GAIANIZING DARWIN
NATURAL SELECTION IMPAIRS THE EFFECTIVENESS OF DAISYWORLD TEMPERATURE SELF-REGULATION

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Abstract

Many neo-Darwinists have rejected the Gaia hypothesis, arguing that organisms cannot reach a common good by natural selection and that natural selection cannot act on the whole planet. In response, Watson and Lovelock put forward a model they called Daisyworld (Dw), a hypothetical planet which can regulate its temperature over a wide range of solar luminosities. This is accomplished by ordinary physical processes rather than by natural selection. As Daisyworld refuted the objections, the critics have responded by developing Darwinian Daisyworlds (DDw) involving natural selection in terms of adaptation, competition, cheating and selfishness. Here we show that the more Darwinian characteristics are added to Dw, the less planetary temperature regulation is attained. Rather, to explain the generation of habitable dynamics on Earth, we propose to Gaianize Darwin by: i) showing that symbiotic coordination of daisies is at stake in the planetary temperature regulation, ii) introducing more efffectively self-regulation Worlds without natural selection, such as Butterflyworld (Bw) and Pandoworld (Pw), iii) intoducing a simple altruistic-like Gaia constraint on daisies that results in a much more effective temperature regulation than the original Dw.

Keywords: *Gaia hypothesis, Daisyworld, temperature self-regulation, natural selection, symbiotic coordination, Gaia constraint.*

1. Introduction

The Gaia hypothesis (Lovelock and Margulis 1974) was originally dismissed by neo-Darwinists for two chief reasons: its apparent teleology (Doolittle 1981) and the argument that organismic traits can only arise through natural selection and natural selection cannot have operated on Gaia because there has only ever been one Earth (Dawkins 1982). In response, Watson and Lovelock (1983) developed what they called the Daisyworld (Dw), a mathematical structure of a hypothetical planet which regulates its own temperature, despite a steady increase in solar radiation. It does this by varying the numbers of black and white daisies and so altering its albedo, and it accomplishes this by ordinary physical processes. Even though it is a simplified representation of a Gaian planet, Watson and Lovelock took care to use realistic mechanisms and parameters of the Earth system.

After the Doolittle (1981) and Dawkins (1982) arguments were shown to be wrong, Darwinists raised a third objection. In the evolutionary synthesis, there is the assumption that, in the evolution of populations the entrance of organisms with selfish behaviours (e.g. cheaters) cannot be avoided. These organisms will not work for a global common good and hence could destroy the stability and regulatory properties of the system. Thus, the question was how planetary self-regulation can emerge from a community with selfish organisms (Maynard-Smith, 1988). This has been said to be the "*central theoretical problem of Dw*" (Saunders 1994).

In response, Darwinists have developed Darwinian Daisyworld (DDw) simulations with such characteristics as adaptation to the optimum temperature of growth (Robertson & Robinson 1998, Lenton & Lovelock 2000), the entrance of cheaters (Lenton and Lovelock 2001, Williams 2006, Nicholson et al. 2017), inter-specific competitive exclusion between daisies

(Cohen and Rich 2000, Pujol et al. 2005) and/or including albedo variation (e.g., Stöcker 1995).

Here we show that the Dw temperature self-regulation is weakened by Darwinian mechanisms of natural selection. The more Darwinian characteristics are added, the less planetary temperature self-regulation is attained. In Section 2, we set up and explain the equations of the original Dw. In Section 3, we compare the original Dw with the DDw. In Section 4, we show how the symbiotic coordination of black and white daisies is at stake in the planetary temperature self-regulation and we introduce self-regultory worlds without natural selection: the Butterflyword (Bw), Pandoworld (Pw) and active Pandoworld (aPw). In Section 5, we propose the idea of Gaianizing Darwin by introducing and discussing the existence of a Gaian constraint acting on the "altruistic" Daisyworld (aDw) within the circular causal dynamics of Dw. We conclude in section 6.

2. The Daisyworld equations and dynamics

2.1 The original Daisyworld equations

Dw is a hypothetical planet in orbit around a star similar to our sun. Its surface is populated by two types of daisies. Where there are black daisies the albedo is 0.25 and where there are white daisies the albedo is 0.75. The albedo of the bare planet is 0.5. The star's luminosity varies very slowly, as does that of our sun (Caldeira & Kasting 1992). The area occupied by the daisies grows or decreases in such a way that the final result is that the mean temperature of the planet is located in a narrow margin of temperature that is close to the optimum for the daisies' growth (22.5ºC). For this parameter, the planet is homeostatic, that is: the temperature is regulated. The equations we use are taken from the original model (Watson & Lovelock 1983).

The populations of white and black daisies are simulated based on the rate of change of the land they occupy:

$$da_i /dt = a_i (x\beta_i - \gamma) \qquad (1)$$

where a_i is the area occupied by daisy species i, γ is the death rate of the daisies (γ is taken to be constant and equal to 0.3) and β_i is the growth rate. The planet is taken to have a unit area and we denote the area not covered by daisies by $x=1-a_b-a_w$. The growth rates β_i are a parabolic function whose maximum is at 22.5ºC:

$$\beta i = \max (0, 1-((22.5-Ti)/17.5)^2) \qquad (2)$$

where T_i is the local temperature of the daisies of species i. This temperature is determined by the average temperature of the planet (T_D) and by the energy transfer between areas of different albedo:

$$(T_i +273)^4 = q(A_D - A_i) + (T_D + 273)^4. \qquad (3)$$

Here, q is a constant factor chosen by Watson and Lovelock to be $2.06 \cdot 10^9$ K^4. A_D is the average albedo of the planet given by:

$$A_D = 0.25a_b + 0.5x + 0.75a_w \qquad (4)$$

Finally, the temperature of the planet T_D is determined by the energetic equilibrium between the radiation of energy entering and leaving the planet:

$$SL(1-A_D) = \sigma(T_D + 273)^4 \qquad (5)$$

Here, σ is the Stefan-Boltzmann constant and S is a scale constant chosen so that $S/\sigma = 1.68\cdot10^{10}\ K^4$. L is the luminosity of the sun; different authors allow this to vary in different ways; we follow the equation suggested by Robertson & Robinson (1998):

$$L(t) = 1/(1-0.08352\cdot t) \qquad (6)$$

where t is measured in Gyr (10^9years).

Next, we shall explain the set up of the Daisyworld and Daisyworld-like dynamic simulations as a preparation for the comparison to follow.

2.2 The dynamic equations of Daisyworld and Darwinian Daisyworlds

Watson & Lovelock (1983) (hereinafter referred to as W&L) assume the daisies' growth is faster than the increment in the Sun's luminosity. Therefore, the derivative of the area in equation (1) is replaced by zero. The changes in the daisy populations are not given in terms of time, but in terms of the Sun's luminosity, which they take to vary between 0.6 and 1.6.

Robertson & Robinson (1998) (hereinafter referred to as R&R) simulate the increase in luminosity by equation (6) and measure time between -3.5 and 7 Gyr with no dynamic simulation of the daisies' growth. Nevertheless, R&R introduce the daisies' adaptation to the temperature simulation using a discrete recursive equation to calculate the optimal temperature:

$$T_{opt}(t)=T_{opt}(t-1)+a(T(t-1)-T_{opt}(t-1)) \qquad (7)$$

where $T_{opt}(t)$ is the optimum growth temperature of the daisies (similar for black and white) in the interval t, T is the local temperature of the daisy population, and a is the adaptation rate, which they chose to be between 0 and 0.05. They use time intervals of 40 Myr and also each 5Myr without significative changes.

A numerical integration based on the Euler method is used in the dynamic simulations of Lenton & Lovelock (2000) (hereinafter referred to as L&L). However, since the time units of the daisy growth and the increase in L are so different, the time span is the same as R&R and it is divided into 262 intervals (every 40 Myr). In each of these intervals, a simulation of 100 iterations of equations 1 to 5, with a fixed value of L, is executed. The time units of each iteration are not given, but each of these corresponds to a "generation" (i.e., their time step or "generation" step here is 40Myr/100 or 400,000 years). Although the generation time seems enormous, the solar luminosity (the driver that provides changes in the daisies' area through changes in planetary temperature) increases by less than 0.5% in 40Myr and is virtually constant (a variation of less than 0.005%) in L&L. This slow change of luminosity means that the adaptation rate chosen by L&L could be qualified as "moderate".

Based on these works, we set up our dynamic simulations with time steps 40 to 800 times lower than the generation time of L&L. This set up defines the adaptation restriction in a realistic-like fashion and, when simulated, is more precise although, given the small variation in luminosity, it gives similar results. In the next section, we compare the regulatory performance of the DDw(s) and Dw.

3. A comparison of Daisyworld and Darwinian Daisyworlds

3.1 Adaptive Daisies

Different simulations with different assumptions have introduced the notion of adaptation to Dw. Keeling (1991) investigated the effect of introducing a third black daisy with a preadaptation to 33ºC (instead of 22.5ºC) that "causes an environmental catastrophe" (Wood et al. 2008). Other authors have researched the effect of adapation in Dw (Saunders (1994), Stöcker (1995), Stanley (2002), Pujol et al. (2005), Robertson & Robinson (1998), Lenton & Lovelock (2000), Williams (2006), Wood et al. (2008), Weber & Robinson (2004)).

Thus, we have replicated the simulation of L&L, where no restrictions to adaptation occur before 40ºC. This shows that there is no temperature regulation until we approach 40ºC, where the restriction on adaptation begins to occur (Fig. 1A). From 40 to 50ºC, the growth rate takes a value between 1 and 0, decreasing linearly. From 50ºC it becomes zero. Before 40ºC, black daisies occupy the planet and adapt to the increasing temperature. The graph simply follows the luminosity of the sun, with a higher temperature in the presence of black daisies than that of the lifeless planet.

When the planetary temperature approaches 40ºC, the temperature restrictions on the growth of black daisies begin and regulation appears around 36 ± 3 ºC. In this simulation, therefore, there is also an optimal temperature point in the equations, a kind of "thermostat", as W&R stated, concerning the original Dw. This "thermostat" is based on the limitations to adaptation. However, it is not an ad hoc thermostat like the 22.5ºC in W&L; it is rather a "natural" one, because the physical restrictions apply here as a universal-external law.

3.2 Cheating daisies

The introduction of cheaters has been proposed by L&L as grey daisies with an albedo of 0.5 and a growth rate 5% greater than that of the black and white daisies, which can be interpreted as an 'advantage'. Grey daisies do not contribute to temperature regulation because their albedo is the same as that of the lifeless planet.
We have simulated both the W&L and the L&L –with biophysical restrictions to adaptation— with the introduction of a grey daisy in the equations (Fig. 1B). The stabilizing feedback in the W&L (see section 5 for details) is strong enough to maintain the regulation. However, if we add the grey daisy to the adaptive L&L DDw, the regulation is strongly impaired, as it is not as robust against cheaters as the W&L Dw.

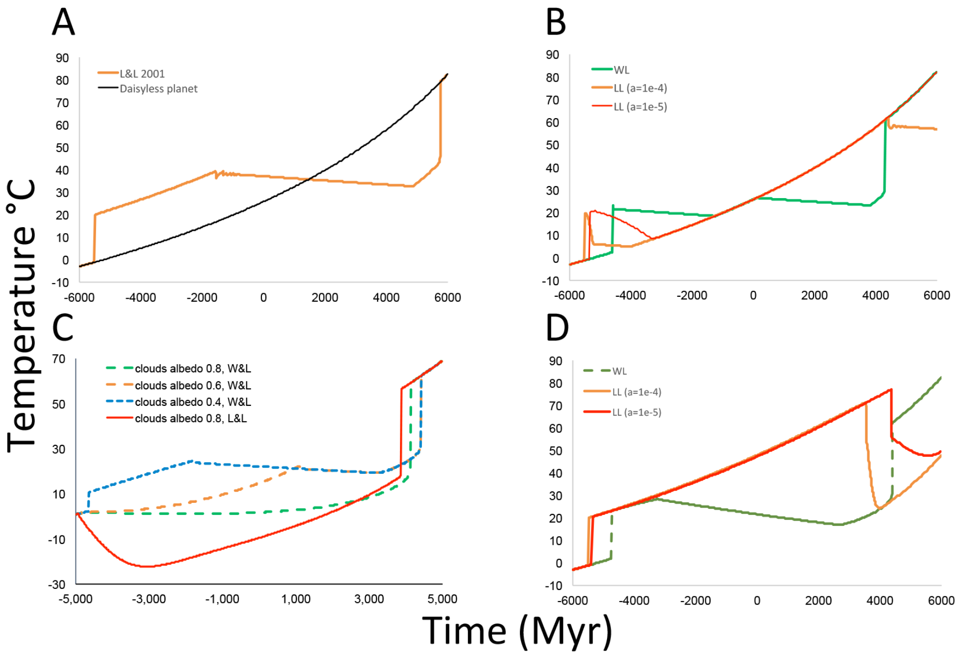

Figure 1. Comparison of Daisyworld and Darwinian Daisyworld with simulation step or generation time of 10,000 years. A) Results of the simulation of the model of Lenton & Lovelock (2000), where the adaptation is only restricted from 40ºC up (see text). Green dashed line is the temperature variation in the lifeless Daisyworld. Orange line is the temperature evolution in Daisyworld with the adaptation rate of $a=10^{-4}$. **B)** Response to the introduction of a "cheater" in the models: simulation with black, white and grey daisies. Orange line: Lenton & Lovelock (2000) adaptation rate $a=10^{-4}$; red line: Lenton & Lovelock (2000) adaptation rate $a=10^{-5}$; green dashed line: original model by Watson & Lovelock (1983). The black and white daisies have a growth rate 5% smaller than that of the grey daisies. **C)** Cloudy Daisyworlds: Green dashed line: albedo of black daisies plus clouds is 0.8, as in W&L with similar results; orange dashed line: the same model with albedo 0.6; blue dashed line: the same model with albedo 0.4. Red line: the model by Lenton & Lovelock (2000) with clouds of albedo 0.8. See text for details and WL (1983). **D)** Regulation of temperature adding a competitive effect between daisies. Death rate is not constant, but $\gamma = (0.3 + 0.1 \cdot \text{area of competing daisy})$. Green dashed line: Original model of Watson & Lovelock (1983); orange and red lines: adaptive model of Lenton & Lovelock (2000) with adaptation rates $a = 10^{-4}$ and 10^{-5}, respectively. See text for details.

3.3 Cloudy Daisyworld.

By suggesting that "not every interaction between the biota and the environment can be expected to operate in such civilized fashion", W&L introduced a modification upon which black daisies generate clouds with a high albedo as a by-product of their growth; the cloudy Daisyworld. Thus, their local temperature is lower than the average of the planet. Their results show that regulation is maintained and the white daisies do not appear.

Our simulation of W&L shows the same results (Fig. 1C). We also show that the regulation is more stable when the albedo of the clouds is greater than the albedo of the white daisies. Otherwise, the regulation tends to be over a narrower range of solar luminosity. We have also found that the regulation is impaired in a cloudy Daisyworld with the adaptive-restrictive DDw of L&L, although the daisies could modify the environment of the planet as a by-product of their growth. That is, the adaptive-restrictive DDw does not respond with temperature stability to a "not too civilized" interaction (Fig. 1C).

3.4 Competitive Daisies

Saunders (1994) considered that ‘space’ could be a resource for competition. Lenton & Lovelock (2001) reinterpreted that “*inter- and intra-specific competition (between and within species) are given equal weighting in the original Daisyworld*”. That is, the daisies may ‘compete’ for space (see equation (1)).

In this DDw a competitive effect between daisies is added. Instead of being constant and equal to 0.3 as in W&L, the death rate of daisies (γ) in our simulations equals 0.3 + 0.1* the area of the competing daisy. Here, each class has a negative effect on the other. Thus, the presence of one daisy inhibits the growth of the other, rather than simply denying space to grow. The remaining equations are unaltered.

Figure 1D shows that temperature regulation in the competitive DDw is impaired when there are restrictions to adaptation. The temperature variation is around 15° C as against around 7°C in the original W&L, while temperature regulation in the adaptive DDw of L&L is never attained in the time scale presented.

The existence of competition[1] in Daisyworld has raised some doubts (Robertson & Robinson 1998). Simulations by Cohen and Rich (2000) and Pujol et al. (2005) found that temperature regulation is weakened with interspecific competition,[2] concluding that “natural selection” may not lead to Dw temperature self-regulation.

Summarizing this section, we have compared the original Dw with the proposed Darwinian mechanisms: the adaptive simulations of L&L with restrictions to adaptation, with the addition of clouds, and the entrance of cheaters or competition. We have performed other combinations with similar results (not shown); the regulation is weakened or impaired when more simultaneous Darwinian characteristics are simulated. The next section shows how regulatory properties can arise without natural selection.

4. Self-regultory worlds without natural selection

4.1 Symbiotic coordination of daisies

The Dw equations (W&L 1983) do not describe the individual behaviour of the daisies, but the variation of the total area occupied by each species of daisy. The growth in the area of a type of daisy depends on the area that remains to be occupied[3]. The total life area remains approximately constant and is almost the possible theoretical maximum over billions of years.

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[1] Competition is a concept in the adaptationist programme of the *modern synthesis*, which stems from the idea that resources are limited for all individuals to have equal access and supply. That is, it distinguishes a relationship between organisms in which one is harmed when both are trying to use the same ‘limited’ resource related to growth, reproduction, or survivability, excluding the ecological balance for such behaviours.

[2] They do impair the growth of the other daisy species. We have also carried out simulations in this way with similar conclusions (results not shown). Instead of impairing the “reproduction”, we have modelled the inter-species competition impairing the death rate (the presence of one daisy increases the mortality rate of the other).

[3] For instance, the growth rate of the ice area of a freezing water pond depends on the area that remains to be occupied, not on competition between ice and liquid water. The same applies here for the area occupied by a Daisyworld with only one daisy species and the bare ground; the mathematical description of ice/daisies and water/bare ground and the behaviour observed is not in fact qualitatively different.

Thus, whether the space area represents competition or cooperation depends upon whether we look at the individual behaviour of daisies, or rather the whole planet. Nevertheless, competence and cooperation are anthropocentrically charged terms (Margulis and Sagan 2002, chapter 1). We prefer the notion of coordination whenever a structural coupling between two or more organisms can be observed (Maturana 1980).

We have simulated Dw with fixed sun luminosities. When the luminosity is L=0.85 (Fig. 2A), the Dw temperature without daisies is 13.9ºC and the growth of black daisies takes up slightly more than 50% of the planet area in around 50 generations, while the white daisies grow very slowly until the abrupt increase in temperature is produced by the black daisies. They then start to grow more quickly and need more than 150 generations to take up almost 20%. When the white daisies occupy more than 10% of the planet, the black daisies readjust their population, due to temperature change, to slightly less than 50%. For a luminosity similar to our present sun L = 1, the stabilisation of the Dw temperature, the area of daisies and the start of the growth of both daisies happens more quickly, in less than 100 generations (not shown). When the luminosity is L=1.15 (Fig. 2B), the growth of the white daisies quickly reaches 45.7%, triggering a temperature change which allows the growth of black daisies up to 20%. Furthermore, when the area of black daisies grows, the area of white daisies also grows from 45.7 to 48.3%. These results show that the growth of the white daisies is coupled to that of the black daisies. Wherever the growth of black daisies takes place, an area of white daisies also grows. That is, the growth of both daisies is not mutually exclusive and seems to follow a coordinated symbiotic pattern rather than a competitive one.

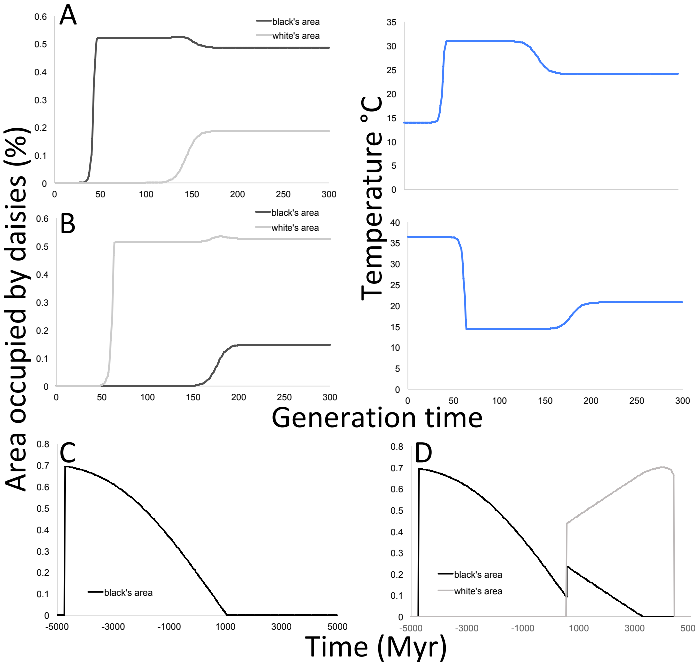

Figure 2. Symbiotic coordination in Daisyworld. A,B) Area of Daisy occupation (left panels) and planetary temperature evolution (blue)(right panels) for 300 daisy generations at a fixed sun luminosity of L=0.85 (A) or L= 1.15 (B). **C,D)** Area occupation of daisies with increasing luminosity, with only black daisies (C) and when white daisies appear at a solar luminosity of L=1.05 (D).

The symbiotic coordination can also be shown when the luminosity is changing (Fig. 2C,D). The life-time of a Dw with only black daisies is shorter (Fig.2C) when compared to a Dw on which the white daisies appear on the planet several thousand million years later, when L = 1.05 (Fig.2D). This shows that the appearance of white daisies allows the blacks to regain their growth rate and expand their life span two thousand million years more than when black dasies are alone.

All these results suggest that the resource space is a symbiogenic rather than a competitive adaptive feature. The area ocupied by black and white daisies is in balance with respect to the luminosity and the regulating temperature of the whole planet, which is "comfortable" for both daisies. Daisyworld constrains a maximum occupation of the planet with respect to a global temperature self-regulation.

4.2 Butterflyword and Pandoword: regulation without natural selection

Butterflyworld (Bw) is a hypothetical planet with a single butterfly species with sexual dimorphism (black male, white female) (Castro 2013, 2019, 2020). Both sexes are required. As such there is no competition, hence no natural selection. All parameters such as factor (q) and heat transfer factor in Bw are the same as in the Dw of W&L. However, the birth rates and mortality of the butterflies with respect to daisies are different.

The growth rate of the butterfly area depends on the presence of butterflies of the other sex and of the area that remains to be occupied (x) (see equation (1) for comparison). The mortality rate depends on the parameter B and the area occupied by the butterflies of the same sex. Then, the rate of variation of the area occupied by males, which replaces equation (1) of the Dw of W&L, is:

$$\frac{da_m}{dt} = \sqrt{a_m \cdot a_f} \cdot x - a_m \cdot (1 - B_m) \qquad (8)$$

where a_m is the area occupied by males and a_f that occupied by females, the same symmetrical equation applies for the a_f variation. Thus, growth is maximized when there are as many males as females, and mortality depends on the temperature (parameter B, equation (2)) in proportion to the number of males (a_m). Therefore, in Bw, area variation with the temperature is not dependent on reproduction but mortality dependent.

When the planet temperature is regulated by means of the change in the relative areas of males and females, B could approach 1 and there may not be any mortality. In fact, this happens with female butterflies that could occupy very nearly 100% of the planetary area, the males being reduced to much less than 1%. However, this situation is not biologically plausible in natural systems. Thus, to overcome this, we modify equation (8), hence the Bw (Castro 2013), assuming that in each generation time, at least 3% of butterflies irrespective of their local temperature, will die:

$$\frac{da_m}{dt} = \sqrt{a_m \cdot a_f} \cdot x - a_m \cdot (1.03 - B) \qquad (8bis)$$

We call this the modified Bw (mBw). Here symbiotic coordination between sexes is observed for reproduction, mathematically reflected in the square root, that requires the presence of both with a maximum when both populations are equal[4]. The results of this simulation show the comparison of the area occupied by male and female butterflies of mBw and of black and white daisies of Dw (Fig.3A) and the comparison of the temperature regulation between them (Fig. 3B). The butterfly area in mBW of each sex never surpasses 85% and, during the temperature regulation time, both sexes have more than 7% presence (Fig. 3A). Overall, temperature regulation of the Bw is longer than that of mBw and Dw, while temperature variability is much less in Bw and mBw than in Dw (Fig.3B).

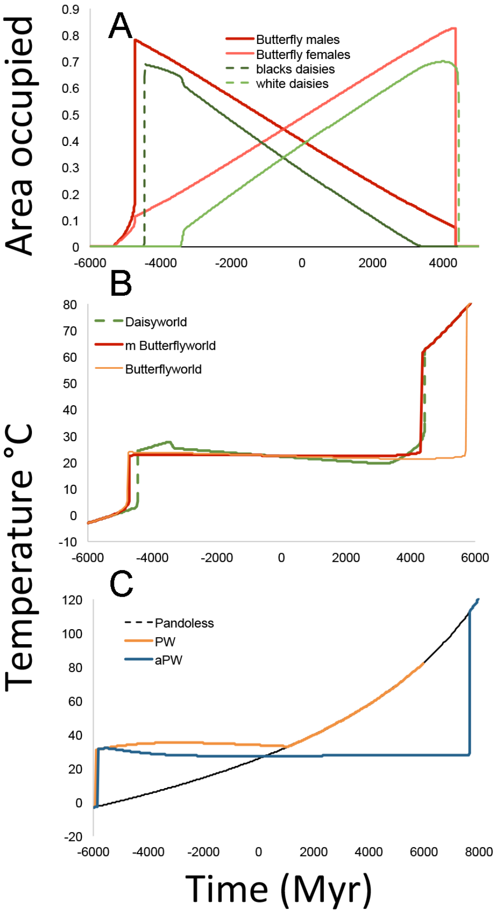

Figure 3. Area and Temperature evolution in Butterflyworld, Pandoworld and Daisyworld. A) Dark green and light green dashed lines are the area occupied by black and white daisies in Dw, respectively. Red and orange lines are the area occupied by male and female butterflies in mBw, respectively. **B)** Temperature evolution in Dw (green dashed line), Bw (orange line) and the modified mBw (red line). **C)** Temperature evolution of Pandoless Pw (black line), Pw (orange line) and the active aPw with the capacity for 'learning' through changing the albedo with an overheating sensor (blue line).

Pandoworld (Pw), inspired by Pando, a notable clonal aspen tree (*Populus tremuloides*) (deWoody et al. 2008), is a planet on which Pando increases or decreases in size at each time

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[4] The "cost of sex" has apparently been resolved from a Darwinist standpoint because it is assumed that sex could increase variability. However Gorelick and Heng (2010) review the evidence and discuss whether this may not be the case. The "selfishness dilution", that sex implies in nature and in our model, shows that it could contribute rather to improving the Gaian self-regulatory properties that, in turn, stabilise this kind of functional processes (i.e., sex could be regarded as a Gaia constraint, see next section).

step. That is, in Pw there is no competition, reproduction or variation upon which Darwinian natural selection can act. Pw follows the same equations as Dw with some constant parameters changed; the albedo is 0.15 –usual for forests-, instead of the black daisies' 0.25, while the fixed mortality rate of the area occupied by Pando is 0.1 instead of the 0.3 for daisies. When Pando occupies an appreciable amount of the surface of the planet, Pw self-regulates its temperature in a similar way to Dw with the black daisies only (Fig. 3C).

Following Rubin et al. (2020, 2021), we have further equipped the Pw with cognition-like properties. We call this "active" Pw (aPw), which detects the increase in solar luminosity (external states) through sensing the temperature (sensory states). The aPw changes its albedo slowly (limiting it from 0.15 to 0.85), losing dark leaves in favor of light leaves (active states). The aPw reaches a remarkably long lasting (more than 13 Gyr) temperature self-regulation (Fig. 3C).

5. Gaianizing Darwin: Planetary constraints and "altruistic" daisies

Our analysis of the original Dw and DDw shows that the mechanisms behind them cannot be interpreted in the light of the natural selection of daisies. We have shown that the addition of Darwinian characteristics into Dw tends to weaken or even impair the regulation of its temperature. How the Darwinian characteristics affect the Dw temperature self-regulation is shown in an influence diagram of the Dw (Fig.4A).

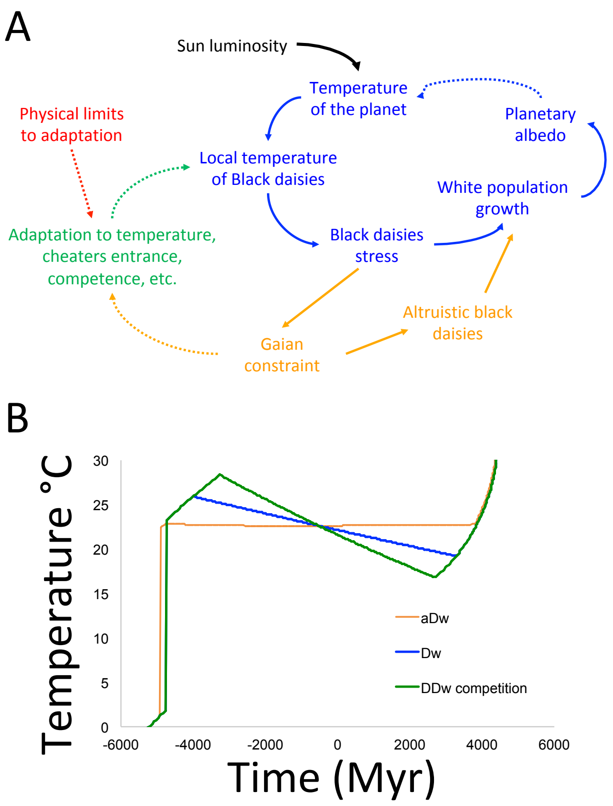

Figure 4. Simplified dynamic influence diagram of Daisyworld(s) and their temperature self-regulation. A) Dynamic influence diagram of Dw, DDw and aDw under a Gaian constraint. Blue loop represents original Dw of W&L. Blue + Green represent the adaptive, competence, cheaters and other Darwinian characteristics of DDw. Red add physical restrictions on

daisy adaptation. Orange represent how a Gaian constraint limits Darwinian influence and adds an 'altuistric' loop on Dw (aDw). Bold arrows indicate positive feedbacks (e.g., the more Sun luminosity, the higher the temperature of the planet; or the lower the Sun luminosity, the lower the temperature of the planet). Dashed arrows indicate negative feedbacks (e.g., the higher the planetary albedo, the lower the temperature of the planet)[5]. **B)** Comparison of temperature self-regulation of Dw (blue line), DDw with antagonistic competence (green line) and aDW with "altuistric" daisies (orange line) (see text for explanations of this model).

When a Darwinean influence (green), which is destabilising, is added to the stabilising blue loop (original Dw), the temperature self-regulation is impaired or destroyed. Adaptive with restrictions (red-green) has a set point temperature which is stressful for daisies. It reduces the strength of the "green" causation, adding a negative causation if and only if the physical restriction happens. Indeed, much of the DDw we have analysed here or from elsewhere adds "green" destabilising causation, in the sense that it impairs temperature regulation. For example, some recent results of the Guild (Williams 2006) or the Flasks simulations (Nicholson et al. 2017), also found that the regulation is impaired with the entrance of adaptive cheaters.

However, the inclusion of a 'Gaian constraint' (orange loop)(Fig. 4A) which strongly restricts the Darwinian influence and/or triggers "apoptosis-like[6]" behaviour in black daisies allows the global temperature self-regulation to stabilize (Fig.4B). The proposal is thus to reverse the logic of the inter-specific competence by an "altruistic" behaviour. That is, instead of the death rate being: $\gamma = 0.3 + 0.1\cdot$area of competing daisies; for the "altruistic" daisies, the death rate becomes: $\gamma = 0.24 + 0.1\cdot$own area of daisies, i.e., they die in function of their own density[7]. The temperature self-regulation of this "altruistic" aDw remains for more than $8\cdot10^9$ years, with the temperature variation lower than 0.3ºC (Fig.4B). These values are much more robust than for DDw or even Dw. A 'comfortable' temperature may be reached for each individual daisy, as well as for the whole Dw, because daisies depend on the regulation properties of the whole system and the whole system constrains the equilibrium population area of daisies.

Darwinian characteristics added to Dw attempt to address the central theoretical problem of how planetary self-regulation could happen with selfish organisms that are selected not to work for global properties or to reach a common good (Maynard-Smith, 1988). Initial simulations show that this was not possible (R&R, Saunders 1994). Then, some authors claimed Gaia to be 'lucky' (Watson 2004). On the other hand, it has been suggested that assuming the existence of an ultrastable[8] natural selection of feedbacks across scales (Lenton et al. 2018), or that the competing of macro/super 'units of selection' such as biogeochemical cycles or hypothetical

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[5] A circular causation cycle is a stabilising loop that could result in planetary self-regulated temperature and also self-regulated daisy populations when an odd number of discontinuous arrows are in the loop; otherwise, it is a positive reinforcing loop (a destabilising loop). Butterflyworld and Pandoworld do not have the green destabilising feedbacks and reinforce the stabilising feedback through i) the coupling of butterflies (in Bw) with selfishless behaviour, ii) the learning of the aPw, or iii) through "altruistic" daisies under a Gaian constraint.

[6] This model is inspired by the behaviour of apoptotic planktonic, photosynthetic microorganisms found in the oceans, as described by Bidle and Falkosvki (2004).

[7] We chose 24% of deaths instead of 30% to be able to compare it with the original Dw, assuming that the area limit for the daisies was 70% of the planet in both simulations.

[8] Ultrastability is a stability of a logical level, higher than the stability to which a system converges without changing its internal organisation, which was introduced by Ashby (1966).

pre-existing clades (Doolitle 2017, Doolitle and Inkpen, 2018), will constitute a ‘probable’ Darwinized Gaia.

Our results obtained from comparing Dw with DDw, and introducing mBw, aPw and aDw, suggests that the central theoretical problem of Dw remains. That is, there is no possibility of planetary self-regulation with the Darwinian mechanisms of adaptation, competence and cheating. Therefore, there should be an alternative explanation for the generation of habitable dynamics on Earth or Gaian-like planets elsewhere that does not involve natural selection mechanisms.

Margulis suggested that Gaia is the “selector” (Margulis and Sagan 2002). For us, “Gaianizing Darwin” rather means that the whole system constrains the Darwinian mechanisms and allows the generation of planetary habitable dynamics favouring such different processes as the equilibrium population of organisms through “altruistic” behaviour, as illustrated in the aDw (Fig. 4B), and/or by symbiotic coordination, as shown above (Figs. 2 and 3A), among others.

6. Conclusion

Although different works showed the Darwinian effects on Dw, none has shown their additive effect at the same time. This is shown through the comparison of the original Dw with DDw including adaptive restrictions, competition, high albedo clouds, by-products and cheaters. The Darwinian responses of the daisies in DDw tend to weaken the temperature regulation in the original Dw with one of them and further impaired when two or three or all four simulated processes are added. That is, the more Darwinian characteristics are added, the less planetary temperature self-regulation is attained.

As Dw regulates its temperature over a wide range of solar luminosities by ordinary physical processes, such processes on Earth, in our opinion, involve at least strong symbiotic coordinated relationships. We have developed hypothetical worlds, such as a Butterflyworld, an active Pandoworld and an altruistic Daisyworld, that cannot be considered subject to Darwinian selection, but which could be regarded as coherent with a Gaian constraint hypothesis. The temperature self-regulation of these worlds is attained much more efficiently even when compared with the original Dw. This casts doubt on the attempts of Darwinizing Gaia and the compatibility between the Gaia hypothesis and natural selection. Alternatively, by Gaianizing Darwin instead, we think that we overcome the lucky and probable Gaia as a hypothesis for the long habitability on Earth and elsewhere in the universe.

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