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Have missing markets for ecological goods and services affected modelling of terrestrial C and N fluxes?

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Abstract

Using the literature on modelling of C and N fluxes through cropland and aggregate semi-natural/natural terrestrial (ASNNT) ecosystems for the period 1991–2002, in conjunction with estimates of total economic value for both systems, we illustrate how missing markets for ecological goods and services might have biased the research output in favour of croplands. Using the results of Costanza et al. [Nature 387 (1997) 253], we can estimate that the total economic value for cropland is US$0.128 trillion ($10^{12}$) per year compared to US$10.491 trillion for ASNNT ecosystems. Fitting trendlines to the research output data, we show that this 82-fold difference in value is accompanied by an average of twice as much study (1.17–2.48 range) for the ASNNT ecosystems group. Through a basic analysis, we suggest that at least three times as much study for ASNNT ecosystems over cropland was justified between 1991 and 2002.

Keywords: C–N modelling; Missing markets; Non-market values; Research output; Total economic value

1. Introduction

A key reason underlying socially unacceptable levels of pollution and environmental degradation is the restricted use of economic markets. Environmental economists use the term *missing markets* to denote the fact that we do not place monetary values upon ecosystem goods and services and incorporate them into decision making. Examples of non-market goods and services include the carbon sequestration properties of natural ecosystems, the flood defence provided by mangroves and the regulation of hydrological cycles by tropical forests. These non-market benefits are also known as *positive externalities* because they provide a positive benefit to society, which is external to the market.

Many ecological goods and services have the characteristic of *public goods* which is why they are not marketed. Public goods are, by definition, indivisible in consumption, i.e. individual use does not reduce collective consumption. Additionally most public goods are non-excludable (Perman et al., 1998) so that one person or organisation cannot prevent another benefiting from a particular good or service. Taking the example of the carbon sequestration benefits provided by ecosystems—we all benefit from the CO_2 locked up in these sinks and this benefit is beyond restriction by an individual or organisation. Accordingly as it is impossible for anyone to control use of, or access to, these services, they remain unmarketed.

Therefore, in the presence of missing markets for ecological goods and services, it is a responsibility of

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governments and international organisations to negotiate policy restricting the environmental impact of industry and consumers and thereby try and correct for this failure. Despite widespread acknowledgement of the ecological problems caused by missing markets, the potential impact of this market failure on influencing our *understanding* of environmental systems has not been examined.

An a priori link between value and research has been established in the literature for other subject areas such as medicine. Peipert (2002) discusses the importance of medical research in terms of increasing longevity and quality of life with results suggesting that the increase in life expectancy due to advances in health during the 1970 and 1980s were worth $57 trillion to Americans. Similarly, research and value are interdependent in the context of environmental systems; research can help optimise our use and management of various ecological goods and services ranging from crops which are marketable commodities to non-market goods and services associated with ecosystems.

Given that there is an economic spur to understand market-oriented systems in terms of financial returns, this provides an explanation as to why modelling might be biased towards cropland with relatively less effort expended on representing and understanding other terrestrial ecosystems where most of the benefits reaped by society are external to the market.

2. Methodology

The key assumption underlying our work is that in the absence of missing markets then the following equality would hold:

$$\frac{\text{cropland research output}}{\text{system value}} = \frac{\text{other ecosystem research output}}{\text{system value}} \quad (1)$$

Put differently, in a situation where all the values associated with cropland and other ecosystems were captured by economic markets, then research would be proportional to the value of either system. For this assumption to hold, the area of research under investigation would need to be equally integral to both cropland and other ecosystems.

Research areas like community ecology and biodiversity are obviously inappropriate because a bias in the literature to non-crop ecosystems is to be expected since this area of study is not as relevant to cropland. Similarly, the deleterious effect of herbicides on non-weed flora, for example, is studied principally in relation to crops, not plants in other ecosystems.

With regard to modelling of C and N fluxes, it can be argued, to an extent, that this is appropriate subject matter for investigation. Fig. 1 outlines the criteria which we think need to be fulfilled in order for a research area to be classed as equally integral to croplands and the rest of the terrestrial environment. C and N cycling are processes common to both systems which satisfies the first criterion, 'commonality'. At this stage, however, neither of the examples discussed above, community ecology and pesticides, would be

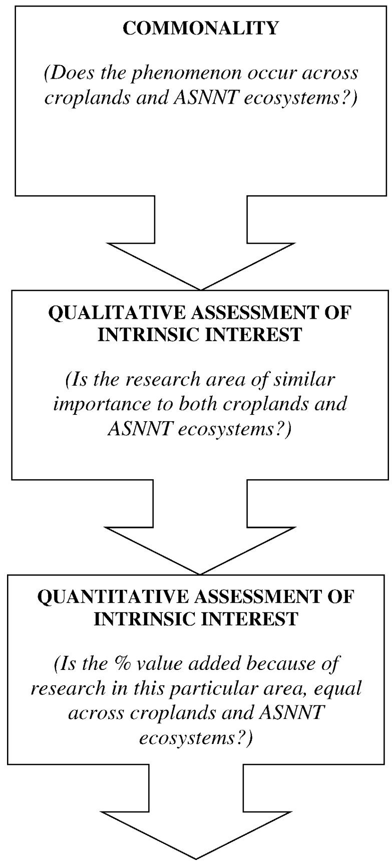

Fig. 1. Flow chart illustrating the criteria that need to be met in order to qualify as an area of research suitable for investigation.

eliminated. Community ecology and pesticides can be investigated in cropland and semi-natural/natural ecosystems, respectively, and limited investigation occurs in practise. However, neither of these research areas satisfies the second test, 'qualitative assessment of intrinsic interest'. This criterion requires the research area to be of similar importance to both systems. C and N cycling fulfils this criterion because, for example, understanding C and N cycling helps ensure optimal yield and carbon storage potential, in cropland and aggregate semi-natural/natural terrestrial (ASNNT) ecosystems, respectively.

The final condition, 'quantitative assessment of intrinsic interest' requires specifying that a particular research area makes the same percentage value contribution in both systems. This would be very difficult to derive for any research area given the complexities of ecosystems and the multitude research areas which contribute to our understanding of either cropland or ASNNT ecosystems. Therefore, assessment of bias proceeds upon a qualitative assessment of suitability.

In this paper, the dynamics of C and N are considered together as opposed to focussing on one biogeochemical cycle to increase the scope of our analysis. Furthermore, it is difficult to decouple C and N dynamics because of the interactions and interdependencies between these two fundamental nutrients. For example, decomposition and N mineralisation are constrained by the need for soil microbes to maintain their own C–N balance (Paul and Clark, 1989) while N content of litter is a major factor regulating decomposition (Aber et al., 1990). Accordingly models of the N cycle are usually presented alongside a model of the C cycle or concentrations of one nutrient in various fractions feature widely in determining the dynamics of the other. For an exception, see ROTHC (e.g. Jenkinson, 1990) where C and N dynamics are not interconnected (Smith et al., 1997).

Using ISI Web Of Science (1981–2002) and the search command (**simulat*** OR **model***) SAME (**c** OR **carbon** OR **n** OR **nitrogen**) SAME (**cycl*** OR **dynamics** OR **flux*** OR **transformation***), we classified the C and N flux modelling literature into those papers pertaining to cropland or other ecosystems. The SAME operator was used throughout to allow for cases where keywords are not adjacent while OR indicates that one or more of the search terms inside each set of parentheses classes as a match for our query. We restricted our search to 1991–2002 inclusive because abstract indexing does not occur prior to 1991; between 1981 and 1990 inclusive only the titles of articles can be searched, and this exercise yielded few results.

All papers were reviewed and classified manually. We have restricted our analysis to terrestrial ecosystems, excluding papers pertaining to non-terrestrial C and N dynamics, geochemistry with no ecosystem component or analyses in geological history.

3. Results and discussion

Fig. 2 shows the result of categorising the C and N flux modelling literature into papers pertaining to either cropland or ASNNT ecosystems. The pattern

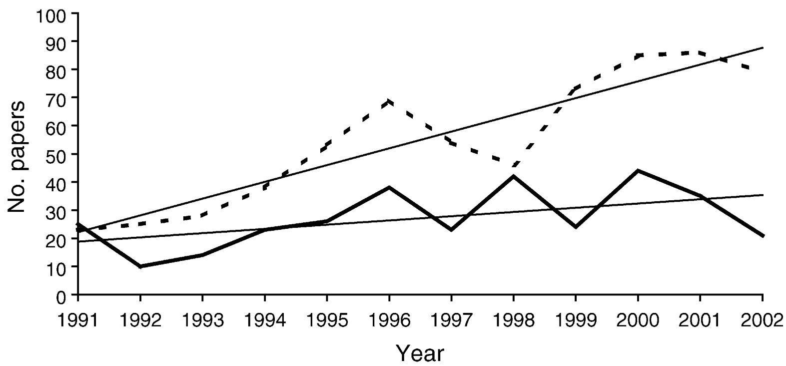

Fig. 2. Modelling terrestrial C–N flux: research output for cropland and ASNNT ecosystems (1991–2002). (———) Cropland ($y = 1.5x + 17.333$, $R^2 = 0.2597$, $P < 0.1$); (– – – – –) ASNNT ecosystems ($y = 5.9545x + 16.212$, $R^2 = 0.8472$, $P < 0.001$).

indicates that over 1991–2002, more attention has been paid to ASNNT ecosystems. Fitting trendlines to the research output data indicates an average of twice as much study (1.17–2.48 range) for the other terrestrial ecosystems group.

Obviously this picture is misleading without any consideration of economic values. Using the results of Costanza et al. (1997), we can estimate that the total economic value for ASNNT ecosystems is US$10.491 trillion[1] ($10^{12}$) per year in 1994 prices compared to a total economic value for cropland of US$0.128 trillion ($10^{12}$) per year.

The value estimate for cropland is composed principally from a known marketed value, that of food production. This accounts for 58.7% of the total value of cropland while non-market benefits associated with pollination and biological control make up the remainder. By contrast, the ASNNT ecosystems estimate is composed mainly of values which are external to the market. These include values associated with recreation, nutrient cycling, disturbance and climate regulation. There is more error associated with the value estimate for this group because the 'infrastructure value' of ecosystems is not included and there have been no studies on valuation of tundra and desert biomes (Costanza et al., 1997). This means that the value of US$10.491 trillion should be treated as a minimum.

The methodology employed by Costanza et al. (1997) to determine these gross ecosystem values involved aggregating smaller scale studies which were based principally on the 'willingness to pay' or WTP tool. This method is known as an *expressed preference* technique because it involves surveying people in order to find out (ask them to express) their willingness to pay for ecosystem services, see for example Johansson (1987).

There is only one other study in the literature which aims to quantify the value for global ecosystem goods and services. Alexander et al. (1998) employ neoclassical economic techniques to establish a global value in the range of US$8–16.2 trillion per year (1987 prices). These results are based on the assumption that the biosphere is owned by a single person (a monopolist) who establishes a market for ecosystem goods and services. However, this value estimate is not broken down across ecotype or function. If we assume that the proportion of this value range which corresponds to ASNNT ecosystems, reflects the proportion in Costanza et al. (1997) then we can estimate that the value of these ecosystems according to Alexander et al. (1998) is US$2.54–5.15 trillion per year.

The results of Alexander et al. (1998) match well with Costanza et al. (1997) given that the 1998 study excludes various ecosystem values which are incorporated in the results of the study used here. Hence, our decision to employ the value estimates derived from Costanza et al. (1997) in order to capture as many components of ecosystem value as possible.

Fig. 3 re-plots the results of Fig. 2 by dividing research output by the associated value of either system. This is to emphasise that the equality of Eq. (1) does not hold and instead:

$$\frac{\text{cropland research output}}{\text{system value}} \gg \frac{\text{other ecosystem research output}}{\text{system value}} \quad (2)$$

In order to converge upon the equality of Eq. (1), massive increases in ASNNT ecosystem research output would be required—an average of 40 times more research into this group. We acknowledge that beyond some critical limit, further study into modelling C and N flux could saturate and start to decline as the subject reaches its limit of understanding under prevailing knowledge which means that attaining this equality is not necessarily desirable. Furthermore, synergies between cropland and ASNNT ecosystem research are another reason why this approach is inappropriate.

The convergence of the intercepts in Fig. 2 where $y = 18.8$ for cropland and 22.16 for ASSNT ecosystems, followed by a divergence due to the relatively steep gradient associated with ASNNT ecosystem research, indicates a greater effort since 1991 to focus study on semi-natural and natural ecosystems.

If the non-market values of natural ecosystems were internalised or given better weight in policy decisions over the 1991–2002 range, research might follow the pattern in Fig. 4. Here, the hypothesised level of research in 2002 equals the actual level of research in that year but the gradient of the line is altered to mimic that for cropland resulting in extra study bound by the area [A,B,C] which is equivalent to three times

[1] Our definition of 'terrestrial' differs from Costanza et al. (1997) who include lakes/rivers. The value estimate for lakes/rivers of US$1.7 trillion is therefore not part of the US$10.491 trillion quoted above.

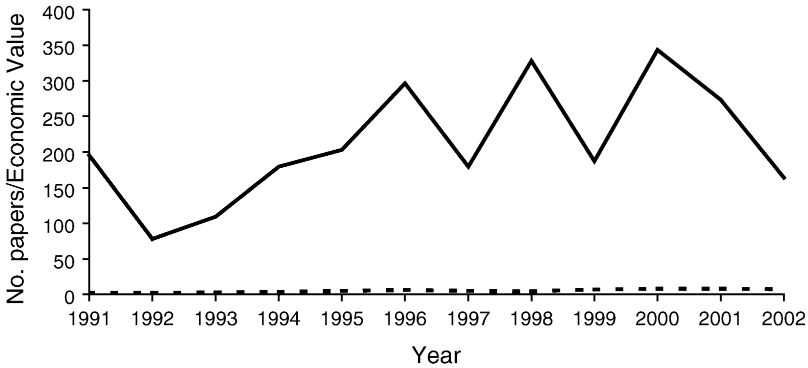

Fig. 3. Modelling terrestrial C–N flux: research output for cropland and ASNNT ecosystems (1991–2002) divided by total economic value (TEV) of each group as estimated by Costanza et al. (1997) in 1994 price terms. (———) Cropland/0.128 (from US$0.128 trillion per year); (– – – – –) ASNNT ecosystems/10.491 (from US$10.491 trillion per year).

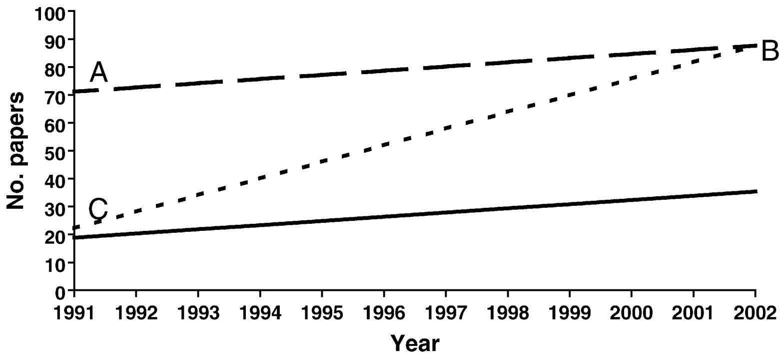

Fig. 4. Modelling terrestrial C–N flux: trendlines associated with the research output for cropland and ASNNT ecosystems (1991–2002). (———) Cropland; (– – – – –) ASNNT ecosystems; (— — —) hypothesised trendline for ASNNT ecosystems under a market correction scenario ($y = 1.5x + 69.66$). Area [A,B,C] is the increase in research output under this scenario compared to the actual output for ASNNT ecosystems.

more study compared to cropland. The gradient for cropland is utilised because this system is composed mainly of marketable goods (food production, 58.7%) and therefore more reflective of research trends in the absence of missing markets for ecological goods and services. The extra research [A,B,C] should be considered as the minimum extra required in order to redress the bias caused by missing markets because a significant minority of the benefits associated with cropland are non-market goods which means the gradient is not fully consistent with the absence of missing markets.

Furthermore, raising this trendline to the actual level of research in 2002 assumes that by then all ecological values are reflected in research output. Although the actual trend for the ASNNT ecosystems group indicates increasing awareness of the importance of non-market benefits, it is unlikely to be fully corrected by 2002.

4. Limitations and further study

The results in Fig. 2 do not account for the fact that a portion of research into C and N flux modelling in cropland focuses on the ecological costs of nitrate leaching, denitrification and volatilisation of ammonium to ammonia gas. These areas of study deal with environmental costs outside the value of cropland quoted at US$0.128 trillion. However, an appraisal of the literature over 1991–2002 indicates that this portion of research is small relative to the total and would have negligible effects on the conclusion stated above given that minimum value estimates have been employed with a cautious analysis in Fig. 4.

Ecological research input, the amount of money allocated to research by governments and other bodies, is another measure that could be used in place of ecological research output. There are a few key disadvantages to using this approach. First, delimiting money for cropland research versus other ecosystems over time is problematic due to a paucity of clear records. More importantly, using research input does not necessarily indicate the level of research if logistical costs are significant as with studies in tundra or tropical biomes.

As far as we are aware, this is the first time that missing markets for ecological goods and services have been invoked to assess bias in the scientific literature towards market-oriented systems. The implications of our results are important in the context of science policy because they suggest that socially optimal research which reflects the importance of natural ecosystems has failed to occur in the past. The balance has clearly started to shift more recently, which suggests that funding bodies have an important role to play in terms of directing science which meets social objectives.

Various research areas could be assessed in future in order to gauge the generality of this phenomenon, after satisfying the assumption in Eq. (1) under a perfect market system. Cursory analysis of the literature on root morphology suggest that this subject area requires further investigation. Gross et al. (1992) acknowledge that studies of root morphology in natural ecosystems lag behind that of cropland and preliminary data indicate a highly significant disparity in research output.

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