“Mathematics maybe, but not money”:
on the nature of numbers, and the numbers of nature’
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worlds (in)visible during moments of socio-ecological transformation’,
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Sian starts..

1. Introduction
The title of this talk “Mathematics maybe, but not money”, comes from a paper I heard
recently at an environmental philosophy workshop on Natural Environments and Cultural Services
(Cooper 2014: 4). The paper was delivered by the Reverend Canon Nigel Cooper of Anglia
Ruskin University, and entitled ‘Cashing in on the language of spiritual services’. In this he
highlights some of the problems associated with the discontinuities of resemblances (cf. Latour
2013) that can occur in the sequence of transitions that of necessity arises in ecological
accounting.

These transitions tend to move from:
1. real material natures, and human uses and experiences of these;
2. to numerical abstractions used to denote these uses and experiences;
3. and then to monetised values used to ‘account for’ these uses and experiences.

In relation to so-called spiritual and cultural services, Nigel Cooper (2014: 3) says, for example,
that ‘[t]he authors of the MA [Millennium Ecosystem Assessment] should be commended for
alerting a world of potential Philistines that “ecosystems” have spiritual value not merely a use
value. But the world of valuing ecosystems has a hard time incorporating these spiritual services
into its methodologies...’. He goes on to say that ‘[o]f course, there are some religious uses of
ecosystem services that are potentially assigned a monetary value by the common
methodologies. [thus] The National Ecosystem Assessment in 2011, in the chapter on Cultural
Ecosystem Services, discusses possible travel-cost valuations based on visits to retreat centres
and the value of proximity of churches based on hedonic-pricing using house prices. One might
even consider the consumptive use of cut flowers in decorating churches. Might not most
people, though, consider these examples as trivial and effectively missing the point?’ (ibid.)

The phrase, ‘mathematics maybe, but not money’, and the examples I have just summarised,
distil for me a key aspect that runs through the endeavour of ecological accounting. This is that
the numbers used to describe, denote and account for nature matter. They matter because their
application is a world-making activity that brings forth the natures that we see and experience;
and they matter because they act to normalise - even to naturalise - particular sorts of
relationships ‘we’ are able to have with these thus accounted for natures. It is this process of
making nature through accounting that I want to speak to in this presentation.

I want to also start with a disclaimer. I am neither a mathematician, nor an accountant – but
nonetheless I want to make some comments regarding the application of both mathematics
and accounting to nonhuman nature. I also have to be honest and say that it was only on
meeting Markus Milne at the inaugural World Forum on Natural Capital in Edinburgh last November that I became fully aware of the domain of critical accounting and the work that is being done to interrogate, as well as to produce, the growing relationships between ecology and accounting (for example, Gray and Bebbington 2001) - hence I really am honoured to be speaking here today.

But also by way of introducing myself, what I can say is that in the course of conducting my PhD research in west Namibia during the 1990s, I spent more time than I care to remember measuring trees and herbaceous plants and using the numbers thus arising for the purposes of statistical analyses. In other words, I have some experience of what goes into making material natures representable in terms of numbers, and the complexity of doing this, at least from an ecological perspective. I have also had a research interest in the intrinsic and unpredictable dynamism of so-called ‘non-equilibrium’ ecosystems, since the Namibian landscape of my research is extremely unpredictably varying in terms of productivity and species presence from year to year - as you can see in the images to the left of the slide below which are of the same site in two consecutive years. I mention this because although much so-called ‘natural capital accounting’ seeks to include and monitor changes to environmental parameters through time, there often is little recognition of the internal and autecological dynamism of ecosystems and species.

<table>
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<tr>
<th>Environmental variable</th>
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In the years since, I have concentrated my attention on what might be called an ‘anthropology of nature’ that considers cultural differences in how nonhuman ‘nature’ is understood and becomes known by people in diverse circumstances globally (cf. Descola 2013). Because I conduct ethnographic work with people who have had rather different conceptions of ‘nature’ to those associated with modernity - and particularly the objectifying impetus of modern science - I have become increasingly alert to the different ontologies – or assumptions about the nature of nature - that exist, collaborate and collide in the world.

It is the differences between what Bruno Latour (2013) is currently calling modes or ontologies of existence that has led to my curiosity over the use of metrological techniques for accounting for, and valuing, aspects of nonhuman nature as the most appropriate route towards managing ecological damage due to economic activity: i.e. as affirmed through recent systematic enterprises such as the influential EU and UN programme on The Economics of Ecosystems and Biodiversity (TEEB), which seeks to enhance nature’s visibility in the formal economic sphere through urging measurement and economic valuation practices.

What I wish to do in this talk is to point to the immense movement in ecological accounting, and particularly natural capital accounting, that is happening globally today, in the concerted effort to make ‘nature’ visible and legible as ‘natural capital’. This seems to me to signal a particular calculative movement that further enrols nonhuman natures into the formal economic sphere, such that it is also becoming possible to leverage nature as natural capital in new monetised products and instruments - I will gesture briefly towards one example of this (for a fuller account see Sullivan 2014). Following this, Mike will provide an additional example of the application of a particular calculative device - DEFRA’s biodiversity offset metric - to illustrate a case study of how nature is being partitioned and calculated so as to facilitate offset exchanges for the mitigation of development impacts. I will then conclude by talking about some different ways historically in which numbers have been used to denote natures, and the possibly different ethical effects these may also engender.
2. Making nature numerically visible as as ‘natural capital’

The last few years have seen a rapid proliferation of interconnected ‘natural capital accounting’
endeavours. These extend an older social accounting and ‘full cost accounting’ impetus to
account for those social – and now environmental – costs that conventionally have been
external to financial transactions (see discussion in Milne, 2007; also Gray and Bebbington
2001). In the run-up to the Rio+20 ‘Earth Summit’ event in 2012, significant global
interventions thus were publicised for more robust and transparent (cf. Turnhout et al. 2014)
‘green accounting’ that incorporates non-manufactured environmental elements. The
WAVES (Wealth Accounting and Valuation of
Ecosystem Services) initiative of the World Bank
Group (WBG), for example, is a key element of
the Bank’s new ‘Environment Strategy’,
comprising a methodology for incorporating
‘natural capital’ and ecosystem measurements into
national ‘wealth accounts’, in part ‘to establish the
true value of biodiversity’ (World Bank Group,
2012a: 48, 51; WAVES, 2012). WAVES is set
within the context of a substantially energised
System of Environmental-Economic Accounting
(SEEA), agreed in 2012 by the UN Statistical
Commission as an international standard for
combining economic and environmental data,
including ‘ecosystem services’ and ‘natural capital’,
into a single global accounting system (EC et al.,

The UN’s reinvigorated SEEA seeks to include ‘the perspective of ecosystems’ in accounting for
national environmental assets, via Experimental Ecosystem Accounts (SEEA EEAs). It is
claimed that these will ‘describe the measurement of the flow of benefits to humanity provided
by ecosystems, and [the] measurement of environmental conditions in terms of the capacity of ecosystems to provide benefits’. Thus, ‘[t]he SEEA Experimental Ecosystem Accounts will describe both the measurement of ecosystems in physical terms, and the valuation of ecosystems in so far as it is consistent with market valuation principles’ (EC et al. 2012: 3). In the corporate world, the World Business Council for Sustainable Development (WBCSD 2011) urges ‘Corporate Ecosystem Evaluation’ (CEV), the design of which has been assisted by international accountancy firm PriceWaterhouseCoopers. An emphasis here has been to design an accounting methodology that will facilitate ‘better informed business decisions by explicitly valuing both ecosystem degradation and the benefits provided by ecosystem services’ (WBCSD 2011: 4, emphases in original). At a national level, here in Scotland, a new ‘Strategy for the conservation and enhancement of biodiversity’ incorporates a ‘Natural Capital Asset Index... to describe to describe changes across Scotland’s ecosystems since the year 2000’ (Scottish Government 2013: 30).

Following Michel Callon and colleagues in economic sociology (see, for example, Mackenzie and Millo, 2003; Callon and Muneisa, 2005; Callon, 2006; MacKenzie et al. 2007; Çalışkan and Callon 2009, 2010), this multiscalar movement towards natural capital accounting - through mutually supportive discourses, institutional assemblages and calculative devices - is creating the conditions whereby nonhuman natures - or, at least, the numbers considered to represent these (cf. Sullivan 2013: 85) - can become further enrolled into the formal economic sphere.

In terms of methodologies for making unpriced nature legible in economic terms, the calculative accounting practices highlighted in these and other examples have certain layers in common (Castree 2003; Kosoy and Corbera 2010). I will mention three:

1. First, they need to find numbers deemed appropriate for denoting and representing the material natures under
consideration. This relies on layers of abstraction and simplification, often guided by the
development of particular calculative devices such as the biodiversity offsetting metric (pictured
above) designed for DEFRA by consultants – an application of which Mike will talk about
shortly. A particular design emphasis of these metrics is to create the appearance of
commensurability between places, times, and entities so that these can be offset, or traded off
against, each other.

2. The second layer is the assigning of monetary values to these nominal values for
‘nature’/‘natural capital’ so as to ‘make nature’s values visible economically’ (as the TEEB
project has urged), via economics methods such as contingent valuation, willingness-to-pay,
benefit transfer, and so on. So, for example, Corporate Ecosystem Valuation is described as ‘a
“value-based” lens through which associated environmental, social, economic and financial
issues can be quantified, and the complex trade-offs between them compared’, – usually
achieved by ‘converting ecosystem dependencies and impacts into a single (and influential)
metaphor of natural capital lends itself to monetisation is neither accidental nor … surprising’.

3. These layers of abstraction and monetisation may usher in commodification possibilities for
newly accounted for monetary values for nature. This is the process whereby newly visible
values for nature are able to circulate within the formal economy at different scales, including,
for example, through Payments for Ecosystem Services, biodiversity offsetting, and perhaps
bonds based on the value of newly accounted for values for natural capital.

I wish to consider the last of these in a little more detail as one way in which the increasing
legibility of ‘nature’ as ‘nature capital’ appears to be transformed into the literal leveraging of
‘natural capital’ as money. This is a process, then, through which ‘natural capital’ takes on an
ontological reality as something that arguably is rather different to ‘nature’.

3. Bonding nature?
As Peter Carter, former Chief Environmentalist of the European Investment Bank, said in
summing up final session on finance at the conference
To No Net Loss of Biodiversity and Beyond
(London, June 2014) ‘there’s an emergent
view that natural capital is the new asset class
for the future’. Creating natural capital as an
asset class requires the design of new
financial products and instruments. One of
these that I have been trying to understand is that of environmental bonds. In the most part,
these have been designed as vehicles for ‘frontloading’ future funds by encouraging government
borrowing from investors with the debt secured on the future economic and environmental (especially climate) benefits predicted to flow from these investments.

But environmental bonds are also being designed to encourage direct investments in nature. In the UK, For example, a recent report on Opportunities for UK Business that Value and/or Protect Nature’s Services suggests that environmental bonds might be invested by ‘[c]orporate industries wishing to purchase bonds as a means of offsetting their residual environmental impacts through the supply chain’ (Duke et al., 2012: 32). Through this ‘[a] number of asset classes such as biodiversity, water, carbon, which are co-located on the same area of land, could be “stacked” and an environmental bond created, providing a stable investment return’, although it is not clear exactly what will generate this return (Duke et al., 2012: viii, also 57-58, emphasis added). These ‘asset classes’ and ‘conservation bonds’ (as termed in the report) would thus capitalise nature-as-natural-capital to produce a new range of ‘green asset classes’ that can generate competitive rates of return on investments.

The creation of investible financial products based on the natural capital values calculated for standing nature is now occurring so as to leverage landscapes of conserved and/or restored nature in the global south as the underlying collateral for capital-releasing loans. These loans would be bonded with the calculated monetary value and projected income-generating capacity of the so-called ‘natural capital’ supported by these landscapes. So, for example, proposals are proliferating for products such as tropical forest bonds and rainforest bonds, that would be serviced at least in part by forest carbon revenue.

‘Forest carbon revenue’ thus is proposed as one of the sources of income that will be used to service natural-capital-based bonds that are entangled with new financial values associated with southern tropical forests (Cranford et al., 2011; also Forum for the Future and EnviroMarket Ltd, 2007: 9; Duke et al., 2012: 33). Specifically, forest carbon revenue is a reference to the ‘future streams of payments for expected emissions reductions’ (World Bank Group, 2012b: 1) that will be provided by the carbon contained in standing forests, as it becomes ‘unlocked’ through measurement and accounting under REDD+, i.e. the UN programme for Reducing
Emissions from Deforestation and Forest Degradation in Developing Countries. and local people globally are being recruited to measure and account for this carbon in a huge socioecological experiment that is fundamentally altering peoples’ relationships with forests in many localities.

materialising the ‘natural capital’ of tropical forests so as to ‘leverage additional finance from global capital markets’ (pp. 6-7).

rainforestbonds.com
“Conserving the world’s natural capital”

Emissions from Deforestation and Forest Degradation in Developing Countries. and local people globally are being recruited to measure and account for this carbon in a huge socioecological experiment that is fundamentally altering peoples’ relationships with forests in many localities.
Arguably, REDD+ is akin to a giant global offsetting scheme whereby industrial emissions are maintained in part by linking these emissions with the sustenance of forests as stored carbon in the south. Making southern forests ready for REDD+ means making the carbon value associated with these forests legible as an income-generating natural capital asset. The process involves significant and supervised monitoring and conservation work by local communities globally. Controversially, REDD+ and carbon-offsetting schemes have been linked with evictions of forest-associated communities, generating questions regarding the property and sovereignty rights residing in local ecologies as their natural capital values become calculated, accounted for and start to circulate in globalised REDD+ and other Payments for Ecosystem Services (PES) markets (see, for example, Checker 2009; Cavanagh and Benjaminsen 2014; Dunlap and Fairhead in press).

‘Natural capital’ (ac)counting under REDD+ thus can mean the giving up of alternative production practices and prior relationships with forested areas. Nonetheless, this new asset class - as it is brought forth through measurement and calculative accounting devices - might then serve both as ‘collateral to loans to finance the upfront investments in [REDD+] programs’ (collateral to loans to finance the upfront investments in [REDD+] programs', in effect creating ‘REDD+ bonds’ through placing REDD+ credits onto the portfolios of investors (World Bank Group, 2012b: 1-2), and as the source of revenue streams for servicing interest payments on loans bonded to this value. Somewhat tautologically then, it appears as though investment in forest bonds associated with REDD+ will also assist with funding the creation of the future carbon revenues that will service the loans associated with these bonds (as demonstrated by rainforest bonds established by Bank of America Merrill Lynch, see Gilbert 2012).

An example of how this is now manifesting is offered by the Althelia Climate Fund, one of a handful of a group of investment funds raising capital to invest in REDD+ and Payments for Ecosystem Services markets (Abusaid 2011). Established and managed by asset management platform Althelia Ecosphere, and advised by Ecosphere Capital LLP and environmental NGO Conservation International, the fund is working through REDD+ accounting to bind the increasingly legible natural capital carbon value of standing tropical forests to investors from elsewhere, through ‘creating new environmental assets that reflect the value of natural capital’ (see http://ecospherecapital.com/). Initial investments from the EIB amongst others totalled $80 million in June 2013, enhanced by more than $130 million lent from the USAID in 2014. The fund comprises ‘a diversified portfolio of investments in Africa, Latin America and Asia that take the form of real assets (certified commodities and agricultural produce) and environmental services (verified emissions reductions and other ecosystem services [including carbon accounted for under REDD+])’. It is these assets that will deliver ‘cash dividends to investors’ (Althelia, 2013: 1). Indeed, Althelia Ecosphere describes ‘[e]cosystem goods and services from Natural Capital’ as ‘worth trillions of US dollars per year’ (2013: 3).
To schematise this - We might have an issuer of a bond for the funding of infrastructural development in a southern country that is based on the calculated natural capital value of forests in this country, with this bond transferred to an investor, which might be a private fund in the north. This fund loans money to the issuer of the bond, with the expectation of future returns in the form of cash dividends, to arise from income accruing from the country’s natural capital, such as via REDD+ payments. So far perhaps so good, even if this situation seems reminiscent of familiar north-south inequalities.

But what happens if the future dividend or interest payments are not forthcoming for some reason? Who then owns the ‘natural capital’ underlying the bond? Would situations of foreclosure then arise?

Given questions such as these, I have suggested that the metaphor of natural capital, and the technical accounting practices this is enabling, constitutes something of a ‘double-edged sword’ (Sullivan 2014). It may indeed encourage better practices of care towards non-human nature by making nature visible within an economic system that has tended to bank instead on its invisibility as economic externalities. But it may also make possible new enrolments of nature in the economic sphere that are problematic - both for the natures that become the underlying value for these instruments, and for the peoples who are associated as dwellers with, and ‘primary producers’, of these natures.

I will now pass over to Mike who will take us through a different technique for ecological accounting and an example of the natures that are thereby being created.
Mike continues..

4. The economics of the last resort: offsetting the offset in Thaxted
By way of illustration I want to briefly describe a biodiversity offsetting case in Essex, one of the six areas involved in DEFRA’s recent pilot schemes. This is, I should make clear, very preliminary work and certainly not an authoritative case report.

What is biodiversity offsetting?

- Developers compensate for “unavoidable” impacts on biodiversity by paying for habitat conservation on an offset site somewhere else.
- A commercial market in “biodiversity units” is thus made possible, with these units traded as offset credits. Offset providers can sell credits to developers from a “habitat bank”, i.e. an area of conserved habitat somewhere different to the development site.
- DEFRA 2-year pilot schemes: finished April 2014.
- In context of a global movement towards biodiversity offsetting, linked with lobbying and promotion by brokers, globally active consultants, developers and extractive industries.
- EU “No Net Loss Initiative” is under development. Existing schemes in US, Australia, etc: cited by DEFRA as examples to follow.

I don’t have time to explain the whole of DEFRA’s scheme - you can find the details online (see https://www.gov.uk/biodiversity-offsetting), or summarised in our 2012 paper (Hannis and Sullivan 2012). But here’s the basic matrix which makes the whole thing possible:

<table>
<thead>
<tr>
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<th>Low Distinctiveness (2)</th>
<th>Medium Distinctiveness (4)</th>
<th>High Distinctiveness (6)</th>
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<td>12</td>
<td>18</td>
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<tr>
<td><strong>Moderate Condition (2)</strong></td>
<td>4</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td><strong>Poor Condition (1)</strong></td>
<td>2</td>
<td>4</td>
<td>6</td>
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This is the “calculative device” which creates commensurability between habitats, setting “rates of exchange” between them, and of course suppressing a lot of complexity in the process. Each “distinctiveness band”, for instance, contains dozens of different habitat types. Briefly though, both the development site and the offset site are assessed according to this matrix, before other multipliers are applied.
Planning Policy
Current land-use planning policy for England and Wales views biodiversity offsetting (BDO) as a potential last resort, at the bottom of the mitigation hierarchy:

“If significant [biodiversity] harm resulting from a development cannot be avoided (through locating on an alternative site with less harmful impacts), adequately mitigated, or, as a last resort, compensated for, then planning permission should be refused.” (National Planning Policy Framework 2012, para. 118, emphasis added)

This needs to be understood in the context of an ideologically-driven reorientation of the planning system aimed at making it a driver of economic growth rather than a brake on it. This is illustrated for instance by the statement in the 2012 Natural Environment White Paper that “we reject the outdated idea that environmental action is a barrier to growth.”

Offset brokers The Environment Bank however call BDO “a very important last resort, because it gives developers more options to make sure that what they do is sustainable” (The Environment Bank 2013: 1). In other words, compensation – or offsetting – can make unsustainable development permissible, by turning it into ‘sustainable development’.

Thaxted
This is nicely illustrated by a recent case at Thaxted in Essex, in which permission was granted on appeal for a development of 47 houses (see images below).¹ These will be built on a grassland site which was providing ‘wildlife mitigation’ for the same developer’s adjacent earlier development of 55 houses, granted permission on appeal in 2012 and still under construction. Lizards and orchids were moved onto the current development site as part of this former mitigation role.

¹ PINS case ref. APP/C1570/A/13/2206357. Documents available at http://tinyurl.com/thaxted-docs
The decisive element in the current planning application was an offset agreement, calculated for the developer by the Environment Bank, using the DEFRA metric (see calculations below). The application stated:

“As a last resort, it is proposed to use the new biodiversity offsetting scheme. [...] The offsetting site would provide 20 credits through an agreed enhancement plan. This represents an overall gain of 2.9 credits, i.e. an increase of >10% [over the value of original site, 17.1].” (emphasis added)

Application
Uttlesford District Council refused permission. Their ecologists pointed to local policies mandating no loss of old grassland, except in very exceptional circumstances. They also raised detailed ecological concerns regarding:

- the “salami slicing” of habitats;
- the developer’s assessment of the condition, quality and history of the grassland;
- the developer’s estimates of specific fauna and flora on the site;
- the developer’s interpretation of “significant harm”;
- whether lizards can be included in an offset scheme;
- the use of BDO in principle;
- the details of the developer’s offset calculations, particularly the assessment of the site’s distinctiveness as ‘medium’ rather than ‘high’.

Appeal
At appeal, the developer’s own ecological consultants argued strongly against all these objections, presenting the grassland as being of much lower ecological value than the Council claimed. The developer obtained a combative barrister’s opinion backing their view, and making clear that the Council would be risking substantial costs if they didn’t reconsider. The Environment Bank also recalculated the offset using a ‘high’ distinctiveness assessment, raising it to 25 units.
The Council gave in, and in the end didn’t contest the appeal. The planning inspector gave permission, saying:

“Whilst it is accepted that the proposed compensation site is not located next to or close to the appeal site, it seems clear that, with suitable management, it would provide a suitable habitat for the Common Lizard and would provide a grassland of greater value and size than the appeal site does or could. In these circumstances, I consider that the proposal would not have any unacceptable effects on biodiversity, when taken as a whole and would enhance it.”

The result then is that an area of old grassland, which was being managed to compensate for an earlier loss, will itself now disappear. The developer states that “91.5% of the biodiversity onsite will be lost”. This lost ‘biodiversity value’, plus an additional amount to offset the loss of agreed mitigation for the earlier development, will be compensated for by improving the condition of 5ha of different grassland at Hempstead, 9 miles away (see image above), from its current ‘poor’ condition to ‘good’ by year 10 of a 25-year management agreement. This will be achieved by bringing in seed-bearing green hay from another (fourth) site. The lizards will be moved (again) to the offset site. Grassland experts have expressed considerable doubts about how effective any of this will be.²

Without the ‘last resort’ of compensation, the biodiversity impacts would probably have justified a refusal of permission. The development would not have happened, and there would have been no loss to offset. As predicted in theoretical work, including our own (see Hannis and Sullivan 2012; Sullivan and Hannis 2014):

²http://anewnatureblog.wordpress.com/2014/06/01/biodiversity-offsetting-planning-appeal-agrees-housing-on-essex-flower-meadows-will-create-environmental-gain/
• Development has happened which otherwise would probably not have been permitted;
• The apparent simplicity of the offset calculation disguises fierce battles over alternative expert interpretations of ecological data;
• Claims that value has been conserved rely on questionable commensurability assumptions;
• A previous mitigation site has quickly become a development site, requiring “offsetting the offset”;
• The broker’s role was central, and raised major conflict of interest questions.

Sian contd..

7. On the nature of numbers, and the numbers of nature
I want now to return to the title of this paper “Mathematics maybe, but not money”, and to touch on some very different relationships between numbers and nature.

We have suggested that the numbers used to account for nature in applications such as natural capital accounts and biodiversity offsetting can have a reducing impetus that nonetheless works to enrol nature into capitalist enterprise in new and possibly concerning ways. What I want to do now is bring into the frame some of the different ways in which numbers have been used to describe and invoke nature, arguably with markedly different effects in terms of attuning cultural with natural spheres of existence.

Mathematics arose in ancient times as the signifying system that echoed the numinous quality of nature’s mysteries and particularly its patterned yet dynamic order. At the dawn of mathematics, the Pythagoreans engaged in a mystical relationship with numbers as embodying ultimate reality – as seen in the repetitive sacred geometry of nature (such as in the logarithmic spiral as represented below) (Martineau 2010; Watkins and Tweed 2010).
Thus Aristotle in his *Metaphysics* writes that for the Pythagoreans: ‘all ... things seemed in their whole nature to be modelled on numbers, and numbers seemed to be the first things in the whole of nature, they supposed the elements of numbers to be the elements of all things, and the whole heaven to be a musical scale and a number’ (*Metaphysics*, 985b 23-986a 3; see also 1090a20-29).

Indeed, for the Pythagoreans the perfect, sacred number 10, as embodied in the mystical symbol the Tetraktys, was considered the “source of the roots of ever-flowing nature” (attributed to Iamblichus, Syrian neoplatonist philosopher³).

Such uses and applications of numbers have worked in myriad ways since to describe and explain nature’s form and dynamics. A key example is the magnum opus *On Growth and Form* by D’arcy Wentworth Thompson, which was first published in 1917 when he was Professor of Zoology here at St. Andrews.

³ http://www.mycrandall.ca/courses/grphil/Pythagoras.htm
More recently, and building on such work, the field of fractal geometry extends these observations of the relationships between numbers, often relatively simple but greatly iterated ones, and the description of form, pattern and complexity in nature. Fractals exhibit a repeated pattern at different scales, such that the pattern can be recognised at these different scales, even if the repetition is not identically the same at each scale. Thus ‘the structure of every piece [of the fractal] holds the key to the whole structure’ (Mandelbrot 2006: 52). Benoit Mandelbrot, the mathematician that has been so associated with developing the field of fractal geometry states that fractals assist with understanding how the world is put together - both statically and dynamically (Mandelbrot 2006: 51).

What is interesting is that fractal numbers and the images they are able to generate through using modern computers, are indistinguishable from images that may have been taken as a photograph, i.e. of a real thing ‘in nature’. Importantly, what these numbers seem to do is to include and honour the non-linearity, unpredictability and nonequilibrium dynamics exhibited by nature – all of which tend to be treated as noise in conventional economics and accounting.
Arguably, then, the numbers gestured towards here and the images they provoke are tremendously powerful in describing and invoking qualitative aspects of the natural world. Mandelbrot (2006) thus describes fractal geometry as ‘a geometry able to include mountains and clouds’ (p. 46), noting that ‘people respond to fractals in a deeply emotional way’ (p49), so as to strike ‘almost everyone in forceful almost sensual, fashion’ (p61). These are numbers the modelling of which has an affective resonance that seems to connect observers with the forms and dynamisms of the natural world in a way that pulls in a completely different direction to that emphasised by the calculative, abstractions of ecological accounting. The mimetic possibilities of the images that fractals are able to generate thus perhaps permits nature to ‘speak back’ to us (Taussig, 1993: 97) more completely: through evoking qualities of mystery, complexity, self-similarity and immanence, rather than quantities of numbered units that can be lost or accumulated.

Importantly, the connections between mathematics and the mystery embodied in the simultaneous order, diversity and dynamism of nature has, since ancient times, also been associated with an ethical praxis built on honouring what was experienced as the cosmic harmony of the universe. Ethics here is seen as the intentional choices that arise from one’s view of the basic structure of things, i.e. from one’s ontology, such that actions are understood to be connected from assumptions about the nature of Being. For the Pythagoreans, their view
that the cosmos is harmonious led them to the ethical position that the task for human beings is to ensure that they live in conformity with the harmony of the cosmos, a harmony that was embodied and described in numbers.

As such, Pythagorean ethics emphasised a ‘care of the self’, as theorised by Foucault in his later work (e.g. 2005(1981-1982): 48), that appears to have been based on

- a certain temperance in relation to the consumption of things,
- the sharing of property by those in the Pythagorean community,
- a high value placed on self-responsibility, self-testing, and self-care as connected with the care of others and living in accord with cosmic order,
- and relative gender equality.

Given contemporary hyper-consumption, the displacement (or ‘offsetting’) of responsibility, and extreme inequality – as well as the effects of these on non-human natures – this ethical praxis seems a relevant corrective for our times.

Natural capital accounting, payments for so-called ecosystems services etc. seem to do exactly the opposite in that they are designed to remove ethical considerations from decision-making processes and from individual action. They do this by turning ‘nature management’ into technical accounting exercises - creating incentive structures intended to trigger and control right behaviour in the absence of any internalisation of ecoethical values or agencies by ‘actors’ in society. As such I think they require critical reflection, and for this reason I am completely delighted to have been invited to be part of this very relevant workshop on ecological accounting.
References


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