Appendix F: Cycling rates of Gaia, other organisms and non-organic open dynamic systems

We have stated that one way to quantify the degree of organicity, the organic character of Gaia, is to compare the RAMO properties observed in living beings with those of other dynamic physical systems that are not organisms. Although this work is in progress, here we will present (see table) a comparison of some of the cycling rates (CRs) estimated in different systems, focusing on water.

Table F.1. Cycling ratios of water in different dissipative open systems or processes.

Cycling rates (CR)	Gaia	Human Body	Cyclone	Human civilization
H_2O	**>>250**	**570**	**≈10**	**<1.04**

We can define the recycling rate (RR) as the probability that a given atom or molecule comes from the internal processes of an open system with respect to the total number of molecules used (i.e. internal processes plus flow external to the system under study). Thus, for instance, a RR = 0.5 means that 50% of the material used in a given time comes from former material use inside the system, and 50% has been generated outside the system. The cycling ratio (CR) is the number of times a molecule is more likely to come from an element of the system rather than from outside the system. CR=1/(1-RR), i.e. if RR is 50%, then CR=2 as reflected in Fig. C2 (Appendix C). The interiority of an organism, which in turn distinguishes it from the environment, can be measured through these cycling ratios[1].

Gaia:

To estimate the CR value of water for Gaia, we start from the flux entering or leaving the Earth's mantle (the "exterior" to Gaia). Andrault and Bolfan-Casanova (2022) estimate that the outflow from the biosphere to the mantle is 1-2 GTn H_2O/yr, while the degassing from the mantle to the surface would be, assuming their "rain hypothesis", 1-1.5 GTn H_2O/yr. We will take 1.5 GTn/yr as the abiotic input of water to Gaia.

[1] The system must be open. Margulis repeatedly denied (e.g., 2008) that Gaia was an organism because an organism could not live off its own waste. In our definition, this means an infinite CR or RR = 100%. However, with that argument, she was actually denying the organic character of the entire planet Earth, a quasi-closed system since it exchanges almost no matter with its exterior. For us, Gaia is not the Earth, since it is the organism that inhabits and builds the biosphere. The biosphere is a materially and energetically open system, since there are exchanges of materials with the mantle. For example, the exchange of water is relevant: the hydration of tectonic plates, that is, the material exchange between the biosphere and the mantle, allows for the maintenance of the dynamics that give rise to plate tectonics, which raises mountains and moves continents, and which allows for the dynamics of material exchanges in the lithosphere/biosphere, along with volcanic phenomena.

The standard reaction of photosynthesis gives us a first estimate of the “metabolic” use of water, that is, the water consumed to produce materials such as glucose:

$6CO_2 + 6\ H_2O + \text{light} \rightarrow C_6H_{12}O_6$ (glucose) + $6O_2$ (eq.1)

For every mole of C fixed by photosynthesis (12 g/mol), one mole of H_2O (18 g/mol) is consumed. Huang et al. (2021) estimate that around 250 GTnC/yr is fixed by photosynthesis globally (Gross Primary Productivity (GPP), with 112-149 GTnC/yr terrestrial and 103-150 GTnC/yr marine). Applying this value to eq. 1, we would obtain a metabolic use of about 375 GTn H_2O/yr, which gives a CR = 375/1.5 = 250. In reality, the water used by Gaia's cells is much greater, since animals drink water and plants, fungi, bacteria, etc. absorb water directly from their environment to maintain their processes.

The literature estimate Gaia rates for other elements, e.g. Lenton et al. 2020, give cycling rates for C (270), N (100) and P (1250), at Gaia level of essential elements for organisms.

Human body:

We take the cycling rate of water from de Castro (2019) estimation. De Castro (2020) gives around 100 for the CR of proteins.

Cyclone:

The average time between evaporation and precipitation or the residence time of water in a cyclone is about 2.5 days (Pérez-Alarcón et al. 2022). In this time, we consider the cyclone CR as the number of times that a molecule of water circles the “eye” of the hurricane. If we take an average speed of 100 km/h and 600 km per lap (typical values for a cyclone) this yields around 10 laps in 2.5 days, i.e. a CR around 10.

Human civilization:

Most of human used water is for irrigation, with negligible reuse. Jones et al. (2021) estimate that 40.7 km^3/yr of treated waste water in domestic and industrial production is reused at global level, and Ritchie et al. (2019) estimate a global human use of more than 4000 km^3/yr, being about 30% the domestic plus industrial use. Therefore, $40.7/(0.3 \cdot 4000) = 0.034$ is the RR of water (3.4%), which means that CR < 1.04.

For comparison, the elements that are most recycled by our present civilization at global level are some metals. Haas et al. (2020) give 49% of RR for the bulk of metals at global level, i.e. a CR around 2.

The fact that the cycling ratio of elements used by Gaia is higher or as high as cycling ratios within the human body (a highly complex organism) while other systems of a certain complexity lacking an organic quality, such as a cyclone or the human civilization display very low cycling ratios, suggests that Gaia’s interiority and organicity are comparable with the most complex organisms. Furthermore, since Gaia is the organism of organisms, and our theory assumes that organisms are like Gaian cells that have transferred their functions, what is expected from the OGT is that most of its cells do not cycle as much as Gaia itself because they wait for the rest of the body to supply the flow of materials she needs. For example, humans and other mammals do not need to know how to synthesize vitamin C because the natural ecosystem that surrounds us - the physiology of Gaia's body - usually provides it easily, which renders us dependent on Gaia but also frees us from the energetic and genetic cost that knowing how to do it would entail (de Castro 2019).

At its core, we assume that organicity is an emergent property that represents a qualitative leap from quantitative parameters (RAMO), where the specific point of the "leap" is difficult, if not impossible, to estimate and likely context-dependent. It is not easy to define boundaries: where does a human body end and the holobiont composed of bacteria and cells with 23 pairs of chromosomes begins? Even in much simpler systems, how many fish do we need to name a group of fish as "school of fish" with emergent properties in the way they move? Obviously, five fish cannot form a school of fish, while thousands can. Since the quantities reflected in the table differ by orders of magnitude, if we find an organism with a low R, this does not mean it ceases to be an organism. But conversely, it is difficult to believe—since this is the only known example to our knowledge—that a system with a high R is not an organism, precisely because we do not find open physical systems that have high R in multiple molecules or atoms.

References:

Andrault, D., & Bolfan-Casanova, N. (2022). Mantle rain toward the Earth’s surface: A model for the internal cycle of water, Phys. Earth Planet. In., 322, 106815. https://doi.org/10.1016/j.pepi.2021.106815

De Castro, C. (2019): Reencontrando a Gaia. A hombros de James Lovelock y Lynn Margulis. Ediciones del Genal, Málaga

De Castro, C., 2020. El Origen de Gaia. Una teoría holista de la evolución, Reedición de 2008. ed. Ecologistas en Acción, Madrid.

Haas W. et al. 2020. Spaceship earth's odyssey to a circular economy - a century long perspective. Resources, Conservation and Recycling. 163, 105076. https://doi.org/10.1016/j.resconrec.2020.105076

Huang, Y., Nicholson, D., Huang, B., & Cassar, N. (2021). Global estimates of marine gross primary production based on machine learning upscaling of field observations. Global Biogeochemical Cycles, 35, e2020GB006718. https://doi.org/10.1029/2020GB006718

Jones, E. R., Van Vliet, M. T., Qadir, M., & Bierkens, M. F. (2021). Country-level and gridded estimates of wastewater production, collection, treatment and reuse. Earth System Science Data, 13(2), 237-254.

Lenton, T. M., Dutreuil, S., & Latour, B. (2020). Life on Earth is hard to spot. The Anthropocene Review, 7(3), 248-272. https://doi.org/10.1177/2053019620918939

Margulis, L., 2008. Symbiotic planet: a new look at evolution. Basic books. “No organism eats its own waste”

Pérez-Alarcón, A. et al. 2022. Estimation of mean water vapour residence time during tropical cyclones using a Lagrangian approach. Tropical Cyclone Research and Review, 11, 76-87 https://doi.org/10.1016/j.tcrr.2022.08.001

Ritchie H., Fiona Spooner and Max Roser (2019) - “Clean Water” Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/clean-water' [Online Resource] Water Use and Stress - Our World in Datahttps://ourworldindata.org/water-use-stress