The Biodiversification Resistor: Ramifications for Life on Extreme Exoworlds

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It is now well known that life can live in environments previously deemed too extreme; however, what constitutes extreme environments concerning life? It has been observed that there are environments with high species diversity and environments with low species diversity. Thus, the latter are the ones that have been deemed extreme. The relations between decreasing biodiversity and increasing extremity have been studied in this work, and several proportionality relations, and their ramifications for potentially inhabited exoworlds, have been clarified. Thus, it has been found that a biodiversification resistor exists as a boundary condition for life and that a biovelocity resistor exists as well as a boundary condition on inhabited worlds. Thus, the fact that the environment is extreme implies a lower biodiversity and a lower biodiversity entails a greater vulnerability to potential environmental changes, external as well as internal. This means that life in an extreme world does more poorly than in a relaxed world. Thus statistically, the number of inhabited extreme worlds will decrease compared to inhabited relaxed worlds. Based on the abstracted proportionality relations, a classification of worlds has been put forward: Population I worlds (no life), Population II worlds (biodiversity poor), and Population III worlds (biodiversity rich), where the proportionality relations allow to evaluate how the conditions for potential life elsewhere must be, and thus provides an essential tool for astrobiology.

Keywords: astrobiology, biotic shield, proportionality relations, biovelocity resistor, differential habitability, Population I, II, III worlds.

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1. Introduction

Astrobiology is the multidisciplinary field that investigates the deterministic conditions and contingent events with which life arises, distributes, and evolves in the universe (von Hegner, 2021). Thus, merely understanding life in a functional biology context, i.e., the physical,

chemical, or physiological responses of organisms here and now and the effect of environments here and now, is not sufficient. Adequate descriptions of life need the evolution and ecology of life as well.

This is important as it is now well known that life can live in environments previously deemed too extreme, which has gained significant interest. This gives reason for optimism regarding the existence of life on exoworlds previously deemed to be too extreme for life. Thus, with e.g., extremophiles in mind, extreme environments are no longer considered obstacles in astrobiology.

However, life existing in such environments comes with a built-in limitation that could be more evident, because what constitutes extreme environments? Defining what an extreme environment concerning life is can be challenging. A world like the Earth is characterised by many different environments and species. So even among potential Earth-like exoworlds, it is not straightforward to establish common characteristics regarding the nature, distribution, and size of different environments and the life present in them. There are of course different types of extreme environments on the Earth, meaning there are various environmental conditions, such as temperature, pressure, nutrients, pH, and saline concentrations, which can be high or low or vary significantly from each other. The same applies to extreme exoworlds, which in principle, can possess a multitude of different environments simultaneously or possess few environments, with implications for the potential life existing on them.

This work's approach to what constitutes extreme environments is that life and environments are intrinsically connected, and relaxed environments versus extreme environments with regards to life must be considered.

Some observations can be made. Thus, life exists in almost all environments on the Earth, but it is the case that multicellular life only exists in some environments, while unicellular life exists virtually everywhere. Thus, microbial life has a greater biodiversity than multicellular life. Therefore, a habitable environment on an extreme world may be defined as an environment where at least one known terrestrial extremophile can live. However, apart from being limited by being a geocentric definition, more than what given specific organisms are capable of is required.

Evolution is an adaptation to changing local environments. Thus, both the dynamics of life as well as environments are necessary to describe life in a world. Therefore, understanding what environments can do to life, and what life's response to environments means will be essential to clarify for searching for exoworlds where life can be expected. It has been observed that there are environments with high species diversity and environments with low species diversity. Thus, the latter ones have been suggested to be those that should be designated extreme (Brock, 1979). There is justification for this, as, e.g., life does exist in Antarctica, yet despite the large area here, the diversity of life is not high compared to the diversity in a rainforest. It is not puzzling that this is the case. There is a limit to what biomatter can do, especially when it first has to undergo adaptations. There is only so much e.g. a cell membrane or biopolymer can endure. While this is not puzzling, it still has consequences that can have significant ramifications, as extreme exoworlds with life can thus be expected to be poor with regard to biodiversity.

Of course, it has yet to be discovered how the distribution of life is in a galaxy like the Milky Way, and it is still open whether life even exists elsewhere in this solar system. However, here for the sake of argument, it will be assumed that life exists elsewhere and is distributed according to the Disparitas conjecture, in which microbial life is common in a galaxy, while multicellular life is rare in comparison (von Hegner, 2022). As mentioned, there are different types of extreme environments, but for the sake of argument, extremity in a generic sense will be implicitly used here unless otherwise noted.

Thus, in the following work, the relationship between decreasing biodiversity and increasing extremity will be investigated, and several proportionality relations and their ramifications for the research and search for potentially inhabited worlds in the galaxy and beyond will be abstracted.

2. Discussion

In this paper, Section 3 presents and clarifies how environments can increase or spread extremity in a world and the effect of this on life. Section 3.1 presents and explains how biodiversity can decrease due to an increasingly extreme environment but that cell density can increase. Section 3.2 presents and discusses that although the remaining life may be well adapted, it will still be at a disadvantage compared to life in relaxed environments. Section 4 presents and clarifies how the cell density can fall due to an even more increasingly extreme environment and that life can endure but not thrive in this environment. Section 4.1 presents and discusses that although the remaining life can exist in a large area abundant with energy sources, resources, and lack of competition, it does not benefit from it. Section 5 presents and discusses a classification of worlds where biodiversity-poor worlds, due to the proportionality relations, will statistically decrease over time in a galaxy in comparison to biodiversity-rich worlds. Finally, Section 6 summarises the results of this work and its implications for the research and search for potentially inhabited worlds in the galaxy and beyond.

3. Biodiversification Resistor

There are several definitions of what an extreme environment is with regard to life. It has been observed that there are environments with high species diversity and environments with low species diversity. It has therefore been suggested that those environments keeping low species diversity, in which entire taxonomic groups are absent, should be designated extreme (Brock, 1979). This is an ecological definition that was established for multicellular species. It was put forward before the importance of extremophiles in extreme environments became clear. However, the observation is still essential, as there is no reason why this should not apply to microbial life as well.

It is the case that the adaptability, robustness, and versatility of microbial life are higher than is of multicellular life. However, it still applies to them that there are environments with high species diversity and environments with low species diversity. Thus, in some environments, conditions, such as temperature, pressure, pH, nutrients, or saline concentrations, are extremely high or low, meaning that only a limited number of species exist.

A world can have many different environments; this is true for the Earth. For extreme exoworlds, there are two different points to address.

1. The different environments in a world may eventually have disappeared, leaving few large homogeneous extreme environments.
2. The different environments in a world, including relaxed environments, can eventually all increase in extremity, so there are many extreme environments.

There are two additional points to address regarding life and extreme environments.

1. In the first, life migrates ever closer to the extreme environment and constantly adapts to get further into it.
2. In the second, environments become more extreme, so the inherent life constantly adapts to them and becomes more extremophilic.

In both scenarios, the extreme environment acts as a parameter on evolution, forcing adaptation in an overall direction that evolution does not experience to the same extent in relaxed environments.

These points are essential to address for the purpose here because life occurs in its most rudimentary functional form, and this must occur in a relaxed environment. This is a boundary condition for life in any world (von Hegner, 2019; von Hegner, 2021). Thus, it applies to worlds that go from having different environments to few homogeneous or many extreme environments, that if life has arisen on such worlds, then those worlds must have originally had relaxed environments, even if they have since become extreme environments, as it applies that the native life either continually adapts to be able to get further into them, or emigrates ever closer to the extreme environment.

There are many different extreme environments, but when we talk about extreme exoworlds, we only mean worlds where life presumably has the opportunity to live. Thus, an extreme environment can be defined as one where at least one known terrestrial extremophile could live. However, this definition is very specific; it is an inductive inference. Thus, while being a practical working definition, it is limited due to the knowledge of extremophiles on the Earth.

A more generic definition is, as mentioned, that since there are environments possessing high species diversity and environments keeping low species diversity, those environments keeping low species diversity can be defined as being extreme. This second definition is general; it is a deductive inference. Thus, although nothing is yet known about potential life elsewhere, it will still be valid.

Thus, in the following, inhabited worlds will be discussed, where the existing environments increase to an extremity or the extreme environments are expanded so that only a few large homogeneous environments are left. Worlds with many different relaxed and extreme environments will be Earth-like in that respect, and therefore not so important to discuss here.

3.1. Cellular density

Section 3 mentions that environments with low species diversity can be called extreme. Life can exist in extremely high or low conditions, such as temperature, pressure, pH, nutrients, or saline concentrations. However, as a result, only a few species exist in those environments. This decrease in biodiversity is faster and more markedly in multicellular life, but it is still present in unicellular life.

Thus, it is the case that there is an arrow of extremity going from a rich biodiversity to a poor biodiversity. This, in turn, means that there is an arrow of biodiversity going from a relaxed to an extreme environment.

Thus, there is a direct proportionality between increasing environmental extremity and decreasing biodiversity. In other words, a direct proportionality exists between the environmental extremity increasing or expanding and the species variance decreasing, see Figure 1a.

If the number of environments in a world decreases, then the number of species also decreases, even though several different species can live in the same environment. But if the number of environments does not, but instead environments increase in extremity, then the number of species decreases.

So, there is the following relation:

$$\text{relaxed environment} < \text{extreme environment}$$
$$\rightarrow$$
$$\text{high biodiversity} > \text{low biodiversity}$$

Thus, an increasingly extreme environment means biodiversity decreases, and species centre around the mean in a Bell curve, see Figure 1a. Therefore, genetic diversity will be low in such environments, as the environment here pushes a low diversity, though, as only a few specific variants can cope with the environment.

But even if biodiversity decreases when the environment increases in extremity, it is still possible for the remaining species to be well adapted and thrive in these environments, i.e., they may grow at high cell densities. When one species disappears, there is more room for other species, and it can thus increase its cellular number. Thus, it follows here that in extreme environments, it can be the case that a species exists in high numbers but not a high number of species.

So, there is an inverse proportionality between many species, each in a limited cellular number and a limited number of species in a potentially large cellular number.

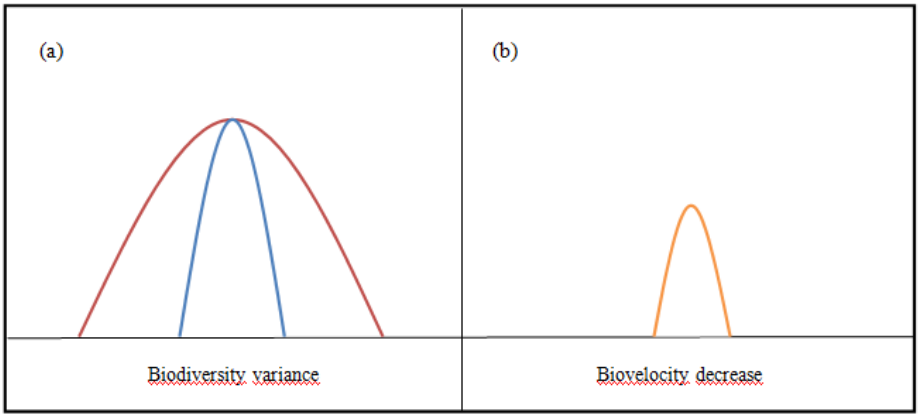

Figure 1. (a) Shows the red Bell curve with the wide biodiversity variance for life on the x-axis in relaxed environments. The blue Bell curve shows that the variance for life in extreme environments has shrunk on the x-axis but has the same centre position and height on the y-axis. (b) Shows the Bell curve for the biovelocity decrease, the low cell density in the more extreme environment, which has the same centre position on the x-axis as the other two curves but is shrunk even more and is shorter on the y-axis than the others.

Such extreme environments may still possess sufficient energy sources and building materials. Thus, for many species, each in limited cellular number, the species themselves and the resources keep the species in check in the same environment. In contrast, for a limited number of species in potentially large cellular numbers, it is mainly the resources that keep the species in check regarding cell density. So if one counts in cellular individuals alone rather than count in species, then there can potentially be an equal number of individuals on both sides of the extremity arrow, see Figure 2.

It can be thought that this decrease in biodiversity mainly applies to multicellular life, that the arrow of extremity going from a rich to a poor biodiversity is more characteristic of multicellular life than unicellular life. Indeed, microbial life is more adaptive, versatile, and robust than multicellular life, which could be different for them.

However, the increasingly extreme environment will mean that the microbial species will eventually centre on the genetic variants that can cope with the environment. Thus, quite a

few species might present here that will react to the increasingly extreme environment by being forced through convergent evolution into more and more uniform organisms. Of course, mutations will continue to occur, but since the environment only allows specific variants to make it, the environment will also maintain these. Thus, although different species may continue to exist here, the diversity between them will still decrease, as the focus will be on the phenotypes that can cope with the environment and the genotypes that make this possible. So ultimately, in this situation, there will be a group of species whose genetic split lies far back but which, through convergent evolution, have become virtually identical.

Of course, microbial life, such as bacteria, differs from multicellular life by, e.g., horizontal gene transfer. Thus, the species barrier is more fluent for them than for species limited to vertical gene transfer. So since the species concept is flexible here, one could say that microbial life in this way circumvents the environment and will push biodiversity down. Thus, a great diversity of species will be able to incorporate genes from this common gene pool, and by doing so, they will be able to achieve uniformity with each other in terms of being able to cope with the extreme environment, being able to incorporate the genes that allow them to cope with the environment. However, the fact that a large diversity of species will contain genes from the common gene pool will, in this situation, mean that the gene variance will decrease, centring on the genetic variants that can live in the environment. This means that the diverse gene pool will decrease to the mean on a Bell curve, while the specific gene pool will increase among the species and be fixed. In this situation, a very similar group of species can be found, whose genetic composition comes from diverse species but has now become an almost homogeneous group.

Thus, the species concept differs for microbial life from multicellular life. However, an increasingly extreme environment will ultimately lead to limited genetic variation or biodiversity. Therefore, when there are many different individuals, evolution in relaxed environments will select between the variants, and different species will gradually emerge.

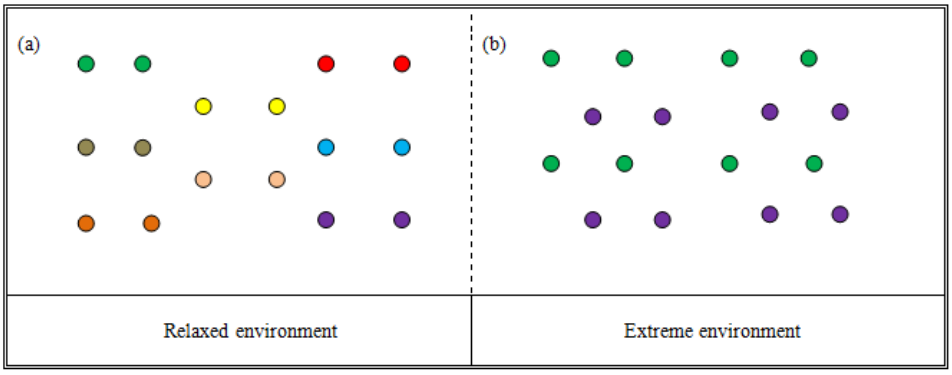

Figure 2. (a) Shows a relaxed environment where many different species exist, illustrated as dots in different colours. (b) Shows an extreme environment with decreasing biodiversity but a high compensating cell density. There are the same number of cellular individuals in both (a) and (b).

Even in these extreme circumstances, the mechanisms that allow different species to evolve eventually, to split off from one species, will be active.

Thus, for both scenarios, it will apply that even if a group of species can live in the environment in the same way, the increasingly extreme environment will eventually mean

that there will be a focus on the microbial species that can better cope with the environment, and among them will there gradually be centred on the genetic variants that can cope with the environment. Thus, a selection will take place between them, meaning that the number of species will gradually decrease, the species variance will decrease; in addition, the extreme environment limits the possibility of species diversification. The second scenario also applies that the uptake of genes is not necessarily the uptake of the useful genes to cope with the environment every time, so there will still be a selection between them, and the species will decrease in this situation.

Thus, species variance will decrease even for microbial life as environmental extremes increase. The extreme environment functions here as a fixed parameter, i.e., species will eventually be trapped around the mean on a Bell curve. There will be an inverse proportionality between the fact that biodiversity will decrease and the number of cellular individuals may increase.

Evolution has no preferred direction. So if an extreme environment with low biodiversity relaxes again, biodiversity can also increase again. This also applies to life that is present in the environment.

So there is an inverse proportionality between biodiversity decreasing or increasing as the extreme environment increases or decreases.

It is not static but dynamic. The variance of environments and biodiversity decreases and increases over time.

It will also be worth mentioning the disproportionality between mesophiles and extremophiles here. Thus, it could be thought that when there are many mesophiles in a relaxed environment, that there will also be many extremophiles in an extreme environment. But here, an inverse proportionality is seen between many mesophile species in a relaxed environment but few extremophile species in an extreme environment.

If the increase in extremities is slow, mesophiles can adapt to become extremophiles. If the extreme environment is relaxed again, then extremophiles can adapt to become mesophiles.

Thus, there is an inverse proportionality here: many mesophilic species decrease into a few extremophilic species in an extreme environment, while few extremophilic species can diversify into many mesophilic species if the environment is relaxed again.

Here it can be seen that a difference between extremophiles and mesophiles is that mesophiles can exist as many species, while extremophiles, in comparison, can only exist as a few species, even though the cellular number may be high.

So a boundary condition for life on such worlds is that extremity acts as a ‘resistor’ on biodiversification. Thus, a biodiversification resistor exists on inhabited worlds.

3.2. Variance and survival I

As discussed in section 3.1, the situation is that while there is a limited number of species in an extreme environment, this may be compensated by these few species being found in large cellular numbers, see Figure 2b.

Thus, there is an inverse proportionality between the number of species decreasing and the number of members of the same remaining species increasing.

As a first consideration, it can be thought that it is an advantage for a particular species both that its competitors in the form of other species disappear and that it gets space and resources to increase in cell number. It could thus become easier to live for the remaining life, even with high cell density, as extreme environments can still possess sufficient energy sources and building materials.

Thus, there could be a direct proportionality between the number of species decreasing and the possibility of survival increasing for the remaining species.

However, apart from the fact that the competition is tougher within a species than between species, in this situation, it also applies that the fact that there is an arrow of extremity going from a rich biodiversity to a poor biodiversity, in turn, means that there is also an arrow heading towards decreasing survival.

Thus, there is an inverse proportionality in that life increasenly endur an extreme environment, i.e., its variance decrease, and by that variance decreasing, life decreases at the same time the possibility of its long-term survival.

It is the case that a single remaining species, a single lineage, is not considered successful from an evolutionary point of view. Thus, bushes represent the correct topology of evolution, not individual twigs. Suppose a sizeable branching family or genus decreases its evolutionary variance to a single remaining species. In that case, that species is not considered successful, even if it survives for a considerable time. Thus, classic examples from the mammalian world are horses. These were once a prolific bush, yet only one genus, the Equus, with horses, zebras, and asses, remains, carrying the entire heritage of a group that previously dominated the history of hoofed mammals. They are single surviving twigs which are unsuccessful lineages from an evolutionary point of view (Gould, 1991). In contrast are rodents, bats, or antelopes, which are great success stories from an evolutionary point of view. They are prolific bushes with hundreds of surviving and thriving twigs (Gould, 1991). This scenario is even more profound if one moves from genus further up the eight major taxonomic ranks.

These classic examples are, of course, for multicellular species. But that, it will be presented here, also applies to microbial life, although it requires more extreme conditions before this becomes clear.

Bottleneck events exist, but these affect a relaxed world differently than on an extreme world. Life can diversify from the first but not from the second (von Hegner, 2021). Thus, although microbial life has several differences and the species concept is different for them, as discussed in section 3.1, it applies that as their gene pool in that situation gradually centres around the mean in a Bell curve, the situation will become the same for them.

This may appear paradoxical if this life is otherwise widespread in an extreme world. But even though there can potentially be the same number of individuals at each end of the extremophilic arrow, the survival possibility between them is different in the sense that one side is the number of species, and the other is the number of cellular individuals.

The remaining species are lines from a bush forced to trade their wide variance to single values to survive in the extreme environment. Evolution works by selecting between variants in a given local environment. But in this situation, the extreme environment keeps the number of variants, the wide variance, down. Here in the form of many similar members of the same species, the shrunken variance may be well adapted to their local environment, yet their numbers will not necessarily ensure their long-term survival. This is due to the fact, that as a species adapts to its environment, it is thus vulnerable to a rapid shift to other environments.

Thus, by trading the wide variance, species in this situation have become more vulnerable to planetary upheavals and environmental fluctuations than they are in relaxed environments, as the variance, the multitude of species, statistically ensures long-term survival, rather than individual species being maintained in the same form in the same environment.

So the existence of a species in high numbers, but not a high number of species in an environment, may not ensure against environmental fluctuations and a potential extinction event. From a purely physical perspective, this may be an unfamiliar way of viewing it. But

from an evolutionary point of view, this is the proper way because even though extreme environments may still possess sufficient energy sources and building materials, this is not the issue.

Because although life has the resources to increase its cell number, the issue is, apparently paradoxically, that it is not the number of cellular individuals that ensures long-term survival but the number of species.

Thus, a high number of similar individuals will have the same all-or-nothing response to the effect of a global environmental impact. Therefore, they will have a different possibility to survive the aftermath of an environmental impact than many different species that may have different responses. Thus, decreasing biodiversity means that the remaining life, even if found in a high cell density, has a more limited response to the aftermath of major planetary events. Thus, since worlds can experience environmental upheavals, and every species is vulnerable to sudden environmental changes, a plethora of species will statistically be better suited to cope with a special effect than a few species.

Thus, there is a direct proportionality between biodiversity and survival in the face of incoming environmental threats.

This can be illustrated through several different scenarios.

The Earth has experienced several environmental impacts over time. A relatively straightforward scenario was the asteroid that hit the Yucatan Peninsula in Mexico over 66 million years ago and formed the Chicxulub crater (Alvarez et al., 1980; Hildebrand et al., 1991), responsible for the Cretaceous-Paleogene extinction event, one of the five major extinction events that are usually mentioned. A high or low biodiversity is in the same situation if it exists in a limited area; however, if spread over a large area, it is in a different situation. Thus, a large number of individuals scattered around can ensure short-term survival in the event of an impact, as the impactor will necessarily hit a particular place in a world. Some life thus disappeared because it was in the impact centre and near the matter and energy deposit. However, long term, this will not necessarily save them. Most of the life that subsequently disappeared, an estimated 76% of all marine animal species and 40% of genera (Jablonski, 1994; Bambach et al., 2004), did so due to the impactor's effect, as the impact blast meant a global increase in extremity, i.e., although several reasons have been proposed, an important reason is that the impact injected large amounts of sulfur-bearing gases into the atmosphere, after which sulfate aerosols caused global cooling, sulfuric acid rain, and reduction of surface light for photosynthesis (Schulte et al., 2010; Gulick et al., 2019).

Interestingly, the impactor represented a relatively mild case, and its effect did not pose a real threat to Earth's life *per se.* However, this could have been different had the Earth's biodiversity been lower when the impact took place. Thus, the fact that many species disappeared while others did not was ultimate because the species that disappeared had the same overall all-or-nothing response to the environmental changes that the impactor caused. However, in this situation, a wide variety of biodiversity existed, which thus had different responses to environmental impacts, and therefore survived the Earth's life. If the impactor had been larger than 10 km in diameter when it struck the Earth (Brittan, 1997), or had a higher velocity, then the effect could have been so severe that biodiversity could have been reduced down to the microbial community and this could themselves have been reduced to single species, and the effect would have had a more profound influence on life *per se* on the Earth.

Another earlier and not-so-straightforward example of environmental impacts is the impact or impacts in the Hadean eon. Life may have arisen near the end of this (Bell et al., 2015). Thermophiles belong to the oldest known life (Gaucher et al., 2010). However, life

must necessarily have arisen as the simplest functional life possible in a relaxed environment (von Hegner, 2019; von Hegner, 2021). This means thermophiles were not the first life, as they are not the simplest functional life possible, but in fact are highly adapted organisms.

Thermophiles being the oldest known life yet cannot have been the first life shows that biodiversity already existed at a time when impacts eventually made them the oldest recorded life today. This biodiversity existed at a time when the Earth was still turbulent, with many impactors and much resurfacing of the planet itself. What happened may differ. An impact may have destroyed the relaxed and restricted subenvironment where the mesophiles lived, leaving only the thermophiles who had adapted to live in the planet's more widespread hotter environments. However, the impactors may also have caused the environment to increase in temperature rapidly.

If it was the latter scenario, mesophiles, but not thermophiles, ultimately disappeared because the former had the same overall response to the environmental changes the impactors induced. At that time, there may have been only limited biodiversity, a limited variation that thus had different but limited responses to environmental impacts, and therefore only thermophiles survived.

Evolution has no preferred direction, so when the extremity fell again, or rather that different environments arose again, extreme and relaxed, then the life that survived, which represent survivors' from what can be classified as the first – and overlooked – 6 extinction event, next to the five events usually mentioned, also gradually gave rise to mesophiles again, so biodiversity grew, and the variance spread again.

The Earth has also experienced environmental impacts not only from external impactors but from internal environmental impacts as well. Thus, the Great Oxidation Event (GOE) was a transformative event in which the Earth's atmosphere and the shallow ocean experienced a rise in O_2 between 2.4 and 2.1 billion years ago (Holland, 2002; Lyons et al., 2014). This event may have resulted from cyanobacterial activity, producing oxygen as a waste product, which accumulated in the atmosphere, thus leading to significant changes to the Earth system (Cloud, 1968; Lyons et al., 2014).

Thus, although this increase in extremity could be caused by life itself, due to cyanobacterial photosynthesis, and life was widespread at the time, biodiversity was low in the sense that the dominant life was anaerobic species. So most dominant species had the same singular response to the effect of what was for them highly toxic oxygen. This may have caused severe extinction events for the many anaerobic species on the planet (West, 2022). Thus, there was a decrease in biodiversity, and species disappeared while the species with other different responses to the environmental changes managed to survive.

Thus, the abundance of many species of life spread over a large area acts as an indirect shield against incoming impacts. This biotic shield is almost like a planet's magnetosphere or atmosphere, which acts as a direct shield by protecting life against the effects of solar radiation and cosmic radiation. This is because life relies on the backup of species and variants to ensure long-term survival.

One has a macro event in case of impact events that change the environment. Such external events present a challenge for all life. However, the higher the biodiversity, the greater the possibility of coping with it, as at least some species will be fit to cope. Nevertheless, even if such planet-wide impactors occur, it is estimated that impactors with a 3 km diameter strike the Earth every million years on average, while large 16 km objects happen approximately once every 100 million years (Paine & Peiser, 2002), so from the perspective of life, these are distant events that may or may not occur.

However, there are also more subtle internal events. Significant external events are not the only thing that affects the environment. Thus, an inhabited world is dynamic; its different environments have fluctuations over time that affects each other. Such micro events also affect life.

Even if the extremity increases, there can still be different environments, just as there can be different environments in a relaxed world. Thus, the environments do not necessarily become homogeneous but merely differ from the previous, more relaxed environment. Therefore, there may still be various environmental stressors, and environmental fluctuations may still occur. The increased extremity is itself an environmental stressor or stressors. It was the one that pushed biodiversity down to begin with. However, there will still be other stressors, which may be the same as before the environment increased in extremity.

Environmental stressors in the form of fluctuations affect the life that is in the environment, but this is an issue as biodiversity has decreased.

The fact that biodiversity has fallen means that the remaining species are, in a manner of speaking, maintained around the mean on a Bell curve. The remaining species are adapted and thrive in the environment, thrive in their particular mean of the bell curve, but since they are fixed, life cannot spread its variation along the curve's tails. Thus, as the biodiversity of the remaining species is maintained, and their specific gene pool is maintained, they cannot respond as well to the various environmental fluctuations through adaptation as the extreme environment maintains them.

Even if the increased extremity remains at this level, the fluctuations will continue to swing back and forth in the environments. Such fluctuations exist in all environments with life, relaxed as well as extreme, and while species can indeed manage to be stable over long periods, there will always be a natural push, their equilibrium pushed eventually.

However, the situation here is different, as the possibility of biodiversification disappears when the extreme environment increases. Their high cell density and their existence in potentially large areas can be a factor that helps ensure their long-term survival. Thus, in some parts of the large area, they can disappear by being impacted by the fluctuations, but in other parts where the fluctuations do not impact them, they can increase their cell density. Thus, life does not necessarily disappear under these circumstances; it can potentially endure over long periods given the right circumstances. Nevertheless, the continued existence of life depends on the number of species, not the number of cellular individuals.

So since life's ability to adapt and diversify is kept in check by the increased extreme environment, but the environmental stressors and fluctuations still act on them with potentially the same force, this means that life will be worse off than if it existed a relaxed environment.

This situation is very complex, with many variables and factors at play. However, the probability that the species' survival in extreme environments will decrease over time compared to species in relaxed environments can still be illustrated simply by modelling life as a game by rolling two dice.

Thus, in the following, there is, for the relaxed environment, a die with 1 pip on three faces and 5 pips on three faces. Thus, there are $X = \{1, 1, 1, 5, 5, 5\}$, where the numbers $\{1, 1, 1\}$ are the environmental stressors, and $\{5, 5, 5\}$ are factors for the species variance.

For the extreme environment, there is a die with 2 pips on four faces and 5 pips on two faces. Thus, there are $Y = \{2, 2, 2, 2, 5, 5\}$, where the numbers $\{2, 2, 2, 2\}$ are the environmental stressors, and $\{5, 5\}$ are factors for the species variance. As can be seen, the species variance has shrunk by a factor, while the stressors have increased for the extreme environment Y.

It is the case that the fluctuations swing back and forth over life, and these fluctuations are set here to be the same for both the relaxed environment and the extreme environment. For

the sake of simplicity, a distinction is made here between stressors and fluctuations. They may in fact be the same, or fluctuations may merely push the stressors and thus affect life. It also applies here that the fluctuations are the medium in which it takes place, i.e., the medium in which the dice are rolled.

So when both dice are rolled out in the same medium simultaneously, the fluctuations, stressors, and variance will all come into play. Thus, how will each die do to the other, that is, which die is affected the most or is more likely to have the high roll?

Since the given dice possess the same number of pips, it could thus appear possible that both dice might have an equal probability of having the high roll. However, while the situation in the relaxed environment and that in the extreme environment is similar in terms of fluctuations that swing over life, there is a difference between life in the form that life in the extreme environment is more trapped around the mean and cannot diversify like life existing in a relaxed environment.

This can be seen in probability Table 1, which shows all 36 possible outcomes of rolling two dice, with winning outcomes in red and green and tie outcomes in grey. By merely looking at the table, one can see that if both dice are rolled out in the same medium at the same time, then the relaxed environment (1, 1, 1, 5, 5, 5) in the green area will be effected less in relation to the extreme environment (2, 2, 2, 2, 5, 5) in the red area. Thus, since it is the die with life in the extreme environment that is trapped around the mean and cannot diversify so well, this die has a greater probability of rolling higher. However, what is the exact probability that the extreme environment will have the high roll?

The expected outcomes of a single roll for the extreme environment are:

$$P_{Red} = \frac{18}{36} = \frac{1}{2} \tag{1}$$

The expected outcomes of a single roll for the relaxed environment are:

$$P_{Green} = \frac{12}{36} = \frac{1}{3} \tag{2}$$

Probability Table 1. Rolling two dice.

	2	2	2	2	5	5
1						
1						
1						
5						
5						
5						

Thus, as can be seen, the extreme environment will have the high roll, and the relaxed environment will be affected less in comparison. However, it is also noticed that the expected outcomes of a single roll can be:

$$P_{Grey} = \frac{6}{36} = \frac{1}{6} \tag{3}$$

This corresponds in terms of the game to the analogy of a tie. This means it does not get worse or better for life in any environment; it does not tip to any side.

However, what if one is to disregard the ties? Then one must forget what corresponds to the grey area in the table and re-roll both dice into the same medium at the same time until one of them comes out ahead. Since the dice keep re-rolling until one lands outside the grey area, the fraction of red or green in the table can be calculated without counting the grey outcomes.

The expected outcomes of a single roll for the extreme environment are thus:

$$P_{Red} = \frac{18}{12+18} = \frac{3}{5} \quad (4)$$

The expected outcomes of a single roll for the relaxed environment are thus:

$$P_{Green} = \frac{12}{12+18} = \frac{2}{5} \quad (5)$$

Thus, if one keeps on re-rolling ties, then the extreme environment (2, 2, 2, 2, 5, 5) die would have a $P_{Red} = \frac{3}{5}$ probability to roll higher.

Of course, each new re-roll is independent of the previous rolls, and as seen, each new roll does not necessarily come out in favour of the extreme environment. However, with many rolls, it will be seen that there is a greater probability that the extreme environment rolls higher than the relaxed environment, meaning that the lower variance and the increased stressors make the extreme environment more fixed over time than the relaxed environment.

These calculations represent a very simple picture of a very complex situation. It is statistics, dealing with probabilities rather than certainties. Thus, the probability differences between life in the example here are modest, and although life may be disadvantaged in the extreme environment, life in both environments could handle these fluctuations almost equally. Nevertheless, these differences may become prominent over a long period.

Thus, in an actual situation with fluctuations that oscillate back and forth over the environments, it could also be the case that for life in the extreme environment, a deterioration gradually occurs so that a die will roll even higher for it. Thus, this could become a self-sustaining effect, where life spirals downwards in an increasingly worse situation. It is not a given that life will disappear on an exoworld that remains at this stage with low biodiversity that thrives; these are very complex systems, but it is statistically a given that a greater biodiversity will ensure the survival of life better on an exoworld over time than low biodiversity will do.

4. Biovelocity Resistor

As discussed in section 3.1, the remaining species may be well adapted to the environment even if biodiversity decreases. When a microbial species is well adapted to an environment, and resources are available, it thrives and can exist in high cell density.

However, a species can also endure but not thrive optimally in an environment. So if the extremity in the environments increases even more than they did in the discussion in the previous sections, then one can have this scenario. Here, conditions such as temperature, pressure, pH, nutrients, or saline concentrations could become so extremely high or low that life can only endure here, meaning that both biodiversity will decrease and cell density will decrease (see Figure 1b). Thus, even if competing species are absent, resources may be plentiful, and a species is thus not kept in check by other species and resources, the cell density will be low anyway.

Here, a distinction is made between several extreme environments, where the next one becomes more extreme than the previous one. An environment can become more extreme than

the previous one by, e.g., temperature changes, but this can also happen by several factors, such as pH or saline concentrations changing in relation to each other.

Thus, many variables are at play here, but for the sake of discussion, the extreme environment in the previous sections will generically be designated environment δ while the increased extreme environment generically will be designated environment φ.

The cell density decrease in environment φ may be due to the organisms' reproduction going slower than it would otherwise do in environment δ. If the extreme environment here, e.g., is a temperature change, then it is well known that this is an essential determinant of the activity of microbial life. Thus, it is, e.g., found that *Thiobacillus ferrooxidans* at 18, 12, and 6ºC yielded average generation times of 23, 44, and 103 hours, respectively, where the minimum temperature for growth was estimated not to be far from 0ºC (Ferroni et al., 1986). So as extremity increases, otherwise rapidly reproducing organisms will find that their reproduction rate decreases.

There is a direct proportionality between the extremity of an environment increasing and the reproduction rate decreasing. Thus, in this scenario, there is an inverse proportionality between enduring an environment and the reproduction rate in that environment.

As a related note, the cell density decrease in environment φ, that their reproduction falls, can also be due to the organisms' metabolism going slower than it would otherwise do in environment δ. Thus, it is, e.g. found that *Geogemma barossii* 121 grew at temperatures between 85 ºC and 121 ºC , where it doubled in numbers after 24 hours at 121 ºC . However, while growth could not be easily detected at higher temperatures, organisms incubated for up to 2 hours at 130 ºC did grow when returned to 103 ºC . Likewise, the organisms remained viable at temperatures below 85 ºC but did not undergo cell division (Kashefi & Lovley, 2003). So as the extremity increases, otherwise fast metabolising organisms will find that their metabolism rate falls.

So there is a direct proportionality between the extremity of an environment increasing and the rate of metabolism decreasing. Thus, in this scenario, there is an inverse proportionality between enduring an environment and the rate of metabolism in that environment.

This can also be a definition of an extreme environment, namely that an extreme environment is one where organisms metabolise and reproduce more slowly than their progenitors did before they gradually adapted to this environment. However, this will only apply when the environment has become as extreme as environment φ, where life barely endures. Environment δ described in the previous sections will not necessarily have that effect on all organisms.

There is the following relation:

relaxed environment < extreme environment

→

fast metabolism and reproduction > slow metabolism and reproduction

A boundary condition for life on such worlds is that the extremity acts as a 'resistor' on the velocity of metabolism and reproduction. Thus, a biovelocity resistor exists on inhabited worlds.

4.1. Variance and survival II

As mentioned in section 4, there is a direct proportionality between approaching an extreme environment and a decreasing metabolism and reproduction rate.

Thus, there is an inverse proportionality between enduring an environment and the metabolism and reproduction rate in that environment.

There are still only a limited number of species. However, by approaching the extreme environment, it is a trade-off to be able to live here with a low cell density, i.e. both the variance decrease and the cell density falls, see Figure 1b. This has costs, as the limitations that apply to biodiversity in section 3.2 will apply to an even greater extent here, as life will be even more vulnerable to environmental fluctuations and the effect of impacts than it was when only dealing with lower biodiversity.

For the macro events, two situations apply here.

The first is that an impactor, as discussed, can hit anywhere in a world, but it will necessarily only hit a specific place. Thus, only the organisms in the impact centre and the vicinity of the matter and energy deposit will perish. However, now, there is a more limited number of cellular individuals than before, and statistically a limited number of organisms will give a greater vulnerability to impacts simply because more organisms than a few have a greater opportunity to make it. Because here, life comes past the possibility of compensating through sheer numbers given by a high cell density.

The second is that an impact, as discussed, will also be able to change the atmosphere. In this situation, environment δ and environment φ will in fact be equal because, as discussed, the number of species ensures survival, not the number of cellular individuals. Thus, the number of species can still be the same in the two environments. Therefore, a particular species will still be able to respond well to the environmental changes an impactor will have globally.

However, many factors are involved, and given the lower number of cellular individuals, and given that they react more poorly to environmental stressors, then life in environment φ will be at a disadvantage to atmospheric changes long term, if not short term, than life in environment δ. So the macro-events discussed for environment δ will apply even more to environment φ.

For the micro-events, two situations apply here at the same time.

First, there are now a more limited number of cellular individuals. As fluctuations continue to swing back and forth in the environment, fewer cells can make it through alive than before, statistically lowering the overall survival chance.

Second, there are now a limited number of cellular individuals that do not thrive in their environment; they have a slower metabolism and reproduction and merely endure the environment. Thus, they react more poorly to these environmental stressors, and statistically they do not survive as effectively as before.

Thus, life is trapped around the mean on a Bell curve for real in this environment. For the decreasing biodiversity, this means that there could still be a limited fluctuation in species and genetic variation around the mean, but here the variation will be close to ceasing. So the statistical differences calculated between species in a relaxed environment and an extreme environment δ in section 3.2 will become even more profound here. The other environmental stressors may still be the same as with high biodiversity and thriving in the environment. However, as life is found in fewer numbers and reacts more poorly, the fluctuating fluctuations will have more severe effects.

In a physico-chemico here-and-now moment, such organisms can be considered successful because they survive and endure here and now. In a evolutionary perspective however, they cannot be considered as such; they represent a very fragile twig on a bush indeed. Thus, life in this more severe extreme environment φ may disappear relatively quickly compared to life in relaxed environments and the extreme environment δ. The micro events discussed for environment δ apply even more to environment φ.

The indirect biotic shield's ability to mitigate the effect of environmental events will be even worse off here than with the decreasing biodiversity, as life, to endure ever-increasing extreme environments, must move away from not only the backup of species that it can otherwise rely on to ensure long term survival but also the number of cellular individuals.

It is the case that a different scenario occurs with increasing extremity. If the extremity increases in a world, then the available area or volume increases from the perspective of life as the cell density decreases.

Thus, there is an inverse proportionality between area or volume and cell density.

This was already evident in the decreasing biodiversity. Thus, although, e.g. Antarctica possesses a large area, there is low biodiversity here. In contrast, islands with limited areas but with relaxed environments have virtually every available niche filled with diverse life.

However, this proportionality becomes even more evident for cellular density, although this is reversed in relation to low biodiversity. For biodiversity, there may be an area with decreasing biodiversity yet, as discussed, life can compensate by filling the area with a distribution of individuals from the same limited number of species. Thus, the same number of cellular individuals can be on both sides of the extreme arrow, see Figure 2.

For the cell density, there can be an ever-increasing area with a steadily decreasing number of cellular individuals from the same limited biodiversity. Thus, a vast extreme area can occur on a world, yet a modest number of cellular individuals will be present there.

Consequently, available resources can increase as cell density, and thus, competition in that area decreases.

Thus, a direct proportionality exists between extremity increasing and available resources increasing for remaining life.

Thus, short term, it may become easier for the remaining life to live as the competition disappears and the resources and the area can increase. However, life will be challenging in the long term, as it will still be more vulnerable to environmental fluctuations and environmental impacts.

In addition, species are specialised for their given environment, which means there is an inverse proportionality between environments and species. Indeed, the more different another environment is from the environment the organism comes from, the less possibility it has to survive in the other environment (von Hegner, 2020). So even if many species start to disappear, the remaining species will not necessarily be able to colonise the different environments, even if they increase in cell density in their own environment. Usually, new speciation will take place through the colonisation of new environments. However, as the extremity keeps the variants down, the cellular individuals will be trapped around the mean on a Bell curve and thus limited to the environments they are adapted to. However, as extremity increases, the environments will become more homogeneous, and the surviving species can colonise the other environments.

Thus, the situation differs from an Earth-like world. On extreme exoworlds, there may be large open areas, available resources and limited competition from other species and individuals from the same species, yet, the number of life will still be limited as life cannot utilise its environment as quickly and efficiently as if living in a relaxed environment. So seemingly counterintuitively, as the extreme environment increases in intensity, the available area and potential resources for the inherent life increase, but the ability of that life to exploit it decreases as their metabolism and reproduction slow.

Thus, the increasing extreme environment provides an inverse proportionality between the area and resources increasing and the possibility of survival decreasing.

Even though life eventually gets trapped around the mean on a Bell curve, specific options are still available.

One option that can be mentioned is that life which metabolises and reproduces more slowly can compensate by the unicellular organism evolving a longer lifespan as an individual than it would otherwise do.

Thus, there may be a direct proportionality between metabolising and reproducing more slowly and living longer.

Metabolising and reproducing more slowly is not necessarily an issue. However, the advantage of unicellular life is their rapid reproduction and high numbers, which allows them to adapt effectively to changing environments, an advantage lost here.

Some life can also enter dormancy in such extreme circumstances. However, the cell density also falls by doing so, and fewer members of a given species exist. So if the velocity of metabolism and reproduction is lowered, or if they periodically enter dormancy, the overall result is the same concerning the current situation.

Another option that can be mentioned is that an advantage life has, as the area increases and the density of cells decreases, is that life always increases entropy in its surrounding environment in the form of heat and waste products, i.e. life always makes its surrounding environment less favourable for itself (von Hegner, 2021). The more densely packed life is in an environment, the more impact this effect has. Thus, it is advantageous since there is more area but potentially the same resources. However, it may be inconsequential as life thrives on the Earth despite this universal limitation.

However, there will not come the point where life merely endures such an extreme environment and can no longer utilise the resources or reproduce itself. Quite trivially, the environment could eventually have increased so much in extremity that it is only a matter of physico-chemico conditions that life can no longer endure the increasing extreme environment, even if life has time to adapt. However, non-trivially, it can also disappear since, as discussed, environmental upheavals and impacts can eliminate the few remaining organisms, which there is a statistically more significant possibility of than with many species and organisms.

The increase in endurance and decrease in variance means an inverse proportionality exists between short-term and long-term survival on an extreme exoworld.

5. Variance of the worlds

Although nothing has been said about the number of inhabited worlds in a galaxy like the Milky Way, which may be at least 300 million potentially habitable worlds (Bryson et al., 2021), this does not change the fact that the given proportionality relations will still be applicable.

Thus, if inhabited worlds in a galaxy are considered as a population of worlds, and half of these turn out to be extreme worlds with decreased biodiversity, then, in light of the previous discussion, it will statistically be the case that many of these worlds, on average, will not do as well as relaxed worlds. Thus, relaxed worlds with a wide biodiversity will leave more surviving ecosystems over time, while the number of extreme exoworlds leaving surviving ecosystems will decrease on average.

So, just as members of a biological population have a differential fitness, and a selection of them over time will take place, members of a cluster of inhabited worlds can be said to have a differential habitability, where a selection of them over time will take place.

Of course, a prime difference is that differential fitness applies to the population of organisms interacting with the environment and each other. Some organisms have traits that

will be selected and fixed in the population over time. However, with differential habitability, the cluster of different worlds is subject to an unconditional probability, i.e. a probability that is unaffected by the preceding of other events, meaning that what happens to an inhabited world at one end of the galaxy does not affect an inhabited world at another end of the galaxy.

Nevertheless, it is still a statistical phenomenon that extreme exoworlds will do more poorly in terms of environmental impacts and environmental fluctuations than relaxed exoworlds.

Naturally, as for differential fitness, it also applies to differential habitability, that since this is a statistical phenomenon, this will only happen sometimes. After all, Earth-like relaxed worlds can still experience random environmental events that destroy their life. However, it is a statistical phenomenon that extreme exoworlds will leave fewer surviving ecosystems regarding environmental impacts and environmental fluctuations than relaxed exoworlds.

However, can relaxed worlds be the majority in a galaxy's history at any time compared to extreme worlds?

Nothing has been said qualitatively or quantitatively about how much biodiversity decreases in a world with increasing extremity or how long it may take to get there. An extreme world can thus still harbour many species, although these are limited compared to if the environment had been relaxed in that same world. However, the proportionality relations will still represent the situation regardless of whether something at present can be said about how much or how quickly these apply between worlds.

Thus, based on the abstracted proportionality relations, it will be possible to distinguish between inhabited worlds. The following classification of the variance of worlds can be established:

- Population I worlds; a world with no life.
- Population II worlds; a biodiversity-poor world.
- Population III worlds; a biodiversity-rich world.

This is more of an astrobiology classification than a planetary science classification, as these designations do not refer to the world's composition or stellar relationship, but are a variance of worlds regarding life, i.e. it refers only to the absence or presence of life. It also applies that they are generically called worlds, as they may be planets and other solar system bodies such as moons that may be abodes for life.

According to that classification, the Earth is currently a Population III world, while, e.g. Venus, if there indeed is life in its cloud layer (Haber, 1951; Greaves et al., 2021), is probably a Population II world.

For Population II worlds, as discussed, they can be biodiversity poor but still have a high cell density so that there can potentially be an equal number of cellular individuals on both sides of the extremity arrow. Thus, such worlds must be divided into environment δ or environment φ, meaning there are Population II(b) and Population II(c) worlds as well.

Population II and Population III worlds will never at any time, if our current knowledge of solar systems is an indication, become the majority in comparison to Population I worlds. However, how they stand in relation to each other is more open.

Thus, there is interchangeability between these populations, as environmental factors change over time, and members of the populations can transform into each other.

All stars go through a life cycle, and the conditions for life on a world about any star will eventually decrease over time. Thus, e.g. the sun undergoes changes towards the red giant stage (Schröder & Connon Smith, 2008), and in line with these phases, the Earth's environment

will also become more extreme. Any Population III world will eventually be turned into a Population II world and then into a Population I world because of this.

In addition, environments on inhabited worlds are dynamic and fluent, and so are the response and effects of life on these environments. Thus, in addition to the fact that environments can change over time, life can also change the environments it exists in, even on a planetary scale. A prime example of this is the Great Oxidation Event (Cloud, 1968; Lyons et al., 2014), while another is that life brings a world's atmosphere out of thermodynamic equilibrium (Hitchcock & Lovelock, 1967).

So relaxed/extreme environments can be imposed externally by impact events or stellar change, but they can also arise internally from life itself. It is only in the relaxed environment and in environment δ that life can have an effective effect back on the environment. However, it is still true that there is a reciprocal relationship between life and the environment. Thus, members of the population can change into each other.

These are trivial facts. However, the question is more nontrivial, whether Population III worlds will become the majority at any given time in a galaxy's history with regards to Population II worlds. The answer to that depends on a distinction between a situation here and now and a situation over time.

So far, there has been discussion of Population II(b) and Population II(c) worlds that are biodiversity poor or have low cell density because they have obtained an overall extreme environment. Thus, life may have existed for a long time in such worlds.

However, Population II worlds can also be biodiversity poor or have low cell density because life has recently arisen in those worlds. Thus, there are also Population II(a) worlds that can have an overall relaxed environment but still limited biodiversity.

However, Population II(a) worlds represent a different situation than Population II(b) and Population II(c) worlds discussed so far.

In the first situation, one has that life arises and must spread against environments in a world. In contrast, in the second situation, one has a widely spread life that decreases due to increasingly extreme environments in a world. The issue here is that when life spreads in a world, the complexity of evolution also increases. However, conversely, when the extreme environment increases, the complexity of evolution also decreases. By this, it must be understood that many variables are at play in the interaction between life and environment in the first situation. In contrast, variables decrease in the interaction between life and environment in the second situation.

Thus, the extreme environment provides an inverse proportionality between 'complex' and 'simplified' evolution.

Thus, while overall biodiversity that decreases due to increasingly extreme environments will happen, it may not be given that rich biodiversity will spread against environments due to the situation's complexity.

A related issue is that a defining feature of life is that it is 'information explosive' (von Hegner, 2021), meaning that as soon as it arises, it will reproduce again and again and spread and eventually colonise every available niche in the world. As mentioned, it also applies that a boundary condition for life is that it can only arise in a relaxed environment. Thus, if a world has relaxed environments, then rich biodiversity will also in principle spread over the planet. It also applies that life from relaxed environments can adapt to entering and living in extreme environments. This appears to have been the initial situation for the Earth's life, as it may have arisen between 4.1 to 3.5 billion years ago (Bell et al., 2015), when many relaxed

environments gradually emerged, allowing rich biodiversity. Thus, the question is whether inhabited worlds generally achieve enough relaxed environments.

As discussed, the existence of a high number of cellular individuals on a world is not the same as rich biodiversity. Population II(a) worlds can be transformed into Population II(b) or Population II(c) worlds, but whether they can generally be transformed into Population III worlds depends on whether the worlds at any given time have sufficient relaxed environments for rich biodiversity to spread across the world. For the Earth, this was evidently the case, but whether this is statistically a general or special case cannot be said at this time.

That said, although Population II(a) worlds represent a different situation than Population II(b) and Population II(c) worlds, all Population II variants still have one thing in common, namely that biodiversity functions as an indirect biotic shield against incoming threats. Although Population II(a) worlds are young in terms of how long they have been inhabited, and Population II(b) and Population II(c) worlds are older in terms of life having existed on them for a long time, they could potentially possess equal amounts of life. Thus, as mentioned, an abundance of species spread over a large area will provide better protection against the impact itself and the effect it can subsequently have on the atmosphere.

This was discussed in the example of thermophiles, the oldest known life (Gaucher et al., 2010) because it was probably the only one that survived. In this case, the newly emerged life survived, but other worlds may not experience this. However, the question is how frequent and severe such impacts can be expected to be on inhabited worlds so that Population II(a) worlds will be prevented from making Population III worlds the majority at any given time. The frequency and severity may be low, but life may only arise in young worlds where the solar system is still turbulent with many impacts, making the frequency and severity high.

Thus, whether Population III worlds at any given time in a galaxy's history will succeed in becoming the majority in comparison to Population II worlds depends on a distinction between a situation here and now and a situation over time. Environments on inhabited worlds are dynamic and fluid; the environmental factors change over time, and so does life in response to these environments, represented by the proportionality relations discussed. So it may be a possibility that Population III worlds through Population II(a) worlds can achieve to be the majority in a here-and-now moment. However, it will still apply that Population II(b) and Population II(c) worlds over time will represent the majority of worlds, just as ultimately, Population I worlds represents the majority over time.

6. Conclusion

This work has carried out a high-level characterisation of the relationship between decreasing biodiversity and increasing extremity. Several isolated proportionality relations show what happens in any world with life as we know it. These relationships are inherently more qualitative than quantitative but are still relevant. They show that although extreme environments are no longer an obstacle in astrobiology, they are still of more limited value than what may be thought.

Thus, the fact that the environment is extreme implies a lower biodiversity and a lower biodiversity entails a greater vulnerability to potential environmental changes, global as well as local. Life faces issues because species' variance decreases and cellular individuals' metabolism and reproduction slow.

So extremophiles have gained importance by being able to live in extreme environments, providing possibilities for life on extreme exoworlds. Moreover, indeed, they can live in such environments, but here it is seen that a difference between them and mesophiles is that

mesophiles can exist as many species. In contrast, extremophiles, in comparison, can only exist as a few species, although the cellular number can be high. Thus, while extremophiles are considered robust, here is an example of a reduced possibility of getting through environmental upheavals compared to mesophiles. Interestingly, despite their name, an ecosystem made up only of extremophiles is more fragile than an ecosystem made up of mesophiles. Mesophiles possess a greater biodiversity and can survive better overall. This is a crucial point to keep in mind when searching for potentially inhabited exoworlds. All this does not mean that extremophiles have no value in astrobiology. It merely means that evolutionary and ecological constraints must be considered, not just life's physical and chemical capacity to survive here and now.

Thus, three boundary conditions for life on such worlds have been clarified. One is that life must necessarily arise in a relaxed environment, the next is that extremity acts as a 'resistor' on biodiversification, and the third is that an even higher extremity acts as a 'resistor' on biovelocity.

This is important, as there may be more inhabited worlds in the universe that can be considered extreme than inhabited worlds like the Earth.

That worlds exist in the habitable zone is no guarantee that they will not become solely possessing extreme environments. In fact, the habitable zone may be too restrictive, as the Goldilocks Edge has also been proposed (von Hegner, 2019), which may be the norm, thus increasing the number of extreme worlds even more.

Even though life has not yet been found on other worlds, these proportionality relations are essential because they allow us to evaluate the conditions for potential life elsewhere.

Venus was once a more relaxed planet, which due to a runaway greenhouse effect, became the inhospitable world it is today. However, if life once arose there and has gradually withdrawn into the cloud layer in step with the rising extremity and still exists in its atmosphere (Haber, 1951; Greaves et al., 2021), it very well applies that a once wide biodiversity has shrunk there now. The question is whether life thrives there or endures, i.e. is the environment conducive for the biodiversity resistor or the biovelocity resistor.

The same applies to Mars, which in the Noachian era was a more hospitable place than it is today (Fastook & Head, 2015; Carter et al., 2010). If life arose there, it might have eventually retreated to sublevel pockets, where it may still exist. The question here is just whether life thrives there or endures, i.e. is the environment conducive for the biodiversity resistor, or is it conducive for the biovelocity resistor.

On the Earth, these relationships mainly play a role at the beginning of the interconnected history between the planet and life and in the later phases of the planet's history. In the early phase of the origin of life, the Earth's environment was extreme, albeit with room for relaxed environments where life could arise. As the sun goes through the stages on its way to becoming a red giant, the Earth's environment will also become more extreme, and these relationships will become more prominent. Thus, in the Earth's middle life, these relationships are less prominent, as the Earth has a diversity of environments, relaxed and extreme, and life does very well indeed. However, in other worlds, the extreme environments may have remained prominent early on.

Evolution has a component of local necessity and a component of chance, and what path a species will take in interaction with an environment is not directly deducible from physical laws. Thus, evolution is more about retrodiction than prediction. The path taken by a species in an environment can be traced backwards with high certainty. However, what path it will take forward is not given, as environmental events are unpredictable and life can take different

paths concerning the same events. However, environment and life are here interconnected in such a way that the fact that the environment is extreme implies lower biodiversity and lower biodiversity means that life in an extreme world does it more poorly than life in a relaxed world, and thus statistically, the number of inhabited extreme worlds decrease compared to inhabited relaxed worlds.

The discussed proportionality relations represent an essential insight for astrobiology and the search for life on other worlds. The critical understanding is that although life such as extremophiles can live in extreme environments, and a given exoworld possesses abundant energy sources, resources and space, life may, seemingly paradoxically, have disappeared in such a world again precisely because of the extreme environment.

Of course, most species that have existed on the Earth have disappeared again. However, the difference is that speciation on the Earth continued to occur, while the possibility of speciation on an extreme world decreased due to the extreme environment. Thus, it is not sufficient to locate an extreme world with abundant energy sources, resources and space fitting for life as we know it.

The challenge is to assess the intensity of the extremity and the distribution and homogeneity of this in a world. If the presence of life is not evident, it may still be there, but it will require a careful assessment based on understanding the proportionality relations that have been abstracted in this work.

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