Submitted version to Wires Water – 12.03.2019

Article Title:

A macroeconomics inspired interpretation of the terrestrial water cycle's role in social well-being and climate stability

Article Type:

○ OPINION ○ PRIMER ○ OVERVIEW

● ADVANCED REVIEW ○ FOCUS ARTICLE ○ SOFTWARE FOCUS

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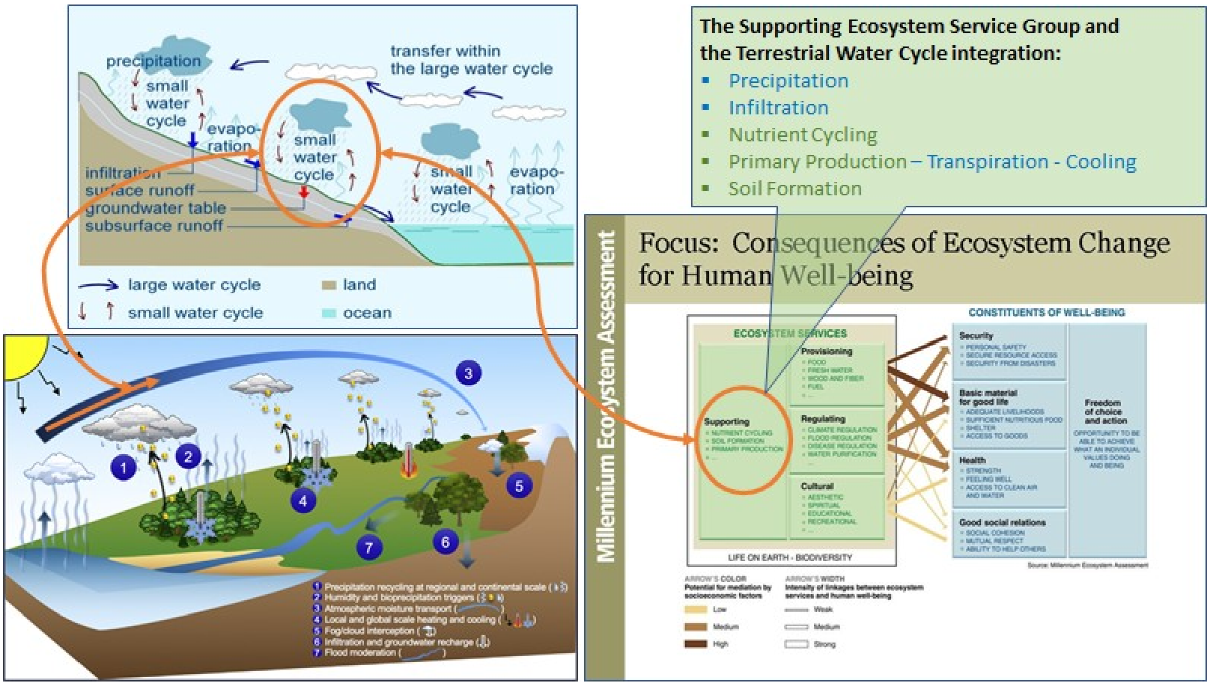
Abstract

The article applies macroeconomic concepts to the interpretation of complex natural processes and, in doing so, helps to sharpen our understanding of the terrestrial water cycle. For economists, it describes climate-forming natural processes in a manner consistent with the fundamentals of the mainstream economic approach. For non-economists, parallels from a more finite observation period can be applied conceptually to identify dynamics over much longer and therefore more elusive natural occurrences, especially considering the role of forests and how recurring land conversion over a millennium have shaped the earth's surface and impact climate stability.

The set of "supporting ecosystem services" highlighted by the Millennium Ecosystem Assessment (MEA) coincides with the ground phase of the terrestrial water cycle, taking the concept beyond an ecosystem service and identifying it as a crucial element of a planetary service as well. Ecosystem and planetary services differ like microeconomic and macroeconomic perspectives do. ***Terrestrial water cycle intensity*** **is a macroeconomic frontier within an ecosystem-based wellbeing production frontier in the same way that *long term growth potential* is a frontier of the economic value creation of a country.** The water cycle intensity of a geographical area may well be related to a rainfall multiplier that measures the ability of continental ecosystems to increase the amount of precipitation over land through re-transpiration and re-deposition of the water content in the air arriving from the oceans. Building upon the MEA's association of social wellbeing with ecosystem features, the rainfall multiplier serves as a physical measure for the natural basis of wellbeing creation.

Graphical/Visual Abstract and Caption



Sources: MEA 2005, Kravčík 2007, Ellison 2017

Introduction

The parallel operation of economies and ecosystems offers up several useful and potentially revealing analogies. In both cases, there is competition over scarce resources; the motivation for businesses to create additional value in the economy is similar to growth by reproduction in nature, representing mutually reinforcing analogous structures. The history of national economies can provide well-documented information that fosters the understanding of complex, system level (macro) processes that we are only just beginning to understand in the context of nature. The similarities are not always easy to recognize due to the vastly different timespan, speed and scale over which we observe these two systems. Complex economic processes occur much faster, are better documented and parallel processes across different countries provide a basis for comparison and improved understanding of the cumulative effects of action and missed opportunities due to inaction. This phenomenon is rarely available in nature. Understanding these similarities can help us to grasp an important characteristic: the cumulative cost of lost opportunities for an area's potential level of succession spanning centuries that was curtailed in order to obtain human benefits (cases like forest destruction or the drying out of land for mostly agricultural production purposes).

From economic experience, there are reciprocal feedback effects at work between micro- and macro-level processes. Efficiency gains boosted by technological development represent firm level effects but accumulate with increased growth at the macro level. Improved (macro)economic stability is self-reinforcing in the sense that it eases the individual burden of doing business and creates income and livelihoods that free up surplus individual resources for further economic activities that again contribute to solidifying favourable macro level circumstances. Of course, this interaction can play out in the opposite direction when forgone opportunities on the ground (micro-level) are the basis for perpetual instability at the macro-level. This paper aims to highlight the analogous disparities that emerge in comparisons between natural processes/systems and economic systems. This outlook connects the core decline of ecosystem production efficiency (micro-level) in nature with the macro-level instability observed as disturbances in climate patterns. Because there is an impact in both directions, appropriate ground level actions will start to accumulate stabilizing forces on global climate.

The historical transformation of landscapes has curtailed nature's potential succession level over very large areas and has weakened terrestrial water cycle intensity. This progressive accumulation of a system-level deficit is analogous to the accumulation of macroeconomic instability in a country due to persistent decline of economic productivity. Climate change should be understood as planetary (macro level) instability due in part to the ecosystem's increasing inability (on a micro level) to transform water, solar energy and soil through the medium of vegetation to primary production, transpiration and the consequent cooling (a macro-level mitigation effect). One obvious feature of this deficit is the warming of the planet surface due to the amassing of unused solar energy. Combustion of fossil fuels further aggravates the burden on this persistently weakening natural mitigation feed-back mechanism. Increased environmental resilience can only originate from the enhancement of ecosystem-based terrestrial water circulation, similar in important respects to the role of economic stimuli driving investment, employment and growth during the worst periods of an economic crises.

Water is an essential ingredient on the ground, but at the same time terrestrial water cycling is a crucial aggregated planetary phenomenon. Therefore, a focus on water can play an illuminating role in the development of such analogies. It is therefore the intention of this article to expound upon this phenomenon of terrestrial water cycling in order to arrive at an improved understanding of its importance for ecosystem service potential.

Analog structures in economic- and eco-systems

Money and water play a similar intermediary role in their respective systems, the economy and nature. Both are used in interactions to create value or enable primary production and then re-emerge unchanged. For the economic actors on the ground, liquidity is crucial and money is a scarce resource, though the economy-at-large is not deficient in money. Rather, money is in constant flow through economic transactions, and scarcity is perceived through the lens of its temporary distribution. It is the same in the case of water. The overall global quantity is constant and immense, but its temporal or spatial distribution can vary immensely from abundance to scarcity and shortage. In both cases, the quality of the internal organizational structure of the systems (the institutions and the ecosystems) is responsible for how effectively these systems can maintain the stability of internal processes among the changing external circumstances.

Production Possibility Frontier's understanding in economics

In an economy, the creation of value added is both the principal motivation for actors, as well as, simultaneously, the instrument of survival. The creation of value added occurs if labour, capital and an idea (a business plan) can be successfully matched. Economists know that this alignment is neither given nor free. An important objective of the economic system as a whole is to enhance the internal organizational structure that underpins the creation of more efficient ways to foster these interactions. The more mature an economy is, the more complex the role of the institutions that lubricate its smooth operation. The seamless circulation of money as a medium of exchange and an intermediary for interaction between resources with only brief periods of scarcity, represents a system level indicator of stability in economic processes in the context of ever-changing external circumstances.

From a macroeconomic perspective, the features of money circulation and the volume of economic transactions they catalyse are important. The more intensive the circulation of money, the more transactions take place, and the bigger the added value an economy can create from a given set of resources.

Production possibility frontier is the curve which indicates the maximum of joint production variations of two commodities when resources are fixed, but the concept can be extended to a wide array of resources. The production possibility frontier (PPF) is the outer boundary that describes this potential value creation (growth) based on a given and finite set of resources. This frontier is strongly connected to the institutional set up (the organizational structure), not just the volume of resources. PPF is a composite overall indicator of a society's functioning and relative wellbeing, based on how successful it is at combining resources for the purposes of value creation.

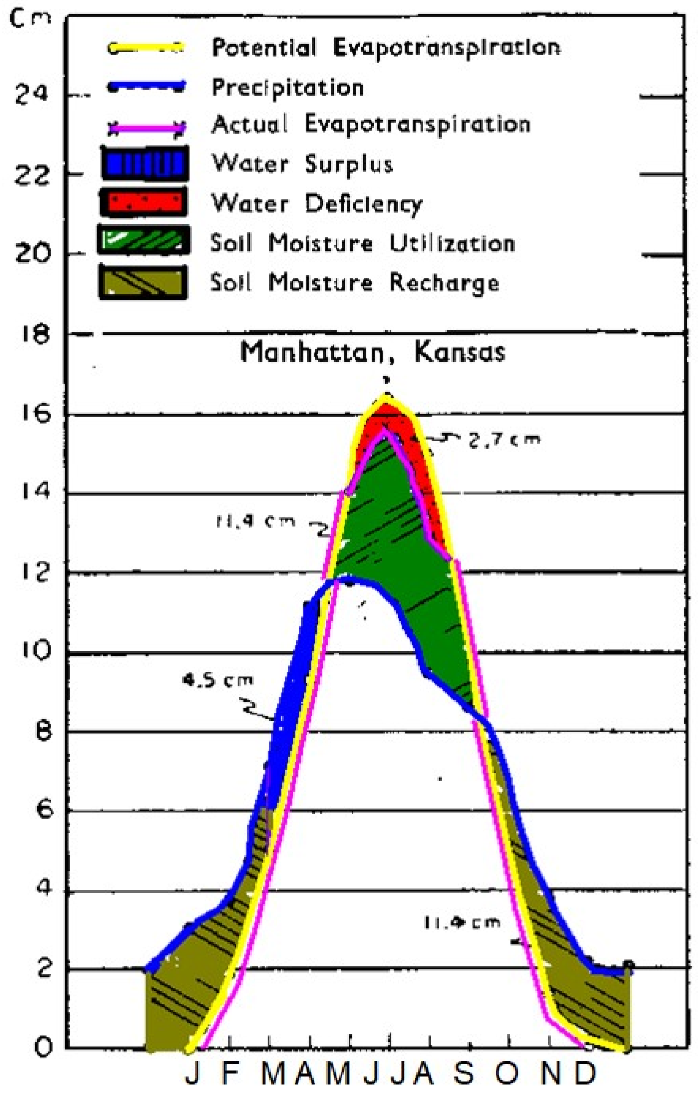
The Production Possibility Frontier's application to Ecosystems

Water circulation plays an analogous role in nature to the flow of money in the economy, serving as a medium of exchange and intermediary for interactions, as well as a constraint on the ground.

In nature, the basis of all terrestrial life is plant life that stems from primary (biomass) production. This encounter happens on the soil where and when water meets solar energy in a plant's kitchen to produce biomass and transpiration. The vegetation period is the time window during the year when there is enough (or more than enough) solar energy to induce primary production, assuming adequate amount of water is available (Thornthwaite, 1955). Thornthwaite essentially describes native tree species (this process is likewise true for virgin ecosystems) as nature's response to specific climate circumstances. That ecosystem is there because it was the most successful among that circumstances in terms of reallocating available water from the precipitation to the vegetation periods. Thornthwaite's principal contribution was the combined representation of water and energy in the same basic relationship.

Figure 1 illustrates this relationship for a geographic location based on monthly average values for available energy, water and the production of evapotranspiration. Solar energy radiation is represented by the amount of water (in centimetres height) it is able to evaporate and transpire from the same land area the monthly precipitation was measured. ("Water surplus" in the figure is the run off. It is the amount of water that the ecosystem in place can't retain.) This way the finite amount of water, solar energy and the significance of the intra year water reallocation efficiency to maximize transpiration is uncovered. The unused, superfluous energy volume represents a "water deficiency" that is generally responsible for warming up both the soil surface and the lower atmosphere. This water deficiency is related to an area's constrained ability to reallocate water trans-seasonally.. (This approach focuses on regions with water limited climate, but fully aware that for example in Nordic areas energy, not water is the scarce resource of ecosystem production.)

Figure 1. Trans-seasonal water allocation and mitigation of warming



Source: Thornthwaite, Hare (Unasylva, 1955, 9. vol./ 2) Horizontal axis is the months. * - The white area below, both the "Precipitation" and the "Actual Evapotranspiration" curves is explained as the transpiration from the readily available precipitation of the given period of the year.

While primary (biomass) production is the micro level "goal" of vegetation, system-reinforcing feedback mechanisms or "side effects" are also present: transpiration and vegetation cover add up to create a cooling effect that prevents both the surface and lower layers of the atmosphere from warming. (This energy allocation feature was also quantitatively described by Thornthwaite, 1955). From the ecosystems' point of view maximizing transpiration is not just growth but consequently it is the instrument of decreasing the risk of harm, what the ecologically unused concentrated summer radiation through local heat shocks could cause. The higher the ecosystems' productivity the higher its protection against extreme circumstances. Moisture condensation (be it precipitation or dew) is the reverse process of transpiration what temperature decrease by latitude or by the shift to night trigger. It is the second level of the system-reinforcing feedback mechanism, the natural redirection of already used water for the ecosystems. Because these reverse processes happen later in time they add a further layer how ecosystem's improve their operation circumstances and resilience.

(Agócs, 2018). Agócs uses the expression “whirl-system” to illustrate how ecosystems on planetary level drives the material and energy flows into circulations, it is an ecosystem based process that mitigate against the extremes of solar radiation oscillation.

These effects cause a feedback that modifies vegetation’s (macro) environment. It is the same type of reinforcing effect that takes place when growing profitability of a firm creates demand for new, innovative and specialised niche services, engendering a friendlier overall business environment and increasing tax revenue increase that can improve quality of life for society in the form of better public services.

Primary production in the terrestrial ecosystem has the aggregate effect of spurring the pendulum, the whirl of the planetary water cycle above the continents (Szesztay, 2004). The more efficiently it functions the more favourable the circumstances are for all members of the community. The same basic total quantity of water can support greater quantities of vegetation/biomass, depending on the intensity of the whirling system..

Succession, and climate-maximum,

In nature’s succession process a higher level of succession means vegetation is better able to make use of the essential ingredients (water, nutrients) available during the period when abundant solar energy offers a window of opportunity to maximize biomass/primary production and the conditions improve for the soil formation (the accumulation phase), . The latter enhances the flow management capacity of the plant community. In the long run this structural accumulation enhances diversity, spawned by the efficiency gains in the area’s material flow management.

The succession process, however, is limited by the volumes of the available basic resources among the given climate conditions. Climax (climate maximum) community refers to the status of an ecosystem that has achieved its maximum succession level. Virgin rainforests are at or close to this status, while heavily cultivated areas are far from that level. This status differs from water basin to water basin and landscape to landscape. (Ecological theory deals with the topic in detail).

The climax community level of the succession process is best understood as a theoretical reference point. It may never be reached in full. But the concept helps to reveal the obstacles thwarting the advance of this essential process. This comparison is analogous to how economists view a mature market with perfect competition. It never occurs in its pure form in reality. But comparing an actual market to the perfect competition reference point will help us to understand the underlining forces shaping the actual structure of that market.

As a combination of the expressions, the actual succession level is the de-facto production possibility frontier of an ecosystem for primary production and soil formation. A shift outward represents gains in production efficiency and an inward shift means losses in production efficiency.

The unused potential of deteriorating efficiency accumulates deficits

Curtailing the succession level of an ecosystem causes efficiency losses represented by an inward shift in the production possibility frontier curve. It opens up a continuous flow of lost opportunities in primary production over time, whereby the unmatched flow of resources accumulates into a kind of hidden deficit.

An economic example

Societal losses from foregone efficiency gains were evaluated recently by the World Bank Human Capital Index (WB, 2018): “The Human Capital Index quantifies the contribution of health and education to the productivity of the next generation of workers. Countries can use it to assess how much income they are foregoing because of human capital gaps, and how much faster they can turn these losses into gains if they act now.” A country with fewer foregone opportunities becomes a more prosperous (and stable) place than countries that fall short.

Returning to the notion of matching resources for value creation, lost opportunities can result if incumbent market actors can prohibit others from starting new ventures, or if excessive taxes on labour discourage employers from hiring and unemployment rises, or the unused labour force moves away. All such symptoms of stalled market entries and rigid labour markets will result in suboptimal GDP production below the potential of what the social resources should make possible, leading to lower tax revenues and lower public spending on education, health, military etc. If a comparison is drawn between two otherwise similar countries after a few decades in pursuit of these two different market regulation strategies (resource matching policies), the contrast in their ability to maintain inner stability against future external shocks (for example a global economic crisis with or without major political instability or accelerated indebtedness) will become evident. The initially (invisible) loss of micro-level opportunities will add up to an actual macroeconomic deficit .

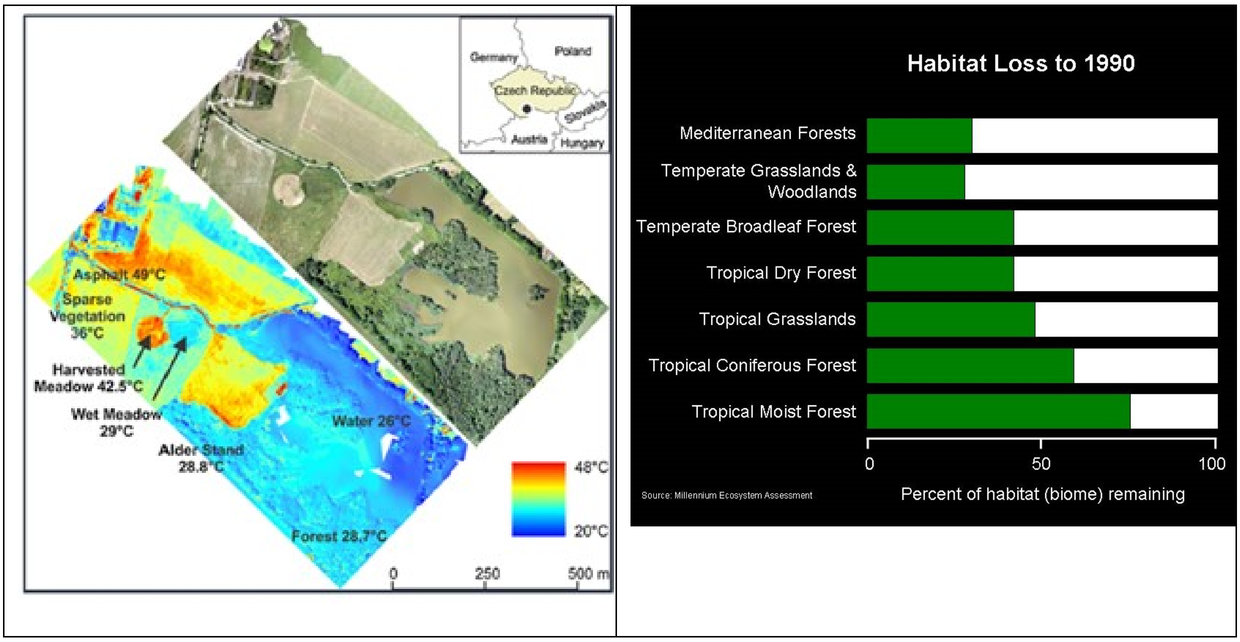
This macroeconomic overview of the cumulative effect of foregone opportunities for growth on overall stability lends a perspective to representation. In nature, there is no straightforward way to demonstrate, by comparison, the consequences of different succession levels from the same area. But as different vegetation levels equate to different production efficiencies, the effect of suboptimal land use practices is analogous to deficit accumulation.

Natural example

Anthropogenic land use change (land reclamation, the drying out of wetlands, deforestation and land degradation) is constantly shifting the production possibility frontier of an ecosystem inward. When land has been converted and water is diverted for social goals, the succession level of that land’s ecosystem is curtailed, meaning its ability to retain water and live up to its primary production potential while retaining the same volume of water circulation declines.

Human land use has advanced at the expense of the accumulation of superfluous and unabsorbed energy that is heating up both the land surface and the lower atmosphere. The contribution of a landscape’s recent land use pattern to the macro-level processes must be compared against the developmental pathway of a more mature ecosystem on the same area, producing more biomass and transpiring away more water from the same annually available water and solar energy resource. Figure 2 essentially translates trans-seasonal water storage capacity into temperature differences resulting from abundant solar inflow on a summer day for different land use types. The higher the temperature, the higher the volume of foregone biomass growth creation. The sheer temperature differences (20 degrees C between the forest and the asphalt) underscore the importance of the foregone natural cooling effect, which otherwise mitigates the formation of extreme heat and serves to secure a more vegetation-friendly environment. The water retention capacity of the landscape, again favoured by extensive vegetation cover, drives the cumulative resilience against such extremes for a given area.

Figure 2; Land use's effect on surface temperature and Habitat loss



Sources: Left; Ellison (2017); Right; MEA 2005

The Millennium Ecosystem Assessment (MEA, 2005) provides a straightforward figure indicating the scale of curtailed succession levels on Earth's land surface (Figure 2; right). By extrapolation, It illustrates the foregone opportunities of cooling. The persistently accumulating loss driven by land conversion and the subsequent decline of the water regulation capacity of the land surface is driven by human intervention of all times. .

The effect of foregone cooling would be better represented as the impact of social activities on the global climate is strongly linked to the persistent accumulation of CO2 concentrations in the atmosphere . Water also shows symptoms of an essential ingredient that is crowded out from the vegetation driven material flow.

The high CO2 level is a symptom. CO2 is an underemployed natural resource:

While the accelerated build up of CO2 concentrations in the atmosphere drives excessive warming, at its core, CO2 is an essential ingredient in the ecosystems' primary production. This primary production is well below its potential volume (and its potential CO2 uptake) due to the fact that human land usage has curtailed ecosystem PPF. The continuous growth of this human obstruction has led directly to an over-supply of CO2 in nature. This situation resembles an economy in peril where (1) labour is superfluous due to rapid population growth (consider youth unemployment) analogous to the excess supply of CO2 released from burning fossil fuels and (2) the destruction of jobs is a slow but ongoing process (crowding out the effect of rising interest rates and the relocation of production). This is analogous to the effect of land conversion on an ecosystem's primary production. In the economy, the result is recession, with diminished capacity for the public budget to maintain a well-functioning social system, risking social instability – the decline of resilience.

Successful economic crisis management cannot solely rely on austerity measures (budget cuts on public services) because it further suppresses the restoration of value generation at the (micro) level of the economy. But without it, positive effects will not accumulate on a macro level. This explains the logic behind counter-cyclical economic policies that governments pursue across economic cycles of downturns and growth periods. In order to re-kindle growth, the availability of the most constrained element must be expanded. The Quantitative Easing policy of national banks, providing the missing liquidity/money supply for the markets/banks during the last crisis, is an example of this type of policy. It is also clear that emigration is not a solution for the unemployed in a country, but the wider possibility of participation in economic activities.

When it comes to nature, water availability for high volume transpiration is the constrained resource on most of the continental surface. This is why even plans for a CO2 neutral society must be coupled with integrated water and land management (e.g. boosting the intensity of water circulation above continents) to overcome the accumulated deficit of previously unrealized primary production.

There is a seeming contradiction here. The IPCC climate change report (2018) predicts that precipitation will be more intense, i.e. there will be more rain when it rains, with a higher probability of floods. This is based on the logic that higher temperatures result in higher atmospheric vapour content which implies a bigger potential for rainfall. This shift is interpreted as the acceleration of the water cycle. But the occurrence of more intensive rainfall events and water shortage do not contradict the notion of the weakening of the terrestrial water circulation intensity. More precisely, it shows that the vegetation driven material and energy flow is losing out to global processes that the accumulated, crowded out, separated elements of ecosystem processes (CO2, run off, warming) have generated. The loss of the ppf for ecosystems means that more energy accumulates in the system, giving rise to more extreme events. Parallels can also be drawn to social movements triggered by unemployment or market bubbles in real estate and luxury goods propelled by the over-supply of savings and the lack of investment opportunities in production and services (the fundamental value generating activities).

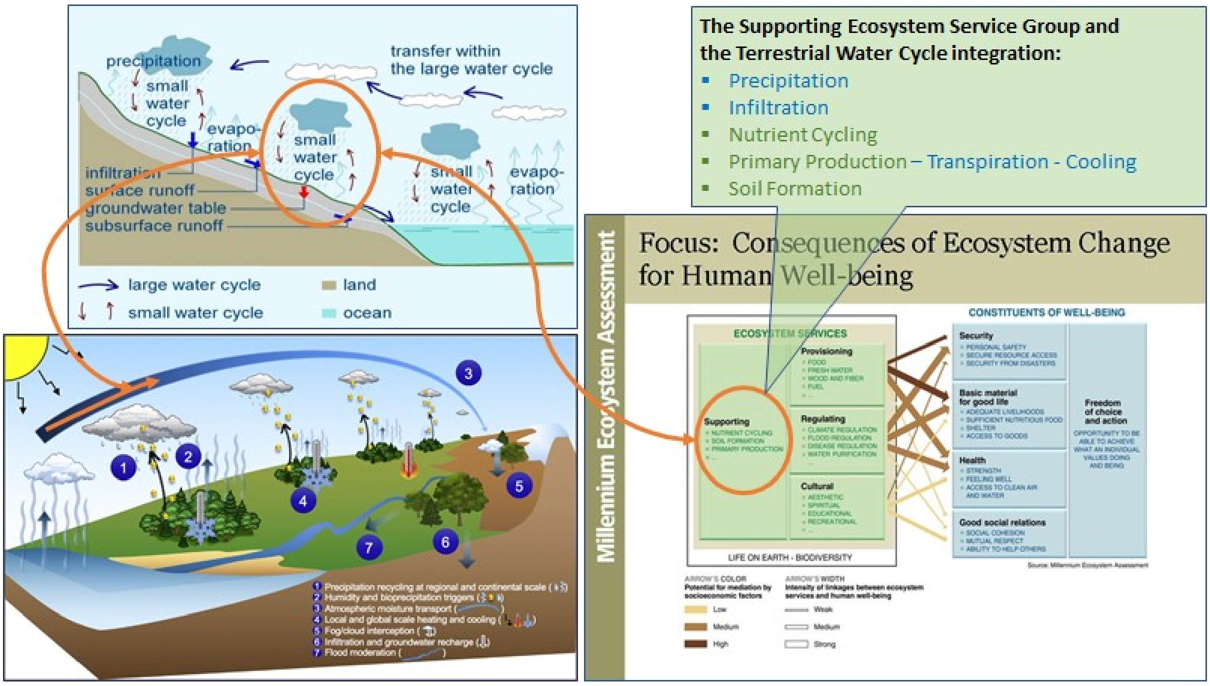
What we experience on a global scale is the deficit from the foregone opportunities due to the long-term inward shift of the land ecosystems' production possibility frontier, the imbalances generated by the diverted management of carbon and water cycling, also known as climate change. The condition of moving toward stability if the balance between carbon, water, solar energy is re-established in the ecosystem, improving upon the threshold of recent land use.

How can these social and natural systems be connected through the terrestrial water cycle?

Terrestrial Water cycle intensity and the Millennium Ecosystem assessment

The Millennium Ecosystem Assessment (MEA, 2005) made a crucial conceptual step forward in recognizing the significance of the terrestrial water cycle in the well-being context. The MEA introduced the set of supporting ecosystem services (SES). Ecosystem services that belong to this set were described as the ones that constitute the basis for the services in the other three sets (provisioning, regulating, cultural). What was missing is the association that the elements which were designated to the supporting ecosystem service set: “**Nutrient cycling, Biomass production, Soil formation”** overlap with the ground phase of the terrestrial water cycle:**.** This represents one combined flow as precipitation infiltrates, transports and dynamically stores nutrients through its way into the soil until a plant uses both ingredients to produce biomass by absorbing solar energy and transpiring water back into the atmosphere. These elements together provide the basis for the directly harnessed ecosystem services of society. This way the Supporting Ecosystem Services framework further supports an asset-based context of thinking with respect to the terrestrial water cycle.

Figure 3; The connection between the weakening intensity of the terrestrial water cycle and the notion of social well-being as a declining asset



Sources: On the right: MEA 2005, top left: Kravčík 2007, down left: Ellison 2017 * - “small water cycle means the terrestrial water cycle in this article’s context.

The most important outcome of the MEA’s structure is that it sheds light on the ecosystem service pillars of social wellbeing, but at the same time it provides the connection between the terrestrial water cycle intensity and social well-being. Two conclusions can be derived from this connection:

1. **The terrestrial water circulation is the materialized production possibility frontier of the set of associated “supporting ecosystem services”.** Therefore it is a quantifiable indicator of the ecosystem service level potential (and its changes) from what a society is able to generate its well-being, while the ultimate level of well-being will depend on how this asset is used (or mis-used)
2. **The set of supporting ecosystem services is not just a compound element of the other Ecosystem Service Groupings. It represents the connection between a landscape and**

another global, planetary service level. The role of these two system levels is analogous to how the quite distinct macroeconomic and microeconomic approaches work, together communicating the status/health of the economy. Their methodologies regarding perceived constraints are different, but both are needed to have a proper management of the economy.

The Millennium Ecosystem Assessment also provides a suitable basis for explaining consequences of human land use activities in the past and present. Land conversion is a process that concentrates ecosystem service potential of an area into the Provisioning Ecosystem Service Group that usually enhances direct and private benefits. This resulted in not only a reallocation of ecosystem resources from the Regulating and the Cultural Ecosystem Service Groups (usually indirect and common benefits) (TEEB, 2010), but caused the decline of the Supporting Service Group, which was the asset base of all Ecosystem Services. The significant decline of Regulating and Cultural Ecosystem Services reflect the combined impact of these reallocation and the asset changes. They have a smaller share from a shrinking pie.

The crucial contextual step our article advocates is that the well-being described by Millennium Ecosystem Assessment can be integrated with the terrestrial water cycle and the biotic pump concept (Sheil, Murdiyarso, 2009). This is the relation along the arrows what we can see in the summary figure ("The connection between the weakening intensity of the terrestrial water cycle and the notion of social well-being as a declining asset") above. This representation emphasizes that land-use management and the subsequent vegetation functioning is the distributor of water between inland precipitation recycling (the biotic pump effect) and runoff. This way **the frontier of precipitation recycling over land is a limited social capacity.** The production possibility frontier of the terrestrial ecosystem primary production is the upper bound constraint of (1) precipitation recycling, hence (2) the availability of precipitation further inland and (3) the basis of potential well-being.

Measuring the terrestrial water circulation intensity for a social interpretation

The terrestrial water circulation intensity is a physical, nature based indicator that describes a surface area's contribution to the terrestrial water cycle's performance, while at the same time providing information about the volume of the supporting ecosystem service of the same area. This way the indicator is also meaningful from the perspective of ecosystem service based well-being.

In the economic context the long-term growth potential (long term growth rate) is a macro level indicator that describes the multiplication potential of an economy in quantitative terms. It accumulates the interconnected effects from several sub-parts of the society (from education, trust, quality of institutions to health, demography and innovation, management culture, reinvestment attitude, quality of regulation in the economy etc). Long term comprehensive inner development (a succession process) can result in the sustainable outward shift of the production possibility frontier that will "materialize" in an increased level of the long-term growth rate. Meanwhile the effect of bad policies and the dismantling of capacities behind the long-term growth potential can be calculated as lost production in the future (as the previously mentioned Human Capital Index showed).

Because the intensity of the terrestrial water cycle is the aggregated affect of ecosystems' effectiveness to increase the primary (biomass) production level over land, its measure, applied to a larger area provides a similar system level information as the growth rate does.

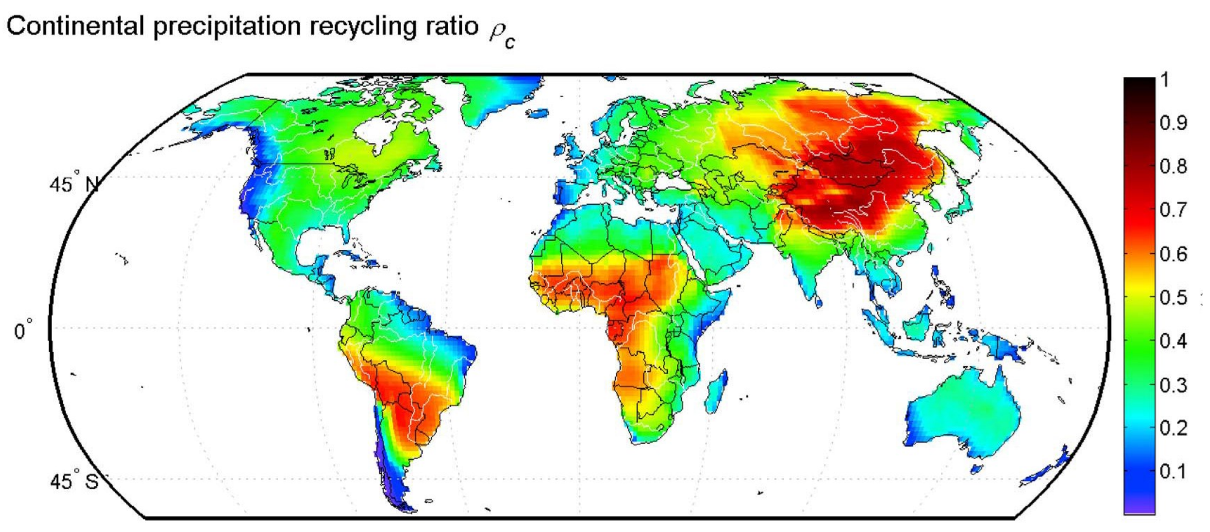
The developments of the scientific debate/thinking about forests' role on water availability for social purposes (Ellison 2012) revealed the importance of understanding the role of massive transpiration mechanisms (what forests are) on precipitation patterns. This line of thinking turned the focus on quantifying the contribution that ecosystems' functioning (transpiration) add to the volume of precipitation over land supplementing the volume that the oceanic originated circulations provide.

There are several calculation methods (Bosilovich et al 2002, van der Ent et al 2010, Keys et al, 2016) that Ellison (2012) comprehensively reviewed. This multiplication phenomenon is the information that describes the recent success of ecosystems' material flow management across the sum of the landscapes. Through the connection of the supporting ecosystem service set, however, it can also serve a wider use in social decision support context.

For a brief, two-step understanding of the concept the approach of Van der Ent et al (2010) is used.

Van der Ent et al, (2010) provided quantitative calculations about the spatial differences in the rate of precipitation recycling: how does the share of water from transpiration changes as the source of precipitation over land? Along the main wind tracks above the continents the gradual rise in the share of recycled precipitation over those with an oceanic origin is clearly visible. For example, a 0-10% share of terrestrial precipitation recycling in rain's origin on the Atlantic shore of Europe shifts to a 70%-80% share of recycled precipitation of rain's origin in Central Asia. This shift from oceanic to terrestrial vapour dominance as precipitation's water vapour resource goes hand in hand with the downwind decline in precipitation volume. This decline reflects the actual efficiency of ecosystems in retaining water and recycling it as precipitation. This actual efficiency to manage water on land is a key driver of how much water remains in circulation over the continent versus flowing back to the seas. In this sense, the Figure 4 from the van der Ent et al, (2010) article quantifies Ellison's (2017) in figure 3.

Figure 4.; Precipitation recycling ratios over land



Source: Precipitation recycling ratio is the share of terrestrial evaporation in precipitation. (van der Ent et al, 2010)

The rainfall multiplier accumulates the spatially diverse precipitation recycling ratios (effects) of larger areas. It is the same type of aggregated information about the successfulness of the co-functioning of sub-systems as the growth rate describing an economy. van der Ent et al (2010) measures the amplification of precipitation by continental transpiration over the volume that arrives from an oceanic origin: "Globally, recycled moisture multiplies our fresh water resources by a factor 1.67". (Continents vary between 1.45 – 1.95), "but locally there are bigger differences that amount to factor three, or even factor ten."

Ellison's (2012) calculations on major river basins show that shifting the scale to smaller territorial units is a possible way forward to get distinctive results on areas with diverging land use policy. As the ecological succession status drives ecosystems' production efficiency, the rainfall multiplier as an indicator provides the connection between the effects of small scale land use change activities on the ground and the global climatic processes. Raising the rainfall multiplier is a desirable goal, although a long term one.

Because the indicator is a relative one, it helps to compare the cumulative contribution of different regions'/watersheds' land use to the terrestrial water cycle intensity, identifying which territories contribute more to sustain the actual multiplication level of the terrestrial water cycle and the connected potential of beneficial ecosystem service effects. Or from a different angle, which are the territories where cultivation resulted in a stronger curtailment of natural succession resulting in a lower level of contribution to the multiplication effect than the average of other territories, this way overexploiting a common resource.

Conclusion

Applying macroeconomic language to ecosystem processes helps to put emphasis on an overlooked aggregation effect. Biomass production is the basic life function of vegetation, an infinitesimal process in a plant, but on global scale it performs a solar radiation and water management function that the terrestrial water circulation embodies. This is the planetary level mitigation feedback service that helps the ecosystems to buffer against the maturation of extreme (cold, heat and dry) conditions which threaten their existence. Enhancing this regulating feedback service is a global challenge of the same magnitude as the management of CO_2 concentration in the atmosphere. This limited flow management capacity has been depleted gradually through the long history of human land conversions. Global scale curtailing of the natural succession process on the land surface resulted in lost opportunities of primary (biomass) production that left volumes of Co_2 and radiation influx diverted from water and unassimilated by vegetation. The weakening of the terrestrial water circulation resulting from lost opportunities in the ecosystem's primary production gave way to the buildup of these unused resources and subsequently a cumulative system deficit that nurtures the growing climate instability. (This trend was exacerbated by the increase of unassimilated CO_2 concentration in the atmosphere from fossil fuel burning.)

The Supporting Ecosystem Service Group of the Millennium Ecosystem Assessment is the framework that substantiates the interpretation that the terrestrial water cycle intensity is the finite natural capacity that social well-being creation and development is based on. It could be approximated by the rainfall multiplier, a complex numerical system index that describes an area's contribution to terrestrial water circulation. Moreover, it connects the effects of small scale land use change activities on the ground to the global climate processes.

Hints for further connections:

(1) Rainfall multipliers can play a role as a point of comparison for areas/riverbasins contribution to global climate stability the same way that the atmospheric CO2 content is an indicator and a reference measure for country-level contributions or depletion of the common struggle for a more friendly climate.

(2) Mature forests are the most efficient propelling force of the terrestrial water cycle's energy and water regulation. The role of forests' succession path on water availability downstream should be handled as a joint investment of stakeholders from the proper water basin and beyond in a dispute resolution context, e.g. filling up flow-through reservoirs.

(3) Floods should be considered as the most appropriate additional source of water to reach additional land surface to enhance vegetation, the terrestrial water circulation and prevent drought.

Acknowledgments

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Notes

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Further Reading

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