The Economics of Threatened Species Conservation: A Review and Analysis

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Chapter 8

THE ECONOMICS OF THREATENED SPECIES CONSERVATION: A REVIEW AND ANALYSIS

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ABSTRACT

Stabilizing human population size and reducing human-caused impacts on the environment are keys to conserving threatened species (TS). Earth's human population is ≈ 7 billion and increasing by ≈ 76 million per year. This equates to a human birth-death ratio of 2.35 annually. The 2007 Red List prepared by the International Union for Conservation of Nature and Natural Resources (IUCN) categorized 16,306 species of vertebrates, invertebrates, plants, and other organisms (e.g., lichens, algae) as TS. This is ≈ 1 percent of the 1,589,161 species described by IUCN or ≈ 0.0033 percent of the believed 5,000,000 total species. Of the IUCN's described species, vertebrates comprised relatively the most TS listings within respective taxonomic categories (5,742 of 59,811), while invertebrates (2,108 of 1,203,175), plants (8,447 of 297,326), and other species (9 of 28,849) accounted for minor class percentages. Conservation economics comprises microeconomic and macroeconomic principles involving interactions among ecological, environmental, and natural resource economics. A sustainable-growth (steady-state) economy has been posited as instrumental to preserving biological diversity and slowing extinctions in the wild, but few nations endorse this approach. Expanding growth principles characterize most nations' economic policies. To-date, statutory fine, captive breeding cost, contingent valuation analysis, hedonic pricing, and travel cost methods are used to value TS in economic research and models. Improved valuation methods of TS are needed for benefit-cost analysis (BCA) of conservation plans. This Chapter provides a review and analysis of: (1) the IUCN status of species, (2) economic principles inherent to sustainable versus growth economies, and (3) methodological issues which hinder effective BCAs of TS conservation.

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INTRODUCTION

Pessimism pervades biological conservation. The slowed loss or *status quo* maintenance of species lacks the optimism inherent to most discovery and problem-solving sciences. A burgeoning human population, coupled with the depletion of finite natural resources, is assumed to produce the continued decline of threatened species (TS), biodiversity, and human (*Homo sapiens*) lifestyles (Daily and Ehrlich, 1992; Pimentel et al., 1999).

Biological conservation links biological (e.g., population biology, ecology) and resource management disciplines (e.g., forestry, fisheries, wildlife) to document Earth's biological diversity and preserve natural resources for future generations (Primack, 2002). Species, communities, and ecosystems are monitored, with mitigation or recovery plans implemented to limit extinctions, maintain genetic variation, protect/restore organisms/ecosystems, as well as titrate consumption of resources (Primack, 2002).

Human population growth and related environmental impacts are viewed as the sole greatest threat to the loss of species (Forman, 1995; Czech et al., 2000). These accumulated atmospheric, climatologic, hydrologic, and physiographic impacts are viewed to decrease the survivability of animal, plant, and other (e.g., lichens, algae) species (Forman, 1995; Czech et al., 2000). The public is bombarded daily with articles about increased population growth, suburban "sprawl," emerging diseases, climate change, and pollution alerts, not to mention decreased ocean fisheries, arable cropland, and carbon "sinks"—but with seemingly little consequence (National Geographic Society, 2007; World Overpopulation Awareness, 2007).

Earth's human population was roughly 6,701,260,000 at the end of 2007, with about a 76,000,000 net increase during the year (United States Census Bureau, 2007). World population growth now equates to a birth-death ratio of 2.35 annually (United States Census Bureau, 2007). If unchecked (i.e., assumptions involving disease rates, birth rates, mortality rates, etc.), the projected human population of Earth by 2050 is $\approx$ 9.5 billion (United States Census Bureau, 2007). Some scientists consider this human population growth incompatible with the preservation of biodiversity and animal/plant populations (Daily and Ehrlich, 1992; Pimentel et al., 1999). Remote, deep habitats will be depleted or altered to accommodate man. Habitat fragmentation will produce increased "edge" (i.e., $<$ deep core), with greater dispersion of individual animals/plants yielding smaller, more vulnerable populations and communities (Forman, 1995). Even if adaptations to a world with logistic population growth are possible, slowing human population growth can only ease adaptations and enhance future lifestyles.

Carrying capacity refers to the maximum population size that an area (habitat) can support without decreasing the capability to support an equivalent population in the future (Daily and Ehrlich, 1992). The idea can be traced to the early 1800s, when Malthus argued that human populations would eventually grow until the productive capacity of the land was exceeded, then constrict in line with this capacity (see Czech, 2000). Climate, behavior, fecundity, physical habitat, disease, parasite, mortality, disturbance, competition, and predation factors interact to influence carrying capacity (Schamberger and O'Neil, 1986).

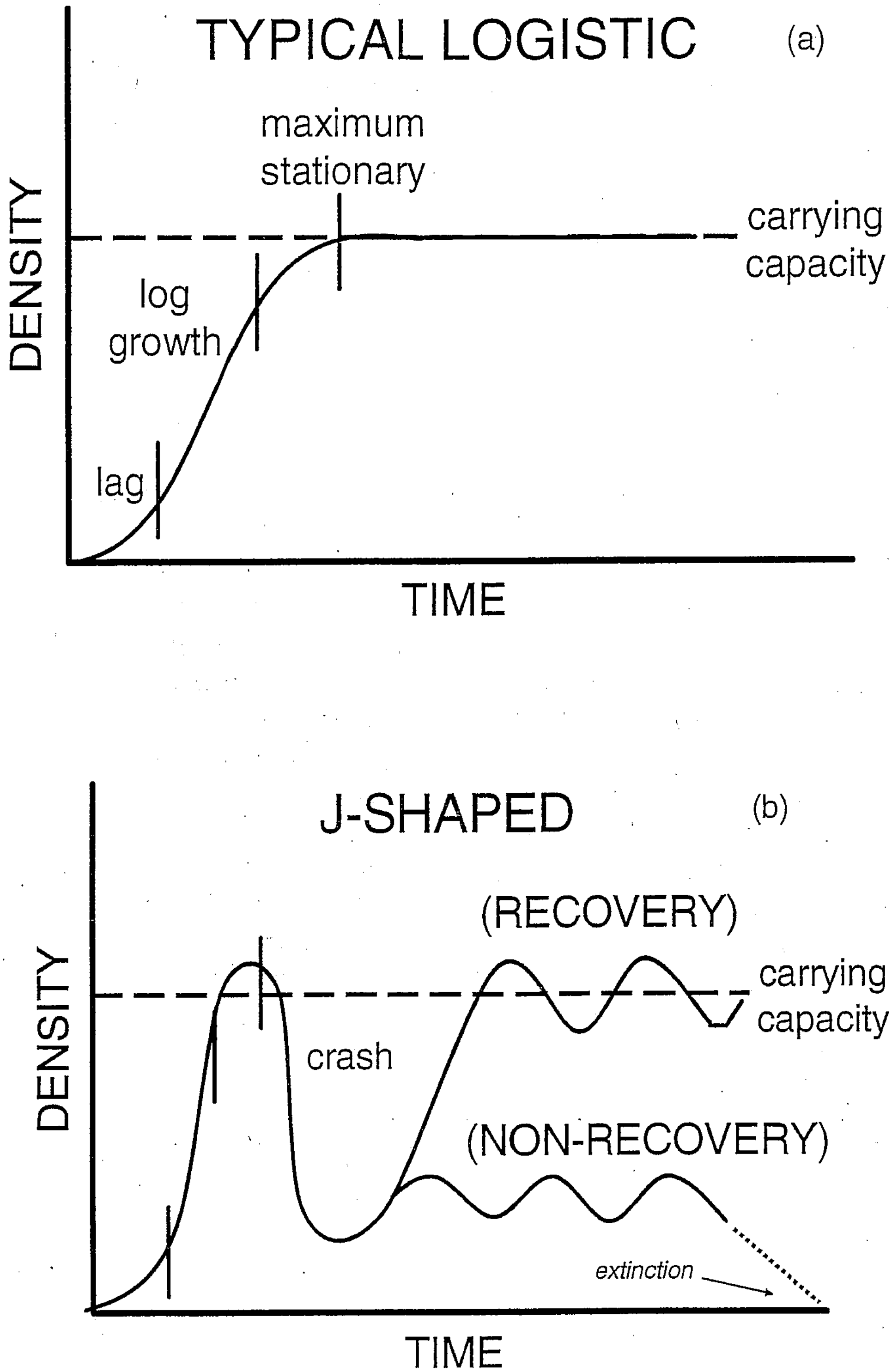

Figure 1. Schematic illustrations of carrying capacity: (a) a typical logarithmic population growth function, with eventual maintenance at carrying capacity and (b) dual overlapping "J-curves" with attainment of carrying capacity followed by a "crash" due to some catastrophic disturbance or other ecological variable (e.g., disease, predation, climate), with "recovery" to carrying capacity or "no recovery" (i.e., ecological factors have changed) and a subsequent low sustainable population or a further decline (extinction) possible (Adapted from Allee et al., 1949, p. 306).

Figure 1 illustrates the carrying capacity concept. Initially, a typical logarithmic growth function with asymptote was envisioned for carrying capacity (Alee et al., 1949; Figure 1a). Later, annual fluctuations in births, deaths, predation, and etc. were viewed to cause oscillations at carrying capacity until a catastrophic environmental disturbance occurs (Figure 1b). Significant disturbances were found to produce a population "crash" with recovery if ecological factors were not permanently changed or a "crash" with failed recovery (i.e., oscillate at some low population size), or possibly a further decline (i.e., extinction) if ecological factors were severely or permanently altered. Inherent to these population growth functions are notions that carrying capacity is not optimal capacity. Local/regional habitats form a mosaic of greater or lesser capacity to sustain particular populations, and populations oscillate at some "equilibrium-type" set point due to perturbations in available resources (see Allee et al., 1949; Schamberger and O'Neil, 1986).

Estimation of Earth's human carrying capacity is difficult (if not impossible) and fraught with assumptions (see Cohen, 1996; Daily and Ehrlich, 1992; Pimentel et al., 1999). Nevertheless, some researchers have estimated the world's sustainable carrying capacity at between 2 and 12 billion people, but this lower estimate has been exceeded since the 1930s (see Abernathy, 1993; Cohen, 1995; Pimentel et al., 1999; United Nations, 2008). This wide estimate is again due to multiple assumptions. A population of 2 billion people living at a "European" standard has been projected to require 0.5 ha/capita of cropland, 8 million kcal/ha of agricultural production, 1.5 ha for renewable energy, 1 ha of pasture production, 1 ha of forest production, with future water resources set as unlimited due to expected technology for waste water purification and desalination (Pimentel et al., 1999).

Ultimately, economic policies affecting industrial development, international trade, resource use, and non-market valuation determine TS conservation efforts. What "standard of living" will suffice for individuals in a world that approaches carrying capacity? Will a "great extinction" occur as human population growth continues or will replacement of resource extraction and use due to scientific innovation and perpetually greater efficiency obviate improved conservation? Is the doomsday scenario (i.e., The Litany) for planet Earth attributed to human-caused damages false (see Lomborg, 2001)?

This Chapter presents a review and analysis of published data on the status of Earth's species and the economics of TS conservation. It involves mainly Western literature. While many Eastern countries (e.g., India China, Indonesia) are at the forefront of world economic growth, research of the potential impacts of these economies upon resident TS is limited. In retrieving relevant materials, I found that the recent scientific literature entails considerable information related to the status of TS, the implications of sustainable versus growth economic policies for wildlife/fisheries conservation, and the methodologies used to value TS and estimate benefits and costs associated with TS conservation plans.

DETERMINING THE STATUS OF SPECIES

The Red List of the International Union for Conservation of Nature and Natural Resources (IUCN) is the most recognized inventory of enumerated species and populations worldwide (IUCN, 2004; 2007). This organization (or its former namesakes) has assessed extinction risks of animal, plant, and other species for > 50 years (Scott et al., 1987). It purports to be the largest conservation network, with over 80 nations, 110 government agencies, 800 non-government agencies, and 10,000 scientists represented in its membership (IUCN, 2007).

The Red List is derived and updated regularly by panels of scientists that assign species to risk categories based on a tiered approach (IUCN, 2007). Major tiers are: Evaluated Species or Non-evaluated Species and Adequate Data or Data Deficient. Seven categories comprise species assignments within the Evaluated Species and Adequate Data Tiers: Extinct (EX), Extinct in the Wild (EW), Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN) and Critically Endangered (CR). An added category of Conservation Dependent (CD) is sometimes used. Species included as VU, EN, and CR are lumped as TS, i.e., a category roughly analogous to threatened and endangered (T&E) species used in the United States (Federal Register, 1994; United States Department of Interior, 1973). Species included as CD, NT, and LC are grouped as Lower Risk (LR). Table 1 provides concise definitions of the IUCN tiers and categories (IUCN, 2007).

Criteria used to assign species to categories (i.e., IUCN uses taxa for species) are extensive (see IUCN, 2007). Briefly, criteria address: (1) *Extent of population reduction*, (2) *Extent of occurrence*, (3) *Population estimate with a stability rating*, (4) *Population estimate (absolute number)*, and (5) *Quantitative analysis related to the probability and projected time to extinction in the wild.* Elaborate descriptors accompany each rating, which serve as caveats for the quality of available population data, the attitudes of panel experts (i.e., precautionary or evidentiary), and the set of criteria used in assigning the rating (i.e., population decline, geographic distribution, population stability, population size, and probability of EW).

Table 2 provides selected 2007 Red List data for described and evaluated species (IUCN, 2007). Inspection of these data reveals several points. First, assuming that an estimated 5,000,000 species exist worldwide (see Primack, 2002), only 1,589,161 (32%) and 41,395 (0.8%) have been described and evaluated, respectively. Thus, biological and ecological information important to the life histories of about 3,410,839 (68%) organisms are virtually nonexistent. Second, of the 1,589,161 described species, a total of 16,306 vertebrates, invertebrates, plants, and other organisms were cited as TS. This is $\approx$ 1 percent of the 1,589,161 IUCN species or $\approx$ 0.0033 percent of the 5,000,000 species estimated for Earth (Primack, 2002). In short, 1 percent and 39 percent of the total described (16,306 of 1,589,161) and total evaluated (16,306 of 41,395) species were designated as TS, respectively. Third, except for the gymnosperm plants [33% of described pines (*Pinaceae* spp.), hemlocks (*Tsuga* spp.), etc.], accomplishment of extinction-risk ratings for the remaining classes of invertebrate, plant, and other species are 2 and 3 orders of magnitude less complete than those of vertebrates. Finally, based on the IUCN described species, vertebrates contributed relatively the most TS listings (5,742 of 59,811), while invertebrates (2,108 of 1,203,175), plants (8,447 of 297,326), and other species (9 of 28,849) provided relatively fewer listings. Of the 59,811 vertebrates cited by IUCN, species of mammals (22%) and amphibians (31%) were the most frequently listed TS; whereas, fewer species of fishes (4%), reptiles (5%), and birds (12%) were assigned TS ratings. A *post hoc* explanation for this emphasis is that mammals have high "charisma" (e.g., altricial, nurse offspring, fur bearing, lengthy ontogenetic development) and amphibians serve as sentinels of environmental health impacts (see National Research Council, 1991).

Table 1. Abbreviated definitions for assigning taxa (i.e., a species or some lower taxonomic classification of organism) to Red List categories where adequate data on risks of extinction in the wild are available (IUCN, 2007)

Extinct (EX)	Refers to a taxon when there is no reasonable doubt that the last individual has died
Extinct in the Wild (EW)	Refers to a taxon that is known to survive only in captivity, cultivation, or as a naturalized population; exhaustive surveys in former or expected habitat have yielded no evidence of an individual
Threatened (TS)	Encompasses CR, EN, and VU
Critically Endangered (CR)	Refers to a taxon that has an extremely high risk of being classed as EW in the "immediate" future[1]
Endangered (EN)	Refers to a taxon that is excluded from CR, but has a very high risk of being classed as EW in the "near" future[1]
Vulnerable (VU)	Refers to a taxon that is excluded from CR and EN, but has a very high risk of being classed as EW in the "medium-term" future[1]
Lower Risk (LR)	Encompasses CD, NT, and LC
Conservation Dependent (CD)	Refers to a taxon that is the focus of a continuing taxon-specific or habitat-specific conservation (recovery) program, which, if stopped, would lead to the taxon being classed in a TS category
Near Threatened (NT)	Refers to a taxon that is excluded from CD, but has some risk of being classed as VU
Least Concern (LC)	Refers to a taxon that is excluded from CD and NT; this category reflects species judged to have sustainable populations
Data Deficient (DD)	Refers to a taxon for which insufficient data are available to assign a taxon to a risk category based on distribution or population estimates
Not Evaluated (NE)	Refers to a taxon that has not been assessed using the risk criteria

[1] The terms "immediate," "near," and "medium-term" are vague; the IUCN (2007) website provides no operational definitions for these terms.

Table 2. Selected data from The Red List (IUCN, 2007) [1]

Species	Number Described	Number Evaluated	TS Number (as % of described; as % of evaluated)
Vertebrates			
Mammals	5,416	4,863	1,094 (20%; 22%)
Birds	9,956	9,956	1,217 (12%; 12%)
Reptiles	8,240	1,385	422 (5%; 30%)
Amphibians	6,199	5,915	1,808 (29%; 31%)
Fishes	30,000	3,119	1,201 (4%; 39%)
Subtotal	59,811	25,238	5,742 (10%; 23%)
Invertebrates			
Insects	950,000	1,255	623 (0.07%; 50%)
Mollusks	81,000	2,212	978 (1.21%; 44%)
Crustaceans	40,000	533	460 (1.15%; 83%)
Corals	2,175	13	5 (0.23%; 39%)
Others	130,000	83	42 (0.03%; 51%)
Subtotal	1,203,175	4,096	2,108 (0.18%; 51%)
Plants			
Mosses	15,000	92	79 (0.53%; 86%)
Ferns and allies	13,025	211	139 (1.00%; 66%)
Gymnosperms	980	909	321 (33.00%; 35%)
Dicotyledons	199,350	9,622	7,121 (4.00%; 74%)
Monocotyledons	59,300	1,149	778 (1.00%; 68%)
Green Algae	3,715	2	0 (0.00%; 00%)
Red Algae	5,956	58	9 (0.15%; 15%)
Subtotal	297,326	12,043	8,447 (3.00%; 70%)
Others			
Lichens	10,000	2	2 (0.02%; 100%)
Mushrooms	16,000	1	1 (0.01%; 100%)
Brown Algae	2,849	15	6 (0.21%; 40%)
Subtotal	28,849	18	9 (0.03%; 50%)
TOTAL	1,589,161	41,395	16,306 (1.0 %; 39%)

1 Note.—For the website-accessed Table on January 4, 2008, column labels were incorrect. Number of described species appeared beneath the header "Number of species evaluated by 2007"; whereas, the evaluated species appeared beneath the header "Number of threatened species in 1996/98" (IUCN, 2007).

Despite the IUCN's alleged use of empirical data, the Data Deficient tier highlights the difficulty in obtaining unequivocal population and habitat estimates for many of the world's organisms (IUCN, 2004; 2007). For example, the Puerto Rican parrot (*Amazona rittata*) ranks in the top 10 of the 1,217 endangered birds of the world (IUCN, 2004; United States Fish and Wildlife Service, 1999). A single wild population comprised of 30-40 parrots is found in the Caribbean National Forest, Puerto Rico—a rainforest of ≈ 113 km^2 (44 mi.^{2}). Obviously, population estimates for this extremely small, localized population vary greatly (25-33%)—an expected effect with rare populations (United States Fish and Wildlife Service, 1999).

Adequate data to evaluate the status of TS is biased for several factors: geographic distribution, accessibility of habitat, diurnal observation, and charisma to humans. Species that inhabit limited areas in remote environments and are secretive or non-charismatic receive less study. The costs of species inventories and population assessments become more expensive and more labor intensive as a species approaches extinction. Population data for abundant species can be acquired relatively easily and inexpensively, but population data for rare organisms can only be obtained at a relatively high per unit detection cost.

Because relatively few of the plant, invertebrate, and other species have been evaluated, the significance of numbers of TS for these genera is difficult to determine (Table 2). Lack of money for field inventories and lack of consensus among botanists/horticulturists regarding taxonomy has hampered evaluations of plant species more than animal species (see Synge, 1981). Additionally, entries and counts for all taxons are dynamic—the majority of TS populations continue to decline, many species are unevaluated, and new species are discovered/reported monthly (see IUCN, 2004; 2007; Science Daily, 2007a; 2007b).

UNDERSTANDING CONSERVATION ECONOMICS

Conservation economics involves ecological, environmental, and natural resource economics. Ecological economics is a relatively new discipline that studies relationships between human-caused ecosystem damages (e.g., cutting hardwoods in Indonesian rainforests, overfishing of The Grand Banks) and relationships between these damages and TS, biodiversity, and natural resources (Constanza et al., 1991; Czech et al., 2003; Daly, 1991; Gowdy, 2000). Many ecological economists discuss "systems" approaches to conservation, ascribe to an ethic of preservation, and favor sustainable economic principles as a means to this end. Environmental economics is the study of human-caused atmospheric, biologic, climatologic, hydrologic, and physiographic impacts; it emphasizes research of governmental incentives (e.g., tax rebates for solar panels reduce fossil fuel consumption, inspections of automobile emissions to curb regional air pollutants) to improve environmental quality usually within an economic-growth framework (Field and Field, 2006). Natural resource economics is the study of cyclic, consumptive resources (e.g., timber, wildlife, fisheries) and programs that aid maintenance and replenishment of these resources within an economic-growth framework (Loomis, 1993, 2000).

Both microeconomic and macroeconomic principles apply to these disciplines (Blight and Shafto, 1984; Mankiw, 1997). Microeconomics refers to small-scale programs and functions (e.g., Mexican Wolf Recovery Plan, City of Portland Waste and Recycling Program)—factors affecting the individual or local economy (Blight and Shafto, 1984). Macroeconomics applies to large-scale policies and sectors (e.g., North Pacific Fisheries Treaty, Agriculture)—the whole national, regional, or international economy (Czech, 2002; Daly, 1991; Mankiw, 1997). Essentially, microeconomic activities comprise macroeconomic systems; however, large-scale market forces, "black-market" activities (e.g., illicit wildlife trade, clandestine "bush meat" sales), and international geopolitical issues make large-scale conservation economics more than the simple sum of its microeconomic parts (Mankiw, 1997).

Traditional Western economic systems have fostered expansion (wider trade and diverse services), growth (greater productivity), and development (higher living standards) policies (Mankiw, 1997). The term "neo-classical" is used to characterize these economies. This term is derived from the "classical" influence of Adam Smith, John Stuart Mill, and others through the theoretical developments of 20th Century economists such as John Hicks, Alfred Marshall, Arthur Pigou, and Paul Samuelson (see Baumol and Oates, 1988; Czech, 2000; 2003; Loomis, 1993, 2000; Mankiw, 1997). This is the economics of The Industrial Revolution. It placed a premium on manpower, not agricultural production—labor was considered capital (Mankiw, 1997; Simon 1996).

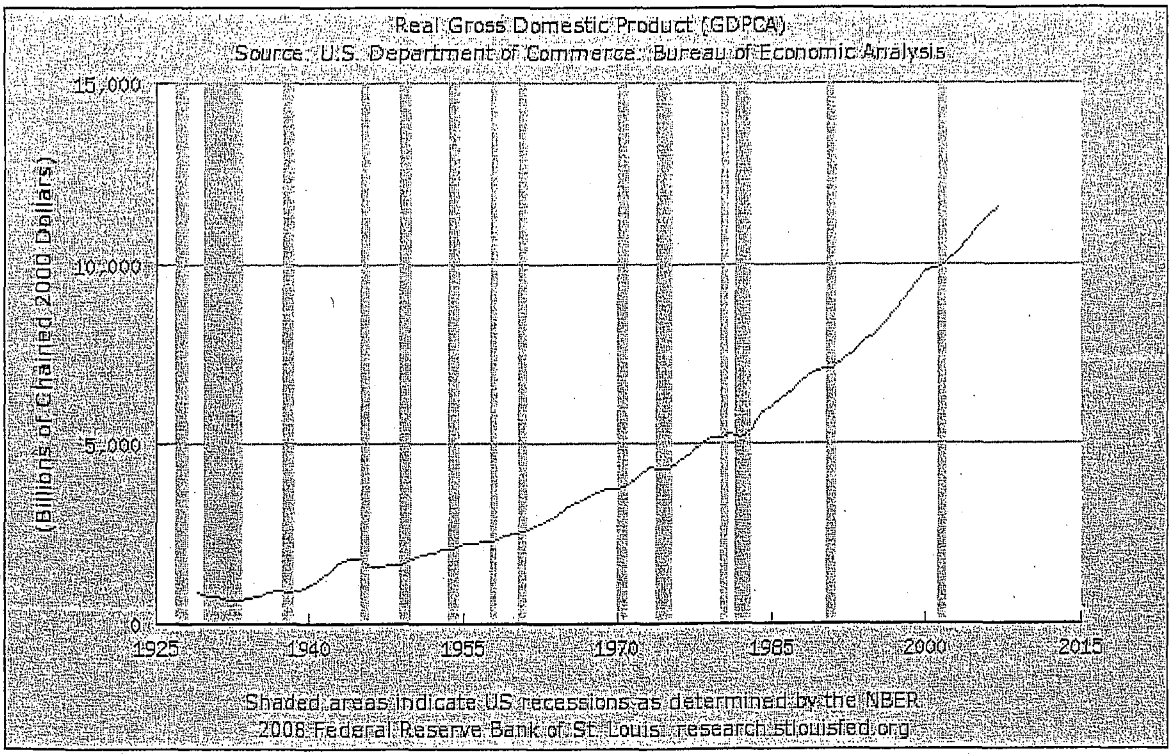

Figure 2. Graph of real GDP values (billions 2003 US$) in the United States, with periods of crashes/recessions shown as shaded. (Reprinted from Federal Reserve Bank of St. Louis, 2008).

Extracted resources are processed into intermediate goods and value-added products, but "market failures" (i.e., society may value some resources highly, but markets may not) are recognized, and corrective procedures for these failures may be required—Pigouvian taxes or subsidies (Baumol and Oates, 1988). Essentially, consumers purchase and consume the goods and services to gain increased utility (satisfaction). Population growth, greater productivity, and greater consumption of capital goods and services lead to expansion. Capitalistic market forces determine price structures, with principles of supply and demand, equilibrium, and market clearing (i.e., temporal price adjustments to demand) setting the values of specific goods and services for sellers and buyers.

Figure 2 is a graph of annual real GDP in the United States since 1925 (Federal Reserve Bank of St. Louis, 2008). Real gross domestic product (GDP) is the main measure of economic health used in neo-classical economics (Mankiw, 1997). This refers to the total incomes received and expenditures paid for goods and services using constant monetary units, e.g., dollars, euros adjusted for inflation (Federal Reserve Bank of St. Louis, 2008). During the 50-year period between 1947 and 2007 (3rd quarter) real GDP in the United States increased 10,086.5 billion dollars (from 1,590.9 to 11,677.4 billion chained 2000 dollars, respectively), with 11 multi-month recessions of flat or declining GDP characterizing the period (see Federal Reserve Bank of St. Louis, 2008). Thus, annual GDP in the United States now equates to about 12 trillion dollars.

Since the 1990s, sustainable (steady-state) economic principles have been posited as crucial to the maintenance of biodiversity and TS (Constanza et al., 1991; Czech, 2000). It is argued that increased quantities of production (growth) and a concomitant improvement in the quality of life (development) cannot be continued indefinitely on a planet with finite resources (Constanza et al., 1991). "Most relevant to wildlife conservation, ecological economics theorizes that there are biophysical constraints to the scale of the economy and that testing these constraints threatens our ecosystem and, ultimately, the economy itself."— B. Czech (2000, p. 5). Main tenets of a sustainable economy are: (1) generally indicated by stabilized (or mildly fluctuating) real GDP, (2) the North American economy grows as an integrated whole consisting of agricultural, extractive, manufacturing, and services sectors that require physical inputs and produce wastes, and (3) there is increasing evidence that North American economic growth is having negative effects on the long-term ecological and economic welfare of North America and the world (Czech et al., 2006). An "Iron Triangle" [i.e., corporate community, politicians (fundraising from corporate entities), and traditional economists] is alleged to promote continued economic expansion in the United States (Czech, 2003).

Evidence cited to support conversion to the sustainable economy is diverse, but consists largely of statistics confirming lowered environmental quality coincident with continued growth and development (see Czech, 2000; Czech et al., 2004; Trauger et al. 2003). These correlative data are interpreted to show that ecosystem degradation, urbanization, and numbers of TS have increased in the past 40-50 years (Czech, 2000; Hall et al., 2000; Trauger et al., 2003). Linear regressions between 30 years of U. S. GDP values and numbers of T&E wildlife species (Figure 3), as well as between U. S. GDP values and numbers of T&E fish species, yielded R^2 values of 0.98 and 0.94, respectively (Trauger et al., 2003; Reed and Czech, 2005). A descriptive study involving 18 key "causes" (*sic* "factors"—cause was not proved) of species endangerment alleged that aquifers (depleted), urbanization (increased), agriculture (increased), pollution (increased), reservoirs (increased), roads (increased), and diseases (increased) yielded high frequencies of T&E species (Czech, 2000). Still, correlation is not causation. High correlation coefficients would be expected for any major human growth related factor and numbers of TS (e.g., human population size, numbers of automobiles/ roads/utility poles). Interestingly, areas of agriculture cropland and temperate forests remained essentially stable during the past half century, as crop productivity increased (Trauger et al., 2003).

Economic issues surrounding species conservation via a sustainable economy are contentious. Endorsement of principles favoring sustainable versus growth economics in the United States has been debated by several professional scientific societies in the past five years (see Czech, 2000; 2007; Czech et al., 2004; 2006; Trauger et al., 2003). However, as of this date (to my knowledge), neither the American Fisheries Society, the Ecological Society of America, the Society for Conservation Biology, nor The Wildlife Society has made a formal statement advocating sustainable economic principles. The populace comprising most Western countries and many thriving Eastern countries (e.g., China, India, and Indonesia) has expectations that increased GDP is related to prosperity; whereas, slowing or declining GDP is associated with recession and unemployment. The events of 2008-2009 highlight these issues, with the United States government pouring > 2 trillion dollars into "economic stimulus" packages, jobs creation, "bailouts" of financial institutions, and infrastructure improvements. Will a sustainable world economy be immune from international "linkages," with rapid 30-50 percent "crashes" of markets, 5-10 percent increases in unemployment, and periodic government interventions to break spiraling downturns?

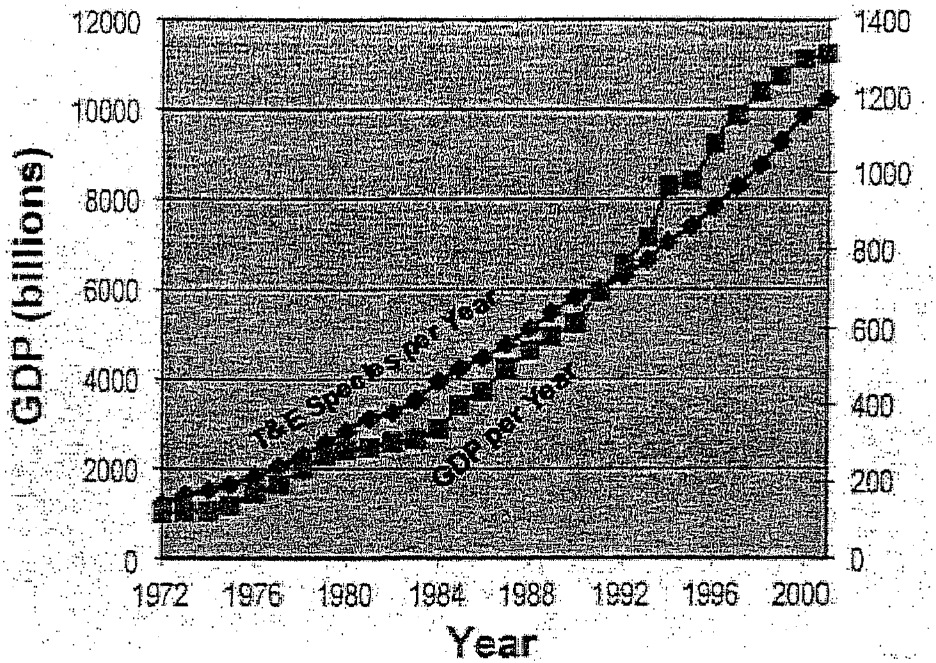

Figure 3. Comparison of 30 (1972-2001) annual GDP values (billions 2003 US$) and numbers of threatened and endangered species (T&E) in the United States (as of December 31 of each year) listed pursuant to the Endangered Species Act of 1973 (R2 = 98.4%) (Reprinted courtesy of The Wildlife Society; Trauger et al., 2003, p. 13).

Devising Methodologies for Conservation Economics

Benefit-cost analysis (BCA) is the most recognized quantitative approach to assessing the conservation programs (e.g., Boardman et al., 1996; Loomis, 1993; Loomis and Walsh, 1997; Zerbe and Dively, 1994). A BCA computes all of the gains and losses associated with a conservation or resource protection plan over time and in similar units (Loomis, 1993; Zerbe and Dively, 1994).

Six steps comprise a BCA: (1) specification of the region/environment considered in the analysis (e.g., ecosystem, habitat types, population sizes), (2) overall design/plan of the analysis (e.g., scope of the analysis, cost factors involved, potential savings to be gained), (3) data collection (e.g., assembly of *ex post* records, acquisition of *ex ante* surveys), (4) econometric analysis (e.g., quantification of the ecological/environmental factors using "monetized" values for the variables, regression of expenses and potential savings/benefits),

(5) sensitivity analyses (uncertainty reduction) to determine the effects of a changed input/independent variable (e.g., 10% less program cost, 5% increased TS recruitment/year) and the "shock" to the output/dependent variable (e.g., savings from the TS recovery plan; duration of TS benefits), and (6) interpretation of results (e.g., explain the projected, multi-year, or "break-even" point for costs and savings in TS recruitment, habitat improvement, ecosystem indices) (Boardman et al., 1996; Nas, 1996; Sterner and Smith, 2006; Zerbe and Dively, 1994).

A BCA evaluates program efficiency; it is used to find the cost of a conservation plan that maximizes benefits (e.g., greatest TS recruitment per unit cost, maximum habitat restoration per unit cost). A benefit-cost ratio (BCR) provides a value < 1.0, 1.0, or > 1.0, which indicates that savings (benefits) are smaller or equal to or larger than the costs expended to preserve or recover TS, respectively. This ratio is descriptive of relative costs and savings; it's constant across areas, locales, and regions. A crude threshold of expenditures is implied, whereby savings from monetary investments become cost efficient through mitigation of ecosystem destruction or TS loss. If projected returns of saved TS equal or exceed the expenses of surveillance and ecosystem preservation, then the conservation plan and effort is deemed worthwhile and a BCR ≥ 1.0 is obtained (see Boardman et al., 1996; Loomis, 1993; Loomis and Walsh, 1997; Nas, 1996; Zerbe and Dively, 1994).

While cyclic natural resources (e.g., timber, fisheries) have prices determined in competitive markets, no markets exist to determine price structures for TS within the constraints of neo-classical economics (Baumol and Oates, 1988; Erickson, 2000). Novel valuation techniques for clean air and water, wilderness areas, and viable populations of diverse vertebrates, invertebrates, plants, and other species must be devised (Loomis, 1993; 2000; Field and Field, 2006). Recent literature on TS, particularly the use of predator management to enhance TS recruitment, is replete with novel schemes to value TS, albeit often simplistic, conservative estimates (Engeman et al., 2002a; Shwiff et al., 2005).

Federal legislation provides for statutory fines that can be used to value TS; this is perhaps the most direct technique. The 1973 Endangered Species Act led to statutory provisions for illegally harming or disturbing listed species, with ≤ $25,000 per life unit promulgated as fines for the intentional killing of a T&E animal (United States Department of Interior, 1973; Federal Register, 1994). Recently, valuations of protecting rare wildlife were also reported based on state statutes or captive-rearing values (Engeman, et al., 2002a; 2002b; 2003). Statutory fines imposed in Florida for killing endangered sea turtles (i.e., loggerhead, *Caretta caretta*; leatherback, *Dermochelyscoricea*; and green, *Chelonia mydas*) place each turtle at $100 (Engeman et al., 2002b). In addition, the median cost (1997 to 2001) of recruiting a captive Puerto Rican Parrot was estimated at $22,105, with minimum and maximum costs per parrot of $8,602 and $35,667, respectively (Engeman et al., 2003). These latter values reflected recovery plan costs for both wild and aviary-reared birds, with recruitment of wild parrots lessened due to predation by raptors or mongoose.

Alternative methods (i.e., contingent valuation, hedonic pricing, travel-cost procedures) have also been devised to gain estimates of the monetary value (i.e., "monetize") that people place on TS, ecosystems, environmental quality, and natural resources (Adamowicz, 2004; Field and Field, 2006; Loomis, 1993). Although a direct unit price of TS (or other resource) is not derived, "proxy" values are determined indirectly by the amount of money people are "willing to pay" (WTP) in taxes, travel, or other equivalent expenditures.

Contingent valuation (i.e., stated preference) is a subjective, survey-type method in which sampled individuals respond to a questionnaire or an interview by stating the amount of money they would be WTP to preserve, restore, or set aside a riparian area, recharge an aquifer, recover a population of TS, etc. (Loomis, 1993). Extensive effort is devoted to creating validity for the survey/interview by developing elaborate printed materials about the hypothetical recovery plan or land "set-aside" program (Loomis, 1993; 2000). Individuals simply provide an "open-ended" price or "iterative" bids (i.e., respondents answer yes or no to a series of suggested prices that either meets or exceeds the WTP), with independent subjects queried about a range of values in a cross-sectional approach (Loomis, 1993). By altering questions and samples of individuals, a range of estimates is obtained that is used to determine the demand structure for the TS, ecosystem, environment, resource "good" (Loomis, 1993).

Hedonic pricing (i.e., revealed preference) refers to deriving values for non-market goods from their effects on related market prices (Puttaswamaiah, 2002). The hedonic value method (HVM) assumes that people will make accurate value judgments about tradeoffs in ecological systems using relative market prices. For example, the market value of lake-front property attributed to water quality has been shown to yield higher real estate values than lake front property adjacent to "fouled" waters (Wilson and Carpenter, 1999). By sampling and altering questions, a demand curve can be determined for the resource in question (Loomis, 1993).

The travel cost method (TCM) derives non-market valuations for ecological goods by determining trip costs incurred to view TS or critical habitats; these serve as a proxy for prices of those TS or habitats (Loomis, 1993; Field, 2001). Multiple assumptions are involved [e.g., trips to see TS are single trips to view 1 TS (not a connecting loop to see > 1 TS), trips need to be computed from several originating locations to compute the demand function, and travel itself (riding) provides no utility for the individual (Loomis, 1993).

Again, much economic analysis relies heavily on regression-based (correlation-type) studies—"cause and effect" statements cannot be discerned (Mankiw, 1997). Ex *post* data (i.e., fiscal or accounting records) comprise most analyses, with *ex ante* data (i.e., planned collections of preservation/recovery program costs) of conservation costs and savings rare, if not nonexistent.

ANALYSIS AND DISCUSSION

Status of Species

Determining the status of the world's species (even a single population) is a difficult, dynamic endeavor. Taxonomic lists are enormous. While attempts to categorize extinction risks for organisms have been refined in the past 20 years (Fitter and Fitter, 1987; Mace and Lande, 1991; Mace et al., 1992; IUCN, 2004), data and risk categorizations for most TS are tenuous (Mace and Lande, 1991). Numerous biological (e.g., density, mortality), ecological (e.g., succession, niche), geographic (e.g., latitudinal, longitudinal), meteorological (e.g., precipitation, temperature), physiographic (e.g., altitude, topography), and temporal (e.g., diurnal, nocturnal) variables interact to impede or aid surveillance of organisms. Issues of sampling and surveillance also affect quantification of the enormous number of animals, plants, invertebrates, and other species and populations comprising the Red List. Population estimation procedures are time consuming, involve repeated sampling, and are not readily adapted to inhospitable environs or rare individuals (White et al., 1982; White and Lubow, 2002). Convenience sampling and short-term indexing methods to estimate wildlife are also problematic, especially with rare individuals (Anderson, 2001; Engeman, 2003).

Uncertainty characterizes TS ratings, conservation economics, and TS-valuation methodologies (IUCN, 2004; 2007; Field and Field, 2006; Zerbe and Dively, 1994). Uncertainty is a parameter of variance, which reflects the range of dispersion in variables subject to influences by many unknowns (Burnham and Anderson, 2002). Use of uncertainty reduction techniques (e.g., sensitivity analysis, Monte Carlo iterative projections, worst-/best-case scenarios) are imperative with IUCN assessments of TS (see Sterner, 2008). An analogy is provided by statistical confidence limits (Cochran and Cox, 1957). Upper and lower confidence limits are computed based on the empirical variance (i.e., sums of squared deviations of sample values from the overall population mean) present in a set of samples of fixed size n. The computations specify the probability (e.g., 0.95, 0.99) that future random samples of this size will yield sample means which fall within the limits.

Pragmatically, the pace of extinction risk assessment is too slow. Socio-political issues related to geographic access, personal safety, data collection, and information transfer constrain biological monitoring. Additionally, methodological limitations in locating, identifying, and enumerating organisms are formidable. There are simply too many unknown biological (e.g., population density, birth rate, mortality rate, age structure), meteorological (e.g., drought tolerance, compensatory growth, climate change), ecological (e.g., colonization potential, habitat viability, eutrophication), and geographical (e.g., desertification, wetlands destruction) parameters that impact extinction risks and make IUCN assessments suspect (Forman, 1995; McCullough and Barrett, 1992).

Conservation Economics

Ecological economics postulates that there is intrinsic value in biological conservation and that the value of TS, biodiversity, and environmental resources will gain value as sources of future medicines (plants), ecotourism, and other benefits (Constanza et al., 1991; Czech, 2000; Primack, 2002). Neo-classical economics acknowledges the intrinsic value of biological conservation, but postulates that TS, biodiversity, and environmental resources will be preserved if they are valued by society more than other goods—competition for products and services will drive pricings of TS and make them more valuable leading to preservation (Loomis, 1993; 2000; Field, 2001).

Sustainable economic principles differ from neo-classical growth principles. Sustainable refers to "the amount of consumption that can be continued indefinitely without degrading capital stocks—including natural capital stocks" (Constanza et al., 1991). Significant savings will accrue from avoiding the costs and problems of TS management, urbanization, aquifer depletion, etc. Proponents argue that sustainable economics would neither yield "static" growth nor stagnation (Constanza et al., 1991; Czech, 2000; 2002; 2003; 2007). Production and consumption of goods and services will oscillate at a stabilized equilibrium similar to the carrying capacity concept of ecology (Constanza et al., 1991; Czech, 2000). On the other hand, neo-classical economics recognizes that continued extraction will lead to exhausted finite natural resources, but it posits that new technologies (e.g., solar power, wind energy, nuclear fission, synthetic materials), greater efficiencies (e.g., food production, manufacturing, transportation), and effective management of cycled resources (e.g., fisheries, timber, wildlife), coupled with future recycling of manufactured materials (e.g., concrete, glass, metal), will supplant the need for these resources (Lomborg, 2001).

Figure 4 is a schematic, which attempts to illustrate analogies between ecological and economic (i.e., both sustainable and growth) concepts. Terms used in both disciplines are similar (i.e., crash, steady-state/carrying capacity, equilibrium, and oscillations), and multiple factors interact to determine steady-state or carrying capacity. Multiple sectors (e.g., agriculture, heavy manufacturing, services, and transportation) comprise any economy (Figure 4a). Recessions may involve only a portion of these sectors, with petroleum, construction, heavy manufacturing, and financial sectors perhaps the most significant to job creation and growth. Thus, while some sectors expand others may contract, producing oscillations in GDP that tend to equilibrate (Poole, 2002). Developed nations usually have more economic sectors than developing nations. Similar to the logarithmic-growth phase of populations (Figure 1b), macroeconomics involves available capital goods (e.g., natural resources), production (supply), consumptive (demand), and labor factors. Oscillations (growth-recession) are theorized to occur, with major government programs or infrastructure revamps acting as boosts, and various natural disasters or geo-political actions serving as drags (Figure 4b).

Expanding-growth economics implies population-driven increases in output (i.e., marked by irregular, multi-month recessions) to an eventual "steady-state," or resource limit somewhat analogous to carrying capacity. Herein is the rationale for adapting ecological concepts to conservation economics. Interestingly, the *Solow growth model* offers a basis for macroeconomics related to production and consumption that actually predicts eventual steady-state economics within growth economies (Mankiw, 1997). This model assumes a production function whereby the supply of goods is based on capital stocks and labor. Investment (rising capital stocks) and depreciation (falling capital stocks due to age/obsolescence) lead to steady-state production and consumption with aged markets. However, analogous to steady-state economics, population growth must become static otherwise the production, consumption, and labor functions constantly induce new adjustments to higher steady-state asymptotes (Mankiw, 1997).

Recessions are a key issue affecting steady-state versus growth economics. A recession is commonly quantified as several months (e.g., two consecutive quarters) of slowed or decreased real GDP, real income, employment, industrial production, and wholesale-retail sales (National Bureau of Economic Research, 2008). Periodic slowdowns in GDP are the bane of growth economics; whereas, the role of recessions in steady-state economies have been poorly delineated by ecological economists. Moreover, correlation is not causation. Regression analyses between GDP and TS can be misleading. What is the correlation between GDP and TS during recessions? Theoretically, it should be near zero or negative, but these analyses have not been reported.

Additionally, an extensive rebuttal to the doomsday scenario of economic growth and associated human-caused damages (i.e., "The Litany") includes numerous counter examples to sustainable economics (Lomborg, 2001). Statistics are highlighted that show: (1) lifespan in developing nations has increased exponentially since the 1900s, (2) infant mortality per 1,000 in developing nations has decreased from roughly 160 to about 40 since 1950, and

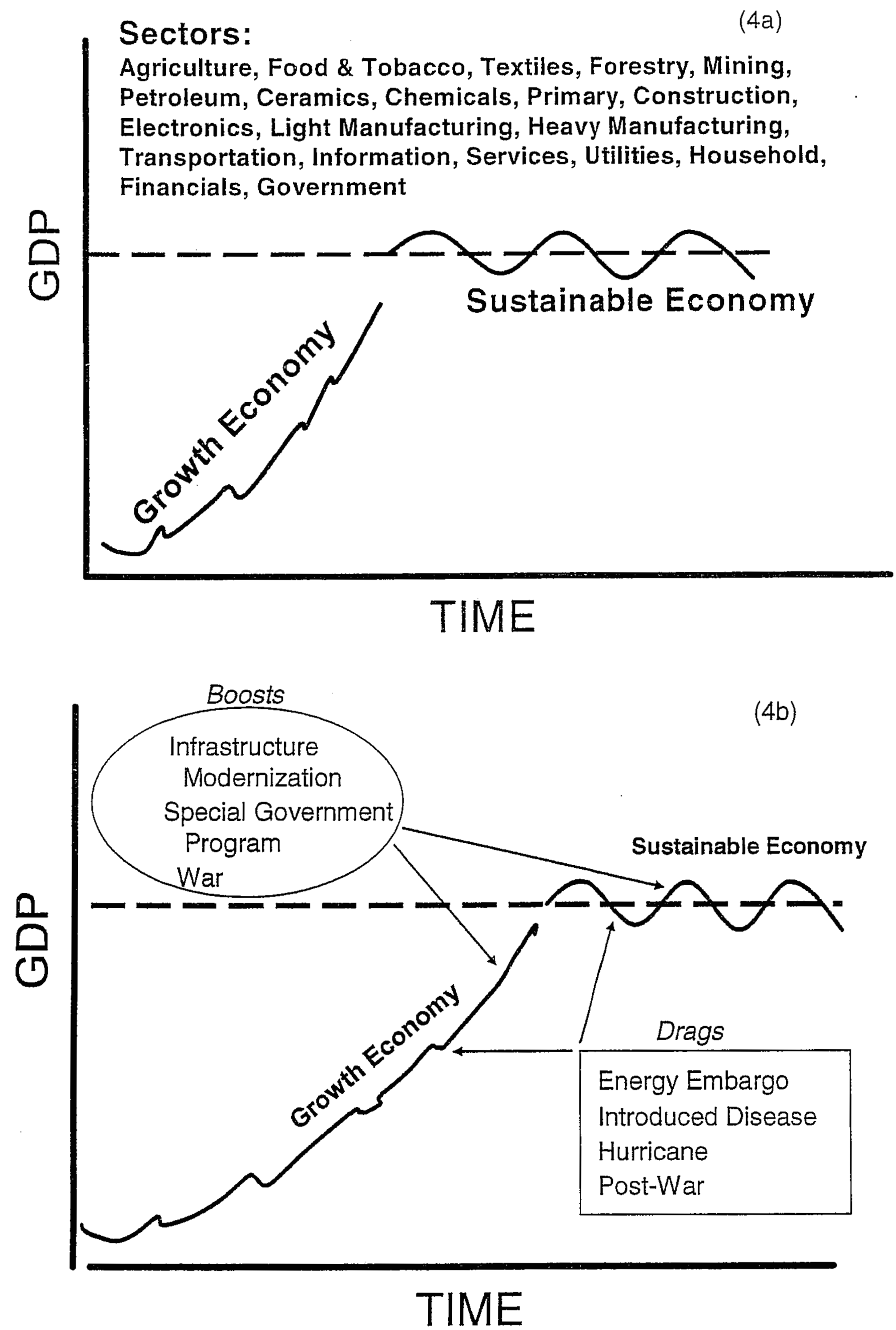

Figure 4. Schematic illustrations of factors impinging on growth and sustained (steady-state) economies: (a) economic sectors comprising economies, with the potential for a mix of sectors to be growing or declining (oscillating around equilibrium) at various times and (b) macroeconomic events that can serve as "boosts" and "drags" on the economy for periods of time, with expansion or positive oscillations linked to boost factors and crashes, recessions, or negative oscillations linked to drag factors.

(3) daily caloric intake in developing nations has increased from about 1,900 to nearly 2,600 per person since 1960 (Lomborg, 2001). Moreover, pollution data are provided that reveal: (1) indoor air pollution has become a far greater problem than outdoor air pollution since the 1970s (possibly due to improved insulation of dwellings), (2) annual oil-spill data for U. S. waters have declined from > 12 to < 1 million gallons since 1970, and (3) daily waste per person has stabilized at about 1.0 kg (2.5 lbs.) since 1995 (Lomborg, 2001). Together, these statistics are interpreted as confirming that despite larger human populations, people in developing and developed countries are living longer, eating better, polluting less, and generally faring better than in prior decades (Lomborg, 2001). Is a "crash" imminent?

Actual conversion to sustainable economics will require a major socio-political shift, and the likelihood of its adoption by a majority of nations seems remote. By their own admission, most ecological economists state that few conservationists fully grasp principles required of a world economy—let alone one characterized by international linkages and fluctuating production and consumption of goods and services (Constanza et al., 1991; Czech, 2003; Czech et al., 2004). (Note.—this could be said of politicians, neo-classical economists, and citizens as well.) At the international leve3l, GDP would be replaced by gross world product (GWP), with much uncertainty about how multiple national economies would interact to yield a ubiquitous GWP (Daly, 1991).

TS Economic Methodologies

To date, conservation economists have provided only primitive methods to "monetize" (i.e., assign € or US$ valuations to a TS or specific animal) the potential loss of rare animals and TS (Loomis and Gonzalez-Caban, 1998; Engeman et al., 2002a; Engeman et al., 2003; Adamowicz, 2004). The use of statutory fines is especially simplistic and circular (Engeman et al., 2000a). Should we rely on legislators to determine the value of TS? Moreover, despite > 40 years of research involving contingent valuation, the criticism remains that respondents often provide a WTP value for protecting TS or natural resources only to later contradict survey results with low monetary contributions or the defeat of funding legislation (van der Straaten, 2002; Adamowicz, 2004). While publication rates of studies using this methodology have soared, most econometricians remain skeptical of the validity inherent to the results (Adamowicz, 2004). Extensive research and development of new, improved methodology is needed before realistic costs and savings from efforts to conserve TS can be assigned. Of course, BCAs afford ranking of programs (i.e., conservation programs should be prioritized based on BCR values), with any outcome yielding a BCR of 1.0 worthwhile.

Economists have long used various methods to reduce uncertainty: sensitivity analysis, decision tree analysis, worst-/best-case scenario, contrived scenarios, and iterative projections of outcomes via modeling (Burnham and Anderson, 2002; Field, 2001; Sterner, 2008; Zerbe and Dively, 1994). These methods assess how changes in a quantified variable (or variables) alter computations in other variables or how a response surface of projections might look after iterative computations of varied inputs. For example, with sensitivity analysis, insertion of a greatly increased or decreased value for one input variable "shocks" the econometric model, producing a set of computations reflecting shifts in the output variable due to the altered input variable (Zerbe and Dively, 1994). Examination of multiple manipulations of inputs can show how the output is affected over a range of inputs. Together, these techniques afford potential ways of assessing unknown (hypothetical) features of TS populations, extinction risks, conservation benefits and costs, or other variables.

Finally, modeling affords a unique tack in the study of conservation and economics; it is the only feasible approach to examining the myriad of factors impacting ecosystems, TS, and BCAs. Models are symbolic (mathematical) expressions of natural phenomena (e.g., disease, population viability) and can entail numerous sub-types dependent upon methodology (Burnham and Anderson, 2002). Assignment of parameters is the defining step of modeling (Smith, 2001; Burnham and Anderson, 2002). Parameters refer to attributes of phenomena that cause or correlate with outputs; whereas, variables are specific values of parameters that can be substituted into a model to assess computational predictions. Typically, assumptions are stated, independent variables are quantified, and iterative projections of the model are obtained, with *sensitivity analysis* (or other uncertainty reduction technique) used to assess how changes in a quantified variable reduce or limit the uncertainty of outcomes (Burnham and Anderson, 2002; Zerbe and Dively, 1994). The predictions, inferences, and explanations gained in conserving TS, deriving the benefits and costs of managing TS and projecting population viabilities of TS will subsequently determine the effectiveness of conceived models (Burnham and Anderson, 2002; Schafer, 1981). Economic models and methods are sorely lacking that apply to the conservation of invertebrates, plants, and other organisms, especially for implementation of a sustained, global economy.

CONCLUSION

So what is the "end game" of the many scenarios that must be entertained in any discussion of the economics related to TS protection, survival, and maintenance? Governments, corporations, and individuals are typically reactive. Conservation economics entails numerous deontological (i.e., ethics, lofty rules) and teleological (i.e., mechanistic, natural design) problems. It subsumes microeconomic and macroeconomic principles, including interactions among ecological, environmental, and natural resource economics, containing many parameters and unknowns. To date, the IUCN has performed status evaluations for only 41,395— 2.6% of identified species (IUCN, 2007). While commendable, this number reveals a major limitation of conservation efforts. Adequate funding and manpower cannot be applied in a timely manner to identify and conserve untold populations of unknown TS. At best, preservation of TS and a Western standard of living is uncertain; risks of extinction in the wild remain high for most TS regardless of short-term funds dispensed for conservation (or discounting these costs into the future). At worst, countless new TS will be induced in the coming decades, with thousands of extinctions in the wild occurring during the 21st Century. Benchmarks of TS status, such as those provided by The Red List, afford assessment of relative changes in TS due to conservation efforts and new technologies, but these offer too little documentation too slowly. The need for improved, valid "monetizing" methodology for TS is real. Lack of this methodology precludes the development of pragmatic benefit-cost models for TS management. The prospect of having a TS become extinct is difficult to accept. Nevertheless, rarity increases valuations in market economies. I contend that solutions to human-caused environmental damages will gain priority only when developed countries (i.e., nations with sufficient technology and GDP) experience economic hardships due to the loss of biodiversity and resources or suffer insufficient technological innovations to offset these hardships. In the meantime, per an exceptionally perceptive biologist: "Finally, we must confront the reality that change is inevitable. Wildlife ecologists suffer from acute nostalgia, and perpetually lament the paradise lost. Nevertheless, the brave new world is here, and we must either adapt or become irrelevant."— D. McCullough (1992, p. 8)

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Use of trade names does not constitute endorsement by the U.S. Government.

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