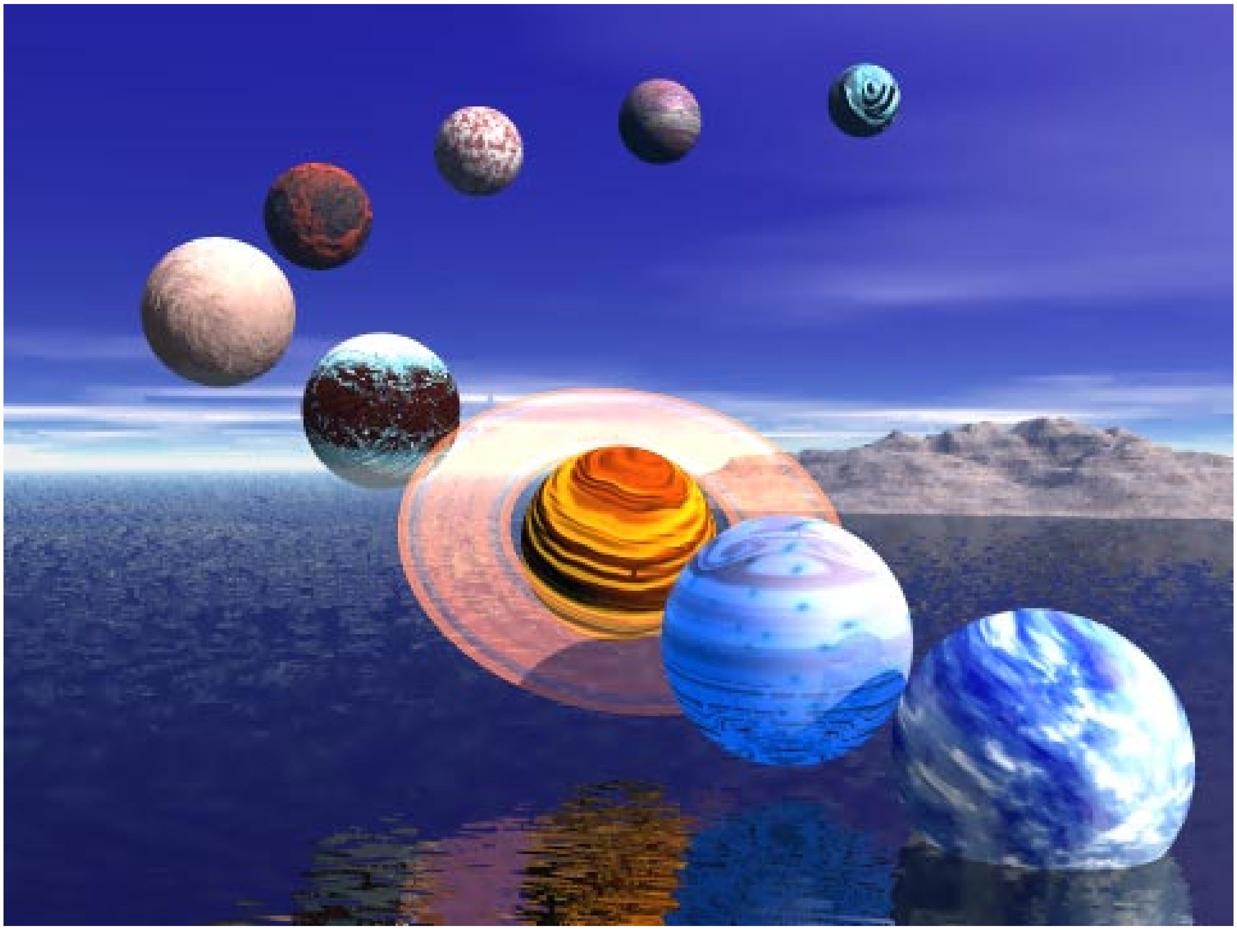
Chapter 1

Introducing Planetary Biology Theory

1.1 Thumbnail sketch of the theory of planetary biology

With this book, I am contributing planetary biology theory as a comprehensive and portable *whole world systems theory*. Its mission is to see how worlds with life work. Use it outright as a working model to investigate and understand whole world systems, especially worlds with life. Consult planetary biology theory to help you grasp how life can gather planetary influence and change a world. Or see why on some planets, life's impact would never be noticeable. Port planetary biology theory to an imaginary planet system and do comparative planetology on life-bearing worlds. Perform 'what-if' scenarios on your chosen life-bearing planet under different conditions. Or compare two planets and see why they are so similar or so opposite. Extend the platform of planetary biology theory to craft high-level whole world systems theories of greater depth, reliability and power.

Even without life, worlds are extremely complex environmental phenomena. Add life to a world, and the complexity surges. A planet with life is by far the most interesting and exciting phenomenon in the cosmos. And yet, because so many different forces influence them, they are extremely difficult to comprehend. To a planet, life is the great confuser. The difficulty lies in figuring out what life is doing to the world and how it came to acquire such power in the first place. Unlike the more linear and predictable physical forces, life has the potential to shape the planet in many different and unexpected ways. So it is understandable that although humans have tried to explain Earth for thousands of years, they have done so with incomplete success. Nonetheless we still want to know how planets with life work.



Planetary biology theory attempts to bring clarity, unity and a common language to the study of whole world systems, particularly worlds with life. It is straightforward, useful, enlightening and long overdue. Specifically, planetary biology theory will help us to more confidently inquire about the histories and fates of Earth and of other worlds, known and imagined.

1.2 Why am I proposing this theory?

While there are already other theories and sciences seeking to understand the workings of planet Earth, planetary biology theory presents a new and more comprehensive way of understanding whole world systems. At its heart lies a core model that explains how life achieves planet-changing stature. Then planetary biology theory embeds and integrates this biological model into a larger and defined network of physical planet-changing phenomena. The result is a whole world systems theory of unprecedented scope, power and portability. With it, we can begin to more completely comprehend the phenomenon of life-bearing worlds, including Earth. And this understanding will give us the ability to more confidently do comparative planetology for life-bearing worlds.

First, let's look at other whole world systems theories.

While the 20th century biologists continue to turn inward (cell-ward and molecule-ward) with unabated vigor, physical scientists have been trying to explain the place outside. Unlike biologists, physicists see the whole cosmos as a consequence of interconnected phenomena happening on scales both tiny and cosmic. In the last hundred years or so, physical scientists began to augment their purely physical explanations for Earth by recognizing the role of life.

Having exhausted completely physical explanations, physical scientists such as Vladimir Vernadsky and James Lovelock turned to biology to help them understand how Earth works. They recognized that the Earth's surface environment is influenced by more than just physical phenomena. They saw that the environment very much is a consequence of vigorous participation by the planet's biota.

Gaia theory, developed by James Lovelock, an atmospheric chemist, gave us the first opportunity to think about Earth as a consequence of intertwined interactions between the living world and the physical environment. Although still beset by controversy, Gaia theory should be credited for alerting us to the exhilarating idea of life from the perspective of the whole planet.

Perhaps inspired by James Lovelock's whole world systems view, Earth systems science is another recent entry into this field. Essentially a branch of geology, earth systems science successfully integrates the activities of life into an understanding of the overall operation of planet Earth.

Another spin-off of Gaia theory is the new field of global biogeochemistry. This science has deepened and broadened our knowledge of chemical cycles on Earth. It pays particular attention to how life's chemistry moves tremendous quantities of materials between the crustal, oceanic and atmospheric realms of the Earth's surface.

So historically, the study of whole world systems mainly has been the territory of physical scientists. Except for a few notable pioneers, the participation by biologists has been lackluster. But, this field needs biologists to share their take on the problem.

Planetary biology theory seeks to bring biological considerations of whole world systems more squarely into the biologist's realm. Life really is the biologist's turf. We understand it best. And we should not neglect our responsibilities toward understanding whole world systems. Planetary biology theory is my attempt to provide a biologist's spin on the idea of whole world systems.

1.3 What distinguishes planetary biology theory from existing theories of whole world systems?

Planetary does not seek to duplicate or challenge existing theories on whole world systems like Gaia theory and Earth systems science. But despite the utility of these theories for explaining Earth, they do not sufficiently allow us to consider Earth under different scenarios. Nor do they provide the tools for characterizing or comparing other life-bearing planets under different circumstances. In short, Gaia theory and Earth systems science theory are not portable. They do not provide the extensibility for doing comparative planetology on any life-bearing world you might imagine. This is because:

1. They do not sufficiently explain *HOW* life achieves planet-changing stature in the first place.
2. They do not sufficiently articulate the comprehensive network of physical phenomena that life would interact with on a planet.
3. They are not portable. We cannot directly apply them to other life-bearing worlds, real or imagined.

Planetary biology theory builds on the ideas of Gaia theory and Earth systems science. It provides a working model that will enable us to better comprehend our own planet and other life-bearing planets. With planetary biology theory, we now have a solid theoretical framework for understanding how worlds with life work. This will help us to achieve a richer understanding of planet Earth. And since planetary biology theory is portable, it will also help us to do comparative planetology on any life-bearing worlds we encounter or imagine.

Planetary biology theory extends our journey toward more comprehensive whole world systems theories and makes available more satisfying studies in comparative planetology because:

1. The core of planetary biology theory consists of a thorough model of *HOW* life achieves planet-changing stature.
2. Planetary biology theory then integrates and embeds this core biological model into a larger and defined network of physical planet-changing phenomena.
3. The result is a comprehensive whole world systems theory that is extensible and portable. In other words we can directly apply the principles of planetary biology theory not only to Earth but also to other life-bearing worlds, real or imagined.

The main contribution of planetary biology theory is its structure. Planetary biology theory attempts to provide the heretofore missing structure that is needed in order to consider the complex and thrilling notion of whole world systems for life-bearing planets. Its disciplined format provides the fundamental infrastructure for understanding how worlds with life work.

Whole world systems studies (like Gaia theory, earth systems science and comparative planetology) need to be consistent with the basic operation of the planet. This idea of consistency to planetary operation has been ‘understood’ by whole world systems thinkers, but no model to test for such consistency has ever been systematically articulated. And this shortcoming has been a major source of confusion, frustration and disagreement. Planetary biology theory painstakingly performs this neglected primary task by laying out a very basic model of how planets with life work.

So, what do we do with it? Right out of the box, planetary biology theory is instantly useful in helping us to see how worlds with life work. It helps us grasp the enormous scope and scale of whole world systems on life-bearing worlds. Planetary biology theory helps us make qualitative predictions regarding the histories and/or fates of worlds. It gives us a sense of the cascading consequences that might result from small changes to a planet’s suite of physical or biological properties.

The heavenly bodies of our solar system and galaxy are part of our extended environment. Perhaps there are other worlds with life. How can we imagine them? If we discover other worlds with life, how do we assess them? For that matter, how do we assess our own world in terms of its infinite possible fates? Considering our recent strides in astronomy, planetary science, geology, climatology, and biology, these are questions that are becoming more reasonable. But without a plan, answering them will not be easy.

1.4 The overall mission of planetary biology theory

The following sections describe the various steps I took in the process of developing and applying planetary biology theory.

Panel 1. Completing the mission to planetary biology theory

Formulate a mission statement

The road to planetary biology theory is a long and hard one. What’s the point? A mission statement explains why I am doing this and what I hope to be able to accomplish.

Develop a plan of attack and acquire intermediate objectives

This explains how I intend to accomplish my mission. In short, I have to explore the sea of knowledge and answer certain key intermediate questions that will help reveal the body of a dormant theory – if it is there at all.

Develop a theory

Based upon my findings, I must compile and organize my findings in light of my mission. If my work has been thorough enough, and if my mission ever had any chance of success, a new theory could emerge that will help me accomplish my mission.

Put the theory to work.

Once properly rendered, I can reap the benefits of a theory about life and whole world systems. I can do this by putting it into action. With it I should be able to make better planet-to-planet comparisons, and better what-if scenarios regarding known and imagined planets.

Mission Statement

My primary mission is to be able to: 1) compare different kinds of life-bearing planets with each other; and 2) compare the outcomes for the same planet under different sets of circumstances. In other words, I want to be able to do comparative planetology for life-bearing worlds.

But I cannot do that until I really understand how life-bearing planets work. In order to do that, I need to begin to see, in a comprehensive and structured way, how physical and biological phenomena combine to shape planetary surface environments. To the extent possible, I want to be able to use this understanding as a tool that will help me make reasonable predictions about the histories and fates of worlds under very different circumstances.

For example, I want to be able to consider how Earth might have fared given different starting conditions. I want to more completely understand why Earth, Venus and Mars are so different. If we could somehow tweak these worlds, what different fates would they experience? If we discover new worlds around distant suns, how can we assess them? Could life be possible there? If so, what might life's impact be on such worlds? What would be the formidable obstacles and fortuitous opportunities that might await life there? And what kind of world might await us should we come calling?

In order to accomplish this mission, I am obliged to journey through extremely huge and diverse realms of human knowledge. In other words, this is a hard, hard mission. If I am to succeed, I must approach this adventure in a very systematic way. I cannot stray from the path unless such diversions promise to help me complete my mission. And I cannot leisurely and randomly sample the delightful array of knowledge I am bound to encounter. For to do so, will only further confuse the shy structure I am hoping to find. I'm not seeking poetic beauty here.

Therefore, I must be steadfastly disciplined if I ever hope to accomplish my mission. I must rigorously examine the clues along the way, collecting the useful ones and forsaking the nonessential. Where is the glamour in all of this hard work? I am not certain. All I know is that I hunger for what lies ahead – whatever it is. I am tired of the confusion that frustrates me every time I think about life and worlds. Now is my chance to find my answers, to ease my anxieties and to know life, my world and my cosmos in a way that no one has ever known before.

In addition, I must be ever vigilant that preconceived notions and wishful thinking do not contaminate my observations and deliberations. Perhaps I would be thrilled to discover that life has the purpose and power to dominate and steer the planetary surface environment, whatever the circumstance. Wouldn't that just be grand – if it were true? But I don't really care because I am not looking for purpose here. I'm not seeking to worship life or to glorify its mysterious wonderfulness. I just want to know what is going on.

During this journey, I must abandon the burden of desire for a purposeful world. In my view, the cosmos just is. Life just is. Therefore in my reductionist way, I will set aside ideas that life somehow has a plan or a destiny. I reject that humans and the Earth are evidence of life's *invisible* powers, or that we are part of something bigger – a germ of grand destiny. Still, I also reject that life can be understood as if it were a machine. For it certainly is not.

While neither a machine nor a mysterious and mystical force, life is nonetheless a delightfully complex phenomenon that leads to no end of variety and to no end of questions. As a scientist, I will strive to see life for what it really is. And I will endeavor not to dishonor the phenomenon of life by imprinting my personal wish list upon it. What I am really looking for is clarity – however it is manifested.

I will tell you now, that I successfully accomplished this mission. That is why I am writing this book. Like all true adventures, it had its share of hardships and dead ends. Still, I was not disappointed. Come with me as I recount the steps of my quest. Let us confront and penetrate the mysterious fog that enshrouds the essence of life on worlds. But be warned. What awaits you could upset your cupboards of scientific knowledge. They needed reorganizing anyway.

1.5 Intermediate objectives that must be achieved in order to successfully complete the overall mission

A mission of this scale cannot be accomplished in one step – at least, not by *me*. I have to approach it little-by-little. I do this by achieving certain intermediate objectives along the way. These will help me begin to understand the scope and scale of the primary mission.

As far as life and planets go, I am particularly interested in the planetary surface environment. For reasons that I will present later, the planetary surface environment is the most fertile realm of the whole planetary environment. It is a place where solar, atmospheric, oceanic, and geological forces simultaneously exert their measures of influence. As a result, the planetary surface environment presents life with the greatest body of opportunities for growth and environmental influence.

In order to accomplish my mission, I must acquire three main, intermediate objectives that help me understand the planetary surface environment. They are:

1. I must understand how physical phenomena can independently influence the planetary surface environment

2. I must understand how biological phenomena can independently influence the planetary surface environment
3. I must understand the planet as a whole world system in which physical and biological phenomena act together and simultaneously to influence the planetary surface environment

1.6 Understanding how physical phenomena can independently influence the planetary surface environment

Planets, moons and stars are physical phenomena. Life might add a layer of interest to a world, but the planet primarily is a manifestation and ward of the physical cosmos. There are many ways in which a planet's own physical circumstances can influence the planetary surface environment. And there are many ways in which forces from *outside* the planet can change the planetary surface environment.

For example, a planet's primary star can exert a tremendous influence on the planet's surface temperature. If it is a bright star, the planet will be warmer. If it is a dull star, the planet will be cooler. If it is a large star, life will have a shorter window of opportunity, as large stars tend to burn out more quickly than do smaller stars.

The way a planet orbits its primary star also can influence the planetary surface environment. Planets farther away will tend to be cooler. Planets closer in will be warmer. Planets with oblique axes will experience seasonal changes as will planets with particularly eccentric orbital paths. Inner planets will tend to have fewer asteroid impacts as outer planets sweep up in-falling debris.

A planet's endowment of geological characteristics is important too. For example, we can generalize that larger terrestrial planets would have more vigorous internal heat engines. This will mean greater releases of volcanic gases, brisker plate tectonics and a stronger magnetic field. High mass terrestrial planets are better shepherds of their atmospheres, employing a combination of stronger gravitation, more robust volcanism, and a strong magnetic field.

Although I have mentioned just a few, there are many individual physical phenomena that can help shape a planet's surface environment. Planetary biology theory tries to organize them so that we can see how they work together.

1.7 Understanding how biological phenomena can independently influence the planetary surface environment

I think it is more easily understood how physical forces can change a world, but my job is more complicated when it comes to life. It is not a simple matter how biological phenomena come to influence the planetary surface environment. Life is so dynamic and its expression on the planetary surface is so complicated. So, I must do some preliminary work before I will be able to see it as an integrated whole.

When considering life's planet-changing influence, I have three main questions I have to answer.

1. What tools are inside life's planet-changing toolbox that it introduces to the planetary surface environment?
2. Given this qualitative potential, how does life attain planet-changing stature on par with astronomical, orbital and geological phenomena? That is, how does life bring its planet-changing toolbox to bear with enough vigor to influence the surface environment in a substantial way?
3. What are the consequences to the planetary surface environment following planetary colonization by life?

1.8 Life's planet-changing tool box

Life's toolbox is essentially chemical. Simply put, life is a phenomenon in which matter assembles, operates, maintains and reproduces itself. It is matter that is animated in very deliberate ways. Life's primary level of operation is on the atomic and molecular level. Traditionally understood as 'biochemistry', life engages the planetary surface by exchanging molecules with it. The 'goal' of biochemistry is to synthesize something useful out of whatever is available (I call this building process, 'biosynthesis'). It can do this either by making small molecules into big ones, or by disassembling big molecules to make smaller ones. In any case, there is consumption and production. Raw materials move into the living world. Wastes move out of the living world and back to the planetary surface environment. If life becomes present on a planet, it will seek to build itself out of molecules that are available within the planetary surface environment.

For instance, let's consider the widely popular biochemical process of photosynthesis. Overall, it moves carbon out of the atmosphere (as carbon dioxide), converts it into solid form (as biological molecules), and puts it on the crust. Photosynthesis also takes oxygen from liquid surface water and ejects it as a gas into the atmosphere. Fine, fine, you all knew this. Still, there is more to biochemistry than photosynthesis.

On Earth, life's biosynthetic toolbox is filled with a variety of processes that move more than just carbon and oxygen. For example, biosynthetic processes move nitrogen into and out of the atmosphere. Same for sulfur and a bunch of others. What makes this interesting is that in addition to being useful to life, these substances also have the potential to influence the nature of the planetary surface environment.

1.9 How life achieves planet-changing stature

So, there is a connection between the shameless and selfish biosynthetic chemistry of life and the state of the planetary surface environment. Ok, you knew this too. We have understood this for a long time. But how do these humble biosynthetic processes come to change a whole planet?

The simple answer is that the instances of biosynthetic activity become more abundant. This is because life becomes more abundant on the planetary surface in two ways: 1) Living things disperse and colonize new territories on the planetary surface; and 2) once settled in new territories, life solidifies and intensifies its occupation there. As life spreads and intensifies, its environmental impact increases.

Seems simple enough. There's just one problem. Planets are complicated places. Their surface environments are not uniform. Some places are hotter than others. Climates vary from place to place. Deep ocean living is very different from life on the rocky shore. There are rainy areas and dry areas, icy mountain tops and baking basins. In addition to geographic diversity there also is temporal diversity. Over time, the nature of the surface environment at any one geographic location may change. For example, a dry climate could become wet, or a submerged seabed could be lifted to become part of a mountain. Keep in mind that the mix of planetary environments will vary from planet-to-planet and from time to time. Nonetheless, the planetary surface environment presents individual living things with diverse and dynamic environmental circumstances. The circumstances that individual living things experience will change over time at each fixed location, or as a result of individuals moving from one location to another.

Despite the changing circumstance of Earth's diverse and dynamic surface environment, life has successfully colonized the planet. If we understand things correctly, life has accomplished this feat because of three main things: 1) adaptation; 2) pre-adaptation; and 3) dispersal.

First, adaptation. In terms of planetary colonization, adaptations contribute in two important ways: 1) adaptations that emerge in a given environment will help life solidify and intensify its occupation of that environment; and 2) adaptations for a given environment may also be useful preadaptations that help living things survive in new and different environments elsewhere.

Adaptations are features that help individuals survive and reproduce in their particular environment. For example, desert plants have special adaptive features that enable them to conserve water. Arctic animals have adaptations that help them conserve heat. Without special features, life might not be possible in many environments. Adaptations are the outcome of numerous rounds of the phenomenon of evolution by natural selection.

As we will see, evolution by natural selection is not a self-contained phenomenon. It is the outcome of two separate phenomena: 1) innovation; and 2) environmental stress. As innovations appear in a given territory, they are confronted with a mix of environmental stresses. More about environmental stress, below. If they can survive the environmental stresses imposed upon them, the innovations may make it into the next generation where they will again be challenged by a stressful environment. In this way, the environment presents non-random circumstances to innovations. If an innovation can successfully negotiate the environment, then it will 'be.' If the innovation fails to negotiate the environment, then it will not 'be.' The next pulse of innovation may contribute refinements to surviving traits. If this evolution by natural selection goes on for many generations, it may give rise to distinctly useful features that help individuals better cope with the diverse and dynamic environmental circumstances within their particular territory. And this outcome will further solidify and intensify life's occupation of the territory. Adaptations also can help in the dispersal of life.

Adaptations can also be preadaptations. Sometimes features that are adaptive to one set of environmental circumstances may be consequentially adaptive to a different mix of environmental circumstances elsewhere. Thus, some adaptations may inadvertently help individuals to pioneer new territories. Such adaptations are called, 'preadaptations.' As individuals disperse into new territories, they will encounter a new mix of environmental stresses. If the pioneers survive and reproduce, dispersal will be followed by more rounds of evolution and the development of still newer adaptations – followed by more dispersal and evolution, and so on. In this way, life can incrementally colonize the planetary surface. With each territorial gain, new adaptations solidify and intensify life's presence there. New adaptations also represent new kinds of preadaptations that can help future pioneers survive in more distant and environmentally unique territories.

But why disperse at all? Dispersal is the phenomenon of leaving the home territory and seeking to occupy territory elsewhere. Dispersal is useful option that helps living things cope with the phenomenon of environmental stress. So, let's talk about environmental stress for a moment. Environmental stress is the outcome of two main phenomena: 1) biosynthetic hunger; and 2) the particular diverse and dynamic physical environmental circumstances that the individuals experience. Biosynthetic hunger is a consequence of life's biosynthetic chemistry. Basically, biosynthesis creates pulses of demand that manifest themselves on scales ranging from the tiniest molecule to the whole organism. Biosynthetically-derived environmental stress manifests itself as individual organisms seek hard-to-find environmental resources to quiet their internal hunger. Biosynthetically-derived environmental stress also comes about as individual organisms try to avoid being consumed by others who are themselves, biologically hungry.

The physical, planetary surface environment also presents diverse and dynamic environmental circumstances to individuals. These diverse and dynamic physical environmental circumstances translate into different kinds of physical stresses that living things are exposed to. Physical environmental stresses include such things as non-optimal temperatures, soil nutrient availability, water availability, sunlight exposure, wind exposure, elevation, depth, and seasonality.

Given that home environments may be stressful, especially if they are densely populated, dispersal to new territories may be a more rewarding option than struggling at home. That is, pioneering new territory may sometimes reduces environmental stress.

So, driven by environmental stress, and aided by evolution, the environmental impact of life's biosynthetic chemistry increases as a function of dispersal and intensification of life in occupied territories. If life is able to colonize a sufficient quantity of the planet, it can achieve planet-changing stature.

So, let's recap. In order to understand how life's biosynthetic tool box achieves planetary influence, we need to understand what drives and enables life to colonize much of the planetary surface environment.

In order to understand what *drives* life to colonize the planetary surface, we need to understand the origins of environmental stress. In order to understand the origins of environmental stress, we need to understand the origins of biosynthetic hunger and the forces that contribute to diverse and dynamic physical environmental circumstances that individual living things are obliged to experience.

In order to understand what *enables* life to colonize the planetary surface, we need to understand how life develops adaptations to the planet's diverse environment. In order to understand how adaptations arise, we must understand the phenomenon of evolution by natural selection. In order to understand the phenomenon of evolution by natural selection, we must understand the origin of genetic innovations and how they cope with environmental stress.

1.10 The consequences of planetary colonization

If living things can successfully colonize a planet, what kinds of changes to the planetary surface environment might we expect? Life will churn the planetary surface environment. This is basic biogeochemistry. Life's biosynthesis will cycle a variety of different gases, liquids and solids back and forth between the living world and the non-living world. Driven by biosynthesis, compounds of carbon, nitrogen, and sulfur move between the atmosphere, the oceans, the crust and the bodies of living things.

If this perfect recycling is not interrupted in any way, then even if life is abundant, we might expect only modest changes to the environment. But if there is no perfect recycling, the activities of life will contribute to big changes to the atmosphere, the oceans, the soils, and the visual appearance of the planet.

For instance, the more life there is, the more fixed carbon and nitrogen will be available for geologic burial. The geologic burial of fixed carbon compounds interrupts the perfect biosynthetic recycling of carbon dioxide and molecular oxygen. This could result in a big buildup of molecular oxygen in the planet's atmosphere. The geologic burial of nitrogen could make continental life very difficult. This is because the atmosphere is the primary source of nitrogen for life on continents.

Forests increase continental cloud cover because of their incessant groundwater pumping. This tends to cool the planet. And, viewed from space, forests darken the continents. This tends to warm the planet. The combined actions of a forest's root growth and the construction of coral reefs in the oceans cools the planet by removing huge amounts of carbon dioxide from the atmosphere and depositing it in the crust as calcium carbonate.

These are just a few of the many ways that a vigorously colonized planet can be influenced by life.

1.11 How physical and biological phenomena act together and simultaneously to influence the planetary surface environment

If you're feeling lost here, or if you're feeling like you are going round and round, then all I can say is, "Thanks for joining me. It's nice to have company". This stuff is inherently confusing, especially if you encounter it only through the small pipe of written text. The problem is that there are dozens of phenomena that are happening simultaneously. There are numerous dynamic interconnections and lots of feedback loops. Worlds and life are complex and extremely dynamic phenomena. We simply cannot understand them one-word-at-a-time. But this doesn't mean that they are incomprehensible. It just means that we have to be creative in order to understand them.

Once I understand separately how physical phenomena and biological phenomena can change a planet qualitatively and quantitatively, then I can begin to consider the whole world system. This is my ultimate mission. But in order to achieve this goal, I have one final intermediate objective. The purpose of this objective is to figure out a way to seamlessly blend a planet's physical and biological influences into a single model. This model should allow me to comprehend the histories and fates of planetary surface environments as a consequence of dynamic and interconnected physical and biological phenomena. The model should accomplish this task in a reasonable and structured way.

The success of this achievement is nothing less than the theory of planetary biology.