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NATURAL CAPITAL

Submitted by Statistics Canada and OECD[1]

1. Using labels such as "natural capital," "ecological capital" or/and "environmental assets" to refer to the environment's capacity to produce services that humans are dependent upon for survival, is quite widespread today (see for example Millennium Ecosystem Assessment Board, 2005, and WCED, 1987). However, within the capital approach to sustainable development, the term "natural capital" is used in a more strictly defined sense, borrowing the notion of capital from economics and extending it into the environmental sphere. This paper describes the way in which the term natural capital is used in this context and briefly discusses some of the main conceptual and practical challenges the concept faces.

EXTENDING THE NOTION OF CAPITAL TO THE ENVIRONMENTAL SPHERE

2. Many researchers have noted that it is not just machinery, equipment and the like that share the characteristics of capital goods, but that elements of both the economy, the environment and society have value for the services they render to humans. These elements, it is argued, qualify for treatment as capital just as much as more traditional goods. Natural capital is the term used to describe those elements of the environment that yield resource materials, sink services and other ecosystem services. The formulation of "natural capital" was popularized by Pearce and Turner (1990) in their book *Economics of Natural Resources and the Environment* (Hinterberger et al., 1997).

3. When economists speak of the capacity of the economic system to generate products on an on-going basis, they refer to its *assets* or *capital stock.* The classical economists included only produced capital such as machinery, equipment, buildings and infrastructure in this notion, while more recently intangible items such as computer software and specialized knowledge are also considered as capital.

4. Within conventional economic theory, the capital stocks are considered to be the *main driving force* for economic growth and that which leads to (human) welfare. Welfare is defined

[1] Prepared by Roberth Smith, Statistics Canada, and Tone Smith, OECD.

as being a function of the consumption of goods and services provided by the capital stocks. From a sustainability perspective, the stocks are therefore that which must be maintained, if future welfare is to be sustained.

5. Economists have identified several *general characteristics* of such goods. First, it is not the goods themselves that are of value, but the services they offer. Second, they tend to depreciate over time; that is, the quality of the services they produce generally declines as the goods age. For this reason, a given level of economic production is not sustainable in the long-term unless there is continual investment to replace capital goods as they wear out. These characteristics can also be applied to natural capital:

- **Natural capital is of value for the services it offers**
  According to the body of thought that exists around the concept of natural capital, the environment contributes to human welfare through the provision of material and service flows (in the continuation, we will use the notion "environmental welfare" to label the environment's contribution to human welfare). The materials the environment provides include metals and minerals, biological products (*e.g.,* timber), water and fossil fuels. The services offered, range from the provision of renewable resources (e.g. cleansing of water), to the assimilation of waste materials and the regulation of the global climate; services that we use both directly and indirectly.[2]

- **Natural capital is subject to deterioration**
  Different kinds of natural capital are subject to differing impacts from human activity (depletion, degradation). This issue is treated further in section 3.

BENEFITS DERIVED FROM NATURAL CAPITAL

6. It is important to note that the adoption of the term capital by no means limits the consideration of the welfare benefits of natural capital to economic benefits. On the contrary, although economic benefits are clearly part of what natural capital offers, they are just a subset of the complete range of environmental benefits. The full range can be grouped into two broad categories: use benefits and non-use benefits.

7. **Use benefits** are, as the name implies, associated with the active human use of an environmental asset by an individual or group of individuals. For a use benefit to be realised, people must be engaged in activities that depend upon a current-period flow of either a material or a service from the environment. This flow could be measurable in physical or monetary terms or both. Use benefits can be further divided into two sub-categories: direct-use benefits and indirect-use benefits.

8. Direct-use benefits include those benefits derived from the use of the environment as a source of materials, energy or space for input into human activities. Also included are the benefits associated with non-consumptive uses of the environment, such as recreation and the psychic enjoyment of wilderness. Some direct-use benefits are clearly *economic* in nature since they manifest themselves in the context of economic activity (the value of resource extraction for example). Other direct-use benefits are *non-economic*; that is, they provide benefits for which there is no associated transaction in the marketplace. The benefits derived by humans

[2] In this context, these service flows are broadly defined to include pure utility flows, for example the psychic enjoyment of wilderness appreciation (existence value).

from the aesthetic appreciation of the environment are an example of non-economic direct-use benefits.

9. Indirect-use benefits are those associated with human use of the services provided by ecosystems. They do not derive from the active use of ecosystems themselves, but rather from the *passive use* of a service that ecosystems render free of charge. They include the benefits humans derive indirectly when they enjoy the clean air and water, stable climate and protection from the sun's damaging ultra-violet radiation afforded by ecosystems. By their nature, indirect-use benefits are always non-economic, as there is never any market transaction associated with such indirect use of the environment.

10. The second broad category of environmental benefits according to the natural capital theory is that of **non-use benefits**. These are the benefits derived from the continued existence of elements of the environment that may one day provide *use benefits* for those currently living or for generations to come. An example is the benefits derived from maintaining a rain forest to protect future sources of genetic material for drugs or hybrid agricultural crops. As with indirect-use benefits, non-use benefits are purely non-economic as there is no current transaction associated with them.

THE TYPES OF NATURAL CAPITAL AND FACTORS THAT AFFECT THEM

11. Three main categories of natural capital are identified as providing the environmental benefits listed above: **renewable and non-renewable resource stocks** (i.e., sub-soil resources, timber, fish, wildlife and water), **land** and **ecosystems**. Each of these plays a different role in terms of its contribution to environmental welfare (figure 1) and each is subject to differing impacts from human activity (figure 2).

12. **Non-renewable resources** (principally the sub-soil resources) represent stocks from which materials can be withdrawn for use in human activity. These materials provide *direct use benefits* as inputs into industrial processes and in private activities like home heating.

13. Because sub-soil resources do not have the capacity to renew themselves (except in geologic time), these resources are subject to permanent depletion as the result of use. They do not play an important role in ecosystems, so their use does not inherently lead to a qualitative degradation of the functioning of the environment. In practice however, the exploration and development activity required to make these resources available can cause significant degradation of the local environment. Also, the degradation of the environment at the local, regional and even global scale, resulting from the *use* of resources once extracted, can be significant.

14. **Renewable resources**: Renewable resources (trees and other plants, fish, wildlife and water) also represent stocks from which materials can be withdrawn for use in the economy. Unlike sub-soil resources, these resources can renew themselves under appropriate conditions.

15. If withdrawals within a given period are less than or equal to natural renewal, then there need not be any depletion as a result of human use. Of course, withdrawals are not always less than renewal, so *depletion* can and does occur. Fish resources are an obvious example.

16. Aside from the possibility of depletion, renewable resources are also subject to *qualitative degradation* as a result of human exploitation. Qualitative degradation does not necessarily

reduce the absolute size of renewable resource stocks, but makes them less productive or less valuable. This degradation can be the result of harvesting activities (*e.g.*, changes to the natural age- and species-distribution of forests, unintended mortality of non-target fish species); of pollution impacts (*e.g.*, acid rain); and of disturbance from urbanisation, agriculture, recreation and other land use changes. This degradation can negatively affect welfare because of reductions in *use benefits* (*e.g.*, lower quality material supplies, reduce aesthetic value) or *non-use benefits* (reduce options for the future).

17. **Land**: When we speak of land as natural capital, it is with reference to its role in the provision of space.[3] Land benefits humans in two ways from a spatial perspective. First, there are the *direct-use benefits* associated with the occupation of land for human purposes (dwellings, transportation infrastructure, agriculture, recreation). Second, there are *indirect-use benefits* associated with the services of the ecosystems that occupy natural and semi-natural land areas, and which benefits humans when we do not appropriate space, but leave it to be occupied by natural process and then enjoy the benefits of the services provided by the processes.

18. Land area is, of course, not subject to quantitative depletion in any significant way (at least not yet – climate change may change this). Nor is it subject to qualitative degradation in the same way as renewable resources. However, land areas of specific types can be augmented or diminished as a result of changes in the way in which land is used. For example, increasing use of land for urban purposes necessarily means reduced use of land for other purposes (agriculture, recreation, wildlife habitat, etc.) in areas around growing cities.

19. **Ecosystems**: Ecosystems (*e.g.*, forests [as opposed to trees]; oceans, lakes and rivers [as opposed to the fish in them]) provide flows of unpriced services that are used by humans in a variety of ways. The waste assimilation services of rivers, for example, are used by industries and households alike to absorb pollutants/waste products that would otherwise have to be disposed of by another means at greater cost.

20. Ecosystems are subject to both quantitative depletion through human activities (*e.g.*, the conversion of forests into urban land) and to qualitative degradation *via* the same mechanisms just mentioned for renewable resources.

21. The treatment of ecosystems as capital is the most difficult of the three forms of natural capital. In theory, the correct approach is to observe the services that are provided by ecosystems and to estimate the benefits that these services provide to humans. A list of the major services provided by ecosystems would include cleansing of fouled air and water; the provision of productive soil; the provision of biodiversity; the provision of a predictable and relatively stable climate; the protection from incident solar radiation; and the provision of reliable flows of renewable natural resources.

22. Even if we can identify what the major ecosystem services are, we cannot observe them directly, just as we cannot observe the transportation service that an automobile provides. In the latter case, economic theory has found a means of assessing the value of the automobile as capital even if it is not possible to observe the services it provides directly. The theory suggests that the present value e of the services rendered by the automobile over its life is equivalent to

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[3] Soil is not part of land in this respect, although it clearly does fit within the framework of natural capital. It could be treated either as a natural resource stock, or more reasonably as a component of terrestrial ecosystems.

the price established for it in transactions between buyers and sellers in a free market. The argument behind this notion is that no rational purchaser would be willing to pay more for the automobile today than the value of the services that he or she could expect to obtain through the use of it over its life. While this theory may be useful in establishing the value of produced capital goods that are commonly bought and sold, it is of little practical value in establishing the value of ecosystems. Another theoretical approach must be found to evaluate ecosystems as capital.

23. One possible approach to evaluating ecosystems is to consider the quality of their service *outcomes*. The list of major ecosystem services given above translates naturally into a list of outcomes that are more or less observable and that could be used as the basis for operationalising the notion of ecosystems as capital, and hence proposing a way to measure it. For example, the service of waste assimilation has a corresponding outcome of clean air and water. If the outcomes of ecosystems services are constant over time (e.g., air quality is non-declining) then one can conclude that the natural capital – that is, the ecosystems – that operate to provide these outcomes is being maintained. Obviously, the measurement of ecosystem service outcomes is by no means straightforward. Nevertheless, it is argued here that this is offers a proxy for ecosystem services that is practically applicable, and which offers considerable promise for measurement.

Figure 1: Different kinds of welfare benefits related to natural capital

	Use benefits	**Non-use benefits**
Economic	• direct: use of the environment as a source of material, energy or space: o type of natural capital: -non-renewable resources -renewable resources -land	
Non-economic	• direct: non-consumptive use: o type of natural capital: -renewable resources -ecosystems • indirect: (passive) use of ecosystem services: o type of natural capital: -land -ecosystems	• protection of nature for future use benefits: o type of natural capital: -renewable resources -ecosystems

Figure 2 Overview of types of human influence on different types of natural capital

	Degradation/ modification	**Depletion**
Natural resource stocks		
- Non-renewable resources		X
- Renewable resources	X	X
Land	X	
Ecosystems	X	X

FACTORS THAT AFFECT THE AVAILABILITY OF NATURAL CAPITAL

24. Sustainable development requires *maintenance* of the welfare-generating capacity of all assets that contribute to human welfare. From a natural capital perspective, this means extending the economic concept of investment from the economic domain to the environmental domain. However, the nature of what can be considered investment in the environmental domains is quite different from that in the economic domain, the notion is nonetheless considered useful. Unlike other forms of capital, no explicit human investment is required to maintain natural capital. Rather, what is needed is that human impacts on the environment are limited so that they do not represent a *disinvestment* in natural capital.[4]

25. For practical application of the capital approach, measurement of the factors that lead to their increase (investment) and decrease (depreciation) is essential. As explained in the introductory section, a given level of economic production is not sustainable in the long-term unless there is continual investment to replace capital goods as they wear out. However, considering the very nature of natural capital, maintenance is more relevant, since we can often not replace or repair natural capital that has been degraded beyond irreversible points.[5]

26. It is important to recognise that natural capital is affected by both natural and human processes. Each has the ability to both augment natural capital[6] and cause its decline. Natural processes were, of course, responsible for the creation of natural capital in the first place and it is natural processes that ensure the growth of renewable resources and the functioning of ecosystems. Natural processes are also responsible for the loss of certain forms of natural capital (particularly natural resource stocks). For example, pest infestations, which are a normal part of the functioning of healthy ecosystems, can wreak havoc upon the quality and quantity of trees found across large tracts of forests. Other types of natural disasters (drought, fire, floods, earthquakes, volcanoes, ice storms, etc.) can have dramatic effects upon all types of natural capital across sometimes quite large areas. When considering the availability of natural capital,

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[4] It must be noted that the 1993 SNA includes several categories of tangible non-produced assets that would fall under the heading of natural capital, although that term is not used in the SNA. These include certain land areas, proven sub-soil mineral and fossil fuel reserves, certain non-cultivated biological assets and certain water resources. In general, these are recognized as assets in the SNA only insofar as they are privately held and profitable under current price and technology conditions.

[5] Relevant to this issue are both the notions of resilience, irreversibility and thresholds.

[6] Planting trees, is an example of how humans can augment natural capital.

one certainly has to take into consideration such events, even though they are largely out of the control of humans.[7]

27. Of greater interest from a policy perspective are the *impacts of human activities on natural capital*, as it is here that the control levers are mainly found. As noted earlier, human activities affect natural capital either through depletion or degradation. Depletion is the result of natural resource exploitation and land use change. Degradation can also be the result of resource exploitation and land use change, but also, importantly, of the introduction of waste products into the environment. Each of these processes is discussed briefly below.

28. **Exploitation of non-renewable resources**: By definition, stocks of non-renewable resources are finite and any use of them today necessarily reduces the amount available for use tomorrow. The practical consequences of such depletion are not so straightforward however. First, not all non-renewable natural resource stocks are known. Thus, when we compare depletion against stocks to calculate reserve lifetimes, we are comparing it against only that portion of the theoretically available stock that we actually know to exist. Of course, known stocks are subject to change – sometimes dramatic change – as a result of exploration activity. Thus, the theoretically appropriate depletion concept is one net of new discoveries.

29. Second, some non-renewable resources are superabundant even if strictly speaking finite; sand and gravel is an excellent example. Economic theory says that these resources derive value mainly from their location rent; that is, the value attributable to them from their proximity to a source of demand. Distant stocks of such resources have no value. Other non-renewable resources that are not superabundant may nevertheless be sufficiently abundant that, in theory, their use today need not preclude any foreseeable future use. Some would argue that many metallic ores are in this category and that any future demand for these ores will be met simply by devising means of extracting deeper reserves.

30. The final complicating factor with respect to depletion of non-renewable resources is that not all resources are gone forever once they are extracted and used in the economy. Specifically, it is possible in theory to reuse metals an infinite number of times through recycling. Of course, in practice some use of metals is dissipative and leads to irrecoverable loss of the metal, so complete recycling is not a practical possibility. Nonetheless, one should not consider the stock of metal available for the future as just that found in underground ore; the "above-ground inventory" has to be considered as well. In the case of non-renewable energy resources (essentially fossil fuels), this is not at all true and all use leads to irreversible loss of the high grade, stored energy.

31. **Exploitation of renewable resources**: Exploitation of renewable resources need not lead to losses in natural capital provided that the rate of exploitation is equal to or less than the rate of natural growth. While true in a logical sense, this commonly accepted notion neglects the tension between renewable resources as inventories of raw material and the same resources as integral parts of functioning ecosystems. Old growth forest, for example, can be viewed as an extremely valuable source of high grade timber or as a special category of forest ecosystem offering very significant indirect-use and non-use benefits. To a large extent, realising the value

[7] Whether or not natural disasters are beyond human control or not is more and more a question of debate. Increasingly, it is understood that human activities, if not the direct cause of natural disasters, contribute to the severity of disasters in a variety of ways. Clearcut logging, for example, is thought to contribute to the impact of severe rain events by increasing surface runoff volumes and speeds.

of old-growth forests as raw material sources precludes realising any value as unique ecosystems and *vice versa*.

32. Even in the case where exploitation of a renewable resource does not lead to any quantifiable change in the size of the stock, there may well be qualitative changes that will affect its value as natural capital. For example, when a mature timber tract is clear-cut it is normally the case that nature will, left to its own devices, restock the land with trees. However, the natural way of things is such that the replacement trees will be of a different species composition than those that were cut. So-called “transitional species” will tend to dominate in the early years. These may be of lower value as natural capital for a variety of reasons: they may be less valued as material inputs; they may be less rich in terms of supporting biodiversity; or they may be less attractive from an aesthetic perspective. Only after many decades, or even centuries, will the forest begin to resemble that which it replaced. Given that the average rotation age for cutting forest is under 100 years, once mature timber tracts are cut, we may never again see them as they would exist in their undisturbed state.

33. **Land-use change**: Land-use change refers to human-induced changes in the functions that land areas are allowed to fulfil. It normally involved physical restructuring of the land surface in some way; for example, through removal of vegetation, soil or rock; modification of slope; or damming of waterways to create reservoirs. As noted above, land areas themselves cannot be depleted or degraded in the same way as other forms of natural capital.[8] However, land-use change does lead to increases and decreases in specific categories of land. An increase in land used for urban purposes can only come at the expense of land used previously for some other end. Equally importantly, land-use change can lead to degradation of other forms of natural capital (particularly ecosystems). The construction of transportation corridors can disrupt wildlife habitat and breeding patterns, for example.

34. It is not clear *a priori* whether a given change in land use represents a net benefit or loss for human welfare. Clearly, at the margin it is generally assumed that decisions regarding land use are made such that the more highly valued use wins out over the less highly valued. There are two reasons to suspect that this assumption might not always be true in the long run. First, it may be that decisions that are sensible at the margin from a private perspective do not make sense in aggregate from a societal perspective. Clearly, a farmer with 100 acres of land on the edge of a major city may see very clearly that his land is valued much more highly for housing than it is for crop production. However, when one recognises that most good farmland is found near settled areas, one sees that the private decision to convert farmland to subdivision may not make sense from a broader perspective of food security. Second, the framework used for valuing land in land use decisions generally recognises only private, direct-use values. If other values of the land (indirect use and non-use) were brought into the equation as the natural capital theory would suggest be done, the decision might look very different.

35. **Emission of wastes**: The final and most complex way in which human activity impacts natural capital is through the emission of wastes.[9] The impact of wastes is mainly felt in terms of a degradation in the capacity of ecosystems to provide the service outcomes we rely upon to, among other things, keep us healthy. Excessive introduction of wastes can, for example,

[8] Note that this is not meant to imply that the soil itself is not subject to deterioration, as it clearly is from such sources as salinisation, erosion and compaction. The point here is that land area is not subject to depletion or degradation.

[9] Wastes in this context include all gaseous, solid and liquid materials rejected into the environment from human activity.

overcome the capacity of the environment to assimilate them (its sink function) and reduce its capacity to provide clean air and water. We increasingly understand that waste materials can have more profound effects as well, on the capacity of the ozone layer to protect us from the sun's radiation for example. Other examples are toxics.

36. Understanding the relationship between waste emissions and the degradation of natural capital is extremely complex. There is no explicit guidance offered on this point in the natural capital theory. It is properly the domain of the environmental sciences (chemistry, biology, ecology, geography, climatology, etc.) and this speaks to the need to engage scientists in identifying the most important waste emissions. Although some wastes are obvious, others may not be.

37. From a policy perspective, waste emissions represent important levers of control. Of great importance would be linking waste emissions data with data from economic information systems so that the full force of our economic understanding could be brought to bear in studying the costs of benefits of reducing waste emissions.

SUBSTITUTION OF NATURAL CAPITAL

38. From a capital view, the requirement of sustainable development is to pass on to the next generation an aggregate capital stock no less than the one that exists now. This "constant capital rule" is also known as *weak sustainability*, and is based on an assumption that different types of capital are *substitutable*. Not all agree to this view, however. An alternative *strong sustainability* view is that possibilities substitution between ecological assets and man-made assets are limited. In this view certain ecological assets are assumed to be critical either to human survival or to human well-being, and are identified as *critical natural capital*, meaning there are no man-made substitutes (Pearce, 1993).

39. An important feature of (natural) capital theory is that natural capital is considered to be at least <u>partially</u> substitutable by other forms of capital. That is, to some extent natural capital can be replaced with either produced or human capital in some particular human endeavour without reducing the welfare that the activity yields. There is diverging opinion on the extent to which this is actually the case. For example, in previous centuries white pine trees were highly valued for use as masts on sailing ships. Technological change eventually eliminated this need as steam and internal combustion engines replaced sails as the motive force aboard ships. This represents an example of welfare-maintaining substitution: the same service (moving ships) is produced using a different form of capital. Here produced capital (the engine) has substituted for natural capital (the mast).

40. At this point, the natural capital school splits into the weak and strong streams mentioned above. In the weak stream, the possibilities for substituting natural capital with other forms of capital are assumed to be great if not <u>limitless</u>. In the strong stream, there are still assumed to be possibilities for such substitution, although they are seen to be far from limitless. The implications of these two currents of thought for the way in which natural capital is measured are great. If the possibilities for replacing natural capital with other forms of capital are limitless (i.e., there is perfect substitutability) then there is a compelling reason to measure natural capital commensurably with produced and human capital. Only when all forms of capital are measured using the same yardstick is it possible to meaningfully compare welfare *trade-offs* when one form of capital is used in place of another. For all practical purposes, the only common yardstick available to us is monetary. This means that all natural capital would have to be

measured in monetary terms (even if it is first measured in physical terms and then valued afterward). This would very certainly be problematic, as monetary valuation of the environment is a poorly developed field. Many forms of natural capital can not be credibly valued given existing methods, and since many benefits are of non-economic nature, it is an open question whether good methods for monetary valuation can be developed for the related assets. In addition, different valuation methods, like cost-benefit analysis or contingent valuation, are still subject to criticism or seen as controversial within certain academic circles (Røpke, 2005).

41. The opposite viewpoint is that the possibilities for substitution of natural capital are limited. Many forms of produced and human capital are of value only when *combined* with natural capital. For example, a fishing fleet is essentially worthless unless combined with healthy fish stocks to exploit. In this case the fishing fleet and the fish stocks are said to be *complementary*. But this is just a limited example of complementarity, where a subset of produced capital is complementary with a subset of natural capital. There is another possibility as well. This is that certain forms of natural capital provide services that are essential to human welfare and for which there exists *no known substitute*. Although examples of this type of capital are few (and there may be no absolute example), global atmospheric systems that provide the services of climate regulation and protection from solar radiation come very close. True wilderness, with its matchless psychic value, is another. The most critical commentators claim that economics can never deal properly with ecosystems anyway. In their view, ecosystems should not be subject to monetary evaluation, since they are outside the sphere of economics and underpin the whole system. Their view is that whether human beings believe in it or not, we are totally dependent upon the functioning of ecosystems (Røpke, 2005).

42. The answer to whether natural capital such as rivers should be measured in physical or monetary terms is not cut and dried. Certainly, a good case for physical measurement can always be made and this should be the starting point in all cases. The desirability of monetary valuation in all cases is less obvious. An argument can be made that when such capital provides direct-use *economic* benefits, there is both the possibility and the reason to value it in monetary terms as at least one way of looking at the issue. However, non-economic benefits (aesthetic appreciation) lend themselves poorly to valuation and are probably best measured in some kind of physical unit.

OPERATIONALISING NATURAL CAPITAL

43. Having defined in general terms the types of variables that natural capital covers, we now turn our attention to how they can be operationalised in terms of variables that lend themselves to observation and measurement. In this section they will be identified more explicitly and some thoughts about the nature of their measurement will be offered.

44. Many of the variables relevant to the natural capital framework have already been alluded to in the foregoing discussion of the theoretical concepts. It is useful to think of the operational variables related to natural capital in terms of stocks, states and flows. The stock variables include those related to assessing the extent of natural resources at a point in time. The flow variables include those related to assessing the qualitative and quantitative changes in natural resources and land from one period to the next, as well as those related to waste emissions. The state variables include those related to assessing ecosystem service outcomes. State variables are distinct from stock variables in that the former are inherently qualitative while the latter are quantitative.

45. Within each of these three major categories we identify the specific variables that would be the actual objects of measurement. It is not possible in this paper to go into the full details of the operationalisation of even one of the categories; just the discussion of a variable as seemingly straightforward as fossil fuel stocks could occupy many pages.

Stocks

46. It is straightforward to see the need for stock variables in operationalising the concept of natural capital. The framework leads necessarily to the measurement of stocks because they provide the material and service flows used in human development. The relevant stocks include traditional natural resources (timber, minerals, fossil fuels, water, fish) and land. The size of these stocks is important from a sustainability perspective because their size determines the extent to which humans can rely upon them as sources of environmental materials and services.

47. While it is straightforward to see that stocks must be measured as part of a natural capital-based system, their measurement can be far from straightforward. Physical measures of natural assets (tonnes of mineral ore, hectares of timber and the like) are relatively easy to produce in most countries, but they present a problem of non-commensurability. There is no obvious way to compare stocks of timber measured in hectares against stocks of oil measured in metres cubed. If one is going up while the other is going down, what does this mean for sustainability? The problem can be addressed, in principle, by measuring all stocks using a common numeraire, typically money. There are a host of difficulties associated with the valuation of natural capital stocks in monetary terms, not the least of which is suitability of market prices for valuing natural capital when the market itself ignores most environmental externalities. These difficulties, while of great interest and importance, are out of scope for this paper.

Flows

48. The second broad set of variables to fall out of the natural capital framework includes the flow variables. These are important because they determine the changes in size of natural capital stocks from one period to the next. The flow variables explain how human interaction with the environment enhances or diminishes its capacity to contribute to human development now and in the future.

49. Several categories of flow variables are relevant. Variables measuring the human activities that lead to *quantitative* changes in natural capital stocks show how activities in one period reduce (or augment) the availability of natural capital in future periods. These measures include timber harvests, oil and gas production and other resource extraction activities, as well as their mirror images - planting of new trees, discovery of new oil and gas reserves and other resource augmenting activities.

50. The second category of flow variables includes those describing human activities that lead to *qualitative* changes in natural capital stocks. Among the most important of these are measures of waste flows.[10] The impact of wastes on natural capital is mainly seen in the degradation of the capacity of ecosystems to provide the service outcomes humans rely upon to, among other things, keep them healthy. Excessive introduction of wastes can, for example, overcome the assimilative capacity of the environment, reducing the provision of clean air and

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[10] Wastes in this context include all gaseous, solid and liquid materials rejected into the environment from human activity.

water. It is increasingly understood that waste materials can have more profound effects as well, on the capacity of the ozone layer to protect us from the sun's radiation for example.

51. Changes in land use and land cover are another important flow measure related to qualitative changes in natural capital. Although land cannot be quantitatively increased or decreased to any great extent, human activities regularly change the land's qualitative features in ways that impact its ability to provide needed environmental services. Sometimes these changes alter the availability of certain types of land (e.g., good farmland is paved over for urbanisation) and other times they alter the availability of land for ecosystem functioning, which then alters the flow of ecosystem services available to humans. Both types of change are relevant in measuring natural capital.

52. A final category of flow variables includes what might be called "environmental investments." These are expenditures made with the purpose of reducing the impacts of current human activities on natural capital (*e.g.*, by reducing waste flows or resource consumption) or correcting the results of activities from earlier periods (*e.g.*, decontaminating abandoned industrial lands). These variables are less directly related to understanding sustainable development than the others mentioned so far; it is more revealing to measure the actual changes in waste flows resulting from investments in, for example, air pollution control equipment than to measure the investments themselves. Still, knowing how large these investments are in comparison with non-environmental investments and knowing who makes them are useful pieces of information when designing and assessing policy in support of sustainable development.

State

53. The last set of variables relevant to operationalising the natural capital framework includes the state variables. These are the variables that are required to qualitatively measure the outcomes of ecosystem functions. As argued earlier, it is theoretically preferable to measure ecosystems using some sort of stock variable, just as timber or fish can be measured. Unlike timber and fish, ecosystems are not measurable in any meaningful and straightforward way as discrete entities. The alternative suggested here is to measure them indirectly by considering the quality of their outcomes. This implies measurement of, among others, air quality, water quality, biodiversity and soil fertility.

54. The measurement of ecosystem outcomes is the least well developed – and arguably the most important – element in operationalising the natural capital framework. Science still does not offer a complete picture of the ways in which ecosystems function, especially in regard to the interaction between ecosystems. Thus, we cannot name with certainty all the ways in which humans benefit from ecosystem functions. Progress is being made however, particularly in the guise of the Millennium Ecosystem Assessment recently undertaken under the auspices of the UN (Millennium Ecosystem Assessment Board, 2005). As scientific understanding of these complex systems evolves, so too must the thinking on how best to measure ecosystems and their functions within a framework for measuring natural capital.

CONCLUSIONS

55. In this paper we have described natural capital from a "capital approach" perspective. Different types of natural capital, of benefits, of influence from humans have been outlined. The most important challenges and controversies have also been mentioned.

56. Given the usefulness for decision making in measuring many forms of capital using money as the yardstick, additional work to develop more agreed *valuation techniques is urgently required*. At the moment, only a fraction of the environmental assets found useful to be measured in monetary terms can be monetized with existing techniques. As a starting point, research on the valuation of fisheries, water, recreational land use and environmental waste assimilation services is required.

57. The question of *substitution* deserves more careful attention. It has been argued here that some environmental assets provide essential and irreplaceable services and, therefore, ought not to be considered substitutable. Many would disagree. To better reveal the nature of this disagreement and attempt to resolve it, a fuller exploration of ecosystem services and the interpretation of "substitution" in the context of these unpriced and, sometimes, unrevealed flows would be helpful.

58. Related to this issue are also other issues of ecosystems resilience, non-irreversibility, thresholds, and how to operationalise the precautionary principle. Our understanding of ecosystems and how to define and measure them from a natural capital perspective is more limited. So is humans' understanding of the ecosystem in general, as the Millennium Ecosystem Assessment clearly showed.

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