Dominica, we introduced a slider into the model, allowing the tourist population to have low, medium or high impact on local social capital.

3.2. Ecological domain

The ecological domain includes a land use sector and a habitat sector. The land use sector is concerned with tracking changes in land use that emerge as society responds to economic and population dynamics. In contrast, the habitat sector deals with the quality and function of the environment supporting each form of land use. We emphasize the mutual importance of these two sectors by adapting the concept of “carrying capacity” as the central organizing principle of the ecological domain.

3.2.1. Land use sector

Land use was determined by visual assessment of satellite data (DBMC, 2001) and IUCN forest data (IUCN, 1996). Six land use categories sum to form all (790 km^2) of the island, and we devote a stock

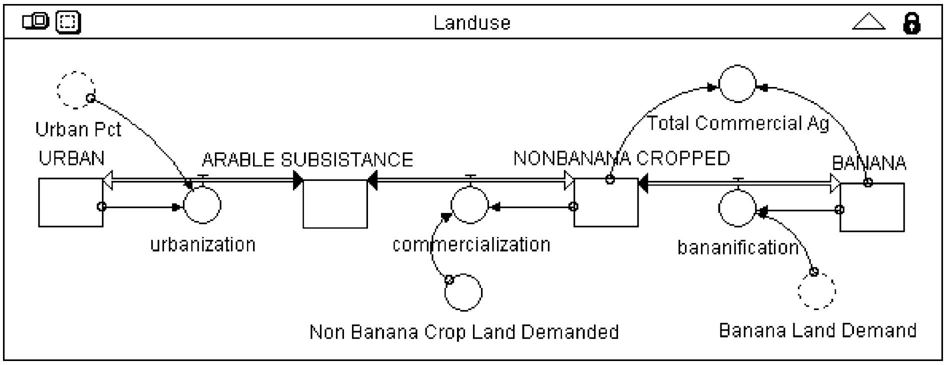

Fig. 4. STELLA diagram of land use sector.

to each: forest, protected forest, urban, arable subsistence agriculture, non-banana commercial agriculture, and land for banana production. As illustrated in Fig. 4, forest stocks can flow into protected forest stocks, but not vice versa. Banana lands can be converted into non-banana commercial agriculture, then to arable subsistence land, then to urban area, and back again according to variables such as banana profits, commercialization, urbanization (see Section 3.4.1.1), and conservation (which remains constant after 1992).

3.2.2. *Habitat sector*

There is a long tradition in Dominica of individuals and families subsisting outside of the market economy (Steiner, 2001; Patterson and Rodriguez, 2003). To be able to support human subsistence sustainably, these habitats must be able to perpetually support the population that uses them, following a common definition of sustainability (WCED, 1987). Therefore, we modeled each habitat with a maximum sustainable carrying capacity. While specific ecological processes vary, all systems within the ecological domain are modeled by total habitat *area* and overall habitat *quality*. The area of each terrestrial habitat was available from historical spatial data sources and is modeled in the land use sector (Section 3.2.1). Initial quality values for both terrestrial and marine habitats were estimated using aggregate and anecdotal data for Dominica or nearby islands (Hughes, 1994; Mumby, 1999; Lugo et al., 2000).

3.2.2.1. Forest habitat. The total forest area is the sum of protected and non-protected forest from the land-use sector. Forest quality is affected by variables reflecting both harmful and regenerative factors. In turn, these variables depend on existing forest quality and quantity. This approach models the genetic reserve function, as predicted for tropical forest recovery (Holling, 1986; Ghazoul and McLeish, 2001). Reduction of forest quality is a direct function of two variables: tourist damage to forest trails and trees (Christian, 1996) and subsistence practices, including cultivation and hunting within the forest.

We initially set forest quality relatively high (95%). Though there has been some limited deforestation in the past 20 years, several sources report that the canopy remains in good condition over most of the forested parts of the island (Thorsell, 1982; CCA and IRF, 1991; CEP, 1996). We take this to indicate that the quality of the remaining forest remains high.

3.2.2.2. Subsistence agriculture habitat. The quantity of subsistence agricultural land within the model is directly generated by the land-use sector. The quality stock is degraded by use and regenerates at a constant rate over time, independent of its current quality or quantity (unlike forest quality, which depends on both). Provided the rate of degradation remains lower than the natural regeneration rate, the quality of the land is perpetually sustained. Subsistence agriculture quality can thus be diminished by over or misuse (e.g., erosion, lack of crop rotation).

3.2.2.3. Marine habitat. The area of Dominica's marine shelf is essentially constant. Accordingly, we modeled the marine habitat through three habitat quality stocks: coral cover, reef fish and demersal[3] fish. Like the forest quality stock, these marine stocks have

[3] Fish whose primary habitat is in deeper, non-coastal waters.

a genetic reserve function that makes stock recovery faster at higher stock levels, and slower at lower levels (Levin and Paine, 1974; Paine and Levin, 1981).

Coral cover. Coral cover stocks are estimated according to Caribbean assessments (Wilkinson, 2000). Stock recovery is adversely affected by auxiliary variables for land-use impacts, tourist and Dominican population. While some data is available for human impacts on coral, data were not available at appropriate scale for precise calibration of this model. However, several sources (Hughes, 1994; Nyström and Moberg, 2000; Wilkinson, 2000) specifically document tourist impacts on coral through diving and anchoring. Because we were unable to quantify the level of these impacts, we include a slider to allow exploration of several values for tourist impacts.

While the island's steep topography amplifies erosion effects, it also limits the scale of terrestrial development compared to islands with wider shelves. For this reason we have calibrated coral loss to the Caribbean average (22% between 1980 and 2000), which is lower than the estimated world average decline of 40% over the same period (Wilkinson, 2000). While water temperature is an important determinant of coral loss in the Caribbean, we do not speculate on warming trends beyond impacts estimated by Wilkinson. When disturbed, the coral stock has a characteristically slow regeneration rate (Rawlins et al., 1998).

Coral cover is influenced by stressors such as soil erosion (from construction, roads, and deforestation) and effluents (from fertilizer use and sewage). Because the tourist population directly impacts Dominica's coastal zone through diving and boating (IRF, 1996), the model includes a modifier to increase coral loss as the tourist population rises.

Reef and demersal fish. Reef fish and demersal fish stocks each respond to variables which diminish the stocks according to fish catch. However, regeneration of the two stocks are modeled differently. Reef fish stock is limited to the island coastal shelf, while demersal fish migrate from other areas of the Caribbean. Therefore, the genetic reserve function of patch dynamics (Paine and Levin, 1981) is comparatively more important in controlling reef fish stock regeneration. Time-series data from Caricom (1995) and FAO (1998) were used to calibrate fish catch (see Fig. 5). According to the data, catch declined steeply in the early 1980s and recovered somewhat by the middle 1990s, consistent with the anecdotal reports that reef fish stocks were largely depleted early in the study period, and that the decline in reef fish stock was partially offset by a shift in fishing technology toward demersal fish (Robertson, 2001). While demersal fish stocks can also be depleted by global fishing pressures, the fishing industry of Dominica is not large enough to contribute significantly to these pressures. The demersal fish stock is therefore exogenous to the model and we assume that it will remain relatively stable over the time scale of the model.

3.2.2.4. Aggregate carrying capacity. Various researchers have summarized different methods for quantifying human use of nature (Wackernagel, 1998; Cohen, 1998). While carrying capacity as a concept is generally accepted, researchers report difficulty identifying agreed-upon values for how many persons a given area can support (Kessler, 1994), contingent on *intensification* (technological change), or *extensification* (expansion of effective habitat) (Wackernagel and Rees, 1996). Neither approach was exactly appropriate to our purposes, as we defined subsistence activities as low-technology traditional practices occurring within the island's natural ecosystems. Instead, we modeled the carrying capacity as follows: the area of each habitat is multiplied by its respective quality modifier to generate the area of "effective habitat." This value was then divided by the number of persons which a single hectare of that habitat type was estimated be able to support.

To arrive at the percentage of carrying capacity used, the total was compared to the total subsistence population (i.e. those not employed in the formal economy or supported by "wage-sharing," described in Section 3.4.2.2). Should the demands of the subsistence population be greater than the corresponding carrying capacity, ecosystem quality is adversely affected.

3.3. Economic domain

The potential range of economic activities to be modeled is vast, even in a small, insular economy such as Dominica's. Our model focuses on the success of place-based tourism—accordingly, we identified five sectors in the island's export and domestic economies:

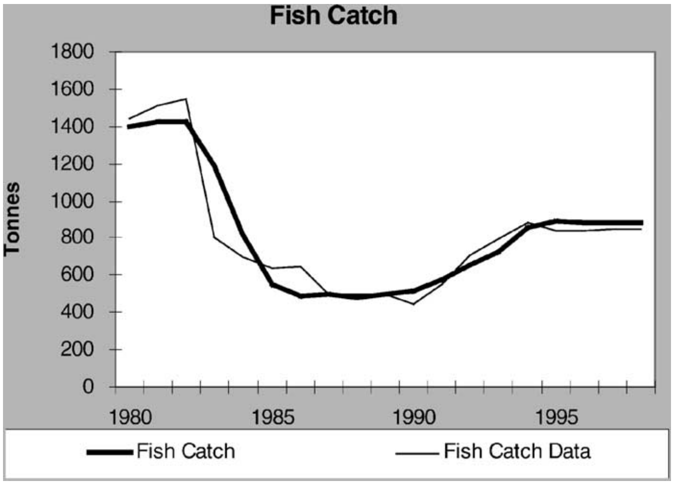

Fig. 5. Comparison of calibration data and model output for the fish catch variable.

tourism (considered a "service export"), export agriculture, export manufacturing, government and the internal domestic economy. This conceptualization is consistent with the structuralist macroeconomic approach as exemplified by the work of Lance Taylor (1979, 1983). While most structuralist work has taken a comparative statics approach to economic analysis, we implement the same concepts as a dynamic model (Ruth and Hannon, 1997). For consistency, we work with constant 1980 prices throughout. Though informal economic activity (subsistence and wage-sharing) could be said to belong to the economic domain, its strong association with the island's ecological and social systems led us to site it within the intersections with those domains.

3.3.1. Tourism sector

The tourism sector includes airport and hotel infrastructure investment and depreciation, general spending (including wages, advertising, overhead, taxation and spending on imports), as well as ties to the environmental and social domains.

The tourism sector consists of three stocks: hotel rooms, airport capacity, and tourism revenue. The stock of tourism revenue has gross revenue incoming, and wages, overhead, advertising costs, taxes, and import spending outgoing. The stock of hotel rooms (Westbrook et al., 1997) is modified by parameters for investment and depreciation. Investment comes from tourism industry profits, with the rate of hotel room expansion limited by the capacity of the building industry. Airport capacity is increased by government investment in a fixed-proportion manner, and depreciates at a constant rate. The government is assumed to maintain current airport capacity, and, in a given year (arbitrarily chosen as 2004) undertakes an airport expansion project, the size of which is a policy parameter (IMF, 2000).

Some debate has centered on whether tourism is limited in Dominica by the size of the airport, or by availability of facilities and accommodations (ibid.). In our model, either factor can be limiting and thus determine maximum capacity. The percent of this capacity used is modified by variables representing island attractiveness and advertising. Island attractiveness is calculated as a function of stocks in the ecosystem module and the social capital stock while advertising is a function of total hotel rooms.

Employment in the Dominican tourism industry is represented as a function of the average number of tourists present, derived from a regression on historical industry employment data (Boo, 1990). Since more mature tourist industries tend to elicit higher spending per tourist (World Bank, 1993), we model spending per tourist as a function of tourism industry maturity, taking average number of tourists present as a proxy for this dynamic.

This sector is calibrated to provide an excellent fit with time series data for tourist arrivals and tourist revenue (World Bank, 2000) (see Fig. 6).

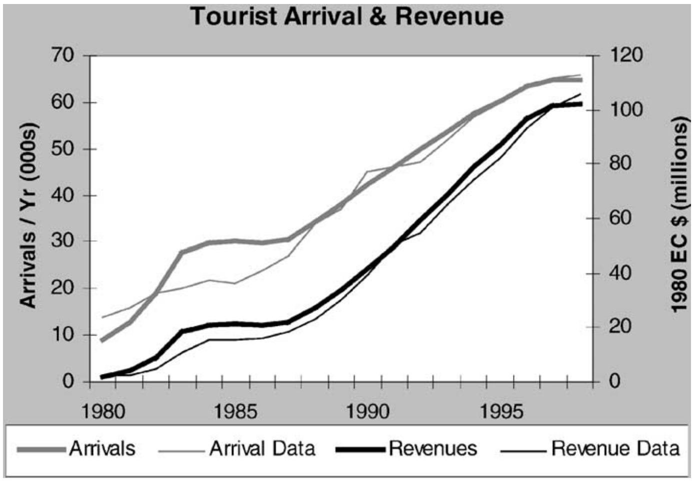

Fig. 6. Comparison of calibration data and model output for the tourist arrivals and tourism revenue variables.

3.3.2. Export agriculture sector

Because exports play such a critical role in an open economy like Dominica's, we modeled agricultural production for export separately from agricultural production for local consumption. While we chose to model export production explicitly (due to its importance for balance of payments); production for local consumption is subsumed in the aggregate domestic economy sector.

The export agriculture sector has two sub-sectors: *bananas* and *other export crops*. Because banana production can vary rapidly depending on the amount of labor and resources dedicated to it, we model banana production as a function of the price of bananas (DBMC, 1998), modified by losses due to hurricanes and the end of the colonial preference system.[4] Non-banana agricultural production depends on the amount of land dedicated to such activity, derived from the land-use sector. Finally, based on the experience of other smallholder banana economies, we assume that profits from agriculture accrue to local farmers and are spent in the local economy (Grossman, 1998).

[4] The colonial preference system ended after the United States filed an action with the World Trade Organization. The effect was a dramatic decline in the prices Dominican producers could expect for their product.

By tuning the dynamics described in Section 3.4.1.1, we were able to achieve a good fit (see Fig. 7) to historical banana yield data between 1980 and 1999 (Wibdeco, 2000) and also to overall agricultural revenue data (World Bank, 2000).

3.3.3. Export manufacturing sector

This sector models only manufacturing for export; production for local consumption is counted as part of the internal economy sector. Anecdotal evidence suggests that virtually all export manufacturing is foreign-owned and that the majority of profits are expatriated (Thomas, 2001). The model manufacturing sector thus contributes only wages and taxes to the domestic economy. Since the contribution of this sector to the Dominican internal economy is relatively small and exogenously determined, we modeled the export industry in a non-dynamic manner, fitted to World Bank's time-series data.

The best fit to the data (see Fig. 8) was given by a sum of a logistic and a sine curve, which can be interpreted as the business cycle superimposed on the gradual growth of productive capacity (World Bank, 2000).

3.3.4. Government sector

Within our model, the essential functions of government are fiscal. Inputs are taxation, borrowing, and foreign aid. Outputs are general spending, payroll, debt

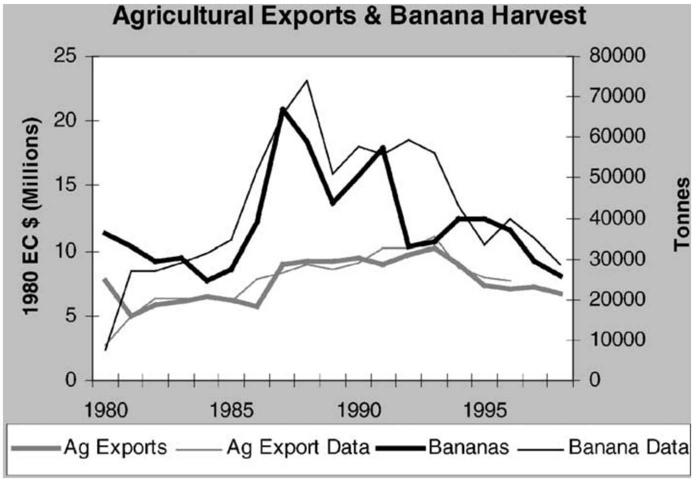

Fig. 7. Comparison of calibration data and model output for the Ag exports and banana harvest variables.

service (at interest rates contingent on the outstanding debt stock), and civic infrastructure investment (airport expansion in 2004).

Since independence from Great Britain (1978), government spending has been consistent at about 21% of GDP (World Bank, 2000). Since this rate has been quite constant over the past 20 years, we have assumed this rate will be maintained (see Fig. 9). While a full reconstruction of the Dominican tax system was beyond the scope of this project, we found data to be consistent with the an average effective tax rate of 14% of business revenues between 1985 and 2000. The resulting disparity between spending and taxation has created a national debt of approximately $250 million (World Bank, 2000). Based on the stabilization program that has been developed for Dominica in conjunction with the International Monetary Fund (IMF, 2000), we have assumed that tax levels will soon be increased to a rate sufficient to maintain a balanced budget. To accomplish this, we introduced a feedback mechanism that adjusts the tax rate to cover government expenditures beginning in the year 2001.

Fig. 8. Comparison of calibration data and model output for the manufacturing exports variable.

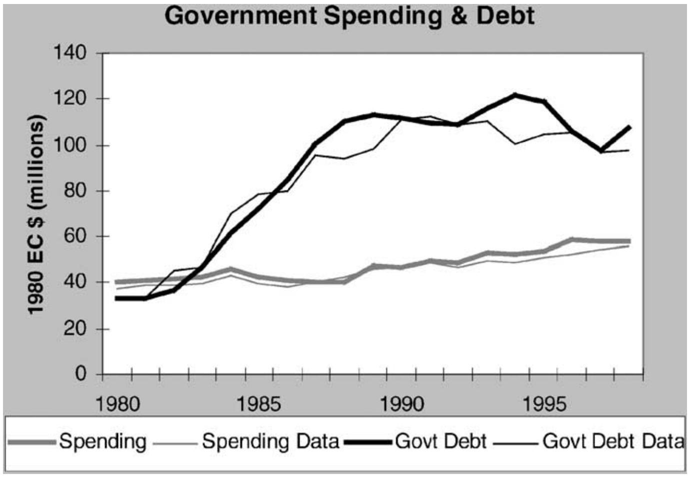

Fig. 9. Comparison of calibration data and model output for the Government spending and Government debt variables.

3.3.5. Domestic internal economy sector

The remaining aspects of the local economy are modeled as a circular flow between households and domestic firms (see Fig. 10). Wages contribute to a stock of household income, a portion of this stock (representing 'purchases') flows into the stock of firm income. Other inflows into the firm income stock are revenues from export agriculture, tourism (depending on the percentage of domestic ownership), and government spending. Firm income stock outflows are taxes which are paid to the government, wages and profits which flow back to household income, and importation of goods according to a constant *marginal propensity to import* (MPI). We achieved excellent calibration performance by assuming an MPI of 44%. We also made the simplifying assumptions that all imports arrive via domestic firm purchase and that all personal income taxes are withheld from salaries.

Modeling the domestic economy as a circular flow allows us to capture the Keynesian multiplier effects of inflows from tourism and government spending. In particular, we are able to periodically estimate the tourism multiplier,[5] as well as the contractionary effects of balancing the government budget.

[5] The additional amount of domestic economic activity stimulated by each dollar of tourist spending Lea (1988), Bull (1991), Saleem (1994), Lundberg et al. (1995b).

3.4. Interaction dynamics

One of the central goals of this project was to demonstrate how Dominica's economic, ecological and social domains intersect. Such linkages can be examined as pairings of ecology–economy, ecology–society, and society–economy, as well as the mutual interdependence of all three domains.

3.4.1. Economy and ecology

The interaction of economic and ecological processes reveals the ways in which an actively growing economy might be expected to impact the island's ecologies, and the ways by which Dominica's economy depends on the health of the environment.

3.4.1.1. Economic influences on the ecosystem. One of the most important linkages between the economic and ecosystem domains connects economic pressures to land use patterns. Relevant variables include: past parks legislation, urban population growth, and export agriculture pressures. Also important are the direct means by which the island's marine habitat is affected by the tourist industry.

We estimated urban population by computing the ratio of employees in the tourism and manufacturing sectors (generally urban) with those in the agricultural sector (which are generally rural) (ILO, 2000). The model then allocates urban and rural populations

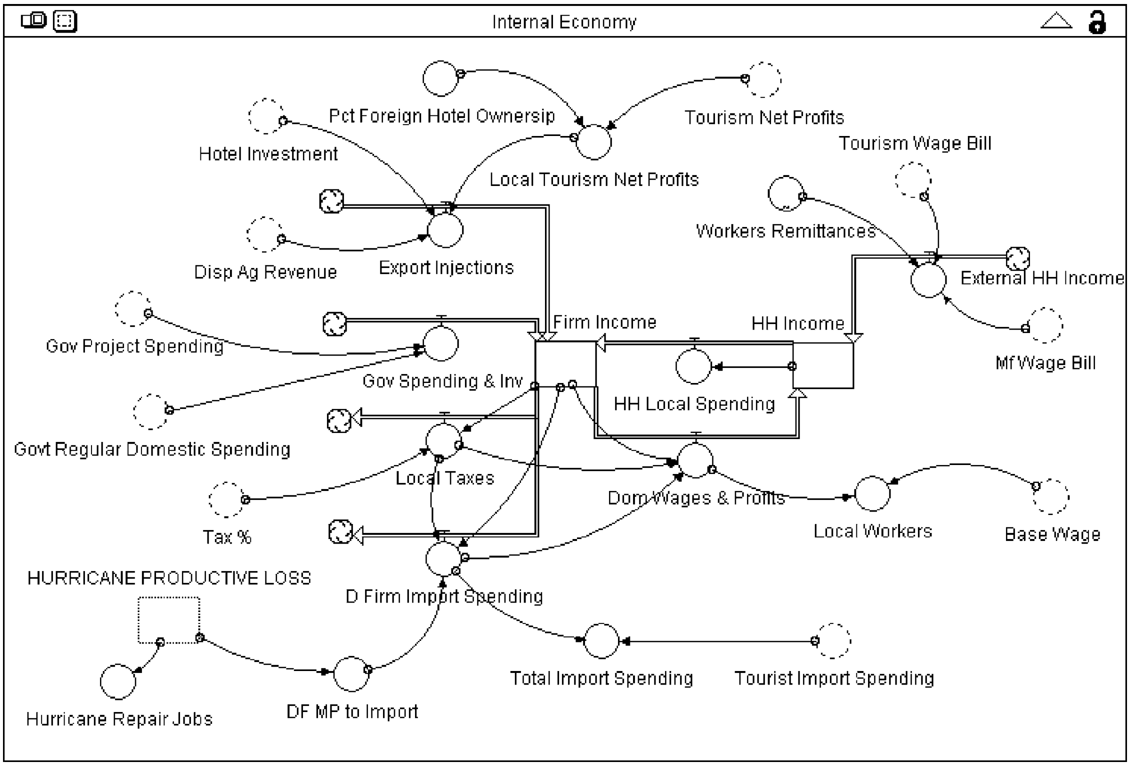

Fig. 10. STELLA diagram of internal economy sector.

according to this ratio. We then assumed a constant urban density (area per person), allowing us to derive total urban area. This estimate appeared consistent with satellite data (DBMC, 2001). Land needed for urban expansion is assumed to be withdrawn from subsistence agriculture (which often occurs at the fringes of urban areas).

Because bananas are Dominica's most profitable export crop, we assume that land for *non*-banana export agriculture shifts in and out of banana production, following the prior year's banana prices (DBMC, 1998). Thus, based on a yearly planting-to-harvest cycle, we estimate a delay of 1 year from such signals to actual land use changes. When the dynamics of banana production reduce the amount of land available for non-banana export agriculture, this engages a slower dynamic which shifts land use away from subsistence agriculture and toward commercial export production. When decreased banana production results in a surplus of commercial land, it is abandoned back to subsistence farming through an even slower dynamic.

Subsistence agricultural land thus serves as a buffer between urban areas and export agriculture. Subsistence agricultural land also, in combination with forest and reef habitats, supports the unemployed population. As described in Section 3.2.2, both subsistence agriculture and forest are described by area and quality stocks that are diminished as the total subsistence population exceeds the current carrying capacity of the ecosystem.

Finally, because the tourist population directly impacts Dominica's coastal zone through diving and boating (IRF, 1996), the model includes a modifier to increase coral loss as the tourist population rises.

3.4.1.2. Ecological influences on the economy. The clearest way in which the island's ecological systems affect the economy is the vitality of the Dominican environment as a tourist draw (Cater, 1996; Evans et al., 1997; Collins, 1999). To model this effect, we defined a variable "natural beauty" to reflect the extent to which perceptions of Dominica's natural aesthetics attract visitors. For these purposes, natural beauty is a function of forest quality and reef cover.

3.4.2. Ecology and society

The intersection of ecological and social domains focuses on the effects of land use dynamics and subsistence activities on Dominica's ecosystems, and the ways in which these activities rely on the quality and extent of the island's natural habitats.

3.4.2.1. Ecological impacts on society. In this model, ecology impacts social capital through two channels: first, "pride of place" is vital to a common island identity (Honeychurch, 2001; Lawrence, 2001); and second, traditional communal resource extraction activities (such as hunting) reinforce social networks to the extent that the natural environment is able to provide for these activities. We modeled the first as a positive relationship between habitat quality and *conformation to norms*, and the latter by linking the level of *conformation to norms* to the percentage of ecosystem carrying capacity used.

3.4.2.2. Societal impacts on the ecosystem. The primary channel through which social capital influences ecology in our model is *wage-sharing*, a term we use to describe a form of income redistribution that reflects the strong informal economy and familial assistance provided by a matriarchal lineage. Thus, the people who cannot be counted as 'employed' by formal sectors, but are directly supported by people who are employed, do not have to live directly off of the ecosystem. Those supported by wage-sharing thereby do not add to the stresses that reduce subsistence carrying capacities. The level of wage-sharing (the fraction of the unemployed who are supported by the employed) is taken to be a direct function of the aggregate social capital (described in Section 3.1.2.3). Therefore, in this model, a decrease in social capital can lead to an increase in ecosystem pressure even when formal unemployment does not rise.

3.4.3. Society and economy

The points of interaction between economic and social processes shed light on the means by which labor dynamics, wages, and migration influence social capital, as well as the importance of strong social networks to the success of Dominica's tourism industry.

3.4.3.1. Societal influences on economy. Apart from being important in its own right, a strong sense of national identity is a critical draw for tourism (Boo, 1990). A vibrant local host community can be as important to tourist expectations to return as are sites of natural beauty—this is particularly true for Dominica (Evans et al., 1997). Social capital, therefore, is modeled as a significant determinant of tourist demand.

3.4.3.2. Economic influences on the social sector. In this model, the economy affects the social sector in two ways. First, it influences social capital through the stress modifier of unemployment and the cultural stress modifiers that are proportional to the tourist population (see Fig. 3).

Second, it drives emigration, as we have assumed that emigrants are chiefly the unemployed who are unable find support through wage-sharing or subsistence. Emigration, in turn, stresses Dominica's social network.

Another important result of employment-driven emigration is population control (see Fig. 2). Due to emigration, Dominica's population has stayed relatively constant over the past few decades, in spite of a positive net reproduction rate (World Bank, 2000). This relationship is realized within the model by a dynamic linking good economic times to reduced (or even negative) emigration and thereby to population growth.

3.4.4. Mutual interdependence

While conceptualizing the interactions between domains is simpler when comparisons are limited to basic pairings, it is clear that maintaining both the quality of life for Dominica's citizens and a quality tourist experience depends on sustaining the health of each domain. When taken as a whole, ongoing success in any single domain is contingent on maintaining the function and quality of systems throughout the island.

4. Conclusion

Our use of the dynamic modeling environment differs in important ways from established techniques such as simulation, predictive, or mediated modeling. We use the modeling environment primarily as an accounting tool to track the interaction of a large set of heterogeneous data and assumptions. The expression

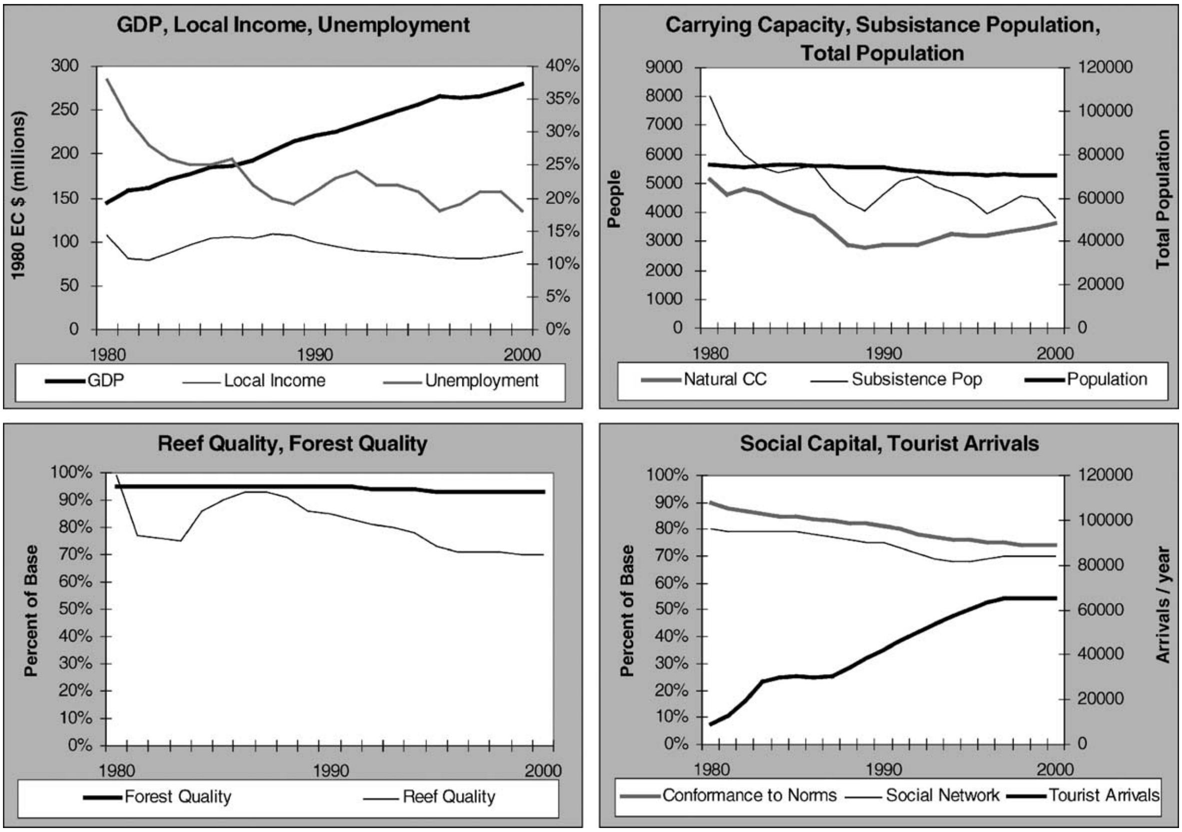

Fig. 11. Model output for the calibration period (1980–2000).

of our research in terms of a model has forced us to make our assumptions clear and has revealed relationships between the data that we would not have otherwise seen.

We had substantial success in calibrating the model to reproduce available data since 1980 as was demonstrated by the figures presented in the various model sections. Fig. 11 tracks the evolution of several key indicators over the 20-year calibration period. All of the indicators display behavior which accords with data and/or anecdotal reports where they were available and with common sense where all data was lacking.

While we designed the model primarily for examining long-run scenarios (which will be explored in a future publication), it has also proven useful for elucidating relationships within the economy over the calibration period. These points were discussed in the in the body of the paper, but bear repeating here. First, it would seem that the Dominican government accumulated debt at the rate of government expenditure during the first 5 years after independence. This indicates that the tax collection system was less than effectual at the time, but has improved. However, we note that the budget remains unbalanced. Second, we observe that GDP growth between 1980 and 2000 has been a particularly poor proxy for economic well-being in Dominica. While GDP has nearly doubled over this period in real terms, the size of the internal economy has remained almost constant, as have real wages (see Fig. 11b).

One way of understanding this disparity is through the use of the economic concept of the *tourism multiplier*—the extent to which tourist dollars are re-spent in the local economy, thereby stimulating further economic activity (Lundberg et al., 1995a). As of 1990, Dominica was estimated to have a higher tourism multiplier than most other Caribbean destinations (Weaver, 1991). The model output tends to support this, yielding a multiplier of 2.1 for 1990. By

2000, however, leakage from the Dominican economy had increased markedly and the multiplier effect has diminished accordingly, falling to 1.45. The primary reason would seem to be either a significant increase in foreign ownership of tourist facilities (with foreign owners repatriating profits), or local owners investing their profits abroad (Cater, 1996).

We believe that a model such as ours can provide a valuable tool for the synthesis of data and theories about development alternatives. New data can be added as it becomes available and the largely explicit assumptions of the model can be changed to examine alternative views. Such a framework allows one to focus on one part of the system without losing sight of the complex interactions which make up the whole system.

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