REPATS

Revista de Estudos e Pesquisas Avançadas do Terceiro Setor

Journal of Studies and Advanced Researches on Third Sector

Planetary Boundaries and Governance Mechanisms in the transition to the Anthropocene

REPATS, Brasília/Brazil, Special Issue, n.01, Jul-Dec, 2018
ISSN: 2359-5299
E-mail: repats.editorial@gmail.com

REPATS Revista de Estudos e Pesquisas Avançadas do Terceiro Setor
Journal of Studies and Advanced Researches on Third Sector

REPATS, Brasília/Brazil, Special Issue, nº 01, p.197-202, Jul-Dec, 2018.

Opinion Paper

Received: August 19, 2018 Accepted: August 21, 2018

Homage to Eneas Salati: The Quest for Amazon Sustainability

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In the 1970s Eneas Salati shattered the long dominant dogma that vegetation is simply the consequence of climate and has no influence on it whatsoever. By examining the isotope ratio of oxygen in rainwater from the Atlantic to the Peruvian border he established unequivocally that half the rainfall of the Amazon basin is internally generated (Salati *et al*., 1979)[1]. Basically, water that falls as rain is largely returned to the westward moving airmass through evaporation off the complex surfaces of the forest and through evapotranspiration. Accordingly, the hydrological cycle recycles water five or six times until the moisture laden air rises up the slopes of the Andes, cools and precipitates out to produce the 20% of the world's river water that is the Amazon river system.

From that moment it was clear that the cycle is essential for maintaining the Amazon rain forest and raised the question of how much deforestation would cause the cycle to unravel and flip the Amazon forest into a savannah state. Modeling was finally applied to this question and suggested that the tipping point was in the range of 30-40% and that the eastern and southern

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[1]Salati, E., A. Dall 'Ollio, E. Matsui, J. R. Gat. (1979) Recycling of Water in the Amazon, Brazil: an isotopic study. Water Resour. Res. 15, 1250–1258.

Amazon was more vulnerable to Amazon dieback[2]. That suggested the tipping point was rather distant.

Subsequently the human footprint globally led to the recognition of the Anthropocene and it became increasingly clear that a sustainable planet depended in part on a stable Amazon. In the same systems sense that led to Salati's amazing contribution, we explore how to achieve a sustainable Amazon from the local to the global scale.

With time, however, it has become clear that there are additional factors pressing on the Amazon and its hydrological cycle. One is the extensive use of fire as highways and sideroads have penetrated the Amazon. The other is climate change. Lovejoy and Nobre (2018)[3] believe that the synergy between those factors and deforestation moves the tipping point to the vicinity of 20% deforestation quite close to the current extent.

Obviously, it makes no sense to discover the tipping point by actually tipping it, and the unprecedented droughts of 2005, 2010 and 2015/16 – which are expressed all the way to the far western Amazon suggest that: 1) they are early flickers of possible state change and; 2) the tipping point is close to hand. It also means that climate change must be rigorously addressed and limited to no more than 1.5 degrees Celsius (Lovejoy and Hannah, 2019)[4]. Indeed, the sustainability of the Amazon and the global climate are mutually dependent because of the immense amount of carbon in the great forests and other ecosystems of the world.

It is also possible and quite sensible to build back a margin of safety by proactive reforestation, some of which could help fulfill Brazil's commitment (Independent Nationally Determined Commitment = INDC) under the 2015 Paris climate agreement.

All of this also means that managing the Amazon sustainably is central not only to the future of the Amazon and global climate, but also to those parts of South America to its south which benefit substantially from moisture deflected southward as a consequence of the encounter of westward moving air masses with the Andes. To some extent Brazil's aspirations as a global agricultural power depend on maintaining the integrity of the Amazon hydrological cycle.

Fundamental to that must be a new vision for a sustainable Amazon: one that integrates human aspirations into – using von Humboldt's term -- a robust functioning Hylea. That will require transforming conventional forms of development by revising infrastructure ambitions from relatively conventional ones to ones that are sustainable and respect the natural infrastructure as well as the social infrastructure. From the outset with the construction of the Belem-Brasilia highway there was spontaneous colonization to the surprise of most. There clearly

[2]Sampaio, G,,Nobre C. A., Costa M. H., Satyamurty P., Soares-Filho B. S., Cardoso M., (2007). Regional climate change over eastern Amazonia caused by pasture and soybean cropland expansion. Geophys. Res. Lett. 34, L17709.
[3]Lovejoy, Thomas E.; Nobre, Carlos (2018). Amazon Tipping Point. Science Advances, 21 Feb 2018: Vol. 4, no. 2, DOI: 10.1126/sciadv.aat2340
[4]Lovejoy, Thomas E.; Hannah, Lee (2019). Biodiversity and Climate Change: Transforming the Biosphere. Yale University Press.

needs to be a radical redesign of transportation infrastructure pivoting away from standard *rodovias* (highways) to other options.

Central to it should be a reversion to the historic transportation system namely the rivers. Obviously, some work will be necessary to make the rivers navigable in certain places but this need not consist of massive engineering works that modify the flow drastically. Where rapids are an issue it is possible to create ways around or through them without drastically affecting -- and in some instances completely destroying -- the natural systems important for fish so central to the local diet. It is quite telling that Manaus is a very successful city while still almost entirely dependent on river and air transport. Water transport is universally much more economical than any other kind.

Where the purpose is transport of goods then a rail system specifically for freight *not passengers* could supplement the always cheaper river transport. Great care will need to be taken to discourage spontaneous colonization along railways (as happened along the railway to Carajas) perhaps by making it elevated in key places.

Where highways already exist one way to curb spontaneous deforestation is to flank them with protected areas of various sorts (indigenous areas, conservation units sensu strictu, and various forms of sustainable development reserves such as the extractive reserves pioneered by Brazil after the assassination of Chico Mendes). This has been experimented with in southern Amazonas along the Tapajos with some success (although there are challenges which have more to do with inadequate budgets for enforcement than anything else).

The last 2-300 km of BR-319 from Porto Velho as it extends to the south bank of the Amazon has been problematical for years as it is very low lying and prone to flooding. There are regular calls for paving it which would only lead to more deforestation. If there is an inevitable and powerful argument to make it more functional then the best course would be to make it an elevated highway. Not only would it be more functional because it would be above the flood zones but also the maintenance would be considerably less.

Ironically maintenance is almost never included in decisions to build highways. In wet tropical areas maintenance for highways is very expensive. In contrast although construction of an elevated highway is more expensive than the conventional one, maintenance is considerably less. Full cost accounting including avoided environmental damage would argue strongly for elevated highways.

Lest the foregoing seem hopelessly dreamy there already is an example in the Atlantic Forest region of Brazil: the Imigrantes highway in Sao Paulo. The actual impact on the forest is literally 2 ½% of the conventional because only concrete pillars displace the forest. Maintenance costs are trivial in comparison because the road is entirely concrete.

There needs to be a drastic revision of the energy plans for the Amazon away from mega-dams to a modern vision that includes run of river. That would permit natural sediment flow (which will drastically shorten the effective life of ones which completely block a river). That

would also permit passage of migratory fish that swim the length of the river in their life cycle and are central in the Amazon diet.

While a lot of the motivation for the Amazon hydro projects is to provide energy beyond the Amazon, within the Amazon, especially in cities, solar energy is still largely nascent and could make a serious contribution while simultaneously reducing the need for other sources.

While solar could reduce some of the pressure for transmission lines it is unlikely to eliminate the need. There is a strong argument for elevated transmission lines in those cases as is already the case in the line that crosses the Amazon bringing power from Tucurui to Macapa and Manaus. Elevating them high above the forest actually eliminates the need for cleared rights of way. The latter are extremely expensive to maintain, are destructive of the forest, and provide access and opportunity for spontaneous colonization. Modern sensor systems can eliminate that expense because they can guide helicopters exactly to where a problem has occurred, so the repair can be done with minimal disturbance to the forest.

Relatively little attention is paid to role urban areas can play in contributing to a sustainable Amazon but with suitable creativity I believe sustainable cities which provide a reasonable quality of life are possible. Manaus is an interesting example not because of the economic free zone which of course helps but is not the key part of the story. Yes, as the economic product of the city grows the Amazonas deforestation rate declines because there is economic opportunity in the city; but almost without conscious planning the majority of the industry consists of assembly plants using materials not extracted from the forest.

Manaus is not a perfect example. There is some urban sprawl. More street trees would make it a cooler and reduce energy needs for cooling. There is some land grabbing and there needs to be serious consideration of the agricultural imprint. Nonetheless if approached seriously and comprehensively a sustainable Manaus could become a valuable example.

Amazon fisheries need serious management improvement. The challenge is complicated because the important catfish species use the length of the river system in the course of their life span and also because many important fish species depend on floodplain forest during the highwater months of the year as their major food source in the entire year. The latter make those species particularly suitable for aquaculture – a potential that has been developed commercially in a significant way by the state of Acre. There remains a serious management challenge not only of the floodplain forests as an important underpinning of a segment of the commercial fish but also of those species the life spans of which include multiple Amazon nations.

Extractive industries could be an important part of a sustainable Amazon. A pioneering example is the Camisea gas fields in Amazonian Peru where the exploration phase pioneered a new model – the Offshore-Inland model – conducted without building a single road. Now in production phase, the wells are connected by pipelines that are both buried and reforested above. There are elaborate sensor systems so if a problem occurs it can be easily pinpointed and then accessed by helicopter. This system has also been followed at Urucu and should become standard practice for fossil fuel exploration and extraction throughout the Amazon.

Other extractive industries require road access but there is no reason the roads cannot be closed afterwards to eliminate the access problem over the long term. In other cases, there needs to be a conscious plan to deal with the necessary workforce to minimize its impact and provide a sustainable trajectory after the resource has been extracted. An excellent example of this is the Juriti mine near Santarem.

Major drivers of deforestation are agricultural sectors like soy and cattle. Neither make sense as growth industries in an Amazon which needs 80+% forest cover to function as a system. At the moment there is a moratorium on soy expansion in the Amazon and there are efforts for more sustainable cattle production as well as supply chains that will not accept beef associated with deforestation. Agroforestry efforts add to tree cover and provide reasonable lifestyles but need to increase in scale. Oil palm could become a major driver of biodiversity loss by replacing forest.

Forestry is often included in the economic possibilities for the Amazon and there have been important efforts involving low impact logging and the Precious Woods sustainable forestry east of Manaus. By and large, however, it is fair to say that to date most of the efforts to practice sustainable forestry have not been very successful and that monitoring/regulation need considerable improvement. Too much of the history of forestry in the Amazon has been illegal logging and high grading of mahogany and the like. It is not easy to find truly sustainable Amazon wood.

One area of important potential economic activity that is surprisingly limited in its development to date is ecotourism. The number of quality ecotourism operations is really limited and there is no ecotourism training center so getting quality information from guides is unfortunately rare. There is tremendous growth opportunity here with the possibility of multiple destination trips which could include more city visits to institutions like the Museu Goeldi in Belem and INPA, MUSA (the Museum of the Amazon) and the Museu do Indio in Manaus. It is encouraging that Belem is developing an Aquarium (many of the great aquarium fish of the world like the neon tetra come from the Rio Negro and tributaries). By and large ecotourism seems better developed in western Amazonian countries like Peru and Ecuador, and a spurt of growth is likely in post-Farc Colombia.

Sportfishing is probably better developed as an industry but also has unexplored potential. The Peacock Bass may be the world's most prized freshwater sportfish.

Above all, the long-term sustainability of the Amazon and its amazing biodiversity requires a sustained investment in science in which the Amazon countries are major partners. The history of biological science is littered with examples of transformations of understanding of the life sciences that provide human benefit and economic opportunity. In a world striving for sustainability the life sciences have some of the greatest promise. Some of the Amazon countries have world class scientific institutions and scientists but they tend to be starved for funding. Modern science and information systems can unlock this potential. Eneas Salati as the first to understand the Amazon works as a system would certainly understand this potential, but would

be the first to acknowledge that many others have understood and will understand the potential of the world's greatest repository of biodiversity.