RIVERS STATE UNIVERSITY, PORT HARCOURT

BIOECONOMIC VALUE OF BIOLOGICAL CAPITAL AND OPPORTUNITIES FOR SUSTAINABLE GROWTH

AN INAUGURAL LECTURE

By

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Fellow of The Nigerian Environmental Society

Professor of Ecosystem Services and Biodiversity

SERIES NO. 75

Wednesday 30th March, 2022

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Deans of Faculties/Student Affairs

Directors of Centers/Institutes

Heads of Departments

Distinguished Professors and other members of Senate

All Academic, Administrative and Technical Staff

Distinguished Members of the Nigerian Environmental Society

Students of this Great University

Distinguished Guests, Sponsors, Friends, Associates and Well wishers

Gentlemen of the Press

Ladies and Gentlemen

PREAMBLE

Today, it is important to remind ourselves of the emerging importance of Biological Capital (biological resources) and its profound positive and negative impact on socioeconomic systems. Humans make progress when they are faced with challenges that are life threatening. I would make bold to say that this topic is trending because of two convergent issues. The first is the emergence of the game dynamics between two Biological Capitals namely homo sapiens (humans) and the tiny virus SARS-Cov-2 or a.k.a COVID-19. The second is the intensive use and depletion of fossil Biological Capital that has generated excessive carbon dioxide with the emerging consequences of climate change.

Paradoxically, the Coronavirus has become an essential demonstration of the ecological dynamics that play out between Biological Capitals (species) in their struggle to change the evolution of one another. Thus, the interactions of biological resources to create capital in a sustainable way must be an intelligent communication of input processes for an outcome that pays off the dominant player. Currently, the dominant biological resource, namely SARS-COV-2, has shocked the very systems on which we rely, kick starting a decade already heading for extreme turbulence. We are set to see wide-ranging change and transitions – both positive and negative. The degree of systemic change and uncertainty of COVID-19 is altering the deepest levels of our assumptions, values and worldviews. From a Biological Capital perspective, the deepest changes come from shifts at these levels because they allow the shifting of the foundational narratives with which we make sense of the world to order our societies, and to organize collective action.

In this extraordinary time, in examining the dynamics for the decade ahead, four broad trajectories would emerge from the COVID-19 discontinuity, and the depletion of fossil Biological Capital with excessive carbon dioxide enabling climate change. These narratives would be characterized by very different basic sets of assumptions and mindsets, namely Compete and Retreat, because there is not enough to share so we must retreat to protect our own kind. Our survival and prosperity comes ahead of the survival and prosperity of others. The second pathway would be to discipline and have greater control in order to maintain public health and security and keep growth and global interconnection going as 'normal'. We can also transform the health of the planet and human wellbeing which are interconnected through a deep change to reset the system because we can't go back to 'before'. Equally, we can feel unsettled because there might not ever be a 'new normal' since the world is now strange and volatile beyond all previous human experience as previous ways of thinking are not helpful now.

These trajectories and their underlying mindsets help us to understand what possible futures are open to us and the role we can play in creating them. They are intimately connected to each of the dynamics, and to the trends, both positive and negative, which we will see emerge for the health of our planet, the equitable transitions we are seeking in our societies, and the future of our economy.

As you listen to this inaugural lecture, I invite you to explore your own mindset – is it firmly in one of the trajectories or in all simultaneously? How does that influence your response to the challenges and opportunities we see? In addition, are you ready to play a role in ensuring that we can transform and be sustainable even in Nigeria?

How can we seize the opportunity that Biological Capital provides to protect the world systems we all depend on seeing as every living thing on Earth is dependent on a healthy, functioning biosphere which is the global ecological system that integrates all life? The whole history of human civilization has been played out within a stable biosphere which has allowed us to flourish and grow.

Now, that benign period is crashing to an end. The planet's living systems are under severe stress from the destruction of biodiversity, the over-exploitation and mismanagement of water resources and the breakdown of the climate. These three, deeply intertwined systems, are in crisis, and as they fall apart, we risk crossing irreversible tipping points to a point of no return. It isn't simply that we can't go back to how things were before, it's that we are set to enter a radically unstable biosphere, a 'Hothouse Earth', unlike anything seen in the past years – including the ice age.

We have to act now – within this decade – to reverse this destruction and embark on a massive drive of ecosystem restoration. That means actively engaging with those drivers of destruction and radically changing their direction before it is too late. In the few minutes we are going to share together, let us examine the role of Biological Capital and bio economics in changing this narrative of the “drive to precipice”.

WHAT IS BIOLOGICAL CAPITAL?

The Vice Chancellor Sir, Biological Capital has been defined as life and the conditions that promote life. Others have defined it as biodiversity plus the long-term effects of having biodiversity. According to Davis (2005), Biological Capital is what allows the ecological processes, water cycle, nutrient cycle and energy flow to function properly and it provides a system of natural checks and balances that limits the populations of pest organisms. The word 'capital' means wealth in the form of money or other assets owned by a person or organization or available for a purpose such as starting a company or investing. In economics, 'capital' consists of human-created assets that can enhance one's power to perform economically useful work.

In book-keeping, 'capital' means amount invested by a businessman in the business. In commerce, 'capital' means finance or a company's capital but, in economics, 'capital' is that part of wealth which is used for production. So, wealth is a broad concept and capital is a narrow concept. If a commodity is having features like scarcity, utility, externality and transferability, it becomes wealth. A motor car has all the above features, so it is wealth but when wealth is used in the production process, it becomes capital. For example, if that car is used for a taxi (cab) business, it becomes capital. Therefore, any commodity, as wealth, becomes the capital if it is used for production. Normally, capital means investment of money in business but, in economics, money becomes capital only when it is used to purchase real capital goods like plants, machinery, etc. When money is used to purchase capital goods, it becomes Money Capital. Capital also generates income. So, capital is a source and income is a result. e.g., a refrigerator is capital for an ice-cream parlor owner but profits which he gets out of his business is his income. However, money in the hands of consumers to buy consumer goods or money hoarded doesn't constitute capital. Money, by itself, is not a factor of production, but when it acquires stock of real capital goods, it becomes a factor of production. For production, we need real capital and money capital but money capital acquires real capital. Thus, all capital is wealth but all wealth is not capital.

In economics some of the main features of capital are as follows:

1. **Productive Factor:** Capital helps in increasing the level of productivity and speed of production.
2. **Elastic Supply:** Supply of capital depends upon the capital formation process. Capital formation depends upon savings and investment. By accelerating capital formation, capital supply can be increased.
3. **Durable:** Capital is not perishable. It has a long life subject to periodical depreciation.
4. **Easy Mobility:** Movement of capital from one place to another is easily possible.
5. **Wealth:** Since capital has all features of wealth viz. utility, scarcity, transferability and externality, capital is wealth.
6. **Derived demand:** As a factor of production, capital has a derived demand to produce finished goods which have a direct demand.
7. **Roundabout production:** Capital goods don't satisfy our wants directly but resources are converted towards production of capital goods and other consumer goods having direct demand.

As a corollary, Biological Capital has these characteristics and more as it is a gift of nature. It is wealth created by the ecosystem as assets of Biomass that are available as goods, services and currency for investment in intergenerational sustainability. Table 1 examines the equivalence of Capital as defined in the market place in reference to Biological Capital.

Table 1: Market Based Capital and Biological Capital Equivalents

	Capital Classification	Equivalent Biological Capital
1	Fixed capital: It refers to durable capital goods which are used in production again and again till they wear out. Fixed capital does not mean fixed in location. Since the money invested in such capital goods is fixed for a long period, it is called Fixed Capital.	Enzymes, Stem cells Mangrove Trees, Freshwater Swamp Forest trees, Oysters, Swimming crabs, “Bushmeat", fish etc
2	Working capital: Working capital or variable capital refers to the single use of produced goods like raw materials. They are used directly and only once in production. They get converted into finished goods. Money spent on them is fully recovered when goods made out of them are sold in the market.	Cassava into Starch, Sugar cane into sugar, Vegetables into Afang, Edikang ikong et, Malt,
3	Circulating capital: It refers to the capital used in purchasing raw materials. Usually, the term working capital and circulating capital are used synonymously.	Snails, Palm Oil, Plantain, Yam, Onions, Crayfish, Palm wine corn proteins, bioethanol, Bioplastics, Cellulose esters etc
4	Sunk capital: Capital goods which only have a specific use in producing a particular commodity are called Sunk capital. E.g A textile weaving machine can be used only in a textile mill. It cannot be used elsewhere. It is sunk capital.	Rubber Trees, Cocoa trees, Pollinating bees, Pollinating Birds, Red Colobus Monkey
5	Floating capital: Capital goods which are capable of having some alternative uses are called floating capital. For e.g. electricity, fuel, transport vehicles, etc are floating capital which can be used anywhere	Corn, Cassava, Black Soldier Fly (BSF), Snails, Periwinkles, Cattle, Goats, Fungi, Herbs, Mangroves,

	Capital Classification	Equivalent Biological Capital
		Waste from soya beans, seed cotton, sugar cane, sorghum, plantain, groundnut, coconut, rice, cocoa, millet, cowpea, cassava, yam, sweet potatoes, cocoyam, maize, oil palm
6	**Money capital:** Money capital means the money funds available with the enterprise for purchasing various types of capital goods, raw material for construction of factory buildings, etc. It is also called liquid capital. At the beginning, the money capital is required for two purposes - one for acquiring fixed assets i.e., fixed capital goods and another for purchasing raw materials, payment of wages and meeting certain current expenses i.e., working capital	Baby Gorillas in Rwanda, the Serengetti animal diversity Gorillas in Oban Hills, Chimpanzees in Ogbaru Anambra, Forest Elephants in Andoni etc
7	Real capital: On the other hand, real capital refers to the capital goods other than money such as machinery, factory buildings, semi-finished goods, raw materials, transport equipment, etc.	Rain forests, Mangrove Swamp forests, Biodiversity, Vanilla, Rubber, Bio-surfactants, lignin, lignocellulose, alginates, pectin, dextrin, chitin and chitosan, proteins, soy proteins, corn proteins, bioethanol, Bioplastics, Cellulose esters, etc

	Capital Classification	Equivalent Biological Capital
8	**Private capital:** All the physical assets (other than land), as well as investments, which bring income to an individual are called private capital.	Fish Farm, Cattle Ranch, Vegetable farm, Crop farms Periwinkle Farm, Apiculture etc.
9	**Social capital:** All the assets owned by a community as a whole in the form of non-commercial assets are called social capital e.g., roads, public parks, hospitals, etc._	Forests, Conservation areas etc.
10	**National capital:** Capital owned by the whole nation is called national capital. It comprises private as well as public capital. National capital is that part of national wealth which is employed in the reproduction of additional wealth.	Yankari Games Reserve, Apoi Creek, Stubbs Creek etc.
11	**International capital:** Assets owned by international organizations like UN, WTO, World Bank, etc., constitute International Capital.	Coffee plantations in Cuba; grapes and olives in Stari Grad Plain in Croatia,

All capital refers to resources that are necessary to be used for productive work. All capital provides a range of sources of value that deliver economic, social and ecological utility but paraphrasing George Orwell's famous line provides that “All capitals are unequal, but some are more unequal than others”. This fundamental dependency indicates a value hierarchy for which Biological Capital is something we can't do without. There is no money without human beings capable of inventing and using it. At the end of the day, there are no human beings without food.

The Biological Capital we discuss today is the living component of natural capital. This living component consists of Biomass which is the material capital within which the intelligence capital is subsumed. In general, the biomass or material capital is an input into production which in turn produces a flow of goods and services that are regarded as ecosystem services. These goods and services are freely produced by nature as renewables and non-renewables. The non-renewables are fixed and have to rely on choices of who consumes, when and with what consequences. Even renewables do not have a potentially infinite yield at zero cost provided they are not depleted to such an extent that they are no longer able to keep reproducing themselves. Despite such goodwill from nature, the damage to our Biological Capital continues to proceed and accelerate apace. We continue to pollute the atmosphere, terrestrial, and the oceans, stripping the planet of its biological capital. In this century, going by current trends, three billion people will be added which is more than the entire world's population in the middle of the last century. Added to this, global temperatures may rise by about 2-4°C. So great are these numbers that it is very hard to grasp their implications. Yet, there is still a path for sustainable growth which lies in placing Biological Capital at the heart of the economy. By viewing the environment as made up of Biological Capital and not a second-hand add on, it becomes integrated with manmade and human capital into the fabric of the economy. Once Biological Capital is viewed as an asset, it can then be valued in economic calculations. Valued assets are worth looking after because the economic calculations help to confront the damage and pollution of man's activity.

Biological Capital (BC) is not simply representing exotic, endangered species, but includes all living things, from genes through species and populations to ecosystems. It is the interactions within and between biodiversity and non-living resources that generate most of the flow of benefits. The interactions that generate these benefits are vast, complex and often poorly understood.

Sometimes, values can be attributed – for example for the role a specific insect species such as bees in pollinating a crop, or the role a forest ecosystem may have in watershed maintenance, production of oxygen, or the role of microbes, annelids, maggots in pollution and waste management, or the role of plants in the pharmaceuticals, cosmetics, or the role of plankton in the complex food chain of marine and freshwater animals that provide protein security, or the role of the biodiversity dilution effect that helps to mitigate zoonotic cross-over of many pathogens from their natural hosts to man, or the role of the whale watching industry which adds over 5000 jobs a year and generates over $1.5 billion dollars while the baby naming of gorillas in Rwanda national parks generates over 41 million dollars annually. For many of these values, particularly those related to underlying ecosystem function, resilience to change or the 'intrinsic' values of nature, tend to be hidden or missing altogether.

According to the UN Convention on Biological Diversity (United Nations, 2011), Biological Capital (Biological resources) supports 40 percent of the world economy and meets 80 percent of human needs, including industrial, ecological, social, genetic, scientific, cultural, and spiritual ones. Thus, ensuring sustainable use of Biological Capital requires recognition that renewable resources must be exploited in ways that allow them to maintain their productive capacity and protective function. As a result, there is a growing recognition that Biological Capital is a global asset of tremendous value to present and future generations. We have come to understand, however, that the underbelly of ensuring the sustainable use of Biological Capital is characterized by a multitude of different economic, environmental, and social objectives. They all appear desirable in isolation but are inextricably connected and internally interdependent. The ambition of the sustainability mantra (SDGs) to address these multiple objectives simultaneously results in tensions since progress on one sustainability issue might have detrimental effects for other sustainability issues. These tensions are exacerbated by two factors namely the long-term orientation to include the needs of future generations and the desire for equitable development opportunities for developed and less developed regions. These inherent tensions produce the paradox perspective where there is persistent contradiction between interdependent elements resulting in tensions between various aspects that seem logical in isolation but absurd and irrational when appearing simultaneously.

BIOLOGICAL CAPITAL - AN ECOSYSTEM PERSPECTIVE

The word ecosystem is made of two words namely eco and system. Eco comes from the Greek word oikos meaning household or the fundamental social, political and economic unit. The Indo-European root is "woikos," which gives us the Latin form, "vicus," a cluster of houses, and words such as village and vicinity. The Nigercentric root is Ama in Kalabari, Oro in Ikwerre, ilo/ulo in Ibo, Adugbo in Yoruba.

At its core, both in Greek, Latin, Nigercentric and Afrocentric settings, "ecos" means home and community — where we live translated into habitat or environment. The word 'system' we are meant to understand is derived from the Greek word systema, which means an organized relationship among functioning units or components. In simple terms, a system is an entity that maintains its existence through the mutual interaction of its parts. In principle, systems have five characteristics namely organization, interaction, interdependence, integration and a central objective. The question is how does this ecosystem work and what is the role of Biological Capital in the underlying systemic interrelationships which are responsible for the patterns of behavior and the events? From a system's thinking perspective, Biological Capital, as a functional unit, is equipped with sets of attributes that sustain ecosystems in one or more alternative viable states. One of the properties of the Biological Capital, through which it provides functional outcomes, is regularity. Regularity is a uniformity or similarity that exists in its multiple entities of species. This regularity makes it possible to have efficient and effective bio-scientific outcomes. Without this attribute or property regularities, we would have no bio-scientific laws, no categories or taxonomies, and each measurement and monitoring effort would start from a clean slate.

Every system, including the ecosystem, must behave in a manner that allows it to sustain itself in one or more alternative viable states. Biological Capital contributes to ecosystem sustainability through natural self-regulation or self-organization arising from the interaction of its elements, attributes or properties. Biological Capital operationalizes its functional role in survival through the homeostatic behaviour where its connected variety (Hitchins, 2007) and the number of connections between its elements, produces behaviour for a "steady state" or "dynamic equilibrium.

Biological Capital becomes the equivalent of those forces fighting off obsolescence, aging, entropy, disorder, or as in physics, Negentropy. Biological Capital, in its homeostatic behaviour, is cybernetic and by embracing the law of Requisite Variety (Ashby, 1956), promotes function that is a trade-off between specialization and flexibility. Specialization of its constituent parts provides focus of ecosystem behavior to exploit particular features of its environment while flexibility provides the ability to adapt quickly to environmental change. This response to environmental change, which takes place through changes in its interacting parts, has an intrinsic capacity for spontaneous order without needing any external agent (*originally until man came into the picture*). Results from such responses are decentralized and distributed within the Biological Capital subsystem. The output provides a function of robust ability for survival and self-repair against substantial perturbation. In the current popular game theory, Biological Capital is an ecosystem regulator of sustainability through strategic interactions that switch strategies, according to rule based revision protocols. One can then submit that Biological Capital performs the function of self-regulation of the ecosystem using various game theory strategies found in best response or replicator dynamics. In context, every ecosystem strives to be dynamically in equilibrium according to the non-linear interactions of the input-output requirements of its constituent Biological Capital. The interactions are described as non-linear because the conditions for sustainability are not a linear combination of the input parameters

BIOLOGICAL CAPITAL– A BIOLOGIST'S PERSPECTIVE

The fundamental material of Biological Capital is Biomass. Biomass originates from three primary sources, namely Plants, Animals and Microorganisms. The concept of biomass was introduced in 1927 by a publication of the German zoologist, Reinhard Demoll (1882–1960): “By biomass we term the quantity of substance in living organisms per unit of surface or volume” (Demoll, 1927). Currently, there is no consensus on the general definition of “biomass”.

When a Biologist considers the term “biomass”, carbohydrates, proteins, fats and oils and around 100,000 – 150,000 different secondary compounds, including a diverse range of sugars, sugar alcohols, vitamins, fats, oils, amino acids, organic acids, nucleic acids, phenolic compounds, odors, pigments come to mind. A chemist would like to see a molecular formula to describe carbohydrates, proteins, fats and other secondary substances, showing the chemical elements together with an amount of binding energy. However, unfortunately, there is no chemical formula for the general definition of biomass. A Physicist or agronomist would calculate the energy value of a certain biomass fraction, from a maize field, for example, using an equation for the heating value of biomass based on its components. A technologist would see biomass as a source of energy.

The term “biomass" can be defined as all resources containing non-fossil, organic carbon, derived from living plants, animals, algae, microorganisms or organic waste streams. Biomass can be further defined as plant or animal tissue or tissue-based material, microorganisms and the substances produced from them as well as organic molecules (primarily) formed by (photosynthetic) organisms such as carbohydrates (e.g., sugars), proteins, fats, fibre, vitamins and other secondary plant metabolites. This includes edible biomass, such as starch, sugar- and oil-rich biomass and nonedible lignocellulosic biomass from dedicated crop production, residues and organic wastes.

Today, the term “biomass” is most frequently used to refer to organic material utilized for energy production and other nonfood applications such as the production of biogenic materials and chemicals. In the following text, we use a more general definition of biomass, which includes edible as well as nonedible organic material. All Biological Capital (or biomass) is essentially derived from inorganic molecules or ions that are assimilated into the biological tissue of autotrophic (primary) organisms (plants and microorganisms) through photosynthetic or chemosynthetic processes. Organisms that produce primary Biological Capital are called “autotrophs” because they are self-feeding and use light as an energy source. In the process of photosynthesis, they take up CO_2 and convert it into chemical energy with the help of sunlight. These organisms provide the basis for secondary biological capital, i.e., heterotrophs. Heterotrophs (animals, humans, fungi, most bacteria) rely on the consumption of either the products of autotrophs or whole autotrophic organisms. Besides the primary elements from carbon (C), oxygen (O) and hydrogen (H) are many mineral macronutrients and micronutrients namely nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S). (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), chlorine (Cl) and nickel (Ni) and silicon (Si), cobalt (Co), selenium (Se) and sodium (Na) that are incorporated into biomass formation.

Currently, the best estimates of Biological Capital, in equivalence of Biomass, keep differing by an order of magnitude or more from previous estimates.

This is because a global quantitative account of the biomass of each taxon is still lacking. The best metric of Biomass to illustrate comparable quantity of capital stocks of elements sequestered in living organisms is mass of carbon, as this measure is independent of water content where biomass is reported in gigatons of carbon, with 1 Gt C = 10 g of carbon. Earlier efforts to estimate global biomass have mostly focused on plants. Despite that, the methods used for each taxon were highly diverse, the sum of the biomass across all taxa on Earth is estimated to be 550 Gt C, of which 80% are plants, dominated by land plants - the embryophytes (Yinon *et al* 2018). The second major biomass component is bacteria 70 Gt C; constituting 15% of the global biomass. Other groups, in descending order, are fungi, archaea, protists, animals, and viruses, which together account for the remaining <10% (Fig 1).

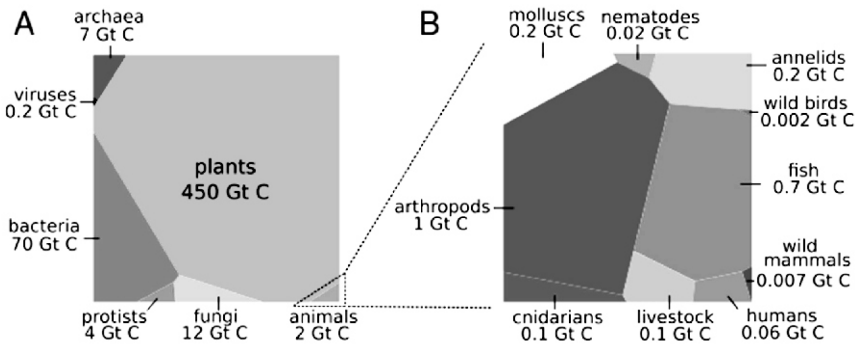


Fig 1: Graphical representation of the global biomass (Biological Capital) distribution by taxa (after Yinon *et al.*, 2018)

These lines of evidence are indicative of the dominance of plants as Biological Capital of the biosphere and are mostly located on land. According to the authors, the marine environment is primarily occupied by microbes, mainly bacteria and protists, which account for 70% of the total marine biomass. The remaining 30% is mainly composed of arthropods and fish. The deep subsurface holds 15% of the total biomass in the biosphere. It is chiefly composed of bacteria and archaea, which are mostly surface-attached and turn over their biomass every several months to thousands of years. Nonetheless, the value in terms of carbon alone, in economic terms, where the current price of carbon in the world market is $50, is equivalent of $27.5 trillion dollars. This is equivalent to 31% of the total world economy currently estimated to be $87.55 trillion. Certainly, Biological Capital in terms of biomass is worth more when we consider the other elements from an analysis of 86 varieties of biomass (Stanislav *et al.,* 2010) which contains Carbon, Oxygen, Hydrogen, Nitrogen, Calcium, Potassium, Si, Magnesium, Aluminum, S, Iron Fe, P, Cl, Na, Mn, and Ti.

The above facts are however proving to be incorrect as during the recent studies of the deep sea, the upper atmosphere, the Antarctic dry deserts, newly opened caves, sulfurous tunnels, and granitic rocks showed that Biological Capital is vigorously inhabited in places that were unknown. Not until giant, mouthless, red-gilled tube worms were videographed in the late 1970s and '80s did the extent and the weirdness of the Biological Capital on Earth begin to be fathomed. Entire large ecosystems were recognized on the ocean's bottom that live not by the usual photosynthesis but rather by chemolithoautotrophy, a kind of metabolism in which organisms make food from carbon dioxide using energy from the oxidation of sulfide, methane, or other inorganic compounds. These discoveries have led to a deeper understanding of the varied modes of nutrition and sources of energy. Bacterial symbionts living in the tissues of some polychaete worms (alvinellids) or pogonophora (such as *Riftia pacytila*) provide the animals with their total nutritional needs. The submarine ecosystems supported by bacteria thrive along the worldwide rift zones that extend along the borders of huge continental plates at the Mid-Atlantic Ridge, on the East Pacific Rise, at 21° north of the Equator off the coast of Baja California, Mexico, and at a dozen other newly studied sites. By the beginning of the 21st century, it had become abundantly clear that there are many forms of Biological Capital in ecosystems that remain unknown or under-studied. Those in the Siberian tundra, in the thickly forested portions of the Amazon River valley and its tributaries, at the tops of remote mountains and inside granitic rocks in temperate zones, and in the center of Africa remain as inaccessible as they have been throughout history. This potential provides large possibilities in our quest for bioeconomic driven sustainability.

CONCEPTUAL EVOLUTION OF BIOLOGICAL CAPITAL

Biological Capital attribute descriptors, over time, are many and can form the subject of analyses for a conference. In this lecture, we shall pay attention to a few characteristics that enable sustainable outcomes. Three descriptors of Biological Capital are Anthropocentrism, Biocentrism, and Ecocentrism.

ANTHROPOCENTRISM

The Anthropocentric view of Biological Capital is the idea that the human-Biological Capital is the most significant being on Earth and that all other plants, animals, and objects are important insofar as they support human survival or give humans pleasure. There are a number of important implications of the anthropocentric view, which strongly influences the ways in which humans interpret their relationships with other species and with nature and ecosystems. Some of these are discussed on the next page:

1. The anthropocentric view suggests that humans have greater intrinsic value than other species. A result of this attitude is that any species that is of potential use to humans can be a "resource" to be exploited. This use often occurs in an unsustainable fashion that results in degradation, sometimes to the point of extinction of the biological resource, as has occurred with the Dodo, great Auk, and other animals.

2. The view that humans have greater intrinsic value than other species also influences ethical judgments about interactions with other organisms. These judgments are often used to legitimize treating other species in ways that would be considered morally unacceptable if humans were similarly treated. For example, animals are often treated very cruelly during the normal course of events in medical research and agriculture. This prejudiced treatment of other species has been labeled "speciesism " by ethicists.

3. Another implication of the anthropocentric view is the belief that humans rank at the acme of the natural evolutionary progression of species and of life. This belief is in contrast to the modern biological interpretation of evolution, which suggests that no species are "higher" than any others, although some clearly have a more ancient evolutionary lineage, or may occur as relatively simple life forms.

Anthropocentrism has caused a horrifying array of global environmental problems. At one level, it refers to the ongoing biophysical destruction of ecosystems, habitats, forests, species, individual creatures, and climate through widely varying processes of extraction, consumption, and production (Mckibben, 1989; Wapner, 2010). The daily extinction of species, the general homogenization of species around the world, and the transformation of terrestrial and marine ecosystems, all due to human activity, all point to the emerging loss of Biological Capital. Biodiversity loss, along with climate change, thus form some of the key conditions for the Anthropocene – an era marked by deep human intervention into the deepest processes of nature. The contamination of the environment with harmful substances is one of the major problems of modern life. The world of air and water and soil supports not only the hundreds of thousands of species of animals and plants, it supports man himself. In the past we have often chosen to ignore this fact. Now we are receiving sharp reminders that our heedless and destructive acts enter into the vast cycles of the earth and in time return to bring hazard to ourselves.

On the basis of the above logic, the anthropocentric approach might seem inconsistent with safeguarding the planet or protecting non-human Biological Capital. A different perspective shows that it does not necessarily imply a ruthless exploitation of nature. Competing philosophical approaches indicate that, individually and collectively, it can be consistent with the protection of non-human Biological Capital. This view contends that the nature of humans gaining satisfaction or well-being should be interpreted broadly to encompass the way satisfaction is generated. They hypothesize that satisfaction should have use and non-use values, hoping this would create an opportunity to recognize and include the preferences of people who have concern for future generations. The use value of satisfaction reflects on placing a direct value on non-human Biological Capital where there is consumption of fish, food etc. or placing a value on plankton because it provides nutrients for other Biological Capital that in turn feed humans. For the non-use value, gaining satisfaction should recognize the importance of the existence value or option value – all of which may be passive but nonetheless generate satisfaction because it can be bequeathed to the next generation. For example, a Nigerian who has never seen the endemic species of the red colobus monkey (*Piliocolobus epieni*) in Bayelsa or the Indigo bird and Rock firefinch in Jos Plateau, or the Malimbe (*Malimbus ibadanensis*) in Ibadan or the Anambra Waxbill (*Estrilda* *poliopareia)* can derive satisfaction simply from knowing it exists. In another situation, many people can experience a loss of satisfaction simply from learning of the ecological damage and near collapse of the oysters in the Niger Delta due to incessant hydrocarbon contamination or the loss of a precious grey parrot habitat in Ikodi due to indiscriminate deforestation and lack of protection from poachers. The parrot case is a loss of existence value.

Clearly the difficulty of the anthropocentric approach is the enormous blind spot created by reducing non-human Biological Capital to instrumental value. Its difficulty is also in the ethical and moral enigma arising from equally counting the preferences of people who have no concern for future generations or who have no sense of the ecological implications of their actions, with those who are more altruistic or who recognize more fully the fragility of Biological Capital. This has led to alternative subjects of moral value, such as biocentrism, in which all forms of life share in some form of value, or ecocentrism, putting ecosystems front and center.

BIOCENTRIC APPROACH

The biocentric approach asserts that value consists in the ability to provide well-being or utility to humans and to other species. Under the anthropocentric approach, the well-being of other species counts indirectly only when such wellbeing is important to the extent it contributes to human well-being. In contrast, the biocentric approach gives weight directly to the well-being of other species. Thus, it allows for the possibility that another species will have a value even if it does not confer satisfaction directly or indirectly to humans. This independent value is sometimes referred to as intrinsic value.

Defenders of the anthropocentric approach point out that since human beings are the dominant Biological Capital on the planet, they are obliged to define ethical principles in terms of human wants and needs. Alternatively, biocentrism which is rooted in nature can be conceptualized as a divine creation that people have a sacred duty to preserve (Wardekker *et al.,* 2009), and this sanctification of the planet has been shown to increase pro-environmental beliefs and behaviors (e.g., Tarakeshwar *et al.,* 2001). The Biocentric approach proposes an embracing of ecological ideas and environmental ethics (that is, proposals about how humans should relate to nature). The Biocentrist holds that the survival of any part is dependent upon the well-being of the whole, and criticize the narrative of human supremacy, which they say has not been a feature of most cultures throughout human evolution (Allan *et al.,* 2011) It presents an ecocentric (earth-centered) view, rather than the anthropocentric (human-centered) view, developed in its most recent form by philosophers of the Enlightenment, such as Newton, Bacon, and Descartes.

Biocentrists oppose the narrative that man is separate from nature, is in charge of nature, or is the steward of nature, or that nature exists as a resource to be freely exploited. They cite the fact that indigenous peoples under-exploited their environment and retained a sustainable society for thousands of years, as evidence that human societies are not necessarily destructive by nature. They believe a different economic system must replace capitalism, as the commodification of nature by industrial civilization, based on the concept of economic growth, or 'progress', is critically endangering Biological Capital.

Only in the final decades of the 20th century did philosophers attempt to develop a more systematic and scholarly version of biocentric ethics. Paul Taylor's book, Respect for Nature (1986), was perhaps the most comprehensive and philosophically sophisticated defense of biocentric ethics. Taylor provided a philosophical account of why Biological Capital should be accepted as the criterion of moral standing and he offered a reasoned and principled account of the practical implications of biocentrism. He claimed that Biological Capital itself is a non-arbitrary criterion for moral standing because all Biological Capital can be meaningfully said to have a good of their own. Biological Capital aims toward ends; they have directions, purposes, and goals.

As a normative theory, biocentrism has practical implications for human behaviour. The good of all Biological Capital creates responsibilities on the part of human beings, summarized in the four basic duties of biocentric ethics: non-maleficence, noninterference, fidelity, and restitutive justice. The duty of no maleficence requires that no harm be done to Biological Capital, although it does not commit human beings to the positive duties of preventing harm from happening or of aiding in attaining the good. The duty of noninterference requires not interfering with an organism's pursuit of its own goals. The duty of fidelity requires not manipulating, deceiving, or otherwise using Biological Capital as mere means to human ends. The duty of restitutive justice requires that humans make restitution to Biological Capital when they have been harmed by human activity

Numerous challenges suggest that biocentrism is too demanding an ethics to be practical. The duties to do no harm to Biological Capital (BC) and to refrain from interfering with the lives of other beings ask a great deal of humans. It is difficult to understand how any Biological Capital, and especially humans, could survive without doing harm to and interfering with other Biological Capitals. Not only would abstaining from eating meat seem to be required, but even vegetables would seem to be protected from harm and interference. This presents a dilemma because a biocentrist has ethical duties to BC with equal moral standing and yet must eat those BC to survive. As a solution to this problem, some argue that strict equality can be abandoned in certain situations and that a distinction between basic and nonbasic interests can provide guidance in cases where the interest in Biological Capital conflicts. In such a case, one would conclude that basic interest should trump nonbasic interest. For example, the interest in remaining alive should override the interest in being entertained. Thus, it is unethical to hunt animals but ethically justified to kill an animal in self-defense though the second alternative quickly threatens the consistency of biocentric equality. In response to such concerns, defenders of biocentric ethics often argue for the principle of restitutive justice. When inevitable harms such as pollution do occur in the conflicts between Biological Capital, a duty to make restitution for the harms is created. Thus, the harms inflicted in harvesting trees or crops can be compensated for by restoring the forest or planting more crops but that response raises the second major challenge to biocentric ethics.

Critics highlight that strictly biocentric ethics will conflict with a more ecologically influenced environmentalism for sustainability. Protecting individual lives may actually harm rather than protect the integrity of ecosystems and species, as is evidenced by the need to remove invasive species for ecosystem health. This holistic approach typically concludes that preserving the integrity of ecosystems and the survival of species and populations is environmentally more crucial than protecting the lives of individual elements of an ecosystem or members of a species. This important environmentalist perspective, identified as ecocentrism, distinguishes it from biocentrism, which holds that ecological collections such as ecosystems, habitats, species, and populations are the central objects for environmental concern. In fact, ecocentric environmental ethics would often condone destroying the lives of individuals as a legitimate means of preserving the ecological whole. Thus, discarding members of an overpopulated herd or killing an invasive non native plant or animal species can be justified.

Finally, challenges remain to the fundamental claim that life itself is the non arbitrary criterion of moral standing. The fundamental philosophical challenge to biocentric ethics thus involves two questions. Is the activity of living really goal-directed in itself, even when non-intentional? Even if it is goal-directed, why assume that a living thing serves its own good rather than the good of something else?

ANTHROPOCENTRISM VERSUS BIOCENTRISM

The importance of public appeal to an environmental ethic cannot be overstated. This is because we are running out of time to slow or reverse the effects of past environmental degradation on Biological Capital and we will need the support of society to combat them effectively. Hence, the most important advantage of an anthropocentric ethic over a biocentric one is public appeal because the biocentric view seems too radical and contrary to the goals of environmentalists. While possibly justifiable, an ethic that treats all Biological Capital and possibly even ecological systems as intrinsically valuable may seem very radical to a large portion of the public. This radical view is also not justifiable when one considers for example protecting a lowly invertebrate from an anthropocentric view because its genetic diversity could yield a cure for some human ailment, or because it holds some key place in the food chain that sustains an animal that yields benefits to humans. A biocentrist would have to justify protection of the lowly invertebrate by appealing to its intrinsic value. However, why a worm or sea sponge is valuable in itself is difficult for many to justify. Weighing the intrinsic value of non-human Biological Capital is significantly more difficult than weighing human Biological Capital values, possibly because of our proximity to and experience with them. If a gorilla has the same intrinsic value as an earthworm, would that justify our killing the gorilla to save two earthworms? If the gorilla does have more intrinsic value, how much more? Why is one ecosystem more valuable than another? If it is not, then why are human-created ecosystems less valuable? This observation about practicality helps explain why more than just being a benefit, a human-centered (anthropocentric) view is the only type of environmental ethic we can practically utilize.

As humans, it is probably impossible to escape a human-centered (anthropocentric) ethic to guide our decision making on Biological Capital and sustainability. Our subjectivity means we can only experience the world from one perspective, and this perspective colours everything we do. Our self-preservation instincts lead us to value ourselves above the rest of the world. What person would reasonably kill themselves, or their children, friends, and neighbors, to save an ecosystem or two ecosystems? Some biocentrists have chained themselves to trees and bulldozers, as a statement to express the critical environmental situation. Nonetheless it is questionable if the same biocentrists would give their life to save two gorillas, or two earthworms?

In this era of degrading Biological Capital, there is very little time to wait for the anthropocentric and biocentrists to settle this esoteric question. Most biocentrists and anthropocentrics would agree that the Earth is fast approaching a point-of-no-return for environmental well-being. The ecological world desperately needs to use the dominant and available Biological Capital to adopt an ethic that will slow, arrest or reverse sustainable growth.

CHARACTERISTICS OF BIOLOGICAL CAPITAL

i. Renewability

Science has made it clear that the earth is a closed system to matter and only open to energy from the Sun. By this construct, the design of elements that would operate this closed system must have an architecture to answer an intended purpose whose outcome must be coherent and purposeful. In this context, the closed system domain must have enablers concerning, structural, behavioral, and transformational properties of its composing parts of materials, energy, or information in order to be sustainable. In such a closed system, sustainability characteristics must have operability, reliability, feedback, and safeguards to adapt to environmental circumstances as they change. In this overall scheme of the design of the earth, Biological Capital became part of the elements, information and data useful and necessary for implementation of sustainability within the closed earth system domain.

A little reflection including an evaluation of the design of the closed earth system in the Bible gives an indication of Biological Capital elements as enablers of self-regulating functions of the sustainability enterprise. I apologize for those who are offended by the Bible. As we examine that narrative in Genesis Chapter 1, Biological Capital was designed as an interconnected whole and mainstreamed to enable sustainability within the closed earth system. The first intriguing algorithm was "let there be light". Therefore, the energy from the sun became the primary enabler of the sustainability architecture of the closed earth system. In this closed earth system, matter would obey the principles and the laws of thermodynamics. In furtherance of the design for sustainability, the teleology of light or energy was substantiated with the next coded algorithm of "Let the earth produce vegetation: seed-bearing plants and fruit trees on the earth bearing fruit with seed in it according to their kinds." And it was so. Similarly, in another coded sequence, we have "Let the water teem with living creatures, and let birds fly above the earth across the vault of the sky." and So God created the great creatures of the sea and every living thing with which the water teems and that moves about in it, according to their kinds, and every winged bird according to its kind. Still, in continuation of the algorithms, we have "Let the land produce living creatures according to their kinds: the livestock, the creatures that move along the ground, and the wild animals, each according to its kind." And it was so. and God made the wild animals according to their kinds, the livestock according to their kinds, and provided all the creatures that move along the ground according to their kinds". In alignment with the architecture for sustainability, these Biological Capitals were given purpose, function, behaviour and structure and encoded with supportive and assimilative capacities that obey the first and second laws of thermodynamics.

Mr. Vice Chancellor Sir, I hereby submit that the first algorithm which produced vegetation as Biological Capital was given purpose by encoding it with the attribute of renewability powered with energy from the sun. This renewable characteristic replenishes itself by replacing the portion depleted by usage and consumption, either through natural reproduction or other recurring processes in a finite amount of time. This intricate process relies on its capability to exploit the inexhaustible reservoirs of sunlight, water, and carbon dioxide to provide most of the oxygen, fossil fuels, and biomass on our planet. In order to code for sustainability, the energy and materials generated at the Biological Capital-Producer group was designed to remain sustainable through a trophic cascade system running on a carrying capacity model. The carrying capacity concept implies that resources shall be used at rates that do not exceed the capacity of the Earth to replace them. This deceivingly simple process forms the basis for all the Biological Capital sources essential to life, from the intake of food to the burning of fossil fuels, and more recently, for the industrial production of value-added chemicals or bio-energy. Thus, even after many years of life on earth these processes unceasingly support life on earth, and have inspired the development of enabling technologies for a sustainable global economy and ecosystem.

ii. Replicability

All Biological Capital on Earth, from the tiniest cell to the loftiest trees, display extraordinary powers because of the coded algorithm of Replicability. This characteristic empowers them to effortlessly perform complex transformations of organic molecules, exhibit elaborate behaviour patterns, and indefinitely construct from raw materials in the environment, more or less, identical copies of themselves. The algorithms encoded in large molecules known as genes, are responsible for the expression of different characteristics of the organism which replicate during reproduction to pass on the instructions for various characteristics to the next generation. Replication refers to the capacity of molecules such as deoxyribonucleic acid (DNA) to precisely copy themselves. The context of replication in Biological Capital was captured succinctly by Chilean biologists, Humberto Maturana and Francisco Varela (1980). Unlike machines, whose governing functions are embedded by human designers, Biological Capital has a self-governing autopoietic process of maintenance of its own identity, its informational closure, its cybernetic self-relatedness, and the ability to make more of itself. Sustainable replication and evolution of genetic molecules are therefore crucial steps in the emergence of Biological Capital.

The intriguing mechanism of self-replication is the creation of variety in all groups of Biological Capital from unicellular to multicellular forms. This resulting variability which comes from repeated mutations, the acquisition of foreign DNA from the environment and epigenetic changes is *sine qua non* to catastrophic crisis management. This constant genetic variability collectively becomes the driving force behind biological diversity that keeps many Biological Capitals from becoming unsustainable. Facing environmental threats, Biological Capital that possessed the right combination of features in their genetic makeup survived environmental changes and passed their attributes to the following generations, and those that did not, became unsustainable. Thus, through the replication characteristic, there is a stunning system that has a built-in mechanism for sustainable generational success. Over the passage of years, through five recognized catastrophic environmental crises, Biological Capital has rebounded through replication with drastic changes in form and function.

The traits of renewability and replicability are both vital characteristics enabling Biological Capital to obtain maximum fitness (sustainability) in response to heterogeneous environments. In Onwuteaka (2015a) this adaptive variability is exemplified along ecological gradients on Bonny River among the Polychaete fauna who are ecosystem engineers. Along the river are contrasting salinity variations (Fig. 2) that produce divergent habitats. Local adaptation in abundance and composition was interpreted to have been produced by replication and reproductive fitness. The study showed consistent unique taxonomic (genetic) divergence between populations along the salinity variations. The taxonomic uniqueness associated with colonization and recolonization in space and time was contrasted by phenotypic variation. Ubiquitous species namely, *Capitella capitata*, *Lumbrinereis abberans, Aglaophamus dibarnchis, Scoloplos (laodamas) johnstonei*, Sternapsis Scutata, *Tharynx dorsobranchialia, Cossura longocirrata, Notomastus abberans, Nephthys assimilis, and Diopatra aciculata* exhibited phenotypic variation along gradients of contrasting sediment structure or levels of hydrocarbon contamination.

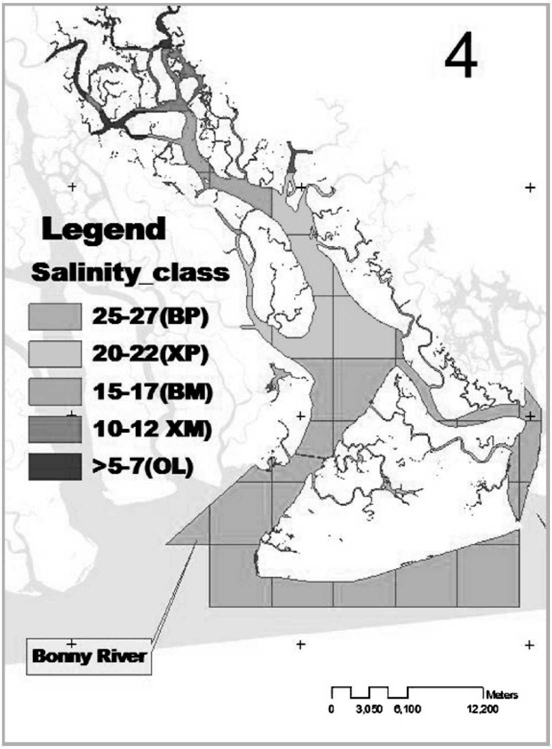


Fig. 2 - BioCapital Resilience along an ecological gradient induced by Salinity on the Bonny River

Similarly, enablers of sustainability among Biological Capital were demonstrated in freshwater fishes in Onwuteaka (2015b). In the eastern delta lie three rivers namely Orashi, Sombreiro and New Calabar whose physico-chemical personalities are classified as clear and blackwaters. depending on the season. Each river experiences different seasonal abiotic stress from annual precipitation resulting in drastic changes in their physico-chemical profiles in terms of pH, conductivity, turbidity, and flocculation. In addition, a significant hydrological gradient exists between the rivers as seasonal changes in the Orashi depend on feeders from the River Niger, while those of the Sombreiro depend only on their headwater swamps and local rainfall. A discriminant analysis of the one hundred and fifty-four (154) species showed replication and reproductive fitness by seventy-seven species for local adaptation specific to Orashi River. In contrast, only six species had the exclusive fitness for local adaptation on the Sombreiro River. Consistent with the fitness effect conferred by reproductive/ replication traits, forty–six (46) ubiquitous species showed evidence of phenotypic divergence, enabling and promoting acclimation for survival in aquatic habitats with variable eco-physiological cost.

iii Game Competent

It is evident from the above facts that Biological Capital is designed and equipped as a system to promote sustainability. To further unravel the mechanics of this intriguing phenomena, biologists have turned to game theory models in order to understand complex behavioural relationships between types of Biological Capital as they interact to sustain life on earth.

Sustainability is the result of different interaction strategies determining the net gain or loss incurred and this value is referred to as payoff. Different interaction strategies, such as combative or cooperative, result in different payoffs based on the nature of the interaction. The most successful organisms maximize their payoff and increase their ability to replicate, reproduce, self-organize and self-regulate. At the end, the Biological Capital with the best interaction strategy has the highest fitness or payoff. Since the interaction strategy (phenotype) can directly relate to fitness, the optimum strategy will be favored under natural selection for sustainability.

In Onwuteaka (1991), the game competent nature of the polychaeta, a Biological Capital, explains the sustainability payoffs in a number of benthic habitats in seven rivers in the Niger Delta. Polychaete diversity in the benthos of seven estuarine rivers, namely Bonny, Opobo – Andoni, Brass, Escravos, Forcados, Warri and Ramos, was examined across gradients of salinity variations. (Figs. 3a and 3b). The diversity metric which is a measure of reproductive and replication fitness demonstrates the two basic notions of game theory, namely strategy and payoff, where an inheritable trait and payoff is fitness (average reproductive success). The accumulated payoffs, shown as a diversity metric, demonstrate the capacity of the Polychaete to absorb disturbance and reorganize, while undergoing a change, so as to retain essentially the same function, structure, identity, and feedback. Higher payoffs (diversity) of 1.78-3.08 were evident in locations where the sustainability game dynamics were being played in environmentally stable systems (ESS) of Alpha (>15ppt) and Beta Polyhaline salinity(>=20ppt) groupings. In this sustainability-game community model, the lower diversity metrics >1.78 in the Beta Mesohaline (BM/<15ppt)), Alpha Mesohaline (XM:<10ppt) and Oligohaline (OL<=5ppt) demonstrated a local fitness gradient in response to boundaries of physiological constraints.

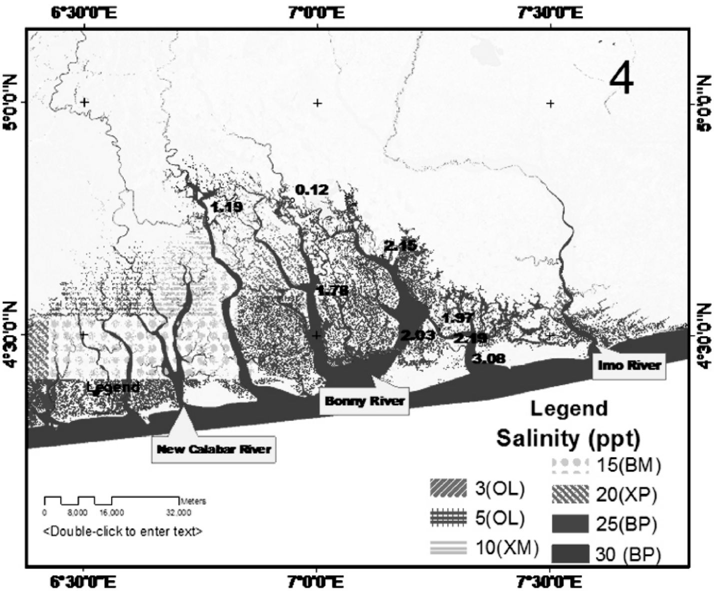


Fig 3a. Polychaete Diversity Values or Reproductive Fitness in Eastern Delta- Salinity Grouping: BP = Beta Polyhaline; XP = Alpha polyhaline; BM = Beta Mesohaline; XM = Alpha Mesohaline; OL = Oligohaline

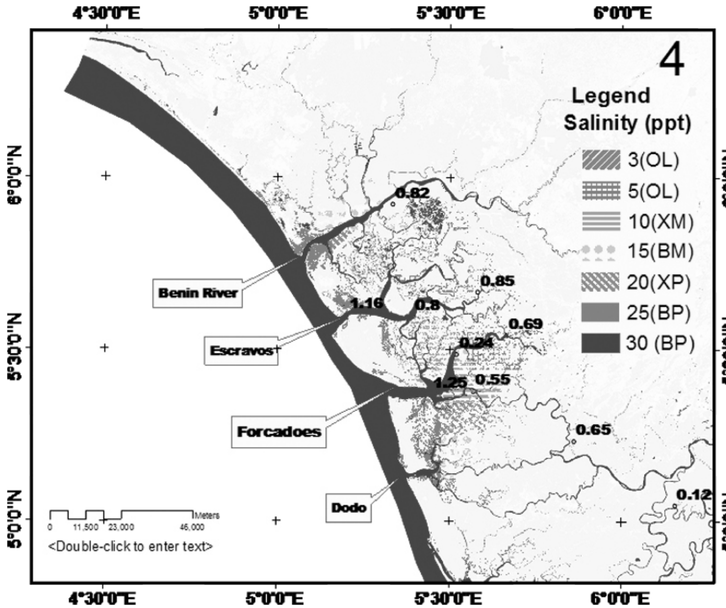


Fig 3b. - Polychaete Diversity Values or Reproductive Fitness in the western Delta - Salinity Grouping: BP = Beta Polyhaline; XP = Alpha Polyhaline; BM = Beta Mesohaline; XM = Alpha Mesohaline; OL = Oligohaline

Mathematically speaking, the diversity values provided the fitness function (reproductive success) of the Biological Capital (Polychaetes) in each location within the game dynamics of sustainability. Drawing from the mathematical expression of game theory, the fitness function which gives each Polychaete group the ability to be sustainable can be denoted as G (v, u, x). This expected fitness became a function of the individual's strategy, v, the strategies of others in the population, $u = (u_1, \dots, u_n)$, and the population sizes (or densities) of the different extant strategies, $x = (x_1, \dots, x_n)$. The strategies of u were drawn from some set of metamorphic feasible strategies. Sustainability in the Polychaete assemblage (biological capital) is therefore a game played within species and populations. Here, the extant strategies, u, represent available behavioral choices employed to respond to current local conditions reflecting what information was available. The fitness generating function conceives that where $n \geqslant 1$ different strategy would be present in the population.

This mathematical expression of the fitness generating function, models (Cohen *et al.,* 1999) both the ecological dynamics of changes in population size ($dx_i/dt = x_iG(v,u,x)_{v=ui}$) and the evolutionary dynamics of changes in strategy value ($du_i/dt = k(dG/dv)v{=}u_i$). This fitness gradient, dG/dv, evaluated at $v = u_i$, determined whether an individual using strategy u_i can improve its fitness by unilaterally increasing or decreasing its strategy. By implication, every strategy by the fitness generating function is what has produced these diversity outcomes within local habitats. It is as if Polychaetes in these systems were rational decision makers. In reality, sustainability in these sediment Polychaetes was maintained by a diversity of strategy dynamics that were complex adaptive processes with non-linear outcomes. They were non-linear because the rate at which Polychaete individuals and species interact to promote sustainability was non-uniform and uniform at the same time. Where the two strategies coexisted or excluded each other due to environmental externalities (pollution, hydrology, organic loading etc.), the strategy dynamics involved in the sustainability game model changed. Thus, the sustainability game dynamics generates a surrogate fitness generating function (G-function) as a diversity metric for a population of Biological Capital such as Polychaetes.

BIOECONOMICS OF BIOLOGICAL CAPITAL

So far, the story of Biological Capital has been told as coded biomass programmed to sustain powerful ecological interactions for the sustainability and satisfaction of human needs.

The use of the term bioeconomics can be traced back to Georgescu-Roegen Bonaiuti (2014) who used the term in the late 1960s to designate an economic order that appropriately acknowledges the biological bases of almost all economic activities. An essential element in Georgescu-Roegen's use of the term bioeconomics was his concern that unlimited growth would not be compatible with the basic laws of nature.

The German government was the first to define Bioeconomy as "the knowledge-based production and use of biological resources (capital) to provide products, processes and services in all economic sectors within the frame of a sustainable economic system. The vision of a sustainable bioeconomy is the comprehensive "biologisation" of the economy, with new bio-based industrial processes and products (e.g., biobased plastics, building materials, etc.) and changes in consumer behaviour. Ultimately, it is about a sustainable growth strategy that creates ecological and economic harmony. The efforts of the EU to promote the concept of the knowledge-based bioeconomy proved remarkably successful. In 2005, the European Commission identified two dimensions of the bioeconomy namely the biotechnology innovation perspective and the resource substitution perspective. The biotechnology innovation perspective was to be an important pillar in Europe's economy by 2030, indispensable to sustainable economic growth, employment, energy supply and to maintaining the standard of living. The second dimension of resource substitution perspective is for the use of crops as renewable industrial feedstock to produce biofuels, biopolymers and chemicals through the conversion of lignocellulosic biomass by enzymatic hydrolysis. However, the increasing concern about ensuring sustainability is reflected in an adjustment of the definition of the bioeconomy. This changing perspective is reflected in the realization that Bioeconomy is based on three main pillars, namely, ecological, social and economics in that order (pers. definition 2022) in contrast to the mainstream order of economic, social and environmental dimensions. This contrast is borne out of the fact that the ecological (environmental) dimension must exist, abinitio, in order to support the social and economic dimensions.

All bio and non-bio activities on earth are based on the insatiable capacity of man to support life and wellbeing through consumption of resources resulting in the divide called developed and developing countries. In high income (developed) societies, the focus is for replacing finite, fossil resources by renewable, biological resources to reconcile macro-economic concerns with climate constraints. However, the current uncontrolled consumption of Biological Capital has triggered critical levels of environmental degradation globally, threatening the capacity of ecosystems to fulfill human needs.

Human needs which are critical and nature dependent have their foundation built on ecological structures (nature/biological), that support and sustain social structures and physical health. Both the ecological and social subsystems are appropriated by the economic system to support the fulfillment of human needs. Current approaches recognize the three pillar or triple bottom line concept of sustainability and the need for an integrated approach of its social, economic and ecological dimensions. However, its application in sustainability assessments tends to lack a systemic approach to the intersection of the social, ecological and economic dimension of the three-pillar concept. In many assessments, pillars tend to be assessed individually, whereby each dimension was given greater priority than another. In particular, economic preferences tend to prevail over other sustainability dimensions, with a tendency towards monetary valuation of ecosystem impacts (costs) and social outcomes (benefits).

Currently, the challenge facing humanity is how to achieve sustainable outcomes using a social-ecological system's (SESs) approach in the formulation of sustainable governance solutions that benefit both people and nature. As a conceptual tool, the SESs framework offers the potential to address how social-ecological sustainability varies with context. However, operationalization has been elusive. Working with Wetlands International in 2014 as the lead Scientist, we used the concept of SES ontologies, to develop an approach that allows for knowledge accumulation that can inform typologies of governance arrangements for particular small-scale Periwinkle fishery outcomes. We were able to demonstrate how this framework can be applied in a new way to identify opportunities and tradeoffs in managing the sustainability of coupled SESs. The SES framework on Periwinkle (issam) fisheries in the Asarama in Andoni area of Rivers State was the focus because of their importance to human communities for both income and food security, as well as the effects this fishery has on estuarine populations and ecosystem health. We defined the potential for social-ecological sustainability as the likelihood that human and nonhuman components of the focal coupled SES will be maintained so as to meet the needs of both people and nature, now and in the future.

Previous work on Periwinkle fisheries (Powell *et al.,* 1985, Onwuteaka *et al*., 2017;) has highlighted the mis-matching of ecological and institutional scales with the likelihood for unsustainable governance of these fisheries as a common pool resource (CPR). Here, we hypothesized that Ostrom's social-ecological system (SES) framework can be useful to build a classification system for the Periwinkle fisheries, regarding their governance processes and outcomes. To test the hypotheses, the area/zones of Periwinkle fishing activity in the area was mapped. Four first tier variables were used to operationalize the SES framework for our focal system. These were Resource Units (RU), the Resource Systems (RS), the Governance Systems (GS) and the Actors (A). The Resource System (RS) is the Periwinkle fishery sector and the Resource Units (RU) are the Periwinkle resources harvested. The Governance System (GS) includes characteristics pertaining to community shaping rules and governance arrangements in Asarama. These determine incentives and behavior for Actors (A) involved in the Periwinkle fisheries. Each of the variables contained in the first tier are resolved into many tier variables. Thirteen (13) variables that linked Periwinkle fisheries SESs variables were nested underneath the first four tiers. Indicators were identified for each of the 13 variables and quantified on the basis of primary data. All 13 variables were normalized to a scale of 0-1 so that they could be combined and compared. In the ecological domain, per capita revenue of the common pool resource (CPR) and the farmed Periwinkle were the two indicators used to calculate a measure of the third dimension - Resource Units. Similarly, the presence of operational and collective-choice rules and the total number of CPR harvesters and farmers were among the indicators used to calculate the measures of the Governance System and the Actors dimensions.

The results in Fig. 4 showed consistent positive relationships between the social and ecological dimensions related to the potential for sustainable resource use. The application of the SES framework demonstrated how social systems can shape ecological systems with feedback loops that influence human activities and wellbeing. As seen in plate 1, the community of Asarama has developed congruence between shared local knowledge/mental models of their resource and developed local leadership conducive to controlling access and use of their fishing areas in three ways. The first is the farming of the resource to promote sustainability followed by an open-source harvesting within a defined intertidal area. A third dimension is the designation of a bio-mangrove bank where no member of the community is allowed to harvest for a number of years in order to allow for genetic conservation of the original gene pool within the locality.

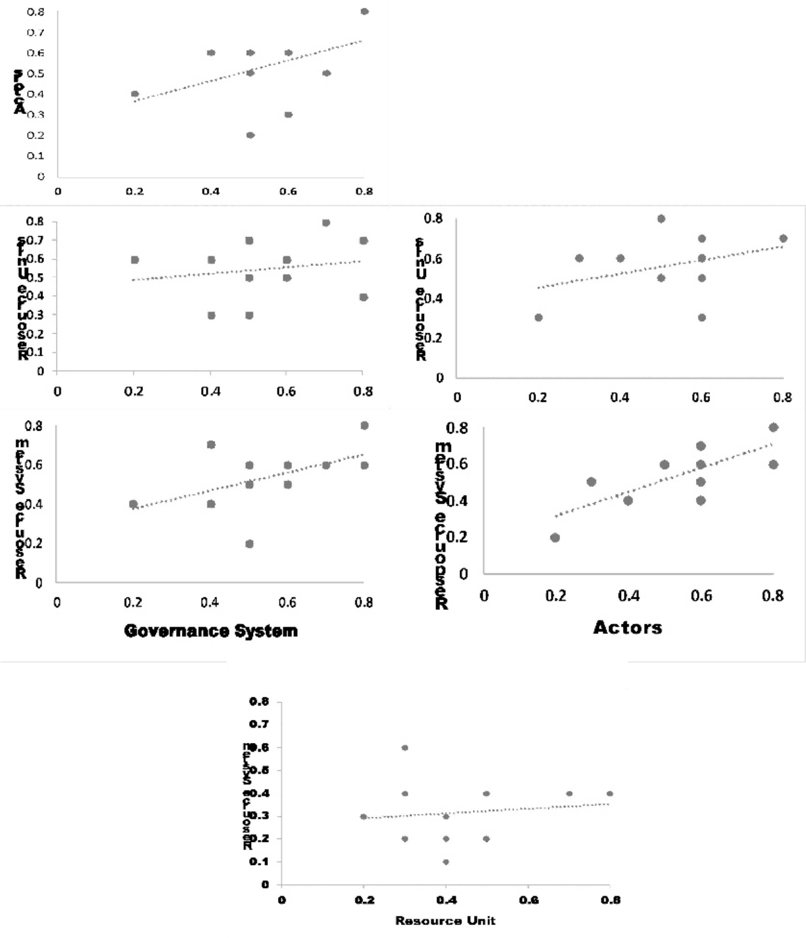


Fig. 4. Scatterplot of the relationships among all four SES dimensions or first-tier variables demonstrates potential for sustainable Periwinkle fisheries from the interaction between the ecological and social dimensions. Values range from 0 to 1, where a larger value is associated with a greater probability that fisheries will be sustainably managed.

Plate 1: Dimensions of the SES framework: Periwinkle harvesters (Actors) of the Resource units (Periwinkle) within the Resources System (Intertidal) flat and the Mangrove BioBank located distally

BIOECONOMICS AND ECOSYSTEM SERVICES

The nexus of a Socioecological framework and Bioeconomics is the promise of reconciling environmental and social goals with economic development. Both concepts are recognized for their multiple and strong links with the UN Sustainable Development Goals (SDGs). Poverty reduction, food security, health, renewable energy, innovation, employment, and climate resilience, among others, are vital contributions of a bioeconomy to wellbeing in society. One other conceptualization and implementation of the bioeconomy is the strong linking to the ecosystem services concept, currently a mainstream concept advanced in policymaking for sustainable land use. Since becoming mainstream in policymaking at the beginning of the millennium (MEA, 2005; TEEB, 2010), the ecosystem services concept has served as a pivotal reference framework for conceptualizing and operationalizing sustainability transformations.

Its main prerogative is to highlight the relevance of natural/Biological Capital and the contribution of ecological processes to human well-being (Braat and de Groot, 2012). Importantly, the ecosystem service framework allows for the identification and analysis of synergies and trade-offs between various societal objectives and impact dimensions (Cord *et al.,* 2017; Schaafsma and Bartkowski 2020). It has been applied in various contexts relevant for the bioeconomy, including multifunctional agriculture (e.g., Albert *et al.,* 2017; Palomo-Campesino *et al*., 2018), forestry (e.g. Makkonen *et al.,* 2015), urban systems (e.g. Gómez-Baggethun and Barton, 2013), and marine ecosystems (Hattam *et al.,* 2015). Moreover, the ecosystem service concept has increasingly been adopted in policies and decision-making (Bouwma *et al.,* 2018).

Ecosystem Services is redefining the basic premise of wellbeing as predicated on the fact that Biological Capital is required for a good life, such as secure and adequate livelihoods, enough food, shelter, clothing, health, including feeling well. The Millennium Ecosystem Assessment (2005) therefore provided the first step in developing a framework that addresses the concept of value in use and exploitation of biological/natural capital. The benefits people obtain from ecosystems were classified into four major services namely provisioning, regulating, supporting and cultural. These include provisioning services such as food, water, timber, and fiber; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling. (Fig. 5)

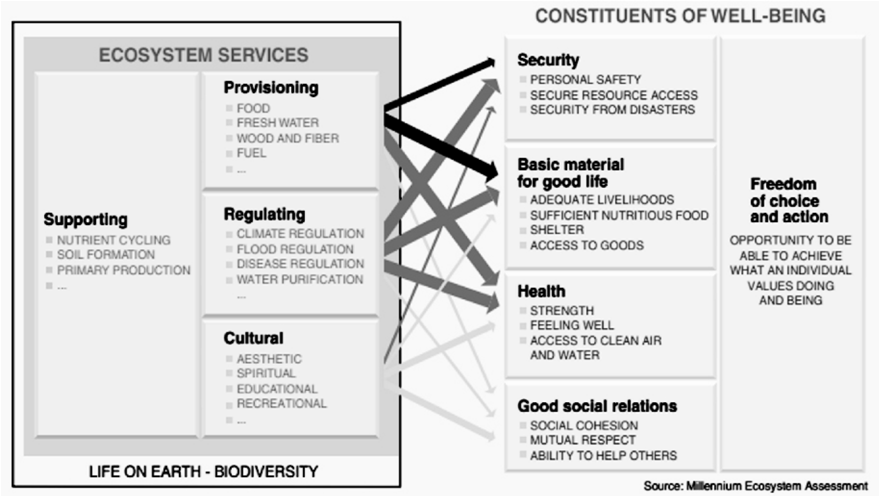


Fig. 5: Ecosystem Services (source: TEEB, 2010)

In contextualizing the ecosystem services paradigm, a transition from a socioecological framework is gradually being shaped by an economic perspective. At the heart of Bayelsa State, in the stunningly beautiful forests of the Niger Delta community of Apoi, is the red colobus (*Piliocolobus epieni*) – an endangered species. Similarly, in the beautiful grasslands of Anambra State are found the Anambra waxbill (*Estrilda poliopareia*). In addition, the honey bee (*Apis mellifera)* provides highly valued pollination services for a wide variety of agricultural crops ranking as the most frequent single species of pollinator for crops worldwide. In our garden city, Port Harcourt, are the periwinkle (issam), the unripe plantain (bole), the fish and seafood species that provide us with culinary pleasures of the palate. In the scheme of things, it is not a "big deal". However, everyone would notice if the oil and gas production in the Niger Delta ceases. Having benefitted for more than four decades from the revenues these reserves have brought, we would find that their absence might create existential crisis. What do these examples have in common? The answer is that they are all specific local or national types of Biological Capital. The red colobus and the Anambra Waxbill yield direct benefits or utility to the observer. They delight but have no obvious uses. The pollinators and the cuisine based capitals are not given the attention they deserve because the public sector and private finance, business practices, consumption choices and attitudes determine resource allocation, degree of environmental concern and development issues, and their environmental impact, whether positive or negative.

Many radical arguments have therefore arisen to insist that because Biological Capital is an elementary foundation for economic activity, its place as a sustainability enabler must be contextualized within the resource allocation framework. That is because of the limitations of standard environmental economics to account for the dependence of costs of production and consumption on natural capital.

However, we look at it, economics forces choices to be made. By making a choice, a value and a price can be put on Biological capital. However, that price cannot be infinite because pricing and valuing the benefits from BC cannot be perfect and would be a limited exercise and fraught with complications. The issue is not what something is worth but how much of this biological or natural capital should be spent to preserve it in a sustainable way for future generations. When services are valued and measured, the composition of benefits can provide an indication of how likely it is that other benefits from indirect, option, or existence values are being managed optimally.

Refusing to put a price or economic value on BC risks environmental meltdown. For instance, in the absence of a carbon price, carbon would continuously be overproduced, In the absence of price, many genetic resources would be overexploited. The collapse of the oyster fisheries in the Niger Delta is because there is no serious price placed on polluters, be they legal or illegal. Oyster larvae called spat are induced to settle through water borne chemical cues which are low molecular weight peptides of amino acids, lysine and arginine. Field and laboratory trials (Garcia *et al.,* 2020) have shown that changes in the physicochemistry of the water, as a result of hydrocarbon contamination, impact the water borne chemical cues that signal these larvae to sink to the bottom or find a mangrove prop root for attachment. By being settlement incompetent, mortality follows in different ways, resulting in poor recruitment increasing social vulnerabilities of wellbeing in humans.

Similarly, the emerging collapse of the Periwinkle (issam) fisheries (Onwuteaka *et al.,* 2017) because there is no price placed on mangrove deforestation is imminent. In a two year study of the "periwinkle" or Issam namely *Tympanotonus fuscatus fuscatus* (smooth issam), *Tympanotonus fuscatus var radula* (the spiny issam) and *Pachymelania aurita* (spiny issam) to assess the economics of nature and its interaction with human economics, two social pressures were observed in operation - an indiscriminate destruction of a mangrove environment for unplanned housing and the extraction of periwinkle by harvesters for economic gain. By using a metric of $1m^2$ quadrats, the lines of evidence showed that the likelihood of obtaining 7-29 snails per quadrat declined by 10-65% in the second year of analysis. In another study (Onwuteaka, 2017), the zoogeography and divergent abundance of *Tympanotonus fuscatus* subspecies presented evidence of the drastic decline/disappearance of the subspecies *Tympanotonus fuscatus var fuscatus* from locations in Rivers and Akwa-Ibom States.

It is therefore necessary that once Biological Capital is viewed as a set of assets, it can be valued in economic calculations. Valued assets are worth protecting and from an economic perspective, the present and the future can be coupled to confront the damage and pollution. Economic valuation of the environment has now become commonplace and the language for environmental policies. Biological Capital is being rephrased in terms of market failure, and market-based instruments for the provision of Ecosystem Services, and are presented as a cornerstone of the new economy for sustainable development. Following the approach by the Economics of Ecosystems and Biodiversity (TEEB) initiative, the economic values associated with Biological goods and services were studied (Onwuteaka *et al.,* 2014) for their total economic value according to the type of use value translated into direct use (DV), indirect use (IV), option value (OV). Non-use value (NUV), Bequest value (BV) and Altruistic Value (AV).

The analyses were approached from a utility perspective in three communities in the Niger Delta. Our argument was that Biological goods in the Niger Delta confer utility to the communities and their valuation will improve utility awareness and hence governance for sustainable management of the biological assets. The study involved the use of Choice Experiments (CE) grounded in Lancaster's characteristics theory of value (1966), which states that any good can be described in terms of its attributes and the levels these attributes take, and consumers purchase the attributes rather than the good itself. Based on different studies and a reconnaissance survey in four communities - Abobiri, Asarama, Obi-Ayagha, and Opume - attributes used in the choice experiment were selected. In addition to the identified attributes, a monetary attribute – volunteer time in hours per day that one would be willing to give to conservation efforts – was included to help in estimating welfare changes (Birol *et al.,* 2008).

Attributes and levels were then assigned into choice sets using a fractional factorial design. Each respondent answered 5 choice questions and each question consisted of a three-way choice: Option A and Option B, which gave an improvement in at least one attribute for a positive cost; and the zero-cost-zero-improvement status quo.

To analyze the Willingness-to-Pay (WTP) estimates, the conditional logit model was used to obtain estimates of WTP. The Multinomial Logistic (Odd and Relative Risk Ratio) Model (MNL) is specified thus:

$$Pr\, Pr\,(X_i) = \frac{1}{1 + \left[\frac{1}{e^{(\delta_0 + \delta_i X_i)}}\right]} \quad (1)$$

For example, in Asarama, the utility or well-being (of the ith respondent for the j different alternatives in the choice set) depended simply (and linearly) on the attributes of the choices presented to respondents and unobserved factors and were analyzed as follows:

$$U_{ij} = \beta_0 + \beta_1(Carbon)_{ij} + \beta_2(Fish)_{ij} + \beta_3(Periwinkle)_{ij} + \beta_4(Mudskipper)_{ij} + \beta_5(Salinity)_{ij} + \mu_{ij} \quad (2)$$

The results for the Asarama community in Andoni, Rivers State showed that all coefficients, except fish catch, were statistically significant at the 1% level (Table 2a). This meant that the utility of the environmental protection alternatives was positively related to carbon sequestration, fish catch, periwinkle catch, and mudskipper catch; while this utility was negatively related to salinity. In conditional logit model, the model coefficients and marginal effects were the same, and hence model coefficients can be interpreted as marginal effects which represent the absolute change in the choice probability for one of the environmental protection options that resulted from a one unit or 1% increase in the explanatory variable.

Table 2a: Estimation results of an attribute only model with volunteer time

Variable	Coefficient
Volunteer time	-0.12187***
Carbon Sequestration	0.00035***
Fish Catch	0.00007
Periwinkle Catch	0.00796***
Mudskipper catch	0.00154***
Salinity	-0.07163***
Pseudo-R2	31.83
Log-likelihood	699.39***
Observations	3000

Notes: *** stands for significant at the 1% level; * significant at 10%:

Source: Wetlands Technical Report (Onwuteaka *et al.*, 2014)

Table 2b shows individual maximum willingness-to-pay (WTP) per attribute in terms of volunteering time per month or monthly opportunity costs. The results showed that individuals are, on average, willing to spend approximately 87 hours per month for an additional ton of sequestered carbon, 18.42 hours per month for an additional one tonne of fish catch, 19.58 hours per month for an additional tonne of periwinkle, 3.8 hours for an additional tonne of mudskipper, and 17.63 hours per month to prevent an increase in a unit of salinity.

The figures about willingness-to-pay in volunteer time were translated to opportunity cost amounts by multiplying hourly time with the local average hourly wage. For this analysis, we assumed a mean rural wage of 850 Naira per day which translated to 106.25 Naira/hour. This results in monetary WTP values of 7645 Naira per ton of sequestered carbon, 1612 Naira per ton of fish, 1714 Naira per ton of periwinkle, 331 Naira per ton of mudskipper, and 1543 Naira prevented increase in a unit of salinity.

Table 2b: Maximum willingness-to-pay per attribute in terms of volunteering time per month or monthly opportunity costs

c	WTP in time (hrs)	WTP in opportunity costs (Naira/Month)	WTP in opportunity costs (US$/Month)
Carbon Sequestration	87.37	9,283	46.65
Fish Catch	18.42	1,957	9.83
Periwinkle Catch	19.58	2,080	10.45
Mudskipper catch	3.79	403	2.02
Salinity	17.63	1,873	9.41

Source: Wetlands Technical Report (Onwuteaka *et al.,* 2014)

From Table 2b, on average, each household was willing to contribute an equivalent of between US$ 46.65 to ensure carbon sequestration; US$ 9.83 per month to conserve fish catch; US$ 10.45 per month to ensure continued periwinkle catch; US$ 2.02 per month to conserve mudskipper catch; and US$ 9.41 per month to reduce salinity, respectively. These figures can also be expressed on an annual basis. The values—both in Naira and US$--are as shown in Table 2c. Therefore, every single year—assuming constant returns to scale of the wetland values—each household will be willing to contribute between US$ 24.3 and US$ 560 for the different ecosystem services.

Table 2c: Maximum willingness-to-pay per attribute in terms of volunteering time per year or Annual opportunity costs

	WTP in time (Days/Year)	WTP in opportunity costs (Naira/Year)	WTP in opportunity costs (US$/Year)
Carbon Sequestration	131	111,397	559.78
Fish Catch	28	23,486	118.02
Periwinkle Catch	29	24,965	125.45
Mudskipper catch	6	4,832	24.28
Salinity	26	22,478	112.96

Source: Wetlands Technical Report (Onwuteaka, et al., 2014)

These unit values were aggregated to evaluate the total benefits of a given option to conserve Asarama wetland. This was calculated from physical increases or reduction in the attribute levels. These was then multiplied by the implicit price for that attribute. For example, for an option that aims at capturing the total benefits from the wetland, the total benefits per household of this policy was calculated as the willingness to pay per year, multiplied by change in attribute levels (highest –baseline). For example, the change in attribute level for carbon sequestration was (1.8-1.39=0.41 tons) (Table 2d).

Table 2d: Maximum willingness-to-pay per attribute for attaining the highest attribute level

	Change in attribute levels	WTP in opportunity costs (Naira/Year)	WTP in opportunity costs (Naira/Year)
Carbon Sequestration	0.41	157,070	789.29
Fish Catch	1.8	42,275	212.44
Periwinkle Catch	2.3	57,420	288.54
Mudskipper catch	3.3	15,946	80.12
Salinity	1.3	29,221	146.85

Source: Wetlands Technical Report (Onwuteaka *et al.,* 2014)

Therefore, to capture the full benefits of the wetland, each individual household was willing to pay between US$ 80.12 for mudskipper catch, and US$ 789.29 for carbon sequestration.

For policy and decision making, these annual household values need to be expressed from the perspective of the selected sample and the total number of people benefitting from the wetland. From Asarama, we sampled 200 households and calculations showed that the sampled households had a total annual willingness to pay that ranges between US$ 16,024 and US$ 157,858 for the different ecosystem services (Table 2e).

Table 2e: Sampled households' Maximum willingness-to-pay per attribute Annual opportunity costs

	WTP in opportunity costs (Naira/Year)	WTP in opportunity costs (US$/Year)
Carbon Sequestration	31,414,000	157,858
Fish Catch	8,455,000	42,488
Periwinkle Catch	11,484,000	57,708
Mudskipper catch	3,189,200	16,024
Salinity	5,844,200	29,370

Source: Wetlands Technical Report (Onwuteaka, *et al.,* 2014)

We also considered the society, strictly the number of households directly benefiting from the different ecosystem values. This figure for Asarama was estimated at 2,500 households and was multiplied by the households' mean willingness to pay per year in Table 2e. The results are shown in Table 2f and they show that the annual total willingness to pay for the society ranged from US$ 50,700 for mudskipper and to US$ 1.17 Million for carbon sequestration. Therefore, the total indirect use value for Asarama wetland was US$ 31.46 Million (Table 2f).

Table 2f: Community' maximum willingness-to-pay per attribute in Annual opportunity costs

	WTP in opportunity costs (Naira/Year)	WTP in opportunity costs (US$/Year)
Carbon Sequestration	392,675,000	1,973,225
Fish Catch	105,687,500	531,100
Periwinkle Catch	143,550,000	721,350
Mudskipper catch	39,865,000	200,300
Salinity	73,052,500	367,125
Total Indirect Use Value	**754,830,000**	**3,793,100**

Source: Wetlands Technical Report (Onwuteaka *et al.*, 2014)

These values were converted to monetary values per hectare. This value was calculated by dividing respective values with the total acreage of 2020 hectares of the wetland in Asarama. These values, also known as average value per ha, are shown in Table 2g. Therefore, assuming each hectare contributes equally to the various indirect use values, one hectare of the wetland in Asarama contributes to an equivalent of US$ 977 towards carbon sequestration; US$ 262 for preserving fish catch; US$ 357 towards preserving periwinkle catch; US$ 99 towards reduction in salinity and US$182 towards improved mudskipper catch. The total indirect use value per hectare was therefore US$ 1,878 (Table 2g).

Table 2g: Average Indirect Use Values across Different Ecosystem Services (Naira. and USD per Year)

	WTP in opportunity costs (Naira/Year)	WTP in opportunity costs (US$/Year)
Carbon Sequestration	194,394	976.84
Fish Catch	52,321	262.92
Periwinkle Catch	71,064	357.10
Mudskipper catch	19,735	99.16
Salinity	36,165	181.75
Average Indirect Use Value	**373,678**	**1,878**

Source: Wetlands Technical Report (Onwuteaka *et al.*, 2014)

We concluded that research participants using the community in Asarama appreciated the existence/non-use values of the parameters of the Biological goods measured. Our data revealed that the average resident at Asarama has positive attitudes towards sustainability when their knowledge level about sustainability is made available through valuation.

INDICATIVE POTENTIAL OF BIOLOGICAL CAPITAL IN THE NIGER DELTA

At present, the utilization of Biological Capital is receiving increasing attention, globally (EC., 2018; UNEP, *2011*). Owing to their impact on life quality, health, and ecosystems, efforts are being made to replace non-renewable natural resources in energy production (EC., 2005; Yang *et al.,* 2016), manufacturing, and services, with renewable alternatives. The world is adopting the EU concept of bioeconomics which is based on knowledge creation with emphasis on three key aspects namely: (1) Strengthen and scale upthe bio-based sectors, unlock investments and markets; (2) Deploy local bioeconomies rapidly across the whole of Europe and (3) Understand the ecological boundaries of the bioeconomy.

Despite the recognition of the importance of knowledge creation and innovation, knowledge on how to develop innovations from the massive inventory of Biological Capital to organizational or value chain levels is scarce in Nigeria and Niger Delta. These innovations range from small and gradual changes to totally new and radical innovations. Innovations in Biological Capital of the Niger Delta and Nigeria in crop agriculture, wood and non-wood forestry (mangrove and freshwater swamps), Algae, wildlife, avifauna, herpetofauna, insect fauna, fisheries and microflora have roles in regional innovation systems in the field of nature based tourism, recreation, pharmaceuticals, bioplastics, Biofuel, biorefinery, biochemicals and bioenergy. Innovations are the mechanism through which companies can adapt to bioeconomy-related challenges; and adapting to these challenges is even more difficult if there is no clear understanding of which inter-organizational factors are critical for success of innovations, what kind of operating environment fosters their development, and what kind of external support is needed to make them work.

The Biological Capital of the Niger Delta currently does not have any government backed policy for market or non-market valuation. Currently, there is, in its infancy, an emerging National Bioeconomy Strategic Framework launched in January 2020 by the Federal Government. Bioeconomy is known to have the potential to address some major societal challenges, such as food security and sustainable natural resource management, as well as reduce the dependence on nonrenewable resources, creating jobs and maintaining international competitiveness. Currently, the European bioeconomy has an annual turnover of approximately 2 trillion euros and employs 22 million people. The EU is able to have good potential for developing its bioeconomy, as it is largely self-sufficient in many agricultural, forestry and marine products. In Nigeria, a Biological Capital such as Palm oil, apart from food security, has great potential for a number of biobased industries in pharmaceuticals (special source of vit. E); biorefinery, cosmetics and feedstock, lignocellulose conversion into adsorbents and bioplastics. The insufficiency of local production in Palm oil and a few other raw materials of Biological Capital, as in fisheries, poses a challenge of attaining traction in the bioeconomic transition to sustainable use of renewables. It is documented that Nigeria imports Palm oil to the tune of 1.3 million metric tons (approx.500 million Naira) while we still import Croakers, Tilapia and many other pelagic fishes to shore up our fish protein security. For a country grappling with population increase, fluctuating and dwindling oil prices and a host of other socio-political challenges, these statistics of insufficiency is an opportunity for innovation in local and national capacity building and entrepreneurship.

In Nigeria and the Niger Delta, access to raw Biological Capital (Biomass) provides a good basis for developing the bioeconomy. However, availability and abundance of raw Biological Capital is not enough in the emerging knowledge-driven bioeconomic world. Systemic innovation from knowledge flows among industry, public/private sectors, technology diffusion must integrate to identify leverage points for enhancing performance and overall economic outputs. This new bioeconomics, which is still in its infancy, conceals a number of interrelated alternatives in four key dimensions: raw materials, conversion technologies, products, and business models. The mapping of raw materials for kick starting the bioeconomic revolution are currently clear priorities for Niger Delta and for Nigeria.

MAPPING RAW BIOLOGICAL CAPITAL OF THE NIGER DELTA

In the mapping of BioCapital, I am singularly privileged to be part of study teams that engaged in the inventory of raw Biological Capital from five major surveys. The first was the Imevbore/ Niger Delta Basin Development Authority survey from 1982 to 1984. The second was the RPI/NNPC (1985) survey of the Environmental Baseline Studies in Nigeria titled "The Establishment of Control Criteria and Standards against Petroleum Related Pollution in Nigeria". The third survey was the Niger Delta Environmental Survey (1997) which was managed by Shell Petroleum Development Company on behalf of the Oil Producers Trade Section (OPTS) of the oil and gas companies. The fourth was a Biodiversity survey of Brass Island – a project required by World Bank as a criterion for the fulfillment of IFC Performance standard 6 and sponsored by Brass LNG Ltd. The fifth was the mapping and valuation of Biological Capital in three states of the Niger Delta namely Rivers, Bayelsa and Delta by Wetland International Inc. The project was domiciled in the Applied and Environmental Biology Department between 2012 to 2014.

From these surveys the Biological Capital inventory provides us with the first generation of raw materials for bio-based innovation and research in bioeconomy. Nonetheless, a common understanding of what bioeconomy is, or what it should be, is still in formation. In our Universities, evidence of quality basic research in related areas of bioeconomy exist. However, the potential solutions from academia lack functional markets, and market-based funding opportunities. Therefore, the jump from research to market has been problematic, and is the reason why many bio-based initiatives tend to generate very little activity at the start-up level. This said, there are specific inventoried BioCapital where novel ideas can become hot topics for attracting venture capital. One of the lowest hanging fruits regarding the future of bioeconomy in the Niger Delta and Nigeria is represented by the multiple opportunities related to algae production in Plant and Biotechnology departments. With a multidisciplinary team, consisting of Plant and Biotechnology scientists and economists, new ways can be explored for growing sustainable and profitable products from algae mass. The exciting thing about algae is that one can potentially develop a very wide array of different products using algae as raw material. You can make biofuels, animal feeds, and different pharmaceutical and health products, using its oil, for instance, to make plastics. In fact, algae are like little bio-factories that can be widely applied for different human needs. The products on the current markets are usually made using about 10 different algae species, where in reality our inventory in the Niger Delta Environmental Surveys (1997) identified 469 species. A related area considered an interesting eco-innovation is the employment of earthworms in the process of decomposition of organic matter. Earthworms fit perfectly into the circular economy concept, as they can transfer different types of organic wastes (domestic and industrial) into renewable energy sources or biosoils. This method known as Vermicomposting is constituting an alternative to other waste disposal techniques considered not to be environmentally friendly. This eco-friendly (reduced $CO_2$and CH_4) approach has a low cost business model and a world market value of USD 63.55 Million in 2019. The two species with the highest global vermicompost capacity namely *Eudrilus euginea* and *Lumbricus terrestris* were identified in our inventory in the NDES (1997) survey.

Another BioCapital worthy of mention is the discovery of the vanilla orchid in Brass island during the BioCapital inventory of Brass island in Fig 6. This BioCapital whose native area is Mexico and Central America but now grown in Madagascar, Caribbean, Mexico, Comoro Islands, Indonesia, Hawaii, and Tahiti provides jobs for at least 70000 farmers in Madagascar but so far none in the Niger Delta.

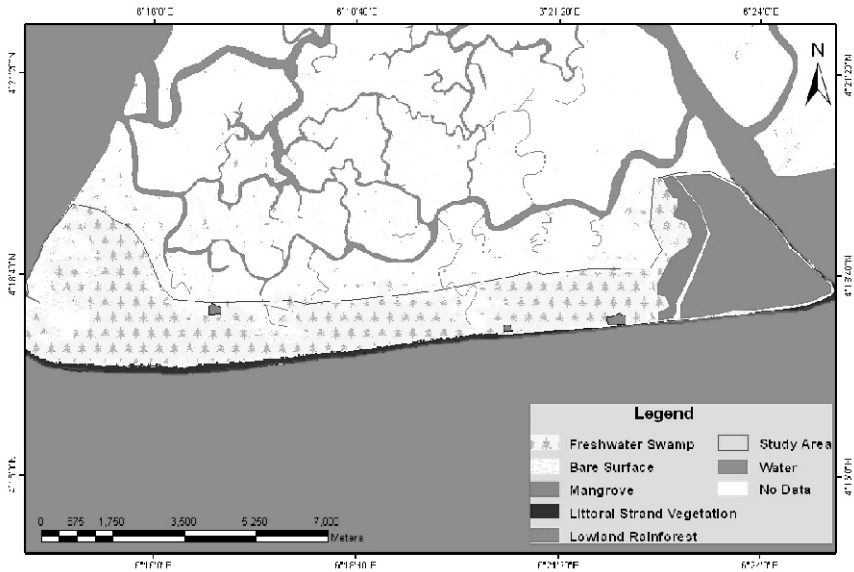


Fig. 6: Lowland Forest location of Vanilla (Vanilla plantifolia) orchid in Brass Island

Another major and unique raw BioCapital required in the bioeconomic innovation startup is the Mangrove Forest and associated ecosystem goods. This peculiar gift from the day of creation is the third largest in the world, and the largest in Africa. Along the various phases of the value chain of ecosystem services, mangroves are critical raw materials to the whole supply chain of extraction and manufacturing of biotic and abiotic raw materials. Current raw material score sheets for mangroves show a fast depletion by Nypa palm. There is therefore a risk of supply disruption in the creation of more sustainable, renewable bio-based products in the transition towards a circular bioeconomy. The maxim by Peter Drucker of “what you cannot measure, you cannot monitor or manage” prompted research into developing an updated referencing system of mangrove stock throughout the Niger Delta.

To enable a Nypa-Mangrove estimator, satellite imagery and geographic information systems were combined with field studies and a TEXVEG algorithm to discriminate Nypa from mangrove (Onwuteaka *et al.,* 2014). The technique, which was the first in the world of remote sensing at the time, utilized a combination of spectral and textural values to achieve discrimination. The technique recognized the similarity in spectral properties but leveraged on the significant difference in textural property resulting in the TEXVEG algorithm. This can provide a tool to map and develop best available data in enhancing research into smart and sustainable biobased products and processes from the mangrove. A summary of the process and results are shown in Fig. 7.

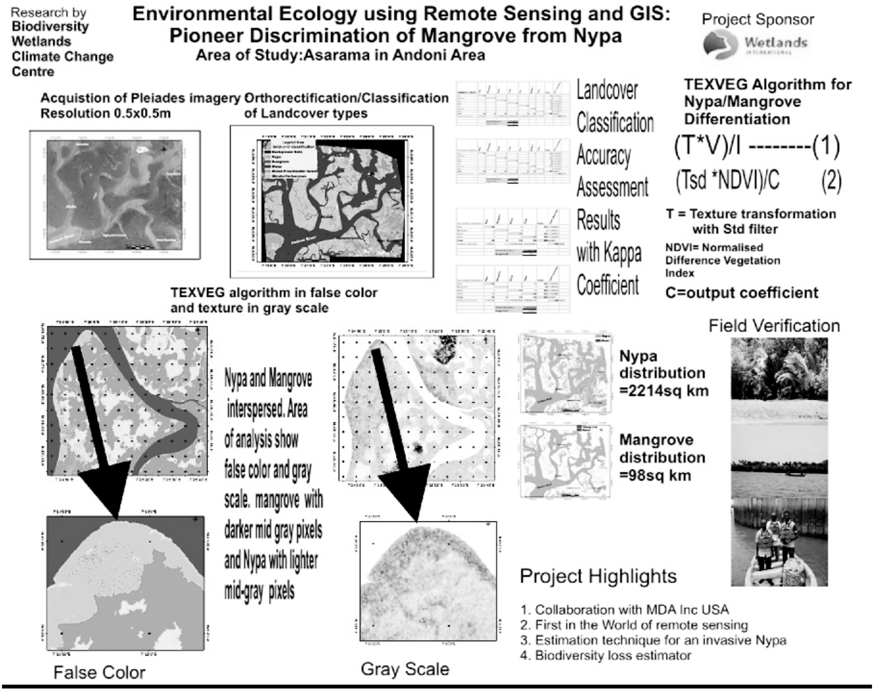


Fig. 7: Nypa-Mangrove Invasion estimation in Asarama in Andoni area of Rivers State.

A fourth and one of the most important raw material BioCapital is the Periwinkle or “issam" also know in scientific literature as *Tympanotonous fuscatus var fuscatus, Tympanotonous fuscatus var radula and Pachymelania auritus.* The Periwinkle is an ecosystem good that is significantly renewable and has a value chain potential of not only a provisioning service for our culinary pleasure but can also provide high pharmaceutical value. Isaam contains an iodine content of 40.785mg/l (Anyalebechi *et al.,* 2001). Iodine is needed by the thyroid to make hormones and its deficiency during pregnancy and in the food we eat has serious medical consequences. An iodine supplement that can provide 150 mcg can be a game changer for many people with potential hypothyroidism (low thyroid function).

REBUILDING PERIWINKLE FISHERIES WITH BIOECONOMICS

The Periwinkle (*Tympanontonous fiscatus var fuscatus, Tympanontonous fiscatus var fuscatus and Pachymelania auritus*) or the famous “issam" belongs to the blue bioeconomy and offers a large potential of contributing to quite a number of Sustainable Development Goals, including food security, food safety, responsible consumption, blue economic startups and climate action. Three major challenges are emerging and they fall into three main themes. The first is the disruption of amphipod based organic matter-algae production from mangrove leaf litter by hydrocarbon contamination (Benson and Essien, 2009; Moslen, and Miebaka, 2017; Gwary *et al.,* 2019; Ihunwo *et al.,* 2019; Edori *et al.,* 2021). The second is the increased deficiency of organic matter production from Nypa palm invasion (Sunderland and Morakinyo, 2002; Isebor *et al*., 2003) and thirdly the declining fish yield and the convenient switch to periwinkle harvesting as a source of livelihood. The last factor is leading to overharvesting resulting in small sized animals (Powell *et* *al.,* 1985; FAO/FIDI, 1994; Bob-Manuel, 2012; Okpeku *et al.,* 2013; Onwuteaka *et al.,* 2017; Numbere 2019) across the Niger Delta. In order to cope with an increasing population, rapid depletion of this resource, increasing environmental pressures and climate change, there is a need to radically change the approach to mass production, harvesting and consumption of this BioCapital.

BIOECONOMIC MODEL DEVELOPMENT

In this inaugural lecture, the focus is on the use of bioeconomic modelling for developing rebuilding strategies. This approach is particularly useful because the Periwinkle BioCapital is an example of the concept of the "tragedy of the commons". This concept is the situation where individual users, who have open access to a resource unhampered by shared social structures or formal rules that govern access and use, act independently according to their own self-interest and, contrary to the common good of all users, cause depletion of the resource through their uncoordinated action. Many BioCapital resources such as Oysters, Anadara, Eigeria, land snails and many wildlife resources we call "bushmeat" are currently being affected by this concept.

In Asarama, in Andoni local government of Rivers state, where the bioeconomic studies are being carried out and much of the Niger Delta, harvesting rights are not established or enforced for harvesters. With such open access harvests, households do not typically consider the value of leaving BioCapital stock in situ to mature and harvest at a later date because other harvesters are likely to harvest it in the meantime. As long as household labour is not in short supply, households continue to harvest until the last harvester cannot make an economic profit from further harvesting. In contrast, at the extreme of open access, harvests of Periwinkle are limited to farmers with exclusive farmed spaces within the intertidal habitats.

Within the bioeconomic rebuilding strategy two aspects of data are being examined namely one in which rate of harvest equals the natural regeneration rate leaving the BioCapital stock unchanged or in a steady state over a harvest period and on the other in which unsteady state conditions persist due to anthropogenic factors that exert pressure on the stock.

BIOECONOMICS OF OPEN-ACCESS AND EXCLUSIVE HARVESTING

The bioeconomic rebuilding strategy was carried out in an area of approximately 595 hectares as shown in Figs 8 to 11. Data collected from both the open access and exclusive harvesters were used to calculate a basic Minimum Sustainable Size (MSS). The idea of the MSS is theoretically the smallest size that can be harvested without permanently depleting the BioCapital over time.

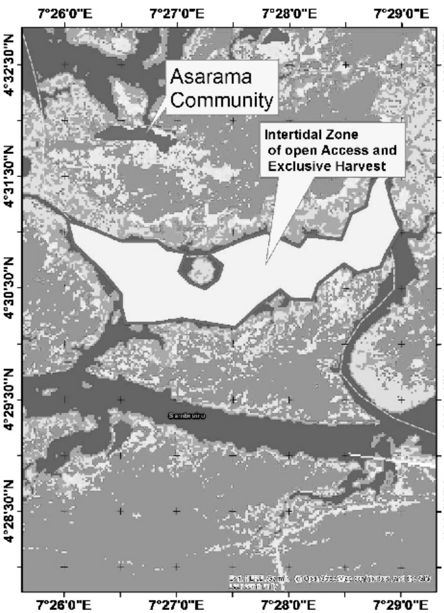


Fig 8: Area of Interest for Periwinkle Study

Fig 9: Exclusive Farms of Periwinkle

Fig 10: Open Access Harvest in Intertidal Habitat

Fig 11: Open Access Harvest in intertidal habitat

The results of the open access harvesting characterize the strategy differentiated by harvest (effort), yield in terms of abundance (catch) and yield in terms of size of the BioCapital. Mathematically this is given by the following equations:

$$H = E^{*} \; V(S) = G(S) \qquad (1)$$

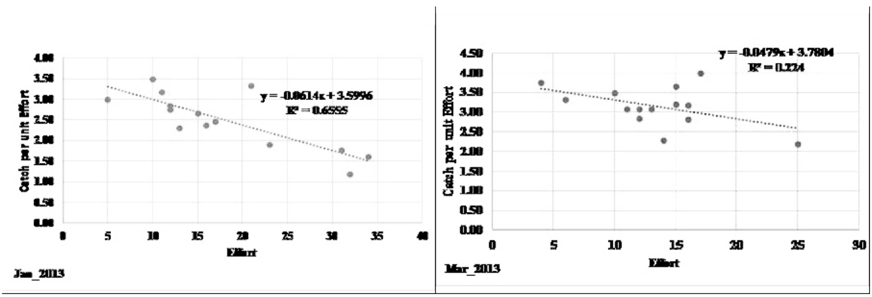
$$G(S) = H = E \times V(S) \qquad (2)$$

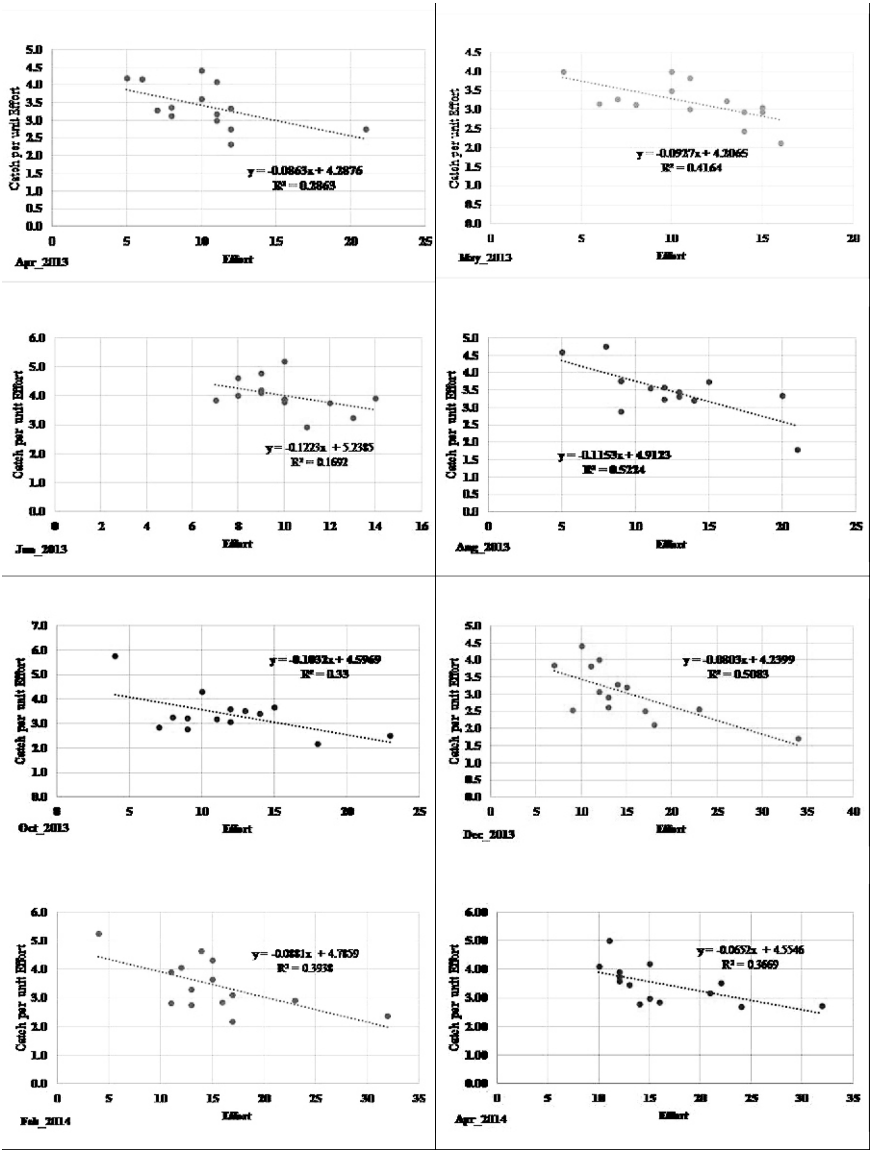
where G(S) indicates the growth of a biological stock per time period where S indicates the level of the stock; V is harvest rate. To compute the value from the harvested stock, given that it is traded in the market, the Net present value NV can also be mathematically described as

$$NV = (p^* H) - C = E \times ((p \times V) - W - Y) \qquad (3)$$

where NV = Net value; p = market value; C = total cost of labour; W = hourly average wage of labour; Y = cost of capital equipment per unit of harvest equipment.

An examination of the results from a two-year study indicate that, as effort is increased in the open access, the catch per unit effort decreases (Fig 12). Additionally, in the open access model, the decrease in catch per unit effort is followed by decrease in the size of the Periwinkle leading to the harvesting of immature stock(<1cm). By intersecting the range of immature sizes from the open access model with the growth curve in the exclusive harvest model (Fig 13), a growth and recruitment overfishing was revealed




Catch per unit Effort
Effort
Apr_2013
y = -0.0863x + 4.2876
R² = 0.3863
May_2013
y = -0.0927x + 4.2065
R² = 0.4164
Jun_2013
y = -0.1223x + 5.2385
R² = 0.1692
Aug_2013
y = -0.1153x + 4.9123
R² = 0.5224
Oct_2013
y = -0.1032x + 4.5969
R² = 0.33
Dec_2013
y = -0.0803x + 4.2399
R² = 0.5083
Feb_2014
y = -0.0881x + 4.7859
R² = 0.3938
Apr_2014
y = -0.0652x + 4.5546
R² = 0.3669

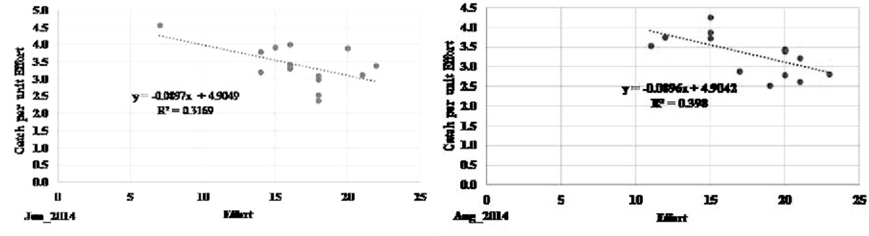
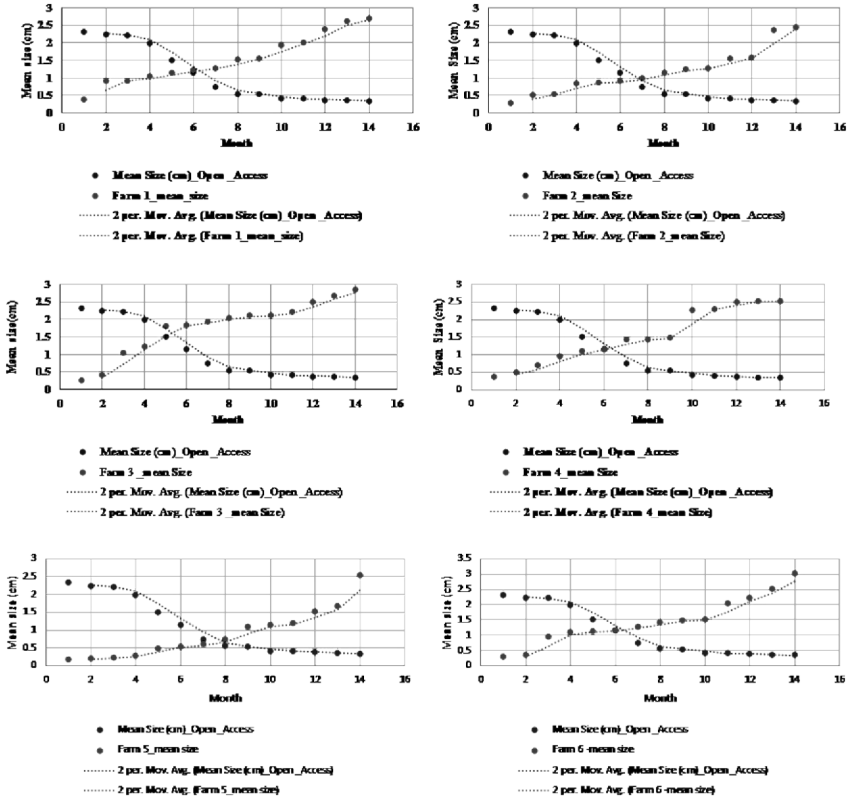


Fig 12. Open Access Harvest unsteady state harvest volume



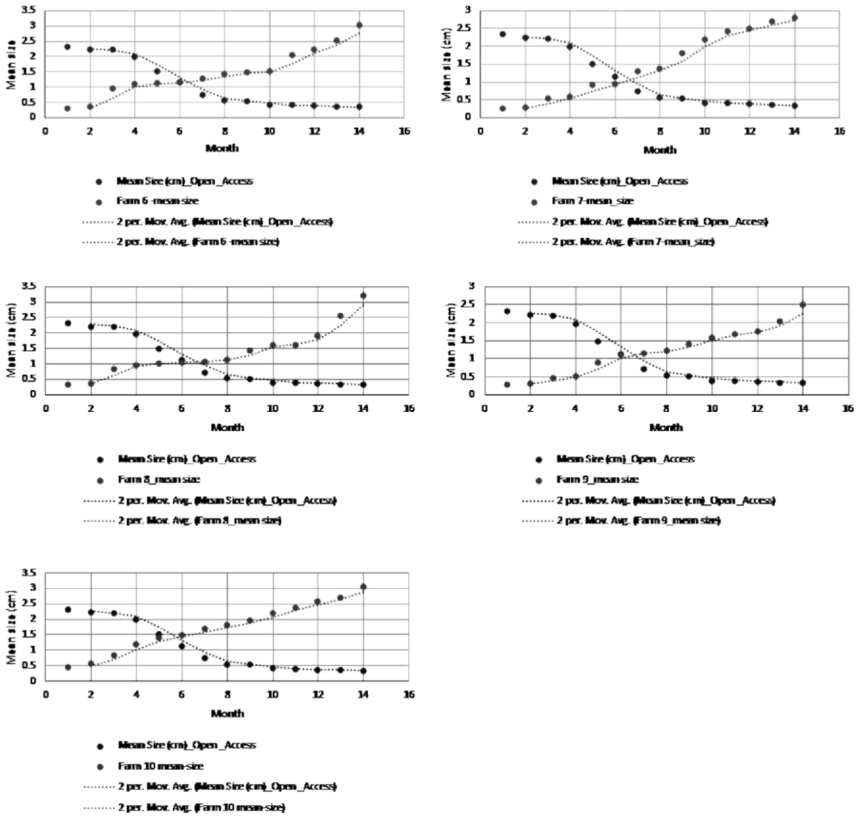


Fig 13: Open Access and Exclusive Access harvest and Growth

The growth and recruitment overfishing was due to the fact that high exploitation rates in the open access was targeting small and immature periwinkle (<1 cm) thereby reducing the abundance of mature individuals. The likely result would be a decline in spawning biomass to the point where recruitment is significantly impaired. The study provided evidence of maturity of Periwinkle at a minimum of 8-10 months when they reach sizes of 2cm. Ideally, in environments with strong community regulatory institutions, one of the ways to support the exclusive harvest model is to impose a size limitation policy on the open access harvest model. Such bioeconomic management policies of imposing a minimum size restriction at or larger than the age or size at maturity would (1) be protecting recruitment (i.e., allowing Periwinkle to spawn before harvest) and (2) maximizing yield per recruit, which typically is highest when Periwinkle starts at sizes near the optimum length (that is, the length that maximizes the cohort biomass).

In response to these trends, our contribution was twofold. The first was to study the basic bioeconomic model of exclusive access to determine the viability of this model of conservative exploitation. The results showed that the largest farm of 5000 m^2 yielded approximately 2000 "custard buckets" at the end of 10 -12 months with a wholesale market price of N1.8 to 2 million Naira which is approximately the salary of an Assistant Lecturer. The second response was to provide the potential of increasing the intertidal habitat for periwinkle farming within the mangrove habitat available to the community. A Satellite-GIS based technique was used to delineate intertidal habitats into classes of one to nine hectares that are contiguous within the boundary of Asarama community (Figs. 14 and 15). A time travel analysis was also developed to provide the bioeconomic value of travel time as a function of distance, and the cost of effort in relation to the optimal harvest value for either those of the open access or exclusive harvest model.

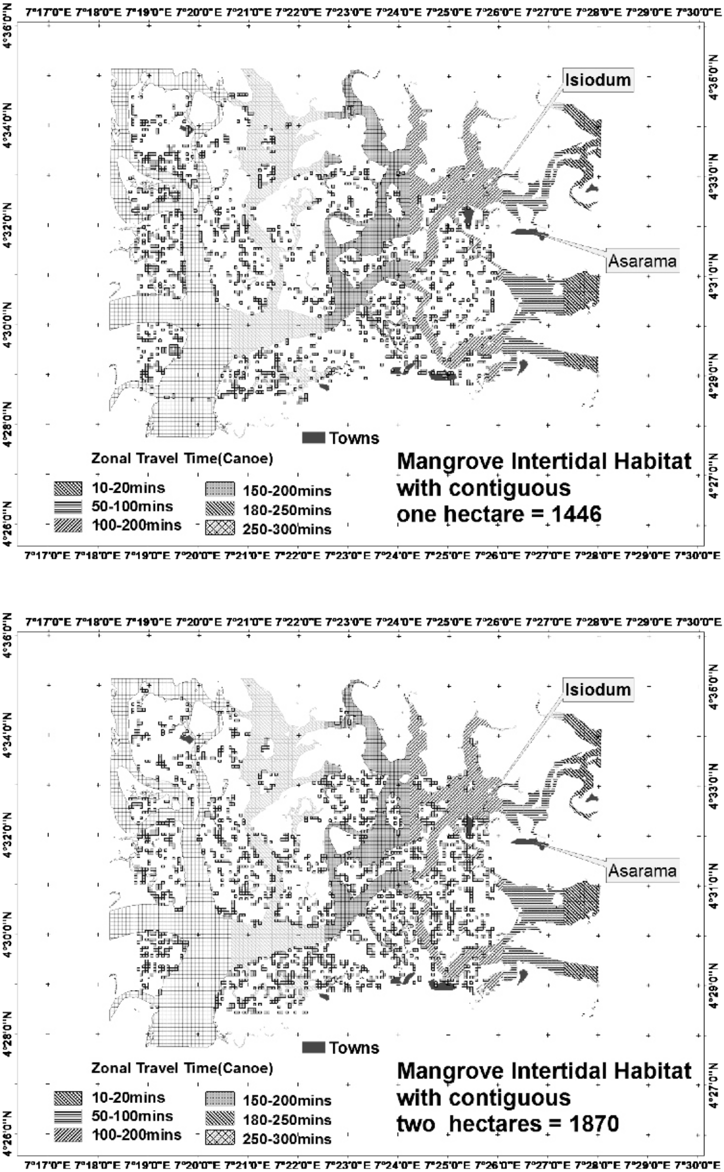
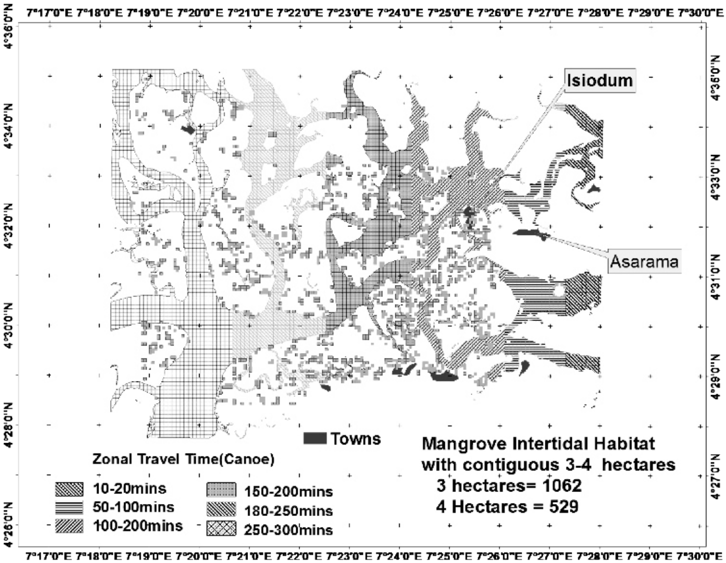


Fig. 14: Travel time and potential mangrove hectares for Periwinkle farming



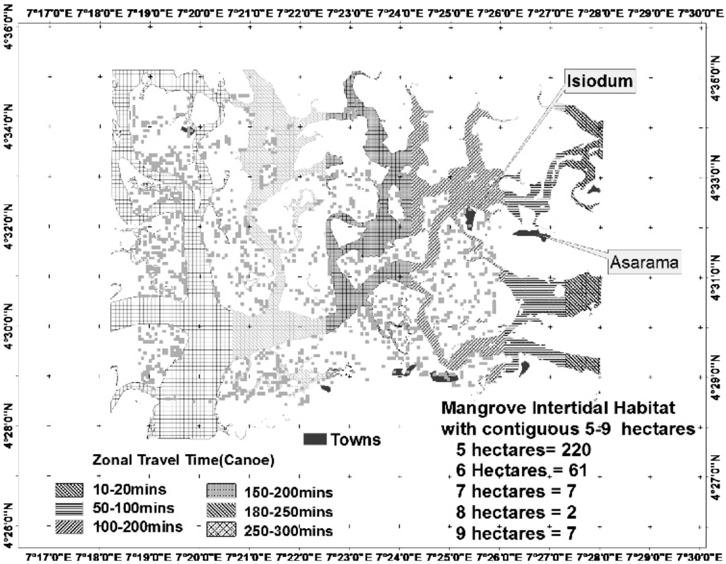


Fig. 15: Travel time and potential mangrove hectares for Periwinkle farming

From this study, there is justification for the use of bioeconomics in rebuilding any of the seafood fisheries as it captures the behaviour of harvesters, helps in identifying winners, losers, or the role of special interest groups for a suite of policy-relevant analysis. The delineation of mangrove habitats, where potential farming can take place, is a bioeconomic win for the community as it can provide jobs and expand economic endeavour with high financial profitability. There are over 5000 hectares of mangrove intertidal where farming can be activated with the potential financial annual yield of over 3 million Naira per hectare. Taken together, these studies provide an example of how bioeconomic models can be used to evaluate economic and social objectives and provide a basis for management debate across a wide range of stakeholders in the Niger Delta.

BIOECONOMICS POTENTIAL OF OYSTER

The oyster, scientifically known as *Crassostrea gasar*,is a Biological Capital with a high esteem value as the Periwinkle because of its local and global appeal. Currently, it is a Biocapital in great decline because of two challenges, namely the hydrocarbon contamination from illegal refining and the lack of a hatchery. Like the Periwinkle, it is a job creator, job facilitator, entrepreneurship startup, business incubator and employer because of the linkage to the global economy. Oysters, unlike oil and gas resources, are renewable Biocapital resources with huge socioeconomic and environmental value and benefits. Many more communities are capable of depending on mangroves than the oil and gas income.

The African Regional Aquaculture Centre in Port Harcourt is the only public institution trying with great difficulty to restore this valuable resource. The oyster which breeds well in salinities between 10-27 parts per thousand is being cultured in Buguma located in 10 parts per thousand. The limitation of a non-existing hatchery has confined the Centre to wild harvesting which requires the location and collection of mangrove prop roots with the oyster Spat. Wild harvesting BioCapital resources such as oysters and periwinkle is no longer sustainable and provides opportunity for new ways. This is made more unsustainable with the massive contamination of the environment by illegal refining in and around Buguma since 2016. Personnel from the centre has to travel many kilometers as seen in fig. 16 to obtain wild spat.

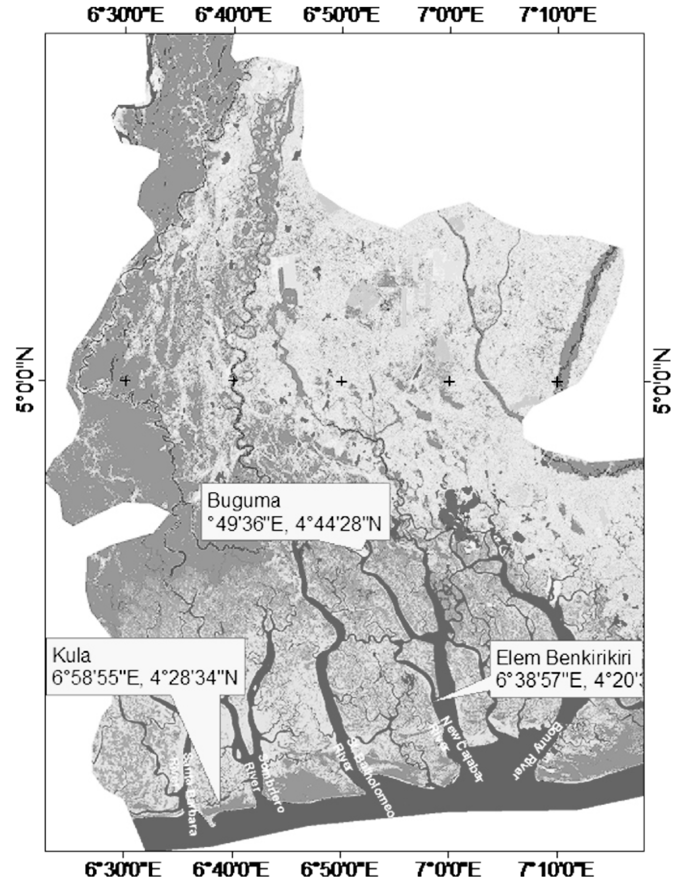


Fig. 16: Locations of likely wild Oyster Spat collection from ARAC in Buguma (Kula = 64 km; Elem benikiriki = 32km)

Given the emerging decline in oil and gas proceeds, due to emphasis on decarbonization and climate change knock–on-effects as well as the rising unemployment among the youth, the Niger Delta oyster BioCapital must move towards a farming-based regime. The socioeconomic opportunities are huge and as can be seen from Fig. 17, approximately 1.2 million hectares of intertidal mangrove habitat are available for small, medium and large-scale enterprises.

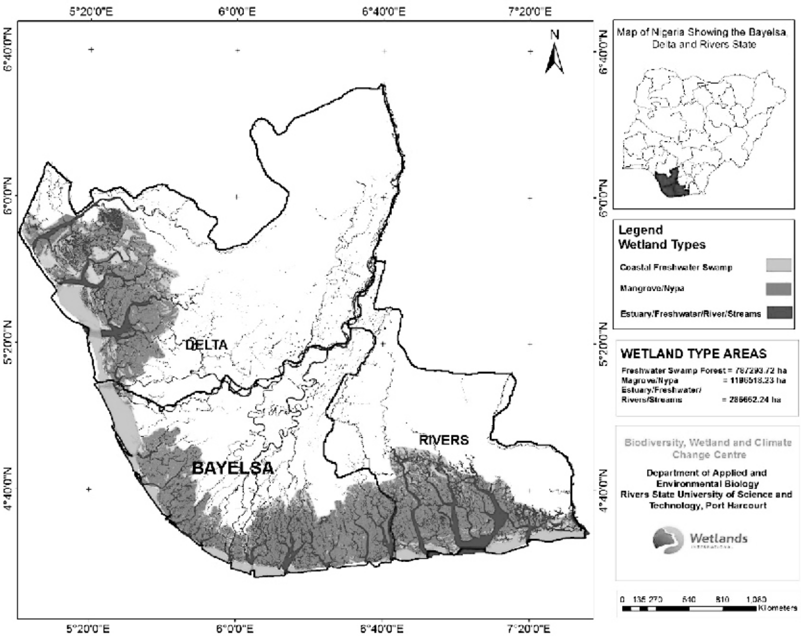


Fig. 17: Potential Intertidal Habitat available for mangrove Oyster (Crassostrea gasar) farming (Source: Wetland technical report (Onwuteaka et al., 2014))

BIOECONOMIC PATH FOR RESTORATION

In order to harness the full potential of oyster BioCapital towards tomorrow bioeconomy a Bioeconomic Entrepreneurship mindset must evolve where there are new rules and new logic. An Entrepreneurship mindset perceive opportunities to create competitive advantages and are able to network actors such as universities, specialized investors and established larger firms considered necessary to catalyze an oyster bioeconomy.

Many of the factors that support the entrepreneurship approach are inherent in the socioecological and socioeconomic framework which include the following:

1. The available size of the intertidal habitat in the Niger Delta – > 800,000 hectares
2. Each ripe female oyster can release over 15 million eggs in a single spawning season.
3. The large number of river mouths in the Niger Delta potentially candidate sites for nurseries – 22 River mouths.
4. The opportunity to develop oyster breeding, production and processing infrastructure value chain such as seed production hatchery, seed production wild capture, tray construction, harvesters and processors.
5. The opportunity for innovation in the development of oyster infrastructure that are cheaper, biodegradable, easier for larvae to settle on, making harvesting easier, and offering more flexibility for use in different environments.
6. The local and international demand with a global market of US$ 10.15 and US$ 9.13 per kilogram compared to US$0.8 per kilogram of Brent crude oil.

7. The opportunity of institutional development, technology and knowledge, consumers' agency, market structure, funding, resource and infrastructure, and training and education.

8. The opportunity for the first time to map, protect and design new oyster sanctuary areas that are conducive to oyster growth and proliferation (i.e., optimum salinity and oxygen levels, ample flow and depth, available substrate for continued larval settlement).

FUTURE DIRECTIONS

The Vice Chancellor Sir, a bioeconomy revolution is sweeping the globe and we cannot be left out. We are facing a number of challenges across the world to deliver economic growth sustainably and in tandem with protecting and improving the environment and reducing greenhouse gas emissions. New innovative technologies can enable us to respond to these economic, environmental and societal drivers. There is a real opportunity for Nigeria and for our businesses to develop and harness new processes and business models and to export solutions to the global market. By recognizing these opportunities, Nigeria and Niger Delta academia and businesses can compete and grow in this global context. This means building an infrastructure that connects the innovation ecosystem to enable effective exploration and exploitation. For such an infrastructure to "hatch", it is crucial that a new mindset and lexicon must recognize the importance of BioCapital, Biological materials, and Bio-based materials in policy, regulation and economics. The transition must be a bioeconomy that challenge the existing linear thinking in relation to production and consumption fostering circularity to create more value from available BioCapital.

The Bioeconomy transition process must develop a policy brief that aims at increasing the understanding of the opportunities and challenges for bioeconomy development. These would include:

1. Cross cutting issues that address import and export tariffs that can be used to stimulate the increased processing and utilization of local raw materials.
2. The need for bioeconomic hubs that would connect all the silos of basic and advanced innovation taking place in many academia, public and private sectors.
3. A national inventory of Bio-Materials – Vanilla, Rubber, Bio-surfactants, lignin, lignocellulose, alginates, pectin, dextrin, chitin and chitosan, proteins, soy proteins, corn proteins, bioethanol, Bioplastics (Polylactic acid (PLA), Polyhydroxy Butyrates (PHBs), Cellulose esters, Butatenol etc.
4. An inventory of potential sources of Biofuel from agricultural waste – soya beans, seed cotton, sugar cane, sorghum, plantain, groundnut, coconut, rice, cocoa, millet, cowpea, cassava, yam, sweet potatoes, cocoyam, maize, oil palm etc.; municipal waste
5. Separation of raw materials that have closed looped value networks from those with global usage.
6. A massive upskilling and skilling along the value chain in all the relevant areas.
7. A developmental plan on BioCapital (green and blue) economic financing scheme that can leverage new and innovative debt financing instruments like green and blue bonds, blue carbon, debt for nature swaps and new ways of Concessionary Finance.

ACKNOWLEDGEMENTS

A very special thanks to our hard working and amiable Vice Chancellor who has re-engineered the Inaugural Lecture series with a new sense of purpose and good intent to give the presenters a sense of pride and accomplishment. Thank you for giving me the opportunity to deliver the 75th inaugural lecture which would remain the Platinum inaugural lecture of this University. I salute you for this and many other strides that have placed the University among the best in the Comity of Universities.

I would like to acknowledge, with gratitude, the contributions many of the Vice Chancellors made in my life in this institution. - Professor T Turner for giving me an opportunity to become a member of staff and releasing me on a leave of absence to pursue a PhD at the University of Port Harcourt. With Professor Barineme Beke Fakae, I had a friend who provided insightful moments of guidance in academic and administrative matters within and outside the walls of Rivers State University. Professor Blessing Didia came on the scene and gave me an opportunity to become a Head of Department, a position that upskilled me in the art of patience and long suffering. Professor Opunebo Owei, as Acting Vice Chancellor, provided a maternal touch to ease some of the challenges of headship of a department. Though not a Vice Chancellor, but a Registrar of many parts, Dr. Sydney Chukwuemeka Enyindah has been a motivator in many ways with grace and charm. Much pleasantries and warm regards to the Deputy Vice Chancellor, Administration, Professor Nnamdi Okoroma and the Deputy Vice Chancellor Academics, Professor Valentine Omubo-Pepple for their continued friendship and camaraderie.

I would like to express my deep and sincere gratitude to my late parents who I am sure are among the cloud of witnesses, for their sacrifices and care and for educating me and preparing me for a day like this.

To my academic mentor, late Bruce Powell, who transformed Zoology for me into ecological philosophy, I am grateful. You gave me an opportunity of a life time because you believed in me to carry the torch into the next frontier. Thank you, for your faith has paid me well. To the late, genteel, and my PhD supervisor, Dr. Samuel Arko Whyte who stimulated my attention in Chirominids and Polychaetes, I am grateful not just because of the knowledge of these great bio-engineers of the benthos but also for your melodious ways in which you imparted understanding of abstract concepts in ecology.

Life in RSU has been a journey filled with men and women of grace and goodness helping to reduce the grind of teaching, and lecturing over the years. I remember the "Aujourd'hui gang" who are late but are still fresh as if yesterday was but a fresh memory. Professor Solomon Amabaraye Braide, Professor Alexander Chukwudi Chinda, Professor Emmanuel Amadi and Dr Anwai Osuamkpe who were never tired of my company. It was a friendship that had respect and conviviality. Thank you for the moments we shared.

My colleagues in the department, starting from the old department of Biological Sciences, were good men of the likes of Dr Ernest Fubara, my first HOD with whom I secured a University research grant for a project at Eagle Island. I do remember, with gratitude, late Professor Frank Ukoli, who was in the department for a few months on Sabbatical but extended a warm hand of friendship that made a difference in my appraisal. Thank you for the heart and soul of the Jazz music you played often in the background at your office. To others like Professor Ogugua Ogbalu, the consummate entomologist, who thought I should have an office and a responsibility as Post graduate coordinator, I remain grateful for your kindness. Growing and bonding together with Professor Ik Ekweozor, Professor Ada Ugbomeh, Mr Lemmy Adimora, Professor David Ogbonna, Professor Emylia Jaja, Dr Lucretia Barber, Dr Nedie Akani, Professor G C Akani, Professor Eremie Daka, Professor Eme Orlu, Professor Omokaro Obire, Professor Ngozi Odu, Professor Blessing Green, Professor Samuel Wemedo, Professor Barth Nwauzoma, Professor Edith Chuku, Professor T. G Sokari, Dr. Miegbaka Moslen, Dr. Karibi BobManuel , Dr Chidinma Amuzie, Dr. Olufunmilayo Williams, Dr Salome Douglas, Dr Victoria Wilson and definitely, the witty late Dr. ENU Okpon, has been a privilege in exchange of kindness and charity. Professor Nwabueze Ebere, many thanks for your quick responses for solutions in administrative challenges in teaching and management of precarious examination maladies. To all the junior colleagues whose names are not mentioned, including my clerical staff, you have been superb and I cherish you for the support you gave me during my headship of the department. I salute you with a warm heart.

Within the Faculty of Science, the irrepressible Professor Valentine Omubo Pepple now the DVC academic, Professor Confidence Wachukwu, Professor Chigozie Cookey. Professor N. Boiser, Professor Friday Barikpe Sigalo, Professor. G. K. Fekarurhobo, Professor Charles Obunwo, Professor Gloria Wokem, Professor A. O Nwaoburu, Professor Felix Igwe, Dr. Joshua Konne, Dr Ike Anireh, Dr. Daniel Matthias, Dr E.O Ibegbulem, Professor E. S Bartimeus, the Late Alex Moore – a Laboratory Scientist par excellence are milesto-nes of friendly encounters and exchange of academic comradeship.

To my winged friends in the Institute of Geoscience and Environ-mental Management. IPS and Faculty of Agriculture, Professor Akuro Gobo, Professor Chibuogwu Eze, Professor S.A Ngah, Professor T.K.S Abam, Professor Patrick Youdouwei, Professor T.J.K Ideriah, Professor N. H Ukoima, Professor Sodienye Augustine

Abere, Professor Onome Davies and Professor B. A Ekeke, 'Bravo' and thank you for allowing me have access to your academic space and life as often as desired.

To my social support group, I am in your debt for surrounding me with an oasis of consistent empathy, true friendship and partnership in all things at all times - Mazi Kingsley and Inyang Achinivu, Bawo Ayomike, Professor Eyo Nyong, Professor Chike Okolocha, Bar Jimmy Ojei, Awinash Dulip, Daniel West, Bar Alozie Echeonwu, Mickey Nwaiwu, Dr Jethro Atukpa, my in-laws, Professor Theophilus Madueme and Bishop Benjamin Akosa, Professor Ebi Amakoromo, Gesi Amakoromo, Dinie Amakoromo, the irrepressible comic relief master, Bar. Mark Amakoromo, Nze Nwankpo Akachukwu, Isoke Omo, Amaebi and Bar.Lyna Okara, Denning Nwobosi, Nnaemeka Okeke, Eyo Mbukpa, Choko Onyinye, and many others too numerous to mention.

There is no gainsaying that I have benefitted from a group of core environmental practitioners whose ardent belief in defending and protecting Mother Earth has been a motivating factor to endure the underpaid labour of toiling for a better environment. These fastidious individuals namely Engr Wai Ogosu, Professor I K Ekweozor, Professor Lawrence Ikechukwu Ezemonye, Victor Imevbore, Chief Noble Akenge, Dr Ebere Ude, Professor Muhammad Bashar Nuhu, Professor Ekom Robert Akpan, Dr Dorothy Bassey, Professor Emeka Ofunne Professor Babajide Alo, Mr Success Ikpe, and many others who are toilers in the field have made the difference. To all my NGO friends in NCF, Wetlands International, Niger Delta Wetlands and CMADI, I salute your courage and bravery in co-labouring with me for the environment.

Without the prayers and support of friends such as Pastor Samuel Udoye, Reverend Dr Clem and Reverend Dr Patricia Emekene, Reverend Dr Gloria Uchefuna, Pastor Oluwadana Andrew, Pastor and Pastor Mrs Odezi Evezi, the Men's League of Christ Church, Dr Idongesit and Nneka Enang and Mazi Bright Njoku, Engr. Nwachukwu Achebe, Pastor Abiye Braide, Rev Jonathan Ikechukwu Udofia, Very Rev Ivan Ekong, Canon Seth Akinro life would probably have gotten stuck somewhere. Thank you for making a difference in prayers and supplications.

To the Men's league of Christ Church, I salute you in the name of our Lord Jesus Christ. Your Fellowship and attention to my inaugural lecture has been exceptional. I have been kept on my toes with gentle reminders of “let us know on time so we will attend”. Thank you for shedding the care and love of God in my direction.

I cannot stop thanking you, my dear brothers and sisters, Dr Joseph Onwuteaka, Professor Ada Akosa, Professor Stella Madueme and Evangelist Timothy Onwuteaka, for your undiluted love and care in many battles and vicissitudes of life. The journey is still in continuum and your prayers have been credited into the bank of divine help.

To my father in Rivers State His Excellency Sir G.T.G Toby I am grateful for your fatherly cover in the State. You never taught me the meaning of integrity; you simply lived it. Thank you for being a role model.

To my family - Seigha, Anita, Enyi, Betty-Maxine, Ngozi and Samuel - I cannot say enough about your love, prayerful and witty care and attention which have remained the anchor on which I have continued to have stability. I am most grateful to you for keeping us together with the right attitudes and a sense of commitment to family values. A special bouquet of gratitude to my wife, full of grace, who endured late nights and long days of computing tasks. Thank you for all the unpaid proofreading and editing works that have served academia, the church and the public. The Lord shall continue to command HIS blessings on all of you.

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John Nnaemeka Onwuteaka holds a Bachelor of Science degree in Zoology with a Second Class Upper from the University of Nigeria, Nsukka. He graduated with a Master's degree in Fisheries-Hydrobiology and a PhD in Marine Zoology from the University of Port Harcourt. He was employed by Professor T Isoun as an Assistant lecturer/ecologist in 1980. His transition to RUST then was due to his refusal to accept an offer by University of Port Harcourt to go to Imperial College to study Animal Physiology. He was determined to be an ecologist having been influenced by his mentor - Bruce Powell. Mr. Bruce Powell then introduced him to Professor Isoun and after an interview was employed as the first batch of staff for the Institute of Pollution Studies. However, early in 1980, the Institute was not yet established and so he was asked to remain in the Department of Biological Sciences where he was welcomed by Dr Ernest Fubara, the HOD and two pleasant personalities namely Dr. ENU Okpon and Dr. Henrietta Etta both of whom are late. Due to the relationship with Dr Etta and family, the son, Captain Femi Etta, who graduated from Microbiology, who is now a pilot and captain with Air Peace Airlines would always upgrade him to a business class seat whenever he was on his plane because of the respect he has for his lecturer. "Our reward is surely here on earth".

John Nnaemeka Onwuteaka, now a Professor of Biodiversity and Ecosystem Services – the first in Nigeria as of the database of Professors in the NUC database - is a man of many academic parts. In his academic journey, he has dared to conquer other sectors of academic and professional heights. He left the shores of Fisheries and Zoology to acquire and conquer the mountains of Remote Sensing and Geographic Information Systems for which he has many skills. Some of his software skills include ERDAS software ARCVIEW, Spatial Analyst and Avenue, ER Mapper, Bentley/Intergraph

Microstation, PC ARCINFO, TNTMIPS n EASI PACE. From 1991 to 1995, these skills qualified him for marketing and demonstration of satellite imagery applications in West Africa by Earth Observation Satellite Company (EOSAT). Many of the successful applications were in the production of Military Gridded Maps for the Nigerian Army, the Landuse and Landcover maps of the Niger Delta for the Oil Mineral Producing Areas Development Commission (OMPADEC), the completion of the 1:50000 maps for the NE section of the country for the Federal Office of the Surveyor General, Nigeria and the planning and zoning requirements for the Awka Capital City of Anambra State. When the conditions were supportive, he single-handedly introduced the Remote Sensing and GIS course in the Post Graduate programme of the Department of Applied and Environmental Biology. That course has metamorphosed from Remote Sensing and GIS to Environmental Assessment and GIS and is also currently being offered in the undergraduate classes. Outside of Remote Sensing and GIS, Professor Onwuteaka has also contributed to Post graduate curriculum development within RSU by developing content and mentoring students in Disease Ecology and Computer Application and Appreciation.

Without missing a heartbeat, within the remote sensing and GIS world, he has featured as lead expert in in most of the wide ranging environmental assessments beginning from 1983. Between 1983 and 1985, he worked with Bruce Powell to conduct field surveys to document a baseline report for the Niger Delta Basin Development Authority. This study was transmitted by Professor A.M.A Imevbore of University of Ife to Bruce Powell to complete, ostensibly because of the unfamiliar terrain of the estuarine and mangrove dominated areas of the Niger Delta. In 1985, Professor John Onwuteaka anchored part of the benthic portion in a wide ranging study by Research and Planning Institute North Carolina. The Environmental Baseline Studies for the Establishment of Control Criteria and Standards Against Petroleum Related Pollution in Nigeria was sponsored by the Department of Petroleum Resources. Specifically, he was assigned to make sense of the taxonomy of the Polychaete (worms) fraction of the benthos which at that time had no dependable Nigerian literature. In another study in 1989, named the Niger Delta Environmental Surveys, executed by the Institute of Pollution Studies, River State University, Professor Onwuteaka was the anchor for Mapping and Habitat Classification.

As a Biodiversity expert, Professor Onwuteaka has provided content development, advice, direction, and effective reporting for Non-Governmental Organizations such as Nigerian Conservation Foundation, CMadi, Wetlands International, and for oil and gas companies notably Chevron, Mobil Producing Nigeria Unlimited (MPNU), Total Energies, Addax, Agip, Shell Petroleum Development Corporation (SPDC) and Brass LNG Ltd. These skills have been applied in many baseline studies, environmental impact assessments, environmental sensitivity indexes, environmental audits, environmental evaluation studies and biodiversity and monitoring studies. This accumulated knowledge was deployed in producing two regulatory instruments for Department of Petroleum Resources and the Federal Ministry of Environment. Between November 2006 and March 2007, Professor Onwuteaka was tasked with developing environmental content for the World Bank sponsored Sectoral Guidelines and Standards for Dredging and Sand Winning in the inland waters of Nigeria. For DPR, Professor Onwuteaka was the lead expert in developing content and implementation of the standards for Environmental Sensitivity Index Mapping in 2007-2008.

Beyond University academics, Professor Onwuteaka, in March 1999, made significant contributions as a member of the Indicative Niger Delta Management Plan (INDMP). The INDMP involved four key sectors namely Biological Environment, Socio-economic Accounting, Funding and Capacity Building, and Data Management. He was also a member of the National Technical Working Group in both Vision 2010 and 20:2020 in the Environment Thematic Area. Outside the Nigerian shores, Professor Onwuteaka contributed significantly to the Workshop of the Regional Mangrove Programme under the aegis of the Regional Partnership for Coastal and Marine Conservation in Western Africa (PRCM) organized by Wetlands International in partnership with the

International Union for Conservation of Nature (IUCN). Since 2015, Professor John Nnaemeka Onwuteaka has been a member and contributing Expert on Biodiversity for the Intergovernmental Science –a policy Platform on Biodiversity and Ecosystem Services. Professor Onwuteaka is currently on the board of the Advisory Group Mangrove Capital Africa (MCA); an Initiative of Wetlands International.

John Onwuteaka has authored and co-authored some environmental books and produced over a hundred articles in Journals, Technical reports and workshop presentations. He is a member of many professional bodies including the Nigerian Environmental Society where he is a Fellow and rose to become the National Vice President 1.

He is currently leading a group of scientists from RSU, University of Calabar and University College Ibadan to develop the first indigenous PCR test kit for COVID-19 which is going through the final stages of validation.

Prof John Nnaemeka Onwuteaka is a firm believer in getting things done even if it means using his personal resources and this attribute of his showed up when he single-handedly renovated and refurbished the toilet facilities and provided a water tank in his department in preparation for accreditation during Prof Fakae's tenure as Vice Chancellor.

Prof John Onwuteaka did not only focus on lecturing his students in his area of specialization but also invested in equipping them with life skills. In the early 80s, he introduced the sport of cricket but lack of funding laid that to rest.

In line with environmental practices, he encouraged the students to be wardens of environmental cleanliness and promoted no litter and no indiscriminate urinating initiatives. He was known not to start any lecture if the students were seated in a lecture room that was littered with rubbish. They would have to tidy it up. They couldn't be students of Applied Biology and not apply the biology they were being taught.

He promoted mutual respect and courtesy. As funny as it may seem, any student who was late for his lecture was able to come in once they tendered an apology to the class with a smile.

In the mid-nineties, some of his students met him outside campus and as he engaged them in conversation, one of them said, 'You can be sure of a lecture wherever you meet Dr Onwuteaka.'

A citation about Prof John Onwuteaka would be incomplete without mentioning his love and passion for the things of God. He is a devout Christian who brings his all to bear in the service of the Lord. At Christ Church, you can see him serving as an usher which requires virtues of patience and long suffering.

He is married to his lovely wife, Seigha Linda Onwuteaka and they have five wonderful children all thriving in their various endeavors.

Mr. Vice Chancellor, Sir, distinguished ladies and gentlemen, I present, **Prof. John Nnaemeka Onwuteaka.**

ISBN 987-987-975-140-4