age extraction and consumption of resources. Such subsidies are used to hide the very signals of scarcity that Arrow et al. wish to identify and amplify. Agricultural subsidies are an obvious example, but perhaps not the most costly. There are countless subsidies to encourage mining of minerals and mining of forests. There are other subsidies to encourage use of the automobile, including road construction and externalized costs due to the destruction of amenities for communities. The foreign policies of all the great powers have been founded upon the perceived necessity of securing access to resources, yet the costs of securing this access are not borne directly by the consumers: instead they are labelled as "national security" costs. The Gulf War was largely fought by the United States and paid for by the countries that consume petroleum, yet there is no "Gulf War" tax on petroleum consumption.

Another class of subsidies are those available to the wealthy. The wealthy are subsidized by the tax collection system: a host of special provisions often result in no taxes for the wealthy. As Leona Helmsley said, "We don't pay taxes. Only the little people pay taxes" (Time, 1989).

International armaments is a heavily subsidized industry that makes no contribution to human welfare. Among the biggest traders and subsidizers are the United States, Canada, England, France, and Russia. This industry, with the accompanying destruction of lives and resources, is not affordable.

Governments all over the world are in difficulty because of budget deficits. Deficits would disappear if some of these subsidies were eliminated. The problem is not ability to pay, it is not an environmental problem, nor a lack of knowledge, but a political problem. Political institutions can be changed in response to changing circumstances, but our dependence upon the environmental resource base cannot be changed. There is no technological fix that will enable the present pattern of consumption to continue indefinitely: that is the message of Arrow et al. (1995). What can and will be changed is ourselves. How will that change be made? Will it be the result of a conscious choice and a weighing of alternatives, or will it be a result of our inability to adapt?

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THE ENVIRONMENT, CARRYING CAPACITY AND ECONOMIC GROWTH[1,2]

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Arrow et al. (1995) argue convincingly that the current economic system fails to account for the depletion of resource stocks and other manifestations of "natural capital." New approaches to include natural capital are urgently needed in Canada, where despite technological capability, a First-World standard of living is still based heavily on an economy comparable to those found in Third World countries, i.e., the exploitation and export of raw natural resources.

The authors validly point out that the inverted U-shaped relationship between economic well-being and environmental protection does not apply to many types of human activities. There are other flaws with using such relationships. Typically, the U-shaped relationships are based on expenditures for environmental amenities, implying that higher spending will necessarily lead to better environmental quality. However, experience shows that this is often not the case. Ex-

[1] Manuscript received 27 July 1995.
[2] For reprints of this Forum, see footnote 1, p. 12.

penditures on the environment typically do not increase until there is evidence of severe environmental degradation. Monies are then spent on extremely costly, time-consuming, and often ineffectual assessment, cleanup, and restoration activities. Examples include billions of dollars spent for relatively little gain in the St. Lawrence Great Lakes, costly and seldom successful rehabilitation programs for recovering endangered species, high expenditures on failing marine fish stocks on both the east and west coasts of North America, cleanup of Superfund sites, etc., etc. Much less money spent early during industrial development to prevent environmental degradation in the first place would have been more effective. It follows that environmentally responsible economic planning would prevent U-shaped relationships from occurring at all. The early sharing of ecological expertise and environmentally friendly technology with developing countries will be essential to their sustainable development. Indeed, for widely dispersed pollutants like greenhouse gases and airborne toxins, sharing clean technology could prevent environmental degradation at global scales (increased coal-burning and sulfur emissions in China and use of pesticides in the tropics with consequences for northern aboriginal people are two examples that come to mind).

CO_2 is but one of many pollutants that cannot be described by a U-shaped function. A host of widely dispersed, persistent airborne toxins would be similarly unrelated to wealth, defying all common measures of economic benefit. Examples include mercury, which is increasing at $\approx$2%/yr (Slemr and Langer 1992), PCBs, a host of pesticides such as toxaphene, DDT, lindane and aldrin, and highly chlorinated dioxins and furans (reviewed by Pacyna 1995). While First-World countries have reduced or eliminated most of these (mercury is an exception), remissions from contaminated ecosystems continue to be sources of pollutants for more remote regions, in some cases decades after uses have ceased. In many remote regions, even trace inputs of such chemicals represent potential hazards to human consumers and other top predators, for trace inputs are biomagnified up to 10^7 or even 10^8 by food chains (Muir et al. 1992, Kidd et al. 1995, Schindler et al. 1995). These problems cannot be reversed or corrected by technological development, and must be tolerated for decades to come. What economic measure accurately assesses the damage to aboriginal cultures whose traditional foods are contaminated to unacceptable levels, or the intergenerational effects on both humans and wildlife (Colborn et al. 1993, Lockhart 1995)?

New approaches must also begin to address the most important of all environmental problems: the homogenization of the world's biota by increased intercontinental transportation (Ruesink et al. 1995). Many ecologists, myself included, believe that these "biological pollutants" are far more insidious than mere chemical toxins, and many have proved to be as persistent as the most undegradable of chemicals. What has changed the North American landscape more, chestnut blight and Dutch elm disease or acid precipitation and climate change? I submit that the former wins, hands down. The damage to agricultural crops and forests from non-native invaders costs billions of dollars each year. Even in remote areas of the west, hundreds of non-native species can be found. For example, in Banff National Park, over 100 non-native species of plants have been identified (Achuff 1991), and over 95% of lakes in the Rocky Mountains of the USA have had non-native species introduced (Bahls 1992). Interregional transportation of both people and goods is largely by the wealthy, making them the most likely culprits in the introduction of pests that both cause economic damage and modify the diversity of native communities.

Canada provides numerous examples of the failure of traditional economics to protect resource stocks. The east-coast cod industry has been totally eliminated, causing massive social problems. Forests in British Columbia continue to be cut at double the rates estimated by the government's own experts to be sustainable, yet recent reductions in allowable cuts will only prolong the inevitable by a few years. Agriculture, having destroyed the long-grass prairie, eliminated many grassland species including the plains bison and passenger pigeon, and supplied all corners of the globe with second-hand pesticides, is in decline. In these cases, widely available scientific studies predicted disaster years in advance, but weak-willed politicians reacting to industrial lobbies and public sentiments chose to ignore irrefutable evidence that sustainable harvests had been surpassed. There is also scientific "stock" to be taken. As the above failures indicate, humans have been about as effective at managing ecosystems as plankton have been at managing lakes. Terms like "ecosystem resilience," "ecosystem health," "ecological integrity," and "sustainable development" continue to be bandied about, and are certainly useful as theoretical constructs, but we know of no consistent way of measuring or comparing any of them. When "cumulative effects" are investigated, the interactions of even a few stressors produce horrendously complicated and counterintuitive effects on ecosystems. For example, climatic warming and lake acidification, which reduce DOC concentrations, have much greater effects on UV radiation fields in freshwaters than declining stratospheric ozone concentrations (D.W. Schindler et al., *unpublished manuscript*). "Adaptive management" must be defined as simply "mistakes are inevitable given our rudimentary knowledge of communities and ecosystems, and we will attempt to correct them." Sadly, these "experiments" are increasingly done on landscape scales where any but the smallest of mistakes cannot be corrected, where the cumulative effects of several simultaneous insults must be interpreted, and where political

and social resistance prevent timely responses. Perhaps it is time that ecologists projected a more realistic image, i.e., that we don't know enough to truly manage natural resources in any but the simplest ways.

The question is no longer whether or not we need the changes proposed by Arrow et al. (1995), but whether we can develop them quickly enough to protect our rapidly dwindling global resources for future generations.

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MANAGING EARTH'S LIFE SUPPORT SYSTEMS: THE GAME, THE PLAYERS, AND GETTING EVERYONE TO PLAY[1,2]

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When asked whether he wanted war, Bismarck supposedly replied, "Certainly not. What I want is victory." The increasing convergence in the worldview of leaders in ecology and economics, disciplines often at war on environmental issues, is remarkable (e.g., Jansson et al. 1994, Folke 1995).

The essay by Arrow et al. (1995) is a fine contribution toward achieving victory in humanity's most important "game": wisely managing Earth's life-support systems. More importantly, it reflects the level of intellectual investment and commitment needed in many academic areas and, indeed, in many sectors of society, to uncover practical winning strategies and tactics. Since we agree with the thrust of the essay, we suggest how the collaboration it exemplifies might be taken further.

Humanity is now clearly the dominant force on Earth. Human activities have dramatically altered important aspects of the character of the atmosphere, the oceans, and terrestrial systems (e.g., Vitousek et al. 1986, Daily 1995, S. Postel et al., *unpublished manuscript*). There is no remaining "natural habitat"—only a few areas (e.g., ice caps, hyperarid deserts, remote mountain peaks) where anthropogenic disturbance has been limited to changes mediated through alteration of the atmosphere. Humanity has reached the point where every cubic centimetre of the biosphere should be *managed*—that is, be included in a broad, global scheme designed to keep human impacts at a sustainable level in order to maintain Earth's life-support systems and human well-being.

While it is essential that ecologists and economists work together, they could not possibly design and implement such a scheme on their own. They can, however, capitalize on the momentum generated by the success of their own intensifying collaboration to foster other needed transdisciplinary efforts. The academic

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[2] For reprints of this Forum, see footnote 1, p. 12.