

# Accounting for ecosystem services as a way to understand the requirements for sustainable development

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Edited by Gretchen A. Daily, Stanford University, Stanford, CA, February 21, 2008 (received for review, September 18, 2007)

**Millennium Ecosystem Assessment documented the importance of ecosystem services. It is therefore important that these services are included in our economic accounts (Standard National Accounts), as long as we believe that these accounts should tell us something about our wellbeing. This requires measures of the ecosystem assets and their accounting prices. This article discusses how the concept of inclusive wealth can be exploited for creating such accounts.**

wealth | prices | dynamics

Since the introduction of the *sustainable development* concept in 1987 (1), this term has become a set of words very much used in environmental discussions. However, the meaning of the concept has remained opaque. Politicians and environmentalists have had their own interpretation and researchers and scientists have also had theirs. Sustainable development was defined as “[. . .] development that meets the needs of the present without compromising the ability of the future to meet their own needs” (1). Although this is not a very precise definition, it gives guidance on how one should make it operational. For doing so, we will follow Dasgupta and Mäler (2) and Arrow, Dasgupta, and Mäler (3). They interpret sustainable development as the one where human welfare (or well being, we will use these two words interchangeably) is not going down over time. Productive capacity of an economy is determined by its capital stocks. These are man-made, human, and natural capital. Sustainable development requires that enough of these stocks are left to subsequent generations. The importance of capital stocks is measured by their accounting prices. The methodological apparatus for estimating accounting prices will depend, in general, on the nature of the stock’s dynamics and on the nature of the institutional framework; we try to illustrate these issues in this article with a few examples.

This article gives a brief and consistent basis for accounting for sustainable development focusing on ecosystem services.

## Brief Literature Overview

Literature on so-called green accounting has a tradition going back to the early 1960s. It has focused on modifying the concept of a net national product so it will reflect the flow of environmental damages (mainly from pollution) and depletion (mainly of nonexhaustible resources, although the depletion of forests is often included). By correcting for these factors a measure sometimes called green net national product (NNP) has been calculated.

In 1974, Weitzman (4) developed a general theory for the net national product as a welfare measure. Mäler (5) extended Weitzman’s work to the environmental areas and introduced into the theoretical model both the flow of environmental damage and damage to ecosystems. The work of Repetto and colleagues in Indonesia is one of the first attempts for adjusting NNP measures (6). Some of the early literature is contained in Ahmad, Serafy, and Lutz (7), as well as in Lutz (8). These studies resulted later on in two United Nations manuals (9, 10). For an overview of many applications of this approach, see Hecht (11). In this article we will *not* follow these approaches, which more or less are based on the

production account in Standard National Accounts (SNA). We will instead focus on the capital account according to refs. 2 and 3, where it is shown that (i) it is theoretically impossible to develop an indicator like the green NNP for measuring sustainable development because of the changes over time in the prices of capital stocks relative to the prices of consumption goods and services, and (ii) a wealth indicator is the appropriate measure to use as an indicator of sustainable development.

Already in the mid-1990s, estimates of the value of the change in capital stocks (called genuine investment) started to be published as a way to continue the work initiated by Pearce *et al.* (12). Currently, the World Bank continues publishing annual statistics on genuine savings (13). It has also published a thorough analysis of wealth accounting and presents many empirical findings in ref. 14. Unfortunately, ref. 14 does not contain anything on ecosystem accounting, except for deforestation and damage from climate change; and it does not take into account population changes. In ref. 3, the theory is substantially extended by introducing population changes in the framework. Lange’s studies of wealth in southern Africa consider man-made real capital, human capital, fisheries, diamonds, cattle, and water as the main assets (15). She shows clearly how wealth statistics give a much different view of the economic development than traditional gross domestic product (GDP) statistics. In Arrow *et al.* (16), a group of ecologists and economists, based on ref. 3 and on the World Bank’s estimates of genuine savings, investigated whether a selected number of countries were on a sustainable development path. This work gives the background for this article.

## Wealth as an Indicator of Sustainable Development

Let  $C_s = (c_{1,s}, c_{2,s}, \dots, c_{m,s})$  be a list (or vector) of consumer goods and services in period  $s$ . The list must contain not only what we traditionally regard as consumer goods, but also environmental amenities, public goods, etc. They are also included because all of them contribute to human well being in one way or another.

We add the critical assumption that we have a forecast of the future consumption vectors. Such a forecast obviously must depend on three factors: the present stocks of capital  $K_{i,t}$  (where the current period is  $t$  and  $i$  denotes the  $i$ th capital stock), a forecast of future technologies, and a forecast of the institutions of the economy.

We assume, as is standard in economics, that there is a utility function  $U(C_1, C_2, \dots, C_m)$  that describes the production of well being in any given period. Social welfare is defined as the present value of the stream of future utilities:

Author contributions: K.-G.M., S.A., and Å.J. designed research, performed research, and wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

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$$W_t = \sum_{s=t}^{\infty} \frac{U(C_s)}{(1 + \delta)^{s-t}} \quad [1]$$

In Eq. 1,  $W_t$  is the social welfare in period  $t$ . This representation of social welfare goes back at least to Ramsey (17), but Koopmans gave the rigorous motivation for it, in three articles (18–20).

Consumption goods are produced with capital stocks as input in the production process. Dasgupta and Mäler (2) showed that there exist accounting prices  $p_1, p_2, \dots, p_n$  on the capital stocks so that

$$W_{t+1} - W_t = \sum_{i=1}^n p_i (K_{i,t+1} - K_{i,t}) + v_t \quad [2]$$

Neglecting the last term, Eq. 2 says that the change in social welfare between two time periods is equal to the *sum over all capital stocks of the value of changes in these stocks, when the value is calculated with the accounting prices*. Thus, the economy is on a sustainable path if the change in welfare from one period to the next is always nonnegative.

This result depends on the nature of the accounting prices. They are defined as the present value of the future perturbations of consumption because of a marginal change in the stocks today. They may sometimes coincide with market prices, but most often they are different. This is because of taxes, lack of markets for most natural capital, and other market failures. We will come across this later in our discussion of ecosystem services.

Mathematically, the accounting price on asset  $i$  at time  $t$  is defined as

$$p_{i,t} = \sum_{s=t}^{\infty} \frac{\partial U(C_s)}{\partial K_{i,t}} \frac{1}{(1 + \delta)^{s-t}} \quad [3]$$

It is worth remembering that forecasted future consumption is a function of the current capital stocks. In the social welfare equation included above, the first term gives the “endogenous” change in social welfare, that is, the change that is due to changes in resources inside the system. The last term,  $v_t$ , reflects changes in social welfare outside the studied system. For example, changes in a country’s terms of trade is, for a small country, independent of changes inside the country. The term will also reflect autonomous changes in technology (i.e., technical changes that are independent of capital accumulation in the country).

Although both terms of trade and technical change can be quite important for social well being, we will neglect these effects in this article, that is, we will neglect the “drift term.” For a motivation for this, see refs. 2 and 21. However, the main reason for not including these terms is that we want to focus on how to include ecosystem services in this framework.

### Man-Made Physical Capital and Human Capital

The value of changes in ecosystem services is not in itself an indication of whether society is on a sustainable path or not. It is only after having integrated all assets to a whole that it is possible to make judgments on sustainability issues. The two most important assets, beside ecosystems, are man-made physical capital and human capital. Man-made physical capital is included in conventional national accounting and the prices used are the market prices.

However, these market prices do not necessarily reflect the social value of the capital well. One reason is that environmental consequences from an investment are not necessarily reflected in the market prices and another is that the market prices are determined by the net return after taxes on capital income. Tax revenues may have a social value and the market prices do not reflect it. The

conclusion is that the social value of investment in physical capital exceeds the value of the investment reported in SNA.

Changes in human capital are not accounted for in Standard National Income, whereas expenditures on education are accounted as consumption, for historical reasons. However, it is far from certain that such expenditures reflect the social value of education. Instead, focus should be on the value of the output from the educational and research system. However, this is a rather complicated, and because this article is on ecosystem services, we will avoid going into it. Interested readers are welcome to contact the authors for further information.

### Ecosystem Services

That ecosystem services are of extremely high importance for human well being has been shown convincingly (22), but it is still not clear how to define units of ecosystems corresponding to capital assets and how to measure them.

**Classification of Ecosystem Services.** The Millennium Ecosystem Assessment (MEA) (22) has also provided us with a useful classification of ecosystem services: supporting, provisioning, regulating, and cultural. Although this classification is valuable, we have to modify it slightly to make it suitable for economic analysis. We have reorganized the MEA classification so that provisioning and cultural services are merged into a new category, final services, and the supporting and regulating services are merged into the category intermediary services. The reason for this is that both the cultural and provisioning services are directly affecting human well being, whereas the two others are doing that only indirectly—they affect the production of the final goods and services, as intermediary goods do in national accounting.

Another important issue on the classification of services is the distinction between private and public services. Public services are characterized by nonrivalry and nonexcludability. Nonrivalry implies that the use/consumption of a service by one individual does not reduce the availability of it for another individual, for example, climate regulation. If climate is changed for one individual, it will also change for all others experiencing the same climate. Nonexcludability implies that it is impossible to exclude anyone from the use/consumption of the service. Climate is also an example of nonexcludability. All other services are then called private services. Note that the distinction between private and public services has nothing to do with who is responsible for management of the production of the service (government or a private firm) or who is distributing the service among households. It is the characteristics of the service itself that are important for the classification. Most of the final services are probably private. Food produced from agricultural lands or the oceans or the forests are private services, as also are biofuel, water, etc. However, most of the intermediary services may be public. Climate has already been mentioned, but also disease and flood regulation are mainly public. Some water purification services can be public, but others may be private.

The distinction between public and private services is important because it makes a major difference for the economic analysis. If most of the final services are private—as assumed previously—the value of most of these services is already included in GDP, but not necessarily in the value of changes of ecosystem assets. Furthermore, valuation techniques for the ecosystem services will be very different. In general, it will be easier to value private than public goods. One reason is that private goods will frequently be sold and bought on a market that gives market values. This cannot happen with public goods! The SNA excludes most public goods for that reason, with the exception of government expenditures.

**Ecosystem Size.** We need a concept of “size” of the ecosystem and we need to know the dynamics of the system. The word size should not be interpreted literally. It will in general be a multidimensional concept that characterizes the system at each moment of time. In

principle, all stocks that affect the growth of any other stock in producing ecosystem services must be included in our measures of size. For example, consider a forest ecosystem. Two natural measures of size is the area covered by the forest or the total biomass of the forest. However, there are other stocks that will be needed for a proper accounting of the forest, such as the distribution of trees with respect to age, size, species, and space. Furthermore, the stocks of nutrients in the soil will influence the growth of the trees. Similarly the stock of birds preying on tree pests will affect the growth of biomass, as was shown by Ludwig *et al.* (23). For simplicity, most of our examples will have only one measure of size.

It is important to understand that ecosystems are production units and dynamic systems. Knowledge of the dynamics is essential in estimating the appropriate accounting prices. In the next section, we develop this idea with the help of some examples

### Examples

In this section, we present some conceptual examples of estimating accounting prices for ecosystem services, and in some of these examples, we present some quantitative approximations of accounting prices. However, the main objective here is to show the great variety of methods that must be used for estimating the accounting prices.

Ecosystems differ in their dynamics and this fact has profound implications for accounting price estimation. In the Standard National Accounts (SNA) the same problem does not occur at all or only to a small extent. This is because of the implicit assumption that market prices capture those differences, and SNA is a framework to account for market transactions.

Because there are no markets for many of the ecosystem services, the accountants must therefore estimate these prices from other data. Fortunately, a great number of techniques have been developed during the past years for doing exactly that. The reader interested in an overview of those techniques is referred to refs. 24 and 25.

**Accounting Prices for a Fishery.** Let us assume that a fishery can be approximated by the Schaefer model (26). This implies that there is one species only, the dynamics of which is given by the logistic model:

$$x_{t+1} - x_t = gx_t \left(1 - \frac{x_t}{K}\right) - h_t \quad [4]$$

In Eq. 4,  $x_t$  is the fish stock at time  $t$ ,  $g$  is the stock's intrinsic growth,  $K$  is the carrying capacity of the fishery, and  $h_t$  is the catch at time  $t$ . Here, we assume that the carrying capacity  $K$  is given (in the next section, the carrying capacity of the fishery will be a function of the size of the mangrove stock). The unit used for the fish stock is the biomass  $x_t$ .

Assuming that the utility function is equal to the net income of the fishermen, the social welfare function is

$$W_t = \sum_{s=t}^{\infty} \frac{q_s h_s - C(h_s, x_s)}{(1 + \delta)^{s-t}} \quad [5]$$

In this last equation,  $q_s$  is the price of the fish in period  $s$ ,  $C(h_s, x_s)$  is the cost of catching  $h_s$ , and  $\delta$  is the social rate of time preference. This social welfare function assumes that the value of catches equals the income from sales of the catch minus the cost for effort. The accounting price of this stock is given by Eq. 6:

$$p_t = \frac{\partial W_t}{\partial x_t} = \sum_{s=t}^{\infty} \frac{\left[ q_s - \frac{\partial C}{\partial h_s} \right] \frac{\partial h_s}{\partial x_t} - \frac{\partial C}{\partial x_s} \frac{\partial x_s}{\partial x_t}}{(1 + \delta)^{s-t}} \quad [6]$$

It should be quite clear that the value of the accounting price depends on what we expect from the future. In the simplest case, when the fishery is operated optimally, the accounting price is

$$p_t = q_t - \frac{\partial C}{\partial h_t} \quad [7]$$

That is, the accounting price for the fish stock is the present marginal profit from harvesting one more unit of fish (in periods with positive harvest). However, the accounting price will be zero when the fishery is an open-access fishery, which is the case when anyone can enter or leave without incurring a cost, as in the Gordon–Schaefer model (27). Simply whenever there is an expected profit (or rent) from the fishery, fishermen will enter increasing the total catch, reducing the fish stock, and by that increasing the harvesting cost until the profit (rent) has completely dissipated! The social value of an increase with one unit of the fish stock is in this case zero! This simple example tells us something very important. The appropriate accounting prices for an asset depends on our beliefs of the future. This basic conclusion is most often neglected in valuation exercises.

As we have seen, our expectation for the future importance of an ecosystem depends on our expectations on the institutional development. Thus, *institutional economics is tightly knitted to the estimation of accounting prices for ecosystem services*. Note that institutions here are something different from organizations. In brief, institutions are the “rules of the game”: legislation, social norms, markets, etc. (28). With bad institutions managing ecosystems, the accounting price will be low and even negative in some cases. However, if institutions improve, because of policy reforms, for example, then the accounting prices will rise and accounting will show an increase in wealth per capita and therefore in human well being!

Accounting looks at the marginal values, not at total values. It is important to emphasize this because in marginal values we start with an accounting price  $p_i$ , and value a change in the “size” of the system as  $P_i(K_{i,t+1} - K_{i,t})$ , that is, the change in the size is valued at a constant price. This is the marginal value of the change. Instead, the total value of the change can differ from the marginal value, because the price may change due to changes in the size, thereby generating changes in consumers’ and producers’ surpluses. This is also a source of errors in many empirical studies. In SNA, it is implicitly assumed that the values involved in transactions are marginal values. For example, the operating surplus is interpreted as the return on the capital stock, although parts of it may be monopoly profits, not related to the capital stock.

**Accounting Price for the Habitat Service Provided by a Mangrove Ecosystem to a Shrimp Population.** We have modeled mangrove habitat service to fisheries, as nutrient provider, in an extremely simplified way just to show how an accounting price for that service may be calculated; with empirical data, this model would calculate the accounting price of the service. Therefore, it calculates the changes in the well being of fishermen that follows a marginal change in the stock of mangrove biomass.

The hypothetical case we modeled includes two biological populations: mangrove forest and shrimp population. These two stocks grow following a Schaefer model and the growth function of the shrimp stock depends on the mangrove biomass, which implies that the ecosystem’s carrying capacity for shrimps,  $K$ , is not a parameter but a variable. The net growth of the shrimp stock will then be a function the shrimp’s biological growth minus the harvest, as usual, but will also depend on the size of the mangrove biomass. The harvest is modeled as a Cobb–Douglas function of effort and the size of the shrimp stock. The effort is a function of capital and labor inputs to the fishery activities.

The model describes a situation in which the forest is small (4,000 ha), which is the size of the mangrove forest that inspired this study, “Los Olivitos” in Venezuela. The forest is modeled as effectively

protected, so that there is no cutting and sales of mangrove timber; is spatially homogeneous in quality; and is only used by a group of local fishermen having no power to change the price of shrimps. Fishermen's access to the resource is regulated by a simple permit system limiting the amount of boats in the fishing grounds.

The dynamics of the two stocks and their interactions with the fishermen's economy is simulated with the software Stella for a period of 100 years. This complex system reaches equilibrium at about that time. We find in this way the values of the mangrove and shrimp stocks when the system is in equilibrium. Assigning these values from equilibrium to the biological stocks, the model is run again to evaluate the changes in fishermen's well being derived from a marginal change (10 ha) in the mangrove stock.

The model calculates the stream of net income and then we compare the net present value (NPV) of this stream before and after having introduced a marginal change in the stock of mangrove. The discounting rate is set at 1.5%—approximately consistent with the one used in the Stern review (29). The accounting price obtained is 200 US dollars per hectare. An accounting price for the fish population can also be calculated with this model.

**Accounting Price for Plaice.** In the Danish and Swedish fishery of plaice (a common flatfish mainly occurring in Europe) in Skagerrak and Kattegat, the plaice stock does not follow the Schaefer model, where food is the basic limiting factor. It seems that the limiting factors are suitable breeding habitats, and the area of these bottoms varies with time because the bottoms can be covered by algae resulting from eutrophication. Thus, the natural capital stock representing the plaice fishery is this area of soft bottoms.

Therefore, the Beverton–Holt model (30) seems better for explaining the dynamics of the plaice stock (31). In this model, when a young fish has been recruited to the stock, its growth will be completely exogenous and described by the von Bertalanffy weight function:

$$w(t) = a(1 - be^{-ct})^3 \quad [8]$$

In Eq. 8,  $w(t)$  is the average weight of fish at age  $t$  and  $a-c$  are constants. The number of individuals at age  $t$ ,  $N(t)$ , is equal to the recruitment at time 0 minus natural and fishing mortality. The total plaice biomass at time  $t$  is thus:

$$B(t) = w(t)N(t) \quad [9]$$

In contrast to the Schaefer model, the fishing manager must now decide which generation is to be caught, that is, which mesh size to use in the nets to avoid catching fishes that are too young. Note that, once again, this decision will depend on the institutions governing the fishery.

The Beverton–Holt model is usually presented as a model with continuous time, which makes it very difficult and sometimes impossible to analyze mathematically, but Silva (32), at the Beijer Institute, rewrote the model into discrete time and solved the model by using the software GAMS (General Algebraic Modeling System, GAMS Development Corporation)

The social welfare function was in principle the same as discussed in the two previous sections, that is, the present value of future net incomes from the fishery. Assuming optimal management of the fisheries (including the unrealistic assumption that the fishing gears are so precise as to select only one generation of fishes), Silva was then able to calculate the change in social welfare from a change in the size of the area of soft bottoms, that is, the accounting price of soft bottoms for use by the plaice for reproduction. However, there is no reason to assume optimization. The model could, in principle, be solved after various imperfections have been introduced. In fact, in one simulation (not included in the publication), Silva assumed that the selectivity in the gears was lacking so that the catch would consist of a mix of different generations (corresponding to the age

distribution in the fishing area). In this case, the accounting price would be lower, showing once again the importance of including institutional considerations as well as technological specification in the estimation of accounting prices.

**Boreal Forests.** Boreal forests generate many different services. The most important service is probably the supply of timber, but besides that, forests are important for the hydrology, for the microclimate, and for a large set of diverse services such as berry and mushroom picking, recreation, fishing, hunting, reindeer, and cattle feeding, etc.

**Accounting price for timber.** The traditional way of looking at timber production is, in some ways, similar to the Beverton–Holt model in that there is an assumption of an exogenous growth function of wooded biomass similar to the von Bertalanffy weight function. However, the model has been extended to incorporate specific management practices such as fertilizing and thinning, which influence the growth rate. We will neglect this in this discussion.

The limiting factor for the growth of a forest is then the area it can grow on and its fertility. The major economic question is at which age to cut the trees. This question was answered in the mid-nineteenth century, when a German forester, M. Faustmann, derived the equation by characterizing optimal rotation (for detailed analysis, see ref. 5):

$$V'(t) = r[V(T) - c] + r \frac{V(T) - c}{e^{rT} - 1} \quad [10]$$

$T$  is the length of the rotation (the number of years from felling the trees to the next felling of trees),  $V(T)$  is the net value of the stand of trees (where it is assumed that all trees have the same age),  $V'(T)$  is the increase in net value due to future growth of the biomass, and  $r$  is the interest rate.

$V(T) - c$  is known as the stumpage value, representing the value of one hectare of forest land minus the cost of felling the trees on that hectare. The value includes the present value of future rotations of the forest. Thus, the stumpage value is the maximum value a buyer would be willing to pay for the hectare with the present stand and is also the minimum price the present owner could accept for selling the land. Thus, the stumpage value is the accounting price.

Sweden and many other countries have public statistics on stumpage values and it is therefore easy to include the timber value of forests in the accounts. But this result is based on the implicit assumption that the only factor that affects the forest is humans.

Crepin (33), at the Beijer Institute, studied a forest consisting of birch trees, pine trees, and moose. Because of feedback between the different species, the dynamics of the system now becomes non-convex, implying that there are several different steady states, and because of this, the system is history-dependent. In such a system the Faustmann analysis is no longer valid. Furthermore, a change in one of the stocks will imply changes in the production of the other stocks and this will not be reflected in the stumpage value. However, we do not know yet the empirical importance of this, and more studies are needed. Because of this and the difficulties of a complete model of the boreal forests, we are using the stumpage value in our Stockholm County Project.

The discussion above has been limited to timber production but, as mentioned earlier, forests produce many other services. One is pollination by wild pollinators, and we will address that in the next section.

Another service is the role played by forests for microclimate control and hydrology. There is no doubt that these are important services of the Boreal forests. However, our knowledge about mechanisms behind the generation of these services is very limited, and it is too early to discuss how to include them in the accounting system. Finally, other provisioning services—berry picking, hunt-

ing, recreation, etc.—are much easier to include. For most of these services, the land area seems to be one good measure of the size of the stock. For hunting of moose, for example, one should also include the initial stock of moose. Valuation of these services for Sweden was done by Lars Hultcrantz (34).

**Pollination of Cash Crops by Wild Pollinators.** Many types of rapeseed (canola), a major cash crop in North America, are pollinator-dependent. For certain canola lines the seed weight per plant can increase >80% with pollination by bumblebees (35). The growing demand for urban development has significant impacts on terrestrial ecosystems (36) and on habitat fragmentation (37), which represents a major threat to wild pollinators (38). In this context, it is relevant to assess the pollination ecosystem service. In our Stockholm County Project we attempt to estimate the accounting price for the pollination *regulating* service by calculating how the pollination potential of canola can vary because of land use change in an urban development.

It has been shown that the availability of mass flowering crops (as canola) has strong positive effects on bumblebee densities, and the strongest correlation between the proportion of mass flowering crops and bumblebee (*Bombus terrestris*, *B. lucorum*, *B. lapidarius*, *B. pascuorum*) densities was found for landscape sectors with a 3,000-m radius (39). The bumblebees also require a 2% area of seminatural habitat within the circles surrounding the canola fields to obtain adequate nesting sites.

By using a geographic information system (GIS; ArcView) and information on area and geographical location of canola fields, we could then place circles (3,000-m radius) around the canola fields of the study area (Stockholm County, Sweden) and calculate the pollination potential in each circle. By changing the land use according to the regional development plan (40) of the study area (the Stockholm County, Sweden), we can then estimate the change in the pollination potential of the canola. The parameters on which our estimates of pollination potential changes are based are the proportion of mass flowering crops within the circle and the minimum requirement of seminatural habitat.

Because there is also a correlation between bumblebee density and harvest index (41), the change in pollination potential can be linked to crop output. The change in crop output can then, in turn, be translated into monetary units through a market price method. By using a similar approach, it has been shown (42) that forest-based pollinators increased coffee yield in plantations in Costa Rica by 20% and estimated that during 2000–2003 pollination services from two forest fragments translated into approximately US\$60,000.

Furthermore, the scales of operation of ecosystem services are of essential consideration when valuing ecosystem services (43). The scale of operation of solitary wild bees (44) as well as some long-tongued bumblebees (45) is in the realm of hundreds of meters, as opposed to several thousand meters, as is the case for the included generalist bumblebees; in our example, there are potentially several scales of operation to consider.

The distribution of resources at the landscape scale is an important issue to consider in the context of mobile organisms contributing to ecosystem services (46). Landscape connectivity is needed for different pollinators and potentially also for relevant pest control species (47), the freedom of choice to switch between different crops, in the face of, for example, climate change, is enhanced. This freedom allows adaptation to future environmental and other changes and should also be considered an option value, at least in part ascribed to the pollination service.

The dynamics of the interactions between the wild pollinators needs therefore at least two capital stocks: the size of the canola plantation and the size of the natural and seminatural habitat. The bee population seems to adjust very quickly to changes in the canola cultivation; thus there is a very fast positive feedback from increases in the canola area to the increase in stock of bees and the following

increase in canola production. However, the increases in impacts on the size of the natural or seminatural habitat seems to reach a saturation point with regard to impacts on the size of the bee populations. If the habitat is smaller than saturation size, a decrease of habitat will result in lower bee population and therefore lower harvest of canola.

**Resilience.** In all ecosystems, there are feedbacks between different components. Some of these feedbacks are positive, which implies that an initial perturbation of the system will be amplified. Sometimes, the positive feedback becomes active when the system reaches a particular state, and the result is that the system will flip to a different state that may be very different from the initial state. The initial state is then a threshold or a bifurcation. If the initial state is judged to be better than the state the system would reach if it would switch, it is of importance to prevent it from reaching the threshold. The largest perturbation the system can absorb without flipping into a different state is known as *resilience* (48).

If there is no uncertainty about the dynamics of the system, we can always manage the system to stay within the bounds of resilience. However, we never have full information and it is better to regard the system as a stochastic process. That implies that there may be a positive probability that the system will reach the threshold and flip to the nondesired state. This probability will be lower if the resilience increases. Therefore, it is essential to manage the resilience. Furthermore, resilience should be regarded as capital stock as it provides us with a kind of insurance against reaching a nondesired state.

As a stock, it has an accounting price and that price is roughly the change in the expected change in net present value of the expected future ecosystem services resulting from a marginal change in resilience today (49). Thus, we can estimate the accounting price if we know the dynamics of the system and the statistics of the system (as a stochastic process). This has been applied in analyzing the Goulburn-Broken Catchment in Southeast Australia. This system contains an area with extensive production of vegetables. The use of irrigation has increased the salinity of the ground water so that, if the water table reached two meters under the surface, the saline water would be sucked up to the surface and the whole production of vegetables would collapse. Thus, the resilience in this system is the distance from the current level of the water table to the level two meters below the surface. The water table is affected by two factors: precipitation and pumps that try to control the water table. Based on historical data (which may no longer be relevant because of global warming), the researchers estimated a probability distribution for the level of the water table and then estimated the increase in expected net income from the agriculture if the water table were one meter lower. Unfortunately, there have been no other attempts to include resilience in accounting for ecosystem services.

## Conclusions

From the brief presentations in the previous sections, it follows that accounting for ecosystem services is very case sensitive, because:

- Ecosystem dynamics varies from case to case.
- The definition of stocks varies from case to case.
- The nature of ecosystem services varies from case to case—sometimes private services, sometimes public services, and sometimes a mixture.
- Institutions vary from case to case with implication for valuation.

It seems to be in startling contrast to the creation of the standard national accounts, because SNA includes almost only market transactions and very few imputations (assessing values to factors that are not transacted in markets) are needed, except for the public sector. Industrial or infrastructural projects take time to carry through and they will have a long lifespan and complicated dynam-

ics. Should not their complicated dynamics inhibit the construction of SNA? The answer is no, because of the existence of market prices. This complicated dynamics has been taken into account by the managers of the projects and will therefore affect the demand and supply of goods and services now and in the future, and therefore the prices. If the markets work perfectly, the prices will correctly represent the social marginal costs and benefits of goods and services, and the data from transactions will reveal the true values.

When we deal with ecosystem services, we the analysts and we the accountants must figure out the accounting prices from knowledge of the working of every ecosystem. It is therefore—at least for now—impossible to design a standardized model for building a wealth-based accounting system for ecosystems. We have to develop such an accounting system by following a step-by-step path, going from one ecosystem to another.

It has often been said that the major problem of including ecosystem services in national accounts is the difficulty of valuing the services themselves. We do not believe that. Progress has been made, for example, on (i) valuation techniques: Bockstael and

Freeman (50), and McConnell and Bockstael (44); (ii) survey techniques: Carson and Hanemann (51); and (iii) dynamic modeling of ecosystems: Xepapadeas (21), Carpenter *et al.* (52), Scheffer (53), and Christiansen and Walters (54).

A strategy for future development of accounting for ecosystems must include:

It is not possible to estimate accounting prices for every ecosystem in the world. Instead a strategy for future development must include:

- Selection of major ecosystems to be studied and included in the accounting framework
- Establishment of the dynamics of the selected systems, as well as possible
- Description of the institutions that control the system now and are expected to do so in the future
- Development of the appropriate valuation techniques for each chosen ecosystem service
- Standardization of methods over different ecosystems, as much as possible.

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