Resource Use, Institutions, and Sustainability: A Tale of Two Pacific Island Cultures

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ABSTRACT. *This paper examines two Pacific Island cultures, Easter Island and Tikopia, and the relationship between natural resource systems, human-made capital, population growth, and institutional change. Easter Island followed a pre-industrial society pattern of overshoot-and-collapse. However, Tikopia evolved cultural practices leading to zero-population growth and sustainable resource use. Using a modified Lotka-Volterra, predator-prey model, we find (1) investment in human-made capital does not necessarily eliminate the boom- and bust-cycles of economic activity and population observed in many past societies; and (2) institutional adaptation and resource conservation can be critical in achieving population stability.* (Q20)

I. INTRODUCTION

The study of Pacific Island cultures, once a specialized field of cultural anthropology, is now a rapidly growing area of multidisciplinary research (Bahn and Flenley 1992; Kirch 1997; Kirch and Hunt 1997; van Tilberg 1994; Vitousek 1995). Kirch (1997) argues that the Pacific islands, each with their own unique geological and biological history, and settled by physically and culturally similar humans, offer a unique laboratory for social scientists. Study of these islands has important implications for the modern quest to find enduring relations among people, environment, and the economic use of earth's natural resources. Economists are beginning to contribute to this evolving research on isolated human communities and their relationship with natural resources (Brander and Taylor 1998; Gowdy and McDaniel 1999; McDaniel and Gowdy 2000). Most significantly, an economic perspective can provide valuable insights into broader questions of sustainability.

The neoclassical economic approach to sustainability is based on the idea of preserving total capital stock, under the assumption that all forms of capital are substitutes. Although questions of resources and growth have long been of concern to economists, this dominant capital theory approach to sustainability surfaced in the mid-1970s in response to the 1973–74 energy price shock and subsequent concerns over resource exhaustion (Heal 1974; Hartwick 1977; Solow 1974). As developed by Solow (1986), building on the work of Hartwick (1977, 1978a, 1978b), the economic definition of sustainability came to mean "the maximum consumption in a period consistent with the maintenance of aggregate capital intact" (Stern 1997, 149). For economic output, or income, to be sustainable, the total stock of capital (including natural, manufactured, and human capital) must be non-declining over time. This is the so-called Hartwick-Solow rule for sustainability. Numerous surveys of the sustainability debate have been published since by Lele (1991), Stern (1997), Pezzy (1989), Tisdell (1994), and Common (1995), among others. As Stern (1997) points out, one positive outcome of the formalization of the concept of sustainability is that it has laid bare the untenable foundations of the neoclassical approach. Criticisms of the Hartwick-Solow rule (sometimes called "weak sustainability") have been offered by Common and Perrings (1992), Perrings and Common (1997), Victor (1991), Norgaard (1991, 1994), and Amir (1992). Perrings (1987) and Common and Perrings (1992) have developed models showing the limits of economic systems in achieving sustainability.

This paper complements these critiques of

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the neoclassical definition of sustainability by showing, in the case of some small island economies, both population control and natural resource conservation are required for sustainability. Archeological studies have suggested that many Pacific islands followed a pattern of initial colonization, rapid population growth, increasing cultural complexity, and intensive use of natural resources, followed by social disintegration and population collapse. This paper first considers Easter Island as an example of this overshoot and collapse pattern. Following Brander and Taylor (1998), a variation of a Lotka-Volterra, predator-prey model was constructed to examine the pattern of rising material wealth, resulting environmental degradation, and eventual decline of the Polynesian occupation of Easter Island.

A particular innovation of the present model is the addition of manufactured capital accumulation. This allows for exploring the premise of weak sustainability through the substitution of natural capital during island development. Archeological research indicates a population decline only after a time lag of several centuries following the extinction of forests and associated biodiversity. By explicitly modeling substitution of natural capital services, we hypothesize that Easter Islanders were able to delay population decline as indicated by the archaeological evidence. However, with a significantly depleted natural resource base, collapse may have been inevitable. This is shown to be particularly likely when manufactured capital is an imperfect substitute for natural capital, and growth of natural resources are assumed to be dependent on maintenance of the resource stock.

A similar initial pattern of natural resource exhaustion took place on the small Pacific island of Tikopia. However, Tikopia avoided collapse through institutional adaptation, including development of an arbor culture that ecologically mimicked the rainforest it replaced and customs that adhered to zero population growth. The case of Tikopia is contrasted with Easter Island in the dynamic model, highlighting the critical roles of institutional change and resource conservation.

II. THE ECONOMICS OF EASTER ISLAND, REVISITED

To study the dynamics of resource use and population growth on Easter Island, Brander and Taylor (1998) built a model based on Malthusian population dynamics, an open-access renewable resource, and a Ricardian production structure. The resulting system of differential equations represents a variation of the Lotka (1929) and Volterra (1931) predator-prey model. This model has been used to describe ecologically isolated predator-prey systems, for example, as in the case of specific fisheries (see Clark 1990) or primitive hunting cultures (Smith 1975).

$$dS/dt = rS(1 - S/K) - \alpha\beta LS \quad [1]$$

$$dL/dt = L(b - d + \theta\alpha\beta S). \quad [2]$$

Equation [1] describes the dynamics of the resource stock (S), or prey, as evolving according to a logistic growth function with an intrinsic growth rate (r), and carrying capacity (K). Harvest of the renewable resource depends on labor productivity (α), a parameter specifying the islander's resource preference (β), the island's population or labor force (L), and current resource stock level (S). Equation [2] describes the Malthusian population dynamics, where ($b - d$) represents the base rate of population change and ($\phi\alpha\beta S$) allows for higher per capita consumption to lead to a higher population growth rate, where ϕ is a positive scaling parameter based on a fertility function. Brander and Taylor (1998) provide a thorough analysis of steady-state and dynamic behavior of this system.

The base-case simulation of the Lotka-Volterra model assumes the following: an initial population of 40 individuals in 400 A.D.; a carrying capacity and initial resource stock of 12,000 units (acting as a scaling parameter); labor productivity of 0.00001 (implying household subsistence when $S = K$ at 20% of available labor time); taste for the harvested good of 0.4 (implying 40% of the labor force is devoted to harvesting S); an intrinsic growth rate of 0.04 (implying the

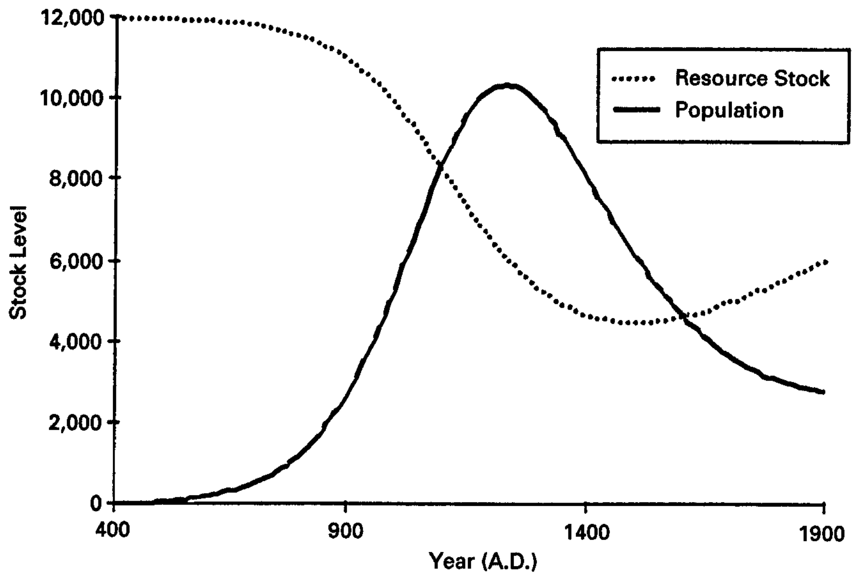

FIGURE 1
BASE CASE SIMULATION OF EASTER ISLAND (FOLLOWING BRANDER AND TAYLOR 1998)

forest/soil complex would growth at 4% per decade if left alone); a base population rate of change of −0.10 (implying a declining population in the absence of the resource stock); and a fertility constant of 4 (allowing for positive population growth when $S > 0.5K$, and negative otherwise). The model is run in 10-year time increments and yields the simulation in Figure 1.

III. MANUFACTURED CAPITAL AND STOCK-DEPENDENT RESOURCE GROWTH

Bahn and Flenley (1992) in their book *Easter Island, Earth Island* completed an exhaustive review of the archeological research of Easter Island to date, ranging from ethnographic and linguistic studies, to expedition records and oral histories, to archeological digs and radiocarbon dating. To their interpretation of the vast collection of archeological research on Easter Island, they have added new research from island core samples to help reconstruct a history of ecological and societal change. Figure 2 summarizes their archeological research. According to pollen analysis, the island forest resources seem to have began to decline shortly after human arrival around 400 A.D., with lower island slopes exhausted by 900.[1] Soil erosion, measured by organic content, also seemed rapid. Erosion accompanied both the destruction of the forest cover and evidence of increased fires through the observance of charcoal particles.

This record of resource degradation and population increase on Easter Island shows a pattern similar to that modeled by Brander and Taylor (1998), with one significant exception. Their model shows the population of Easter Island peaking about 200 years before the trough in resource decline is reached. Archeological evidence, however, indicates that the human population continued to rise for several hundred years after near depletion of the forest and accompanying environmental degradation. The population peaked at perhaps 10,000 individuals in 1600 A.D. and had crashed to about 3,000 when Dutch explorers arrived in 1722.[2]

[1] Upper island slopes were likely cleared last, possibly delaying complete forest exhaustion to 1200 A.D. (personal communication, John Flenley, August 8, 1998).

[2] Peak population estimates range between 6,000 and 20,000 (Bahn and Flenley 1992, 179).

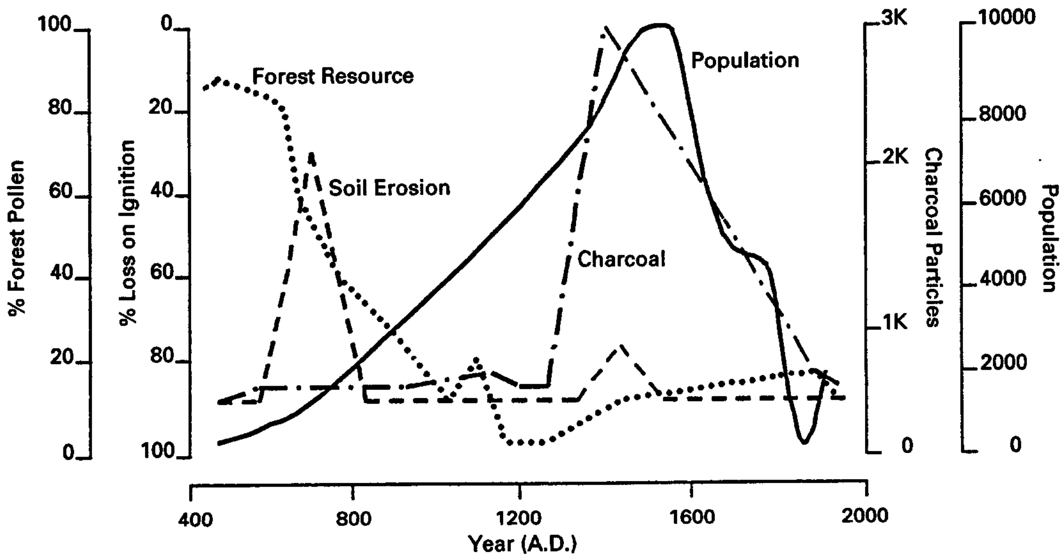

FIGURE 2

ARCHEOLOGICAL RECORD OF EASTER ISLAND (REPRODUCED WITH PERMISSION FROM BAHN AND FLENLY 1992, FIGURE 193)

In the basic model, something must substitute for the natural resource fertility effect in order to maintain population growth following natural resource degradation. Perhaps a lagged fertility effect resulted from the ingenuity of Easter Islanders in finding substitutes for natural resources, at least in the short-run. For instance, as forest resources were converted to tools and boats, the island's ocean and wildlife resources were open to harvest and could substitute for the forest/soil resource. To explore this hypothesis, consider the addition of a fertility effect from manufactured capital accumulation.

$$dM/dt = \alpha\beta LS - \delta M. \qquad [3]$$

In equation [3], capital accumulation (M) is assumed to be identical to natural resource harvest from equation [1] to reflect substitution of labor, tastes, and the fertility effect for production of human-made capital from natural resources. Depreciation of capital is accounted for by the parameter δ. The accumulation of capital is assumed to have an identical positive effect on fertility as natural resource harvest, however the effect is lagged by 100 years to reflect time for the development of human innovation. Thus population dynamics is augmented as follows:

$$dL/dt = L(b - d + \phi\alpha\beta(S + M_{-10})). \qquad [4]$$

This new dynamic allows for a lagged fertility effect from human innovation, however, the Easter Island population still eventually crashed. Once the natural resource base had been irrevocably degraded beyond a certain point, the replenishment of manufactured capital depreciation was no longer possible. Despite innovation and substitution, historical evidence points to inevitable collapse. This may have been in part due to a feedback effect within the natural resource base. The natural resource base need not be completely consumed in order to instigate its irreversible decline. In fact, marginal exploitation of ecological systems may lead to discontinuous, unexpected consequences where the next fish caught, the next species lost, the next acre developed could lead to a systems crash.

To illustrate, consider recent empirical evidence from the collapse of international fisheries. A study by Pauly et al. (1998) measures a progressive move down the marine food web of the international fisheries harvest from long-lived, high-trophic level fish to low-trophic level invertebrates and plankton-feeding fish. As technology has developed, fishermen have been able to scour further and further down the marine food chain. The authors conclude that these fundamental changes in ecosystem structure are the main threat to widespread collapse of the world's fisheries.

To capture this ecosystem crash hypothesis, the growth rate of the resource stock is modeled on the maintenance of the stock itself. A stock dependent resource growth rate (r) is set equal to ω/S, where ω is used to scale r to an initial value where $S = K$.

To simulate the resulting system, a few parameter adjustments to the base case simulation are necessary. First, labor productivity (α) is assumed to double with the addition of manufactured capital accumulation. In order to maintain an initial growth rate of 4% and a population peak of 10,000 individuals, the scaling parameters are set to $K = 5750$ and $\omega = 143{,}750$. Capital depreciation (δ) is assumed 5% per decade. All other parameter values remain the same. The results of this stock-dependent growth rate specification and a 100-year innovation development lag is represented by Figure 3.

Figure 3 illustrates the effect of a stock-dependent growth rate and the substitution of manufactured for natural capital. The human population can continue to expand after environmental degradation becomes severe. Eventually, however, diminishing returns to the application of technology and human capital to a declining natural resource base begins to negatively influence population growth. Following complete manufactured capital depreciation and natural capital collapse, the isolated island can no longer support a human population.

IV. TIKOPIA AND INSTITUTIONAL CHANGE

In spite of warning signs that must have been present on Easter Island, that particular culture was unable to change its relations to the environment so as to smoothly adjust to

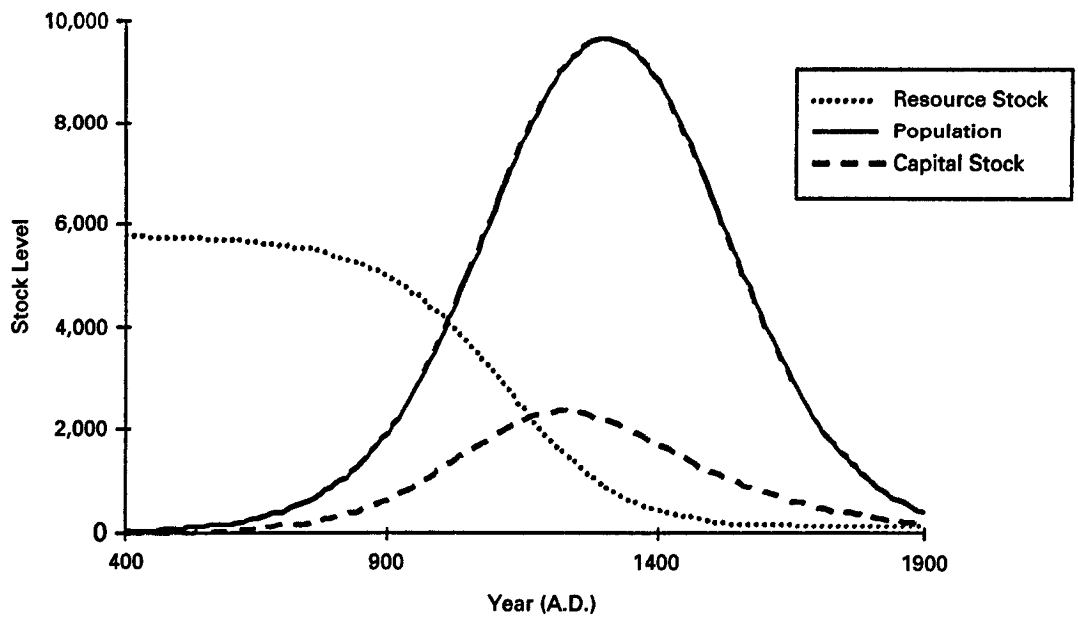

FIGURE 3
POPULATION, NATURAL RESOURCE, AND MANUFACTURED CAPITAL DYNAMICS WITH STOCK-DEPENDENT GROWTH RATE

increasing natural resource scarcity. Instead, archaeological evidence gives some indication of social instability following resource degradation. Warfare, starvation, and cannibalism followed widespread plant and animal extinction (Bahn and Flenley 1992; Diamond 1995; van Tilberg 1994).

Many early Pacific island cultures suffered a similar fate. For example, study of the island of Mangaia shows a similar pattern of overshoot and collapse, with population increasing for several hundred years after forests had been cut down and soils severely degraded (Kirch, Flenley, and Steadman 1991; Kirch et al. 1992). Due to capital depreciation and irreversible ecosystem loss, even the perfect substitution of human-made capital for natural capital was unable to support a growing population in the Easter Island model. Through a combination of agricultural practices, religious beliefs, and overpopulation, Easter Islanders seem to have been locked into a pattern of resource overexploitation.

The archaeological record of another Pacific island, Tikopia, provides an informative contrast to Easter Island, and highlights the role of institutional change. Tikopia, located in the Solomon islands, is a small (5 km^2), geologically young (80,000 years old), fertile volcanic island. Its surrounding reef is biologically rich and diverse. The island was perhaps settled by Polynesians about 900 B.C. who began practicing slash-and-burn agriculture, hunting native bird species to extinction, and in general following the same pattern as the inhabitants of Easter Island. Then, about 100 A.D., archeological evidence demonstrates that this pattern changed. Slash-and-burn agriculture was replaced with a complex system of fruit and nut trees forming an upper canopy, with aroids, yams, and other shade-tolerant crops under these. By the time Europeans arrived, the Tikopians had created an arbor culture, eliminated all pigs from the island, and achieved a stable population of about 1,000 inhabitants (Kirch 1997). Similar to research on Easter Island, Figure 4 represents the major indicators of environmental change on Tikopia over the past 4,000 years, yet in a more stylized format.

In economics, analysis of institutional change has often revolved around the question of intergenerational equity. Bromley (1989) suggests that if the present generation ignores the costs it is imposing on future generations, then it will seem inefficient to impose costs on the present generation to maintain future resource stocks. This is the case in most economic analyses of resource use based on general equilibrium optimization models. In these models "the present stands as dictator over the future" for several reasons. For instance, future generations cannot bid in present markets (Bromley 1989, 182; Georgescu-Roegen 1976, 33). There is also an "intertemporal asymmetry" (Bromley 1989, 182) if those living in the future cannot undo the detrimental effects imposed upon them by those in the past.[3] Judging from past societies, some notion of caring for the future seems to be essential for sustainability (see the essays in Gowdy 1997). Economists have also called attention to the existence and implications of property regimes based on collective management, not individual property rights (for instance, Bromley 1991; Rettig 1995).

In the dynamic island model, "caring for the future" requires maintaining the ability of natural capital to replenish manufactured capital depreciation. Archeological evidence from Tikopia would seem to support the idea that institutional change can drastically affect the well-being of future generations. Evidence of a shift to an arboricultural resource base, the elimination of domestic pigs, and, most striking, the adoption of cultural beliefs that incorporated an ethic of zero population growth each may have enabled Tikopia to achieve population stability in a closed island ecosystem.

To capture these institutional dynamics, population is assumed to evolve according to equation [4], with capital depreciation held at zero to reflect Tikopia's success in stabilizing a managed resource base. Human-made

[3] A reviewer outlined an insightful contrast to this point of intertemporal asymmetry. The present generation controls the description of the past, which gives it some control over the reputation of individuals and societies, although still no control over their resource endowment.

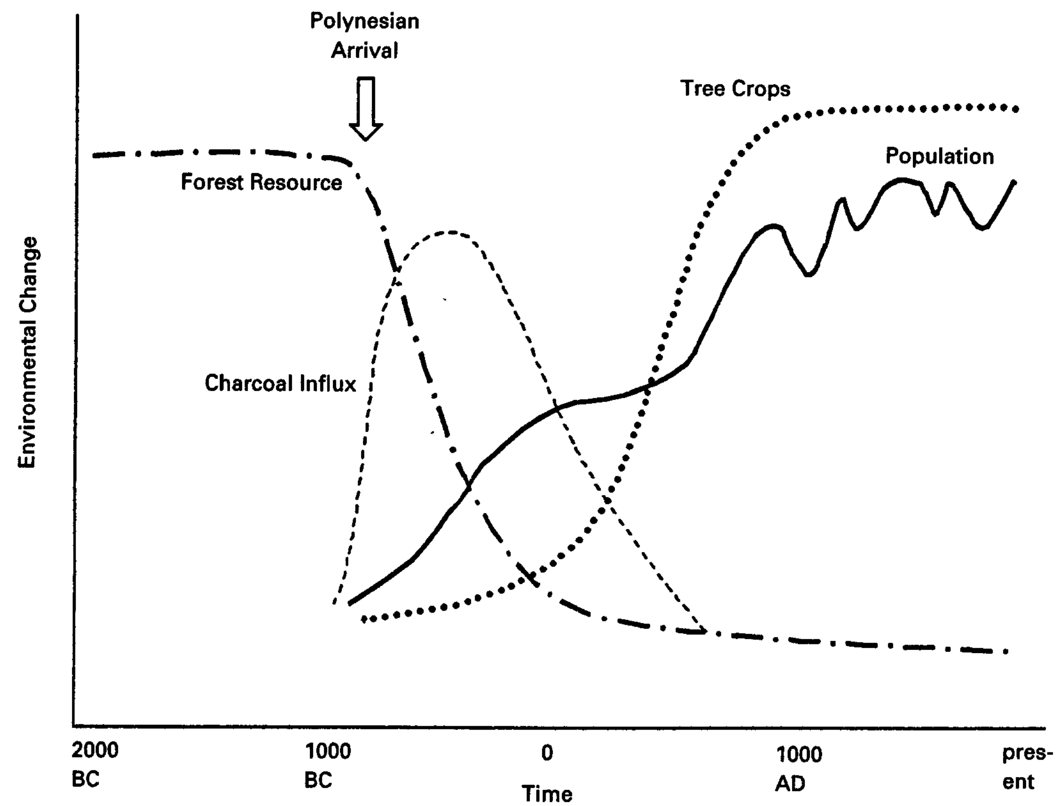

FIGURE 4
DIAGRAMMATIC MODEL OF TIKOPIA (REPRODUCTED FROM KIRCH 1997 FIGURE 5)

capital, however, is unlikely to be a perfect substitute to all services of the pre-crash island ecosystem. Therefore, a unique fertility constant (ϕ_2) is pre-multiplied to $\alpha\beta M_{-10}$, which is set at 2, or half the value of the fertility constant (ϕ_1) pre-multiplied to natural resource consumption. The Tikopian population initially stabilized at approximately 1,000 and an initial resource growth rate of 0.04 is again assumed. In order to calibrate the model to Tikopia, the carrying capacity (K) and initial growth rate parameter (ω) are scaled to 1,000 and 25,000, respectively. Figure 5 displays the simulation results.

This stabilization of population growth and a managed resource base on Tikopia did not come without extreme change of social institutions. Demographic research catalogs population growth mechanisms to include celibacy, prevention of conception, abortion, infanticide, sea-voyaging by young males, and expulsion of certain population segments (Firth 1936; Borrie, Firth, and Spillius 1957; Firth 1967; Kirch 1997). The fono, an annual address by the Chief of Tikopia, has been described by Kirch (1997, 36) as a proclamation encoding the institutional idea of zero population growth. In fact, Kirch (1997) reports the impact of twentieth-century Christian missions was to spur rapid population growth through the prevention of the more stringent customs. The new population levels exceeded the carrying capacity of the island's production system, increasing its susceptibility to periodic natural disasters. Famine ensued following cyclones in 1952 and 1953, and the population subsequently crashed. Social disintegration and a potential

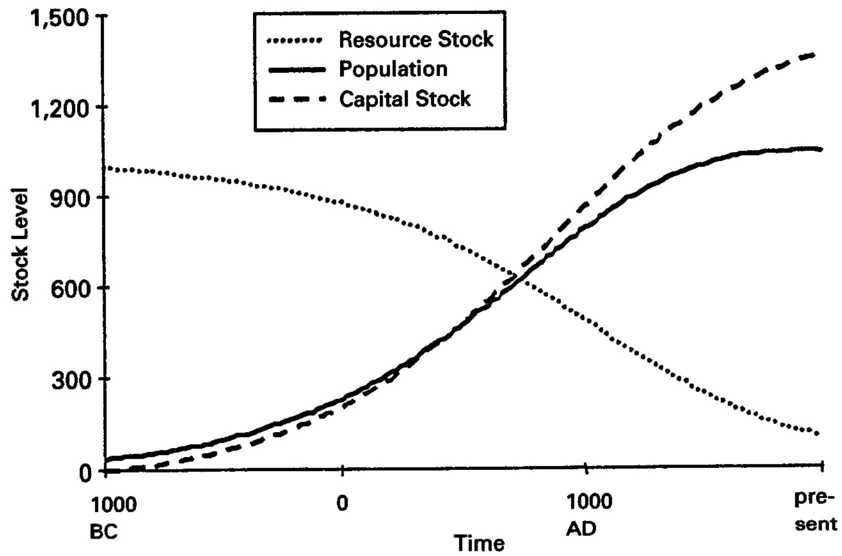

FIGURE 5
SIMULATION OF TIKOPIA

population collapse was avoided only by securing international aid. Tikopia has more recently stabilized population levels by mandating a limit on home isle inhabitation (set at 1,115 in 1976) and arranging for emigration of excess population to other islands of the Solomon's group (Kirch 1997).

Without the intervention of cultural change, emigration, and trade, the fate of Tikopia over the long-run is not clear. Also questionable is whether the managed resource base on Tikopia can replicate all the services of a natural resource base. The dynamic model run over a longer time horizon would stabilize a managed resource stock, however the natural resource stock never recovers under a stock-dependent growth rate specification. Human population peaks at slightly over 1,000 inhabitants then asymptotically approaches zero. Unless perfect substitution of human capital for natural capital is assumed, even with a steady-state manufactured capital stock, population eventually declines in the model.

V. CONCLUDING REMARKS

These simple models of Easter Island and Tikopia provide a tool to explore the key elements driving the interplay of natural resource, population, and cultural dynamics within a closed system. Earlier efforts to build an island dynamic model were extended by adding (1) a lagged effect of resource depletion on population levels due to the substitution of manufactured capital (i.e., boats, tools, managed agriculture) for natural resources (i.e., forests, fish, and in general, biodiversity); and (2) a stabilizing effect on population through introducing a managed-resource base and institutional adaptation. In both general cases, a stock-dependent natural resource growth rate was assumed, and the natural resource base never recovers from initial exploitation.

Two important contributions of this paper are (1) given the non-substitutability of many basic ecological functions of a natural resource base, even a steady-state, human-made capital base is not able to sustain a human population in the very long-run; and (2) institutional adaptation must therefore consider both population control and natural resource conservation in order to sustain a closed system. Judging from the archeological record, there was significant technological progress on Easter Island. However, technological progress could not fully substitute for environmental degradation. The study of Tikopia highlights the role cultural change and environmental conservation could have on stabilizing population. A global extension of these results would imply that the amelioration of natural resource scarcity through trade and emigration might artificially raise carrying capacity in the short-run, but would be limited in the long-run due to the destruction of essential natural resources.

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